Research on Agricultural Food Supply Chain Prediction and Control Based on Microbial Forecast

RECHERCHES SUR LA PREDICTION ET LE CONTROLE DE LA CHAINE D'APPROVISIONNEMENT DES ALIMENTS AGRICOLS BASES SUR LA PREVISION MICROBIENNE

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Abstract: The literature review on applying Predictive Microbiology into the field of agricultural food safety is presented in this paper at first. Then based on related risk analysis theory and considering various stages of agricultural food supply chain, it is calculated the shelf life of agricultural food and predicted microbial quantity correspondingly. On this basis, using probability statistics theory on detection of agricultural food, Monte Carlo simulation is implemented. At last, we discussed the quality security control model of agricultural food supply chain on the basis of Prediction Model, and it can came up with the conclusions that Microbial Predictive Technology plays a good part on quality and safety protection of agricultural food supply chain.
Key words: Agricultural Food Supply Chain; Quality and safety of agricultural food; Predictive Microbiology; Warning Management; Monte Carlo Simulation

Résumé: La revue de l'application de la microbiologie prédictive dans la sécurité de l'alimentation agriculturelle est d'abord présentée dans l'article présent. Et puis, basée sur de la théorie de l'analyse de risque concernée et la prise en compte de différentes phases de la chaîne d'approvisionnement des aliments agricols, la durée de conservation des aliments agricols est calculée et la quantité microbienne correspondante est prédite. Sur cette base, utilisant la théorie de probabilités et de statistique dans la détection des aliments agricols, l'article effectue la simulation Monte Carlo. Finalement, nous discutons le modèle de contrôle de la sécutité de qualité de la chaîne d'approvisionnement des aliments agricols en fondant sur le Modèle de Prédiction, et arrivons à la conclusion que la technologie prédictive microbienne joue un rôle important dans la protection de qualité et de sécurité de la chaîne d'approvisionnement des aliments agricols.
Mots-Clés: chaîne d'approvisionnement des aliments agricols, qualité et sécurité des aliments agricols, microbiologie prédictive, management d'avertissement, simulation Monte Carlo

1. INTRODUCTION

The microbial growth mechanism was firstly put forward based on Microbiology predictive model made by ROSS T at 1980s. Microbial predictive model is on the basis of the integrated use of microbiology, engineering mathematics, statistics and various characteristics for detailed information of microorganism in different environments conditions. The purpose of the model is to estimate and describe the dynamic change of microbial growth, death and survival. Therefore, we can make a rapid assessment of microbial food safety which plays an important role in early warning of food quality safety .[3]

This paper focuses on the research on the application of microbial prediction model to the food safety. The earliest study is that Buchanan (1993) divided different microbial prediction dynamics models into primary model, two-level model and three level models according to the different variables in the model [4] Subsequently, Zwietering (2002) and Maria (2002) expanded the primary dynamics model such as Gompertz equation. They brought forward three kinds of two-echelon dynamics model that is response surface

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equation, and Arrhenius relationship and square root equation.[5] Based on the above model, Angelika (2004) firstly made scientific assessment to microbial food risk considering uncertain factors.[6] Poscheta (2003) and Standaert (2005) emphasized that it should be considered the influence of uncertain factors, attempting to increase accuracy of microbial food predictive results, in the process of making risk assessment of microbial food by the microbial prediction model by Monte Carlo method and probability theory.[7] In addition, the relative domestic research scholars chiefly focused on the introduction and application of theories and achievement abroad. According to the literature [1,2], the concept and principles of implementation of the microbial risk assessment are introduced the literature. The literature of [3-4] have introduced the development condition of predictive microbial models, analyzed the role which predictive models play in the field of food safety, especially on microbial food's risk assessment and shelf life's prediction.

To sum up, the current research in the field of prediction and control of food safety chiefly focused on several professional directions. But under the condition of macro and micro levels combined, from the overall perspective of the whole food supply chain, in the framework of risk analysis, there is few researches to concern the prediction and control of food's quality safety using integrated of qualitative and quantitative risk assessment methods. Therefore, this paper intends to explore in this direction. It is presented the agricultural food's shelf life prediction model and microbial quantity prediction model, basing on microbial prediction model. Considering the different influence of different phrase in agricultural food supply chain and the influence of uncertain parameters factor in the model, this paper makes assessment to parameters in the model by the Monte Carlo simulation method. The final result of this paper is to expound the scientific microbial prediction have a good warning effect on the agricultural food supply chain's quality safety.

2. MICROBIOLOGICAL PREDICTION MODEL OF AGRICULTURAL FOOD SUPPLY CHAIN

Throughout viewing the entire agricultural supply chain, retail that is the last link to the consumers—plays a critical role in agricultural food safety. At the last link, the main basis for the microbial growth prediction of agricultural food and quantitative information for controlling is the shelf life of agricultural food predictive value in the microbial growth prediction model and the number of microorganisms' predictive value. If the model is realistic and the methods are appropriate, it will bring us higher believe degree during the predictive process of food safety. The following will discuss on the predictive model for shelf life of agricultural food supply chain and the method to estimate parameters in the model.

2.1 Predictive model of shelf life and microorganism amounts

In order to estimate the shelf life of agricultural food accurately, we must know about the following three aspects before using predictive microbiology models. Firstly, in order to consider every feasible temperature point, we must know that the key factors which will be a negative impact on shelf life during the important temperature ranges. Commonly the temperature range is 0~（15~20）℃；Secondly，we should ensure the typical environmental factors after the agricultural food going into the normal distribution channels of supply chain; Finally, we must ensure the shelf life end point of agricultural food that is the limit microorganisms' number of agricultural growth be harm to the health of human beings.

The microbial growth of agricultural food is not only influenced by it own identity, but also strongly influenced by the temperature, the active degree of water, pH and some important environmental factors, in which temperature is the most influential factor. The above two aspects influences need to be considered in shelf life of agricultural food and amount predictive model of microorganisms.To enhance pertinency of the model, based on Zwietering (2002), the initial microbial growth elementary dynamics model is put forward. Selecting milk or dairy products in agricultural food as research objects, the model in this paper is capable of

[5] M．H．Zwietering．(2002). *Quantification of microbial quality and safety in minimally processed foods[J]*．International Dairy Journal12(2-3)：263–271.

[6] F． Poscheta, A. H. Geeraerda, N. Scheerlinckb, B．M．Nicola，J．F．Van Impe．(2003). *Monte Carlo analysis as a tool to incorporate variation on experimental data in predictive microbiology[J]*．Food Microbiology, 20(3)：285-295

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[7] F． Poscheta, A. H. Geeraerda, N. Scheerlinckb, B． M． Nicola，J. F. Van Impe． *Monte Carlo analysis as a tool to incorporate variation on experimental data in predictive microbiology[J]*．Food Microbiology, 2003, 20(3)：285-295

A. R. Standaert，A. H Geeraerd，K. Bemaerts，K. Francois, F．Devlieghere, J. Debevere, J．F．Van Impe．(2005), *Obtaining single cells：analysis and evaluation of an experimental protocol by means of a simulation model[J]*． International Journal of Food Microbiology, 100(1-3): 55-66 simulating Bacillus (B cereus bacteria) growth state model. The detail model is as follows (agricultural food has experienced much longer time to microbial growth delay, so here no considering microbial growth lag).

$$N_t = N_0 e^{\mu t} \tag{1}$$

Where N_0 represents the current number of microorganisms（cfu）, N_t represents the number of microorganisms（cfu）at the t period，μ is growth rate of microorganisms (h^{-1}). The model is converted to the logarithm formula formation:

$$\ln(N_t) = \ln(N_0) + \mu t \tag{2}$$

Based on the initial model, integrating with the influences of environmental factors on the growth rate of microorganisms, the calculate formula of the microorganisms growth rate μ is deduced under the combined influences of temperature T, moisture A_w and pH according to the references [5]. (The applicable scope of square root model is from 0～40°C which is in line with the controlled temperature of agricultural food)

$$\sqrt{\mu} = b(T - T_{\min}) \tag{3}$$

$$\mu = b^2 (T - T_{\min})^2 \tag{4}$$

The two-echelon dynamics model (4) is put into the primary model (2), it can be deduced:

$$\ln(N_t) = \ln(N_0) + [b(T - T_{\min})]^2 t \tag{5}$$

Here N represents the number of the microorganisms for the limit shelf life of the agricultural food, therefore, we can get that the predictive value t of the shelf life of the agricultural food:

$$t = \frac{\ln(N) - \ln(N_0)}{[b(T - T_{\min})]^2} \tag{6}$$

Where $b = \sqrt{\gamma(pH)\gamma(a_w)\frac{\mu_{opt}}{(T_{opt} - T_{\min})^2}}$ (7)

$$\gamma(pH) = \frac{(pH - pH_{\min})(pH_{\max} - pH)}{(pH_{opt-} - pH_{\min})(pH_{\max} - pH_{opt})} \tag{8}$$

$$\gamma(Aw) = \frac{Aw - Aw_{\min}}{1 - Aw_{\min}} \tag{9}$$

The formula (6) predicts the time span from the beginning to the limit shelf life of the agricultural food. In practice, the supply chain of agricultural food is under many changes during the period the microbial environment factors are quite different. Therefore, it is essential to make forecast simulation for every aspect of microbial growth.[8]

T_i 、pH_i 、Aw_i are the measured values of environmental factors, t_i is suffering time of the main environmental factors T_i 、pH_i 、Aw_i , b_i is the coefficient value under the influence of different environmental factors at the different stages. N_t which represents the number of the microorganisms of the agricultural food after undergoing i stages can be estimated through formula (10):

$$\ln(N_t) = \ln(N_0) + \sum_i [b_i(T_i - T_{\min})]^2 t_i \tag{10}$$

Thereinto, N_0 is the initial microbial measurement which can be interpreted as the initial detection value of agricultural food in the supply chain at various stages.

The data of the environmental factors are from the agricultural food processing distribution center and terminal detection point of the retail shops. The actual shelf life of the agricultural food at the retail sales can be adjusted according to the detected data and the practical environmental conditions of the agricultural food. Assuming i is the final environment change before the products are on shelf and N is the microorganisms' number when the shelf life reaches the limit. In this case, the actual shelf life of the agricultural food is:

$$t_i = \frac{\ln(N) - \ln(N_0) - \sum_{i-1} [b_{i-1}(T_{i-1} - T_{\min})]^2 t_{i-1}}{[b_i(T_i - T_{\min})]^2} \tag{11}$$

Therefore, in accordance with transference of the agricultural food in the supply chain, and the environmental data at different stages which is supplied by the agricultural food distribution center and terminal detection point of the retail shops, we can make use of the microorganisms forecast model to predicate the shelf life and the microorganisms' number.

2.2 Monte Carlo's simulation to parameters

The data of the predication model of the agricultural food shelf life is from every detection part. The accuracy of the data has great influence on the final outcome. During the process of the actual detection, the quantity of the same batch agricultural food is quite large and it is impossible to detect all products.

[8] Marcelo O．Masana，JÓzsef Baranyi．(2000), *Adding new factors to predictive models：the effect on the risk of extrapolation [J]*．Food Microbiology, 17(4)：367-374

Moreover it is impossible to detect N_0 which is the number of primary microorganisms and b which is concerning with the environmental factors, because they are stochastic variables. In order to obtain a more accurate shelf life, we adopt Monte Carlo's Model to simulate N_0 and b.

It is assumed that we will estimate the shelf life of the agricultural food having same production batch and same packaging requirements. The estimated shelf life is given under the formula (6). N_0 is the number of present microorganisms of the agricultural food which are for detection. For N_0 is a stochastic variable, we can only draw out n pieces of l samples in the same batch of agricultural food. Here, l is probability distribution of the number of microorganism of the agricultural food which is described by Poisson[7]

$$p(N_0 = k) = \frac{\lambda^k}{k!} e^{-\lambda} \tag{12}$$

Among them, $\lambda = lC$ is the agricultural units (such as volume), C is the microorganisms' concentration in these agricultural food. Similarly, the average number of microorganisms in agricultural food is subordinated to the Poisson distribution, and is related with the overall concentration of microorganisms C. Assumed the sample was negative, that is, non-agricultural product samples microorganisms is subject to Beta probability distribution: [9]

$$Beta(s+1, n-s+1) \tag{13}$$

In which n stands for the number of samples, s make clear that the test results were negative (no harmful microorganisms) sample size. According to the Poisson distribution, the probability of no bacteria in one l unit's sample $P(0) = e^{-lC}$. Therefore,

$$e^{lC} = Beta(s+1, n-s+1) \tag{14}$$

thus： $C = -\ln[Beta(s+1, n-s+1)]/l$ (15)

Therefore, N_0 that the microorganisms contained in a m unit of prepare for be analyzed agricultural food is subject to Poisson-Beta distribution:

$$N_0 \in Psisson\left\{\frac{-m}{l}\ln[Beta(s+1, n-s+1)]\right\} \tag{16}$$

Similarly, the value of b in formula (7) is detected by a number of detection values. It is a random variable, the value of b^2 is also a random variable. According to the references [6], the value of b^2 obeys the normal distribution, its deviation is slightly less than one-tenth of the mean. Therefore, as long as the probability distribution of N_0 and b^2 are identified, using Monte Carlo methods can simulate the statistical characteristics of random variables according to the specific characteristics of microorganisms and environmental conditions.

3. SIMULATION TO MICROBIOLOGICAL SAFETY MODEL OF THE AGRICULTURAL SUPPLY CHAIN

Then, applying shelf life of agricultural food and the prediction model of the number of microbial, with a specific category of agricultural food and pathogens, using Monte Carlo method for the given model parameters are subordinated to the distribution of agricultural food under the conditions of shelf life and microbiological quantities, the following text gives both of the mean and deviation of the probability distribution, and introduces the illustration of simulation models.

3.1 The Monte Carlo simulation to the predict model

A number of existing specifications 200ml of the same batches of a certain species Bacillus milk. B.cereus bacteria is its major pathogens, the current of the natural growth of B.cereus bacteria is according to one-echelon growth model as shown in formula (1). Now collecting 100 samples from these Bacillus milk, containing 10m in each of the sample l, the detection result exhibits masculine which means that the number of the sample contain B. cereus is twenty. The ambient temperature of 10 ° C, B.cereus bacteria minimum temperature in the Bacillus B milk is 0 ° C, suppossing that b^2 obey N (0.011,0.001) distribution. According to formula (16), the initial average of B.cereus bacteria in this batch of 200ml milk is subordinate to the following distribution:

$$N_0 \in Psisson\{-20\ln[Beta(81,21)]\} \tag{17}$$

The initial number of B.cereus bacteria N_0 generated by the random numbers subordinated to Beta distribution is shown as following Fig.1.

[9] A. R. Standaert, A. H Geeraerd, K. Bemaerts, K. Francois, F. Devlieghere, J. Debevere, J. F. Van Impe. (2005). *Obtaining single cells：analysis and evaluation of an experimental protocol by means of a simulation model[J].* International Journal of Food Microbiology, 100(1-3)：55-66

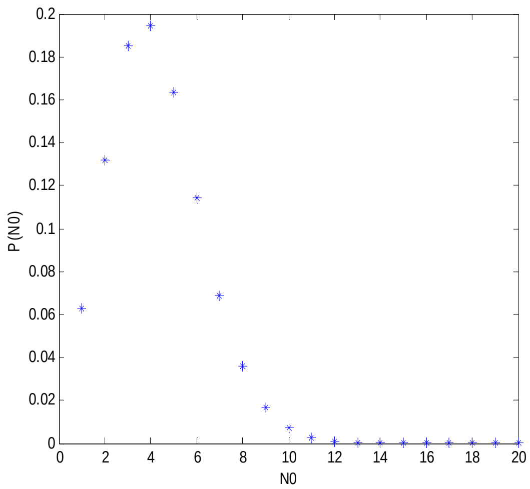

Fig.1. The probability distribution of an initial plan B. cereus bacteria

After determining probability distribution of N_0 and b^2, we can estimate the value of t by means of sufficient samples number, substituting into the formula for calculating shelf life (6); on the other hand, according to formula (5) it can be estimated the microorganisms' quantity in a certain unit of agricultural food after t time. And the result was shown by the mean and deviation.

Firstly, using the Monte Carlo method it can be estimated the mean and deviation of shelf life t at the given conditions. We suppose the limit number of B. cereus bacteria in a 200ml Bacillus milk was 10^5cfu. We will do 10 million values to N_0 and b^2 using Matlab at the condition of T as 10℃ and $T_{\min}$ as 0℃. We can obtain the mean $\bar{t}$ and deviation σ_t^2 of t using the formula (6):

$$\bar{t} = 9.2563\ (h),\quad \sigma_t^2 = 0.0155$$

We look up $\bar{t}$ as t the estimated value of the samples. It means that, in the given conditions, the estimated value of shelf life t is 9.2563 h. According to the central limit theorem, the probability distribution can be considered similar to obey normal distribution which parameters are (9.2563. 0.0155), probability density distribution as shown as Fig.2.:

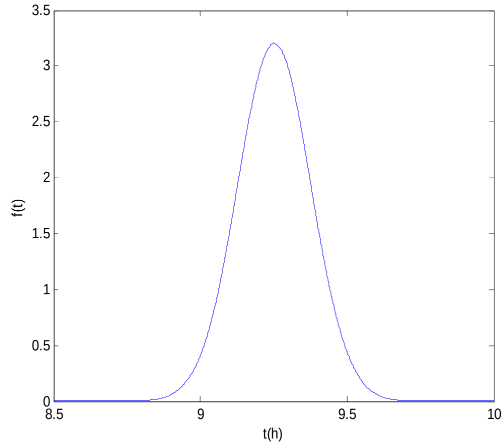

Figure 2 Probability density distribution of agricultural food's shelf life

According to the normal rules of the 3σ, random variables t point is at [9.2563-3×0.1245，9.2563+3×0.1245] with 99.74% probability, which fell within [8.8828,9.6298].

Following, we simulate B. Cereus bacteria amounts by using Monte Carlo in the given time t and the relevant data. Supposing $t = 5\ h$ and other conditions is consistent with the above-mentioned values. According to formula (5) in the use of Matlab for 10 million value of the random sample, we can obtain the natural logarithm of the mean $\ln(N_t)$ and deviation $\sigma^2_{\ln(N_t)}$ of N_t: $\overline{\ln(N_t)} = 6.9099$（cfu）, $\sigma^2_{\ln(N_t)} = 0.5674$. The probability density distribution of $\ln(N_t)$ shown in Figure 3 as follows:

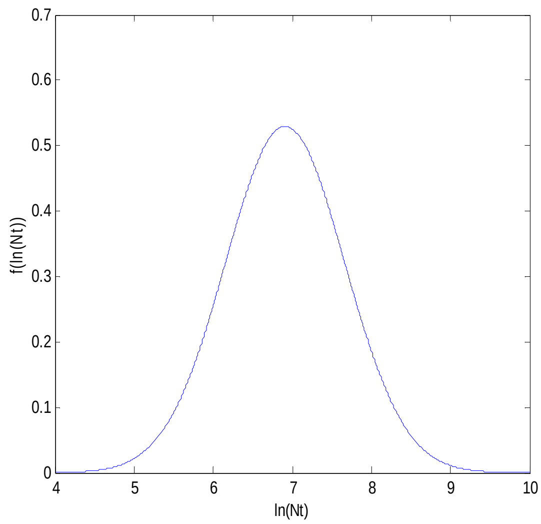

Figure 3 The probability density distribution of microbial number $\ln(N_t)$

3.2 Illumination of simulation models

Using Monte Carlo methods to simulate shelf life and microbial number, being able to handle the influence of uncertainty factors on model parameters better in real conditions, it is can be concluded more accurate forecasting results which is an approach of higher believe degree to security forecast. The above simulation is based on having known the probability distribution of model parameters. Because the predicted results of microbial shelf life and the microorganisms' amount are influenced by agricultural microbial species and environmental conditions, the specific probability distribution of the initial microorganisms amounts as well as their growth rate will be also subject to be impacted. To obtain these required data, it is not only needed to depend on the experience and reference data, but also to build a database stored microbial standards. In this database, it is necessary to store more different agricultural microbial growth characteristics information. For example, the growth rate of microbial parameters is in accordance with the formula (7). As long as its specific environmental factors and relative microbiological criteria are measured, we can obtain the correspond value of b^2 in a designated agricultural food. But in a large number of samples, the value of b^2 is in fact a random variable, it must rely on testing experience, standard reference materials and microorganisms standard to obtain the obeying probability distribution. Therefore, the actual samples of microbial detection and prediction can be more reliable.

4. CONTROL MODE OF AGRICULTURAL FOOD SUPPLY CHAIN SAFETY BASED ON PREDICTIVE MODEL

The purpose of prediction model is to more accurately find out the safety issues in agricultural food supply chain management, and provide the basis for agricultural supply chain microbiological risk analysis and control. Next it will discuss the control mode of agricultural supply chain safety based on predictive model and the expansion area of agricultural supply chain microbiological risk assessment. It can make the research on warning management of agricultural supply chain safety based on microbial prediction to reflect the real applicable value.

The microbial quality and safety control of agricultural food supply chain is based by the shelf life prediction of agricultural food and the number of microorganisms predict model. On one hand, agricultural food distribution center is responsible to the reception and detection the agricultural food supplied by the supplier, according to the test results and using the agricultural forecasting model receive the existing number of microorganisms and the value of the shelf life of agricultural food and the number of microorganisms predictive value under certain conditions. Agricultural food distribution center compare these data with the data provided by the suppliers, assessing the quality of suppliers to supply, reversely evaluate the suppliers' problem in production, processing, transportation and storage, based on new data reorientation shelf life; Under the irregularities production, transport, storage environment, forecasting again the shelf life of agricultural food at the end of agricultural food in the retail will be conducive to more standardized management of agricultural enterprises shelf life, establish a agricultural supply chain quality and safety management systems based on integrity. The other hand, retail shop receipt and detect the agricultural food provided by Distribution Center of agricultural food, using the test data and predict models will also obtain the existing agricultural microbial quantities and the predictive value of the shelf life of agricultural food and the number of microorganisms predictive value under certain conditions, compared with the previous data processed by agricultural food distribution center, clear the point of improvement from the agricultural food distribution center to store shelves to the quality and safety of agricultural food; In addition, according to test results, combining predict model evaluate microbiological risk, as a part of the development of risk management measures important reference materials. The control mode of quality and safety of the supply chain of the agricultural food based on the predict model was shown as figure 4, compared with the basic model of the general quality security management of the agricultural food supply chain, this predict model increase predict content, detection results is more accurate, while reducing the dependency to suppliers' data.

shown in Figure 4, the agricultural supply chain quality and safety control mode, it should include the processing of agricultural food distribution center upstream supply chain quality and safety warning management and downstream supply chain quality and safety warning management Firstly, in the agricultural food distribution center we manage the safety and warning management to the food of the supply chain upstream suppliers: agricultural food distribution center will detect the food provided by the suppliers through microbial predict model, if the test results show that the microbial number and the shelf life differ with the data provided by the suppliers, we know there are two reasons:

First, in the course of the production and processing of agricultural food, existed microbial contamination, suppliers made a false report to the microbial detection value in agricultural food; Secondly, the conditions of the transportation and storage of agricultural food do not meet the standards, make microbial growth in excess of the standard.

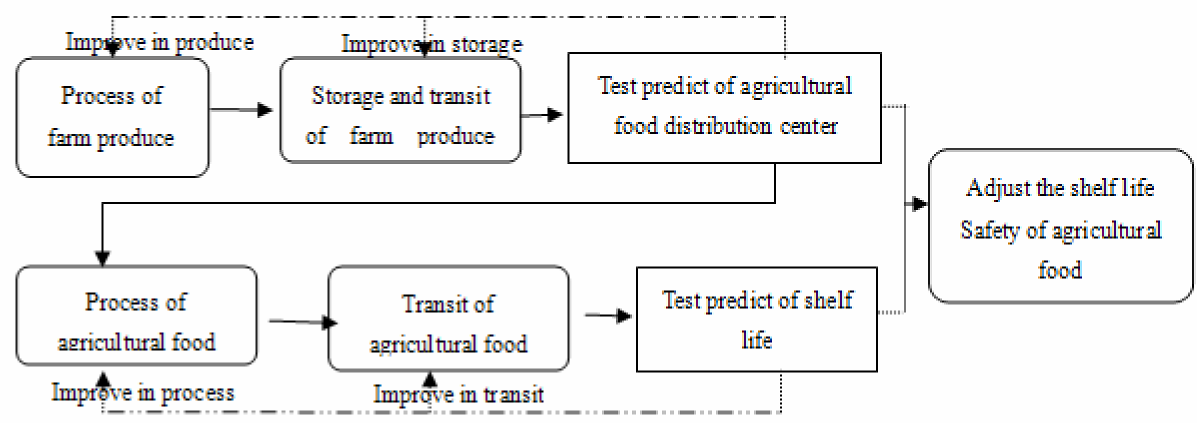

Figure 4 Prediction model based on the agricultural supply chain to control the quality and safety

For the first case, as long as told the environmental conditions and transport storage in the transport of agricultural food during storage, in a allowed error, using the formula (2), (3), (5) and (6) considering the factors of uncertainty, we can infer if the data the suppliers provided is accuracy; Similarly, if the inspected data is true, it can be speculated that the transport and storage conditions accord with the standard. The judgment process can be described as follows :

Supposed that when the supplier transport farm produce, the actual temperature is $T^{'}$, the standard temperature for the transport is T_0; the provided shelf life by the suppliers is t_0, re-measured by agricultural food distribution center is t; the length for a transportation experience is Δt, by formula (2) we can obtain the standard microbiological value N_0:

$$\ln N_0 = \ln N - \mu_0 t_0 \qquad (18)$$

Thereinto, N is the number of the microorganism when the shelf life of agricultural food reached the limit, μ_0 is the microbial growth rate which obtained by formula (3) in a way the standard temperature is T_0, According to the condition of the transport process and the value of microorganisms N_1 detected by the processing and distribution center, actual number of microorganisms $N_0^{'}$ is: $\ln N_0^{'} = \ln N_1 - \mu^{'} \Delta t$ (19)

Thereinto: $\mu^{'}$ is the growth rate of microbial when the temperature is $T^{'}$. The process can be deduced by Figure 5.

For the second reason or coexisted two reasons, make an accurate judgment not to obtain, because there will be an extension to the transport and storage conditions of agricultural food at normal circumstances, we can forecast the upper and lower limits of its shelf life and the number of microorganisms by the microbial predict model, it can be used to judge whether the supplier provide false information. Meanwhile agricultural retail enterprises should also focus on the investigate of the transport and storage conditions of agricultural food, possible to obtain accurate information, so the quality of the agricultural food supply will be effective protection through the application of appropriate scientific microbiology forecast.

5. CONCLUSIONS AND FURTHER RESEARCH

In this paper, based on the summary of some historic literature on food safe, we have studied how to warn and guarantee the quality and safe of the product supply chain from the point of view of the forecast for Microbiology. Considering the effect produced by the phasic variance of the product supply chain, we have proposed a model of microbe prediction and shelf life prediction. Moreover we have introduced Monte-Carlo method to simulate and estimate the parameters in this model. At last through this model we have analyzed the pattern of controlling the quality and safe of the product supply chain, which has showed that this research is also availability in practical application.

However, the research on the quality and safety of product in China still is a new field. In this paper, we have offered some methods of prediction and controlling the quality and safe of the product supply chain, while, admittedly, there are some defects, which should be researched and attested later. For example, failed to implement cost-benefit analysis of the predictive control to agricultural supply chain microbiological quality and safety; not consider interactions of Microbial death and survival and coexistence of various microbial. These factors will reduce the accuracy of the models; Estimating the prediction model parameters of Microorganisms by

Monte Carlo simulation process, we assumpted agricultural initial microbial parameters obey the probability distribution, Perhaps some specific agricultural type is not in keeping with their actual circumstances. And so on. All of these will be the further research work, but from the entire agricultural supply chain security management system perspective, the scientific implementation of the safety forecasting and control of agricultural food, not only provide consumers with a more secure environment and channels of purchasing agricultural food, but also enhance the control efforts of the agricultural quality safety management in the agricultural supply chain upstream and downstream links, help to build the credible and efficient supply chain system of the quality security of agricultural food.

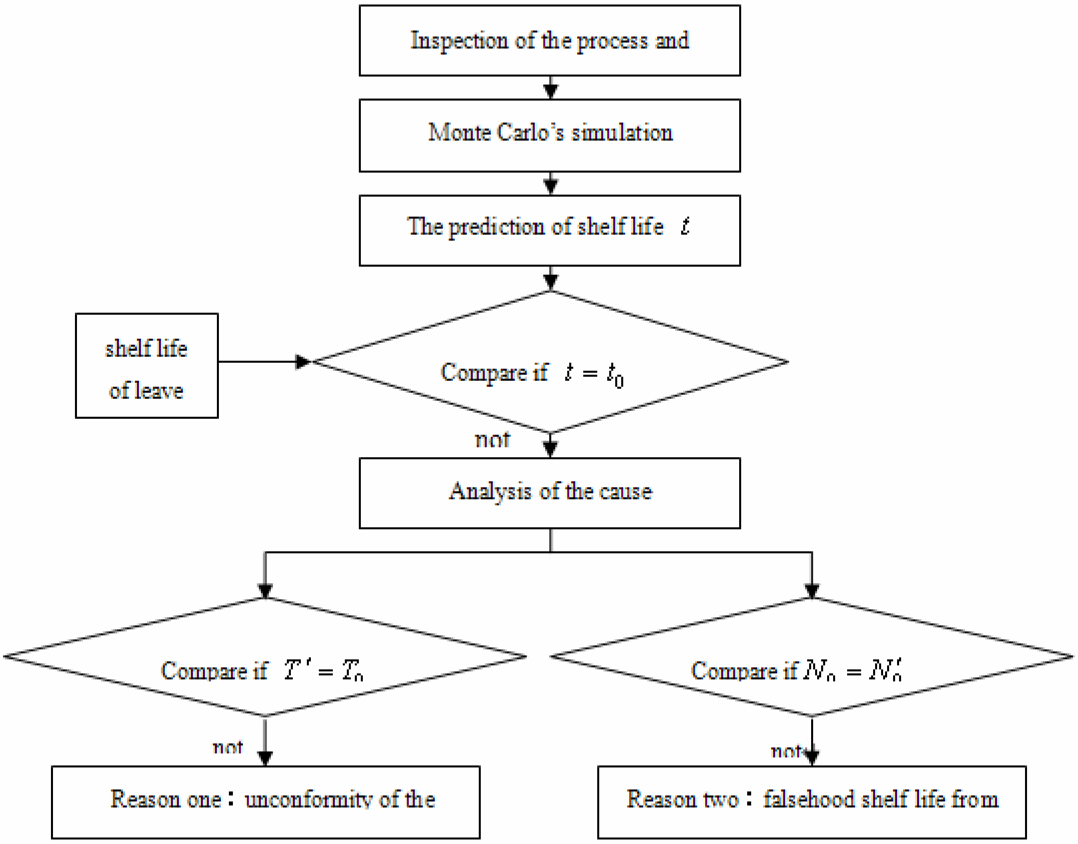

Figure 5 The flow chart of the conclude and analyse to the quality security of agricultural food

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