The Study on Packaged Food Shelf life Based on Back-Propagation (BP)

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Abstract: To predict shelf life of food products has been an important issue in the field of food science and packaging engineering. This article first analyzes the current studies on shelf life prediction, and points out that these evaluation systems are ineffective for their accuracy and practicability. Then artificial neural network methodology is introduced to predict shelf life, using BP network to establish a mathematical prediction model. Incorporation of various factors, including food product compositions, package properties, storage and logistics condition into a single model can be achieved when BP neural network is used. Its self-study and self-adjusting ability make the network can generalize their inherent laws from a large number given data automatically. The prediction results are closer to the actual dynamic environment because the BP model is highly adaptable to the changes of outer circumstances. In this article compared to existing models, BP model was proved to be a more simple, adjective and higher accuracy method for predicting shelf life. It will promote the development trend which to use computer method to cope with the study of food shelf life, and offer a new approach and idea for modeling theory of food's shelf life prediction.

Keywords: shelf-life prediction; dynamics methods; statistical methods; BP network

1. Introduction

Shelf life of food refers to the time when the quality of food is not acceptable to consumers anymore. It depends mainly on the food characteristics, package properties, and storage environment[1]. Because of its complexity, we need to establish a predicting model of shelf life which can connect multifarious factors has been becoming a most important topic.

2. Dynamic Models

The key of shelf-life prediction of food is the quality change. According to Labuza, the comprehensive effects of various factors cause the deterioration, and it follows the dynamic model:

$$\frac{dA}{dt} = f\left\{Cx, Ex\right\}$$

dA/dt is the rate of quality decrease; C_x is internal factors, including the concentrations of the reacting substances, microorganisms, catalyst, pH and Aw; E_x is external environmental factors, including temperature, RH, light, mechanical pressure and so on; First we should identify the main factors and metamorphic reactions, then based on test data, the relationship mode between storage-time and quality changes of food is simulated. The reaction order is defined and life-prediction models are built.

2.1. The Dynamic Models Based on Temperature

As temperature is concerned, different reaction orders correspond to different quality function. Two or three reaction rate constants K under different temperatures were calculated by the Arrhenius equation. Then a line graph is drawn which can describe the relationship of logK and the reciprocal of absolute temperature (1/T). According to this, reaction rates under any temperature can be gained. Then food shelf-life under different temperature is obtained by Q_{10} equation. As stated by Labuza (1982), shelf life of food also can be predicted by shelf-life drawing, which shows the relationship of the logarithmic form of shelf-life (log θ_s) and the relative temperature (℃). It could predict shelf life below 30℃.

Labuza (1982) published information about shelf-life of food, and provided the theoretical basis for shelf-life prediction. Zhang-Rang Han (1993) established a mathematical model to predict shelf-life from different aspects, such as breathability, moisture permeability, storage temperature, and microorganism[2]. Hui-Zhen Liao et al (1995, 1996) established the first-order equation of acid value and peroxide value to predict the shelf-life of vegetable oil, which combined theory with practice. Si-Ming Zhao et al (2002) created multiple models based on different elements, in order to improve the deficiency of dynamic model which can only reflect the impact of single-factor[3]. Jing Xie (2006) studied the quality changes of tomato under different temperature. Making use of the principal factor method of software, the selection of main effects was improved. Pearson correlation analysis was used to analyze the sensory factors and physical and chemical factors, then determined the quality indicators. These improvement provided scientific methods for conformation of main factors and selection of key indicators without subjective errors[4]. In the research of dynamic model of the crap shelf-life, Yi Tong et al (2009) improved the method to determine the reaction order of quality function. The zero-order equation, first-order equation were fitted based on several different indicators, then comparing the regression coefficients and fixing the series to establish the kinetic model of shelf life prediction.

Dynamic models of shelf-life prediction have experienced the development from theory to application then to performance improvement. In order to improve the model's accuracy and practicality, a variety of computer technology and mathematical methods were used, including analysis on multiple-target, optimization of the selection of main factors, correlation analysis of physical and chemical factors and the sensory factors. However, these models depended completely on temperature effects on product quality. But quality deteriorate mechanism don't follows a certain kind of kinetics regularity completely because of all sorts of factors work on food at the same time. And these models were based on laboratory conditions, single factor, resistant environment. In reality this is not the case. These also resulted in difficulties in practical application of shelf-life prediction model.

2.2. Adsorption Isotherm Model and Microbial Growth Model

In addition to temperature, the relative humidity and microbial effects can not be ignored. For low-moisture food products, Adsorption isotherm model was need for shelf-life prediction. Shelf life can be calculated according to the isothermal model and breathable mechanism. For the product which quality losses were caused by microorganism, microbial growth model was needed. The relationship between the temperature, pH, water activity, preservatives and other environmental factors with microbiology was integrated in mathematical model. It can determined the main pathogens, the dynamic changes of the death, surviving and proliferation of spoilage with the help of computer and software supporting, and then to make a rapid assessment on food safety.

Jin-Jian Yang et al (1996) studied on the nonlinear isotherm of donuts according to Fick's law of diffusion and the permeability of packaging materials, moisture content of donuts was simulated under the constant temperature and humidity condition[5]. Mei Feng (1999) studied the shelf-life prediction model of low-moisture packaged food[6]. Wei-Xian Xiang (2003) researched the models for predicting the moisture resistant packaging based on moisture permeability and permeability rate respectively. Lu Lixin et al (2007~2008) researched the shelf life of soft-plastic packaged of green tea and cookie. Four classical models of absorption isotherm was fitted based on experimental data by Matlab, then determined the most accurate one according the related parameters and established the forecast models[7]. Wen-Gu Li (2005) generalized the classification and development of microbial models in the "predictive microbiology and its application in food science". And described applications of microbial models in food industry[8]. Zhen-Jiang Fan et al (2007) established the Gompertz model by DPS software based on the total number of bacteria during the lotus' storage. The experimental results showed that this model can predict the shelf life of lotus root quickly and effectively[9].

In the development of adsorption isotherm model, researchers focus on how to select an appropriate model to describe the moisture absorption characteristics of the particular food. With the rapid development of computer technology, the selection of adsorption isotherm model has been more simple and scientific, using the various computer languages to fit moisture isotherm. But this kind of model considered only the characteristic of moisture absorption at the expense of ignoring the changes of water content during logistics process. Additionally its single factor function has limited its practical applications. And the microbial growth model only applies to the product on which the microorganism takes effect.

3. Statistical Methods (Weibull Hazard Analysis)

Weibull hazard analysis (WHA) is a statistical method which can predict shelf life of product directly. A simple question, "This product can also be accepted?" was asked in the questionnaire. Generally, in the research of shelf-life prediction, weibull hazard analysis will be combined with the physiochemical index which can explain the process of quality changes. It is seen as feasible, economic, scientific method.

Weibull model was introduced into food industry by Gacula in 1975, after that, it has been used on luncheon meat, oats, ice-cream, cheese, butter, milk, coffee etc. Ling Liu (2004) introduced the accelerated destructive test and Weibull sensory analysis from the theoretical standpoint. Jing Xie (2005) established a model to predict the shelf life of Con under different temperature by weibull analysis. Linear regression equations based on data of sensory evaluation and time was established, then obtain the cut-off point of the end of shelf life, which provided the data and theoretical supports for prediction of shelf-life[10]. Mei-Juan Ruan (2005) established a dynamic model and a weibull model to predict the shelf life of high-performance hard tack, and the results showed that the weibull hazard analysis on shelf life was better. Ping Cao et al (2007) predicted the shelf life of UHT milk by weibull analysis based on non-sensory evaluation data. The method of ASLT was used in this study, and the results of weibull method and ASLT method were consistent, which explained the weibull method was available on UHT milk.

In current study, however, WHA only can process the organoleptic data of food, but can not be used to analyze

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chemical and microbiological data. Therefore, there is limit in the application. It can only reflect on the role of microorganisms. What's more, this method is end points assessed, not a dynamic process of quality changes.

4. BP Artificial Neural Network Methods

The artificial neural network (ANN) analysis is a method of data analysis, which is to emulate the brain's way of work. The most powerful potential of the ANN is its nonlinear processing. It is actually a complex network which is connected by a large number of elementary units called neurons. One neuron model describes how to turn his input vector to output vector. The conversion process is seen as a calculation from the angle of mathematics. In other words, the essence of artificial neural networks reflects a function between the input and the output.

4.1. The Work Principle

Back-Propagation Network (BP network) is the most essential and widely-used part of ANN. It can use the input/output data that consistent with actual process to train the structure of neural network, so that the relationship between input and output has the same external characteristics as the recognition process. The training process is known as BP algorithm, which is a supervised learning algorithm. The whole process is divided into two phases. The first stage is to enter a pair of training samples, according to the structure of network and the weight and the threshold of the previous iteration, the output is calculated from the first layer to the back. The second stage is to modify the weights and thresholds. Compared the target vector and the output of network, then the effects on the total error because of the weights and thresholds were evaluated from the last layer back to the front, the modifications of the weights and thresholds were achieved. The above two processes alternately repeatedly until it reaches convergence.

4.2. The Advantages of BP Network

On the studies of shelf-life prediction, the advantages of the BP network can compensate the shortage of existing models. And have a further development in accuracy and practical application of life-prediction models.

- high parallelization
  ANN was composed by a large number of neurons in parallel. The function of each neuron is simple, but the ability of processing information is amazing due to its characteristics of parallelism. The current prediction models only can explain the single factor which plays important role in quality deterioration. For this reason, effects of one factor was enlarged, and there is a hypothetical case generally that other factors are constantly stable even ignoring other factors. This is only applicable to the specific conditions, the availability is limited obviously. So how to incorporate various factors into a single model is becoming a hard task. Then the high parallelization of BP network offers the solutions to the problem. The various influence factors including food product composition, package properties, and storage condition can be treated as input and shelf life of food as output. Through training, BP network can converge an accurate function showing the input-output relationship. In this way, various factors were integrated into a single model.
- high non-linear global role
  Each neuron of BP network will receive a large number of inputs from others and product outputs though parallel network, each output will affect other neurons in the same layer. The interconstraint and inter-impact of network have achieved the nonlinear mapping from input to output space. From the global point of view, the overall performance of the network is not a simple superposition of partial properties, but a collective behavior. In other words, the neurons of ANN accept information form the front layer, which have been weighted and imitated the comprehensive action of multi-factors. Such as the processing of food quality deterioration, not an isolated reaction but multiple physical, chemical and microbiological reaction simultaneously which caused the spoilage of food. And there have different influences with different factors. The cooperative actions of BP network have got over the shortcoming of the traditional prediction model that only can describe the single factor's effect on shelf life. Its working principle reflects comprehensive roles on outputs from every input element. It is closer to the actual logistics processing and reflect the quality changes more really.
- strong learning ability and adaptability
  BP network can obtain the weights and structure by training and learning, and showing a strong self-learning and adaptive ability to the environment. Though learning and training, the network can catch the regular between the inputs and outputs automatically, and then verify other samples using this law. It makes the network own the generalization capability. Then prediction model is still applicable when environmental conditions changed.

Ubonrat Siripatrawan, Pantipa Jantawant et al (2006) established a prediction model using a three-layer BP network to predict the number of Escherichia coli of packaged alfalfa. The transfer function in the hidden layer was sigmoid activation function and a linear function was used in the output layer. The correlation coefficient, R^2, between the outputs and targets is up to 0.903, which proved BP network has a good predictive ability. A.Sofu, F.Y.Ekinci et al (2007) determined the shelf life of yogurt using BP model. The input variables of the network were PH, total aerobic, yeast, mold, and color analysis values measured by the machine vision system. The output variable was the shelf life of yogurt. And the correlation coefficient, R^2, was 0.9996, showing the advantage in predictive ability[11]. Pantipa Jantawat (2008) used the ANN based on multilayer perceptions with BP algorithm to predict the shelf life of packaged rice snack. Many factors could be incorporated into the model including food characteristics, package properties, and storage environments. Compared with traditional prediction models, BP model was more accurate and convenient[12].

5. Conclusion

Data acquisition is more rapid and reasonable; analytical model is closer to actual truth; Consequently the prediction is more accurate. All above is needed for the development of shelf life prediction. BP network can meet these requirements exactly. It can take more factors into account on the comprehensive impacts. It also can simulate the actual logistics because of its learning ability and self –organization feature. BP network provide a new ideas and methods to predict the shelf life of food, and the liveliness was poured into the field of Food Science and Packaging Engineering.

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