Temperature Monitoring for Quality Prediction and Inventory Control in Cold Chain: a Case of 18℃ Ready-to-eat Food in Taiwan

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Abstract

The aim of the study was the development of a quality prediction model combined with the incoming analysis for temperature control in 18 degree ready-to-eat food during logistics flows. And analyzed how temperature monitoring improves inventory decision. Base on the growth of *Pseudomonas* sp., the model was developed by mathematical model with Gompertz model. The model predicts for quality as well as shelf life in the monitoring temperature is about 19.5 h. On the other hand, the incoming analysis shows that the inventory quantities at 7 ℃ and 18 ℃ is more than at 25 ℃.

The model can be considered to be an effective tool (in combination with temperature monitoring) for improvement of quality management with the incoming consideration. Moreover, our results suggest that temperature-controlled food companies could share temperature information with its chain partners which emphases a food quality and logistics cost balance in supply chain.

Keywords: *food, quality, temperature, cold chain, incoming, inventory, logistics*

1 Introduction

Maintenance the quality and inventories of low-temperature foods is a problem of major concern in food cold chain. Especially, since the variation temperature in the chain is dynamic, temperature monitoring during the food cold chain is a common discussion and essential work. On the other hand, seasonality in material production, requirement for air-conditioned transportation and storage means make planning and transportation are very difficult (Grievink *et al*., 2002). For the chilled foods in the cold chain, there has been a market increased called 18 ℃ ready-to-eat (RTE) fresh food products over the last ten year in Taiwan (Fang *et al*., 2003). Although growing numbers of researchers have considered the use of temperature monitoring in food logistics, very little attention has been given specifically to RTE food. In addition, the effect of deterioration of food products cannot be disregarded in inventory systems because almost all the goods deteriorate over time.

The objectives of this study were: (a) to develop a quality predictive model for RTE foods (b) the incoming analysis in various temperature storage with the decay rate for inventory management. The paper is organized as follows: in section 2 we review the literature on food quality prediction studies and inventory control of perishable foods. Section 3, we provide a quality predictive model and derive the incoming analysis with decay rate of the inventory. Section 4, results, problems and solution methods are discussed. Finally, a summary and some concluding remarks follow in section 5.

2 Literature

2.1 Food Cold Chain

Perishable food products are at risk of various damages along the food cold chain logistics. In the part of the Food Industry which deals with the transport, storage, distributions and selling of low-temperature foods (chilled and frozen goods) calls 'cold chain'. The equipment and the operation of that equipment need to maintain low-temperature foods in a fully condition at the correct temperature. According to Codex Alimentarius Commission (CODEX), it maintains a supply chain from produce to consumer at the low temperature, and cannot change the product temperature conditions which the processers have provided (CODEX, 2008). While products pass through the food cold chain, quality decay limits the shelf life of products. To restrict decay conditioned processing, storage and transportation of low temperature food is essential.

2.2 Food Quality prediction model

Food industry aims at ensuring the harmlessness of its products and providing important information for its business partners along the food chain and consumers (Poigné and Schiefer, 2007). The RTE food products provide a source of convenience and nutritious meals for the consumers. However, the problems about safety and microbiological quality of these foods have been raised. Predictive microbiology is a study that combines elements of microbiology, mathematics and statistics that describe and predict the growth of microbes under specified environmental conditions. In general, models can be thought of as having three levels: primary, secondary and tertiary models (Isabelle and Andre, 2006). Primary models describe the change of the bacterial number over time, secondary models describe the evolution of one or more parameters of the primary model vary with environmental conditions, and the tertiary models combines the first two models and incorporated into a user-friendly computer software (MacDonald and Sun, 1999).

2.3 Inventory control of perishable foods

Inventory of perishable products maintaining is a major concern to supply manager of a business organization. The effect of deterioration of physical goods cannot be disregarded in inventory systems. Since the optimal incoming and cost of perishable products is more important focus in perishable inventory of food industry, the parameter of deteriorating rate must be considered for inventory control. Thus, Blackburn and Scudder (2009) showed the appropriate model which was used by the product's marginal value of time (MVT), decay rate and cost to minimize lost value in the supply chain of fresh products (melons and sweet corn). A perishable inventory model was also used to calculate the effect of four unit costs (ordering, holding, shortage and outdating costs) on the optimal incoming quantity. Subsequently, they will also examine the impact of a LIFO issuing policy in the future (Williams and Eddy Patuwo, 2004).

3 Methodology

Firstly, predict microbial (*Pseudomonas sp.*) growth model for 18 ℃ RTE food products using dynamic temperature of storage monitoring was built to estimate the shelf-life of products. Secondly, decision of inventory management was applied based on incoming analysis (including decay rate from predict microbial growth model) of 18 ℃ RTE food. Finally, shelf-life and incoming of inventory will be predicted to optimize inventory decision of 18 ℃ RTE food by temperature of storage monitoring.

3.2 Data on cooked ready-to-eat food industry : Temperature analysis

For one of the cases, we monitored dynamic temperature (5 minutes/ time) in the storage of 18 ℃ RTE food products (chilled pork sandwich) from the food industry by temperature recorder (Onset HOBO Pendant® Temperature/ Light Data Logger). Based on the dynamic temperature monitoring in a period of time, temperature was analyzed to discuss how the loss temperature affects the storage and products, in order to developing the shelf-life prediction model.

3.3 Predict quality model

As initial decay of food quality is hardly observed from surface of food, a few mathematical models for calculated time-temperature parameters which associated with food quality was developed. Parameters on a predict microbial (*Pseudomonas sp.*) growth model of 18 ℃ RTE were included dynamic temperature of storage (T), initial bacterial count of food (N_0), relative growth rate (B) and lag-phase time (T_{lag}). The Gompertz model was used as the primary model to describe the growth of

microorganisms with time (equation (1)) (Gibson *et al.*, 1987). $N(t) = A + C \cdot e^{-e^{-B(t-M)}}$ (1)

Therefore, compute the end bacterial count of food, the steps should be followed:

1. Decide SSO: for chilled pork sandwich, *Pseudomonas* sp. has been identified.
2. Measuring N_0, N_{max}, pH and Aw of sandwich
3. Obtaining B value and T_{lag} value (M value) form database (ComBase) and publish articles.

M: time at which maximum growth rate is obtained (equation (2)) (Kreyenschmidt et al., 2010).

4. Using exponential regression to construct temperature-M and temperature-B.
5. Compute end bacteria count of food after experiencing dynamic temperature.

Furthermore, the end of shelf-life was determined.

$$M = T_{lag} + \frac{1}{B} \quad (2)$$

3.4 Inventory model and quality model

Based on the relative growth rate (B) from the predict microbial growth model as above, the decay rate of the products (b) could be obtained. Since price-dependent demand rate (d(p)) is not our target in this paper, the inventory model (equation (3)) (Mukhopadhyay *et al.*, 2004) is simplified, which only consider remaining products of inventory (I) with decay rate of the products (equation (4)).

$$I(t) = -d(p)\left(t + \frac{bt^3}{6}\right)e^{-bt^2/2} + I(0)e^{-bt^2/2} \quad (3)$$

$$I(t) = I(0)e^{-bt^2/2} \quad (4)$$

Subsequently, the incoming of perishable inventory is estimated as following:

1. Calculating the decay rate of the products (b) and worth (w) from relative growth rate (B) and the end of bacterial count (N(t)) (equation (5)).

$$w = \frac{7 - N(t)}{7} \quad (5)$$

2. Obtaining the amount of original inventory (I(0)), price of products per unit(P), cost of products per unit (C). P: means the worth (w) of the products.
3. Estimating the incoming of perishable inventory (Π) at time (t) by simple formula (equation (6)).

$$\Pi(t) = (w\,P - C) * I(0)e^{-bt^2/2} \quad (6)$$

4 Results and Discussion

4.1 Predict Ready-to-eat food quality model

Observed initial bacterial counts (N_0= A) in pork sandwich of the constant temperature is 2.06 $\log_{10}$ cfu/g, pH 6.5 and Aw 0.997. The obtained relative growth rate and lag time value of *Pseudomonas sp.* on pork and meat broth was calculated with the Gompertz model at eleven constant storage temperatures from 0 to 25 °C are listed in Table 1. As described, the exponential regression fit of B (the relative growth rate) and M value obtained at isothermal temperatures is shown in Fig. 1. The fit with R^2 values of 0.723 (for B) and 0.963 (for M) which made it possible to predict the growth of Pseudomonas sp. for RTE pork sandwiches. Subsequently, the dynamic temperature in the RTE food industry includes three different scenarios which are the standard temperature setting in cold chain: Inventory (2 hours at 7 ℃), transportation (1 hour at 18 ℃) and retailing (24 hours at 18 ℃).

Table 1. Parameters obtained for *Pseudomonas sp.* at different storage temperatures

Temperature [℃]	pH	Aw	B	T_{lag}	M	reference
0.4	5.7	0.993	0.021	64.696	112.089	TNO report V94.207
0.6	5.5	0.993	0.027	58.073	95.667	TNO report V94.207
2.7	5.5	0.933	0.035	44.678	73.168	TNO report V94.207
2.8	5.7	0.933	0.034	41.298	70.538	TNO report V94.207
6.3	5.7	0.933	0.060	24.586	41.253	TNO report V94.207
6.9	5.5	0.933	0.053	19.783	38.830	TNO report V94.207
9.6	5.7	0.933	0.083	13.236	25.313	TNO report V94.207
9.9	5.5	0.933	0.074	15.744	29.331	TNO report V94.207
10.4	5.6	0.933	0.094	7.211	17.838	TNO report V95.764
16	6.4	1	0.251	1.500	5.486	Lebert *et al*., 1998
25	6.4	0.97	0.120	5.100	13.406	Lebert *et al*., 1998

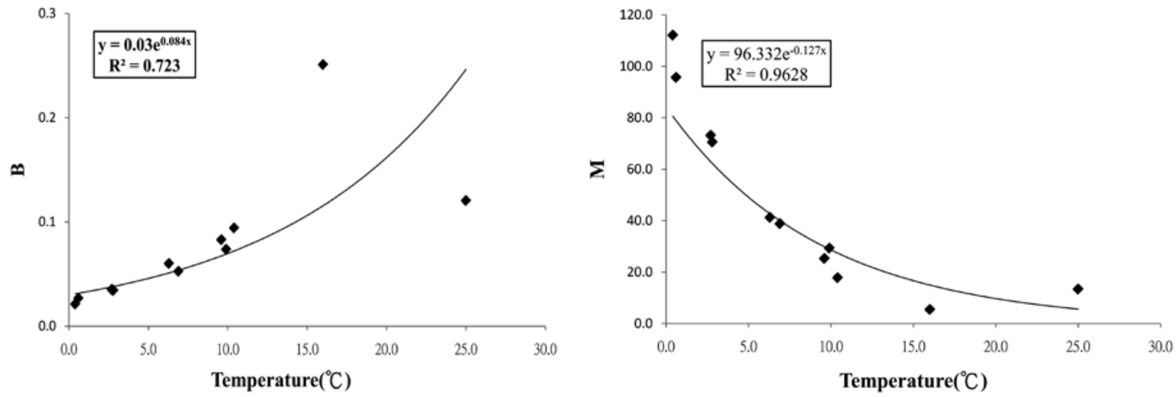

Figure 1. Exponential fit of B (the relative growth rate) and M (reversal point) value.

To evaluate food quality performance in the case, the monitoring temperature was simplified into following scenarios: Inventory (2 hours at 22 ℃), transportation (1 hour at 20 ℃) and retailing (24 hours at 18 ℃). The growth of *Pseudomonas sp.* is predicted, show in Figure 2. The end of count number in convenient store is 9.05 $\log_{10}$ cfu/g. It has already exceeded the standard and causes a critical quality loss. The shelf-life of the products is 19.5 hours and it shows that they can stay 16.5 hours on shelf of the store. Based on the model, the products can be early remove from shelves that can ensure the quality. Therefore, we suggest that temperature controlling and monitoring is important work to extend and predict shelf-life for

RTE food.

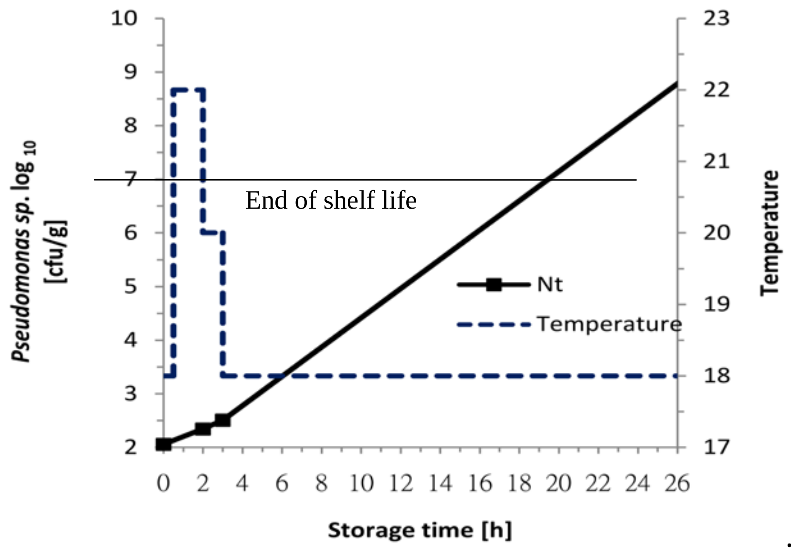

Figure 2. Predicted the growth of *Pseudomonas sp.* on 18 °C RTE food under dynamic temperature condition (monitoring temperature).

4.2 Incoming of Ready-to-eat food inventory

Incoming of the food products inventory during 2 hours for five different temperature (7℃, 18℃, 20℃) is analyzed to discuss optimized temperature. In the present paper, we take C=$1, P=$15 in appropriate units. Subsequence, the worth of the products (w), decay rate (b), and inventory (I(t)) are computed from equation (4), (5) and (6). Finally, the incoming for five temperature of inventory is calculated and get the results show in Table 2.

The following points are noted from Table 2:

(i) The incoming (Π) increases as the temperatures in inventory decrease.

(ii) The decay rate (b) increases as the temperatures in inventory increase.

(iii) The parameter (w) and I(t) are sensitive to incoming, they decrease as the temperatures in inventory increase.

Table 2. Incoming analysis of the inventory for RTE food in different temperature

Temperature, T (℃)	Cost, C ($)	Price, P ($)	Worth, w	Decay rate, b (1/h)	Inventory, I (t) (Unit)	Incoming, Π ($)
7	1	15	0.706	0.0056	99.00	949.41
18	1	15	0.700	0.0115	97.73	928.44
20	1	15	0.686	0.0136	97.32	904.10

The incoming analysis shows that the inventory quantities decrease since the inaccuracy temperature control and loss temperature occurs in the storage. Therefore, the optimal temperature it controls, the maximum inventory quantities it have. Based on this, the optimal control temperature in the inventory of RTE foods is at 7℃ and 18℃. However, since energy plays a strategic role along the cold chain, the energy required at 7℃ is higher than at 18℃ storage. For minimum the total cost and maximum the incoming, temperature control at 18℃ is an optimized temperature for the products.

5 Conclusion

For estimating remaining shelf life of ready-to-eat (RTE) food products, a predicted microbial growth model with an effective and continuous temperature monitoring was generally method during the cold chain. In the present paper, the end count of *Pseudomonas sp.* on the RTE food is predicted by mathematical model for dynamic temperature. Since dynamic temperature easily causes the food quality loss, we compare the standard temperatures setting with the observed values from the temperatures monitoring to understand the difference of shelf-life for RTE food. The remaining shelf life of RTE food products for the standard temperature setting (23.2 hours) and the observed values of the temperatures monitoring (19.5 hours) were estimated. Thus, an effective and stable continuous temperature control is essential for the food quality maintenance.

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