

Research Article

Abalone Muscle Texture Evaluation and Prediction Based on TPA Experiment

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The effects of different heat treatments on abalones' texture properties and sensory characteristics were studied. Thermal processing of abalone muscle was analyzed to determine the optimal heat treatment condition based on fuzzy evaluation. The results showed that heat treatment at 85°C for 1 hour had certain desirable effects on the properties of the abalone meat. Specifically, a back propagation (BP) neural network was introduced to predict the equations of statistically significant sensory hardness, springiness, and smell using the texture data gained through TPA (texture profile analysis) experiments as input and sensory evaluation data as the desired output. The final outcome was that the predictability was proved to be satisfactory, with an average error of 6.93%.

1. Introduction

Abalone, a kind of edible sea snail, is a highly prized and expensive ingredient in Chinese cuisine. The most common variety is *Haliotis discus hannai* Ino, found in northern China [1]. The species, which contains protein, fat, vitamins, glycogen, and many other trace elements, has high nutritional value and is widely used in healthcare [2, 3]. With the recent improvements in living standards, abalone represents an increasingly large proportion of individuals' dietary structure, leading to increasing demand for its texture. Under thermal processing conditions, we should be able to effectively extend the storage period for abalone processing [4].

At present, research into the heat treatment of abalone meat is mainly focused on the sensory evaluation and texture analyzer evaluation methods. The former, which involves the use of human sensory organs, is a relatively accurate texture evaluation method. However, the application of abalone in sensory evaluation is time-consuming, laborious, and prone to errors and omissions. The TPA experimental method is used to evaluate the physical or mechanical indicators of food via a texture analyzer that establishes the relationship between the test signal and the texture parameters to analyze

the food texture. Although the method is fairly objective, the result is far removed from expectations because of the different structures of instrumental and human masticatory organs.

In recent years, with the rapid development of electronic technology, increasing numbers of researchers are beginning to apply electronic sensing technology to the texture analysis of food, including electromyography and the piezoelectric-film sensor [5]. At the same time, many kinds of bionic equipment have been emerging, such as the electronic tongue, which are able to simulate human perception methods for testing [6]. However, these methods are expensive and complicated and therefore do not align with the requirements of enterprise.

Instead, for this paper, the texture parameters of springiness, hardness, chewiness, and resilience of abalone were measured using a texture analyzer. The effects of different heat treatment conditions on abalones' texture properties and sensory characteristics were analyzed. To attain the optimal condition, the researcher used the method of setting up a fuzzy matrix. In addition, an objective, fast, and accurate evaluation model for abalone quality was designed, based on the BP artificial network.

TABLE 1: Factors and levels table for experimental design.

S/N	$T/^\circ\text{C}$	t/min
1	60	15
2	60	30
3	60	60
4	60	120
5	60	240
6	60	360
7	80	15
8	80	30
9	80	60
10	80	120
11	80	240
12	80	360
13	85	15
14	85	30
15	85	60
16	85	120
17	85	240
18	85	360
19	90	15
20	90	30
21	90	60
22	90	120
23	90	240
24	90	360
25	100	15
26	100	30
27	100	60
28	100	120
29	100	240
30	100	360

2. Materials and Methods

2.1. Experimental Materials. Fresh abalones (*Haliotis discus hannai* Ino) were purchased from the Dalian seafood market, weighing 70 ± 5 g (including shell) and measuring 8 ± 1 cm in length. Similar-sized specimens were selected and immediately sent to the laboratory. After the shells and viscera were removed, the abalone meat was kept in icy water prior to the experiments [4].

2.2. Abalone Treatment. The abalone meat was divided into 5 groups for the experiment, each of which would be subjected to a different processing temperature. The meat was set to the power of a 1500 W thermostat in a water bath (HH-4 Changzhou Rui Zhibo equipment manufacture Co. Ltd.) and conducted at 60, 80, 85, 90, and 100°C for 15, 30, 60, 120, 240, and 360 min, respectively [7]. The processing of the meat in the water bath is shown in Figure 1. In addition, an experiment table containing 30 sets of experiments is shown in Table 1.



FIGURE 1: The thermal processing of abalone meat.



FIGURE 2: The texture analyzer.

2.3. Texture Profile Analysis (TPA). Following the heat treatments, the abalone meat was cooled at room temperature for 20 min before starting the experiments. Cylindrical samples of 1.2 cm (diameter) \times 1 cm (height) were cut from the middle of the meat for textural analyses [1]. The upper surface of the sample was the stress surface, which is perpendicular to the muscle fiber. Whole abalone meat was packed in plastic bags, and each sample was set with 5 replicate samples. Using the effect of the height of the sample on the process of sample preparation, the data for the highest and lowest were abandoned and the other data were averaged as the final result of the TPA parameters.

The texture properties of the abalone meat were measured using a texture analyzer (FTC, Virginia, USA), fitted with a P/100 probe. The samples were placed on the texture analyzer according to their number. Each sample underwent 2 cycles of compression analysis with a compression level of 75% (relative to sample height), with a 60 mm/min test speed and 0.1 N trigger stress [7]. TPA parameters were evaluated by analyzing the force-displacement curve, including hardness (HN), springiness (SN), chewiness (CW), and resilience (RN). Figure 2 shows the texture analyzer used for the experiment.

2.4. Sensory Fuzzy Comprehensive Evaluation

2.4.1. Establishing the Evaluation System

(1) Establishing Factor Set U . The factor set, a set of indicators that affect the quality of the subject being judged, is expressed as $U = (u_1, u_2, \dots, u_m)$. When people chew abalone, its springiness, hardness, and smell are the most direct sensory indicators with which they evaluate it. In this paper, the factor

TABLE 2: Sensory index criterion of abalone meat.

Sensory score	5	4	3	2	1
Springiness	Very good	Good	Moderate	Bad	Very bad
Hardness	Moderate	A little hard	Hard	A little soft	Soft
Smell	Rich aroma	Moderate aroma	A little aroma	No aroma	Fishy smell

collection, composed of three indicators, was identified as $U = (\text{springiness } u_1, \text{hardness } u_2, \text{smell } u_3)$.

(2) *Establishing Evaluating Index Set V* . The evaluation set is the collection of quality levels of the evaluated object, which is expressed as $V = (v_1, v_2, \dots, v_i, \dots, v_m)$ (m are positive integers with $2 < m < 8$) [8]. V is the evaluation set and v_i is the evaluation of grade i . In this experiment, $m = 5$ was selected, which established the evaluation set of the abalone as $V = (v_1, v_2, v_3, v_4, v_5)$. v_1 is 1 point, representing very bad; v_2 is 2 points, representing bad; v_3 is 3 points, representing moderate; v_4 is 4 points, representing good; v_5 is 5 points, representing very good.

2.4.2. *Sensory Evaluation of Abalone*. A total of 30 people were invited to form a sensory evaluation team. The oral health status and sensory evaluation interest of the participants were discerned via a questionnaire. Finally, 11 team members consisting of 6 men and 5 women with good distinctions and descriptive abilities were selected for training through a detailed test, including 4 elderly people with an average age of 65, 4 middle-aged men with an average age of 38, and 3 adolescents.

The sensory evaluation was conducted by 11 selected members from the sensory evaluation team, using the double-blind method [9]. The sensory hardness, sensory springiness, and smell of the abalone meat were evaluated on a 5-point scale. The sensory evaluation index criterion is shown in Table 2.

The evaluation team evaluated the sensory parameters of abalone, and the results were processed using the normalization method. Finally, the matrix R (fuzzy relation matrix) was obtained [8].

2.4.3. *Establishing Factor Weight Set a* . According to their evaluation experience, 5 professional teachers were invited to state the membership degree that the impact of the 3 indicators had on sensory evaluation. The membership degree was limited to a range from 0 to 1, before normalization processing was carried out [10]. We could calculate the average value as a power vector in a fuzzy comprehensive evaluation, represented as $a = (a_1, a_2, \dots, a_i, \dots, a_m)$ (m represents the number of evaluation indicators).

2.4.4. *Establishing the Fuzzy Comprehensive Evaluation Model*. The fuzzy matrix composite operator is the key to establishing a comprehensive evaluation model that contains 4 of the most important basic operations. For this paper, the best operator of fuzzy transformation was selected $M(\cdot, \dot{+})$ [11].

The formula for the calculation was as follows:

$$b_j = \sum_{i=1}^p a_i r_{ij} \quad (j = 1, 2, 3, \dots, m), \quad (1)$$

where

j is sample evaluation grade,

m is number of sample evaluation grades,

b_j is fuzzy synthesis evaluation result, vector b ,

p is number of evaluation indicators,

r_{ij} are elements of column j of line i of matrix,

a_j is the membership of the first i element of weight vector a .

2.4.5. *Optimization of Heating Conditions*. The row vector b_j and column vector v_i were multiplied to calculate sensory evaluation scores, marked as A . The evaluation value of A as the heat treatment condition was analyzed to determine the optimum thermal processing condition for abalone meat.

The scoring formula was

$$A_j = \sum_{i=1}^m v_i b_j \quad (j = 1, 2, 3, \dots, 20, m). \quad (2)$$

By comparing the evaluation values (A_j) of 30 heat treatment conditions, the optimal heat treatment condition was determined.

2.5. *Neural Network Analysis*. The ANN (artificial neural network) is an information processing system modeled on the human brain's structure and function. More than 40 types of neural network model are used frequently, which can be classified as the Hopfield network, BP neural network, RBF network, and so on [12]. The BP neural network, a kind of widely used forward neural network, contains many layers of networks, including input, concealing, and output layers.

2.5.1. *Establishing the Texture Evaluation Model*. This network was used to establish the prediction equations of sensory parameters, with the texture data by TPA experiments as the input and sensory evaluation data as the desired output. The TPA parameters of springiness, hardness, chewiness, and resilience were selected as the input layer neurons, while the sensory evaluation parameters of sensory hardness, sensory springiness, and smell were the output layer neurons.

The parameters of the training model were as follows: the allowable error was 1×10^{-6} , the learning rate was around 0.01, the dynamic constant was roughly 0.8, and the maximum number of iterations was approximately 1000 [13].

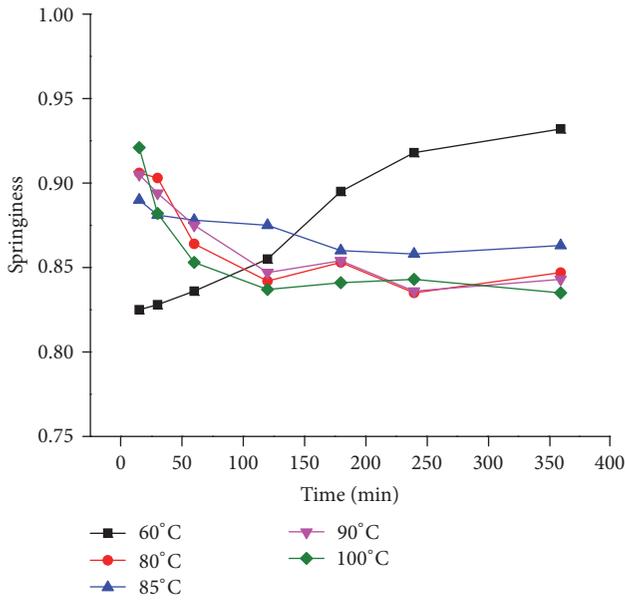


FIGURE 3: Springiness changes during thermal processing.

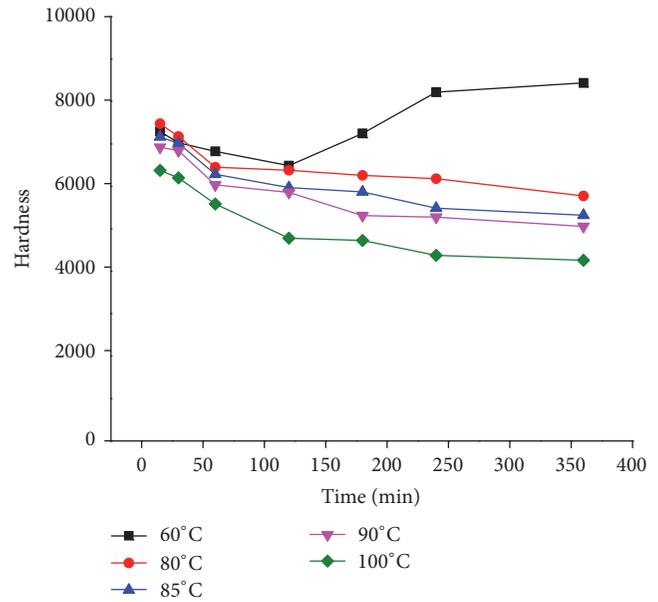


FIGURE 4: Hardness changes during thermal processing.

2.5.2. Validation of Predictive Texture Model. The 12 groups of abalone of nontraining set were randomly evaluated using the constructed neural networks, while being compared with their sensory evaluation results to analyze the rationality of the neural network.

3. Results and Analysis

3.1. Effects of Different Heating Conditions on Abalone Texture

3.1.1. Effects on Springiness. Figure 3 shows the change to the abalone meat's springiness under different heat treatments. The springiness continued to increase after cooking at 60°C before 120 min, with a slight increase from 120 to 360 min. A sharp reduction was observed in meat treated at 80, 90, and 100°C before 120 min, but no significant decrease was seen after 120 min. However, similar results were not observed at 85°C, at which the springiness had not significantly decreased.

3.1.2. Effects on Hardness. Hardness is another textural property of great importance because it can help determine the extent to which consumers accept abalone meat. The change in hardness over time under different heating treatments is shown in Figure 4. The hardness continued to decrease after cooking at 60, 80, 85, 90, and 100°C before 120 min, with the most obvious change seen at 100°C. In addition, it was found that the higher the heating temperature, the more obvious the tendency to reduce the hardness. A slow reduction in hardness was observed in abalone meat treated at 80, 85, 90, and 100°C from 120 to 360 min, but a different result was seen at 60°C. At that temperature, a clear increase in hardness was seen, which was enhanced to the maximum level at 360 min.

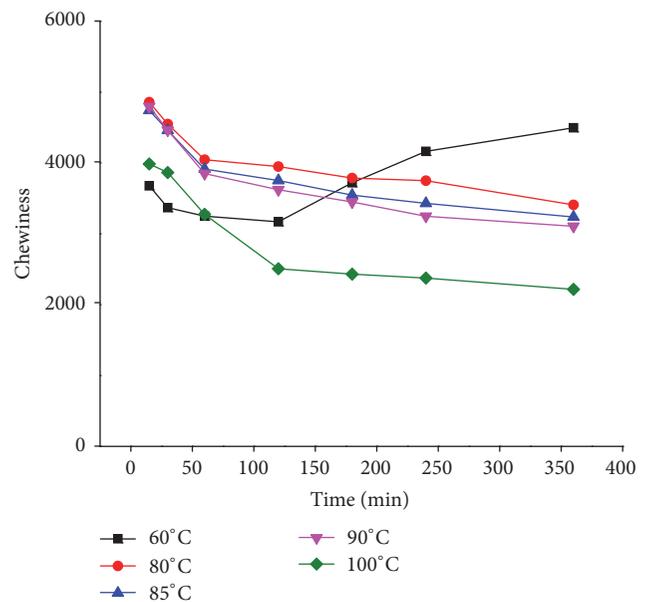


FIGURE 5: Chewiness changes during thermal processing.

3.1.3. Effects on Chewiness. The change in the chewiness was similar to that of the hardness, as shown in Figure 5. The chewiness continued to decrease after cooking at 80, 85, 90, and 100°C before 120 min, with the most obvious change at 100°C. Although the chewiness decreased slowly at 60°C before 120 min, it then increased rapidly as the time was extended until reaching the maximum. Another finding was that the higher the heating temperature, the more obvious the tendency for the chewiness to be reduced. A slow reduction in chewiness was observed in abalone meat treated at 80, 85, 90, and 100°C from 120 to 360 min.

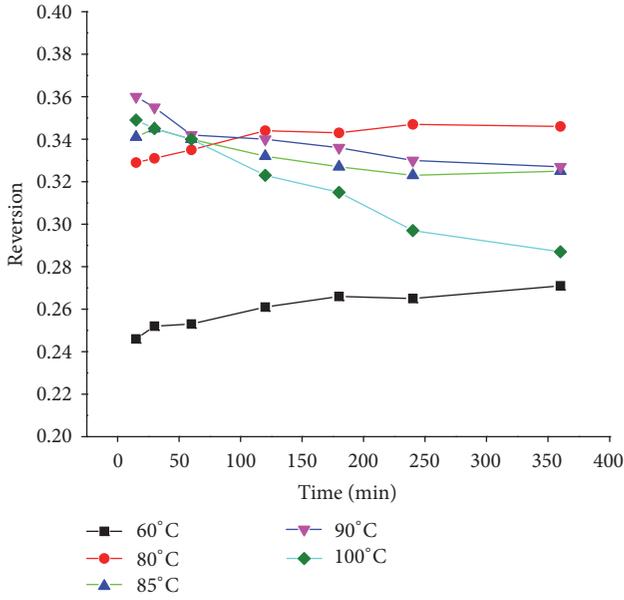


FIGURE 6: Reversion changes during thermal processing.

3.1.4. *Effects on Reversion.* The change in the reversion over time under different heating conditions is shown in Figure 6. The minimum value of reversion was observed at 60°C; it then increased gradually at higher temperatures. The reversion continued to reduce after cooking at 85 and 90°C but decreased significantly at 100°C. A slow increase was observed at 80°C and it continued to rise slightly until 120 min had elapsed.

3.1.5. *Effects of Low Temperature Heating.* As can be seen from the diagram, compared with the higher heating temperature, the springiness, hardness, chewiness, and reversion tended to be abnormal at 60°C. The abnormal phenomena may be explained by its microstructure and chemical forces. Although the samples' pores became smaller at 60°C, their network structure becomes very loose compared to unprocessed abalone, resulting in low hardness, springiness, reversion, and chewiness. When the heating time reached 120 min, the pore structure of the network continues to become smaller and the network structure becomes a honeycomb [14, 15]. The tighter network structure of the honeycomb can increase the abalone's springiness, hardness, chewiness, and reversion.

As the heating time was gradually extended, the chemical forces between protein molecules were destroyed. The mercapto group was exposed to oxidization by disulfide bonds, resulting in complete denaturation and aggregation of the protein, which formed a newly ordered 3-dimensional network structure wherein springiness, hardness, chewiness, and reversion moved towards stability [14].

3.2. Sensory Fuzzy Comprehensive Evaluation

3.2.1. *Establishment of Fuzzy Evaluation Matrix.* 11 selected persons from the sensory evaluation team evaluated the springiness, hardness, and smell of the abalone meat samples.

Taking sample 1 as an example, the distribution of votes is shown in Table 5. After normalizing the evaluation results, the corresponding fuzzy matrix R_1 was observed. The fuzzy matrix of sample 1 is shown below.

$$R_1 = \begin{bmatrix} c_{11} & c_{12}c_{13} & c_{14}c_{15} \\ c_{21} & c_{22}c_{23} & c_{24}c_{25} \\ c_{31} & c_{32}c_{33} & c_{34}c_{35} \end{bmatrix} = \begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.4 & 0.1 \\ 0.1 & 0.3 & 0.4 & 0.1 & 0.2 \\ 0 & 0.1 & 0.1 & 0.3 & 0.6 \end{bmatrix}. \quad (3)$$

The fuzzy matrices of the other samples could be obtained by the same method, as shown below.

$$R_2 = \begin{bmatrix} 0 & 0.3 & 0.4 & 0.4 & 0 \\ 0.2 & 0.2 & 0.4 & 0.1 & 0.2 \\ 0 & 0.0 & 0.2 & 0.5 & 0.4 \end{bmatrix},$$

$$R_3 = \begin{bmatrix} 0.1 & 0.4 & 0.4 & 0.4 & 0 \\ 0.4 & 0.2 & 0.4 & 0.1 & 0.2 \\ 0 & 0 & 0.2 & 0.5 & 0.4 \end{bmatrix},$$

$$R_4 = \begin{bmatrix} 0.1 & 0.2 & 0.3 & 0.3 & 0.2 \\ 0.2 & 0.3 & 0.4 & 0.2 & 0 \\ 0 & 0.1 & 0.3 & 0.6 & 0.1 \end{bmatrix},$$

$$R_5 = \begin{bmatrix} 0.1 & 0.4 & 0.2 & 0.4 & 0 \\ 0.2 & 0.3 & 0.5 & 0.1 & 0 \\ 0 & 0.2 & 0.3 & 0.4 & 0.2 \end{bmatrix},$$

$$R_6 = \begin{bmatrix} 0.2 & 0.1 & 0.3 & 0.3 & 0.2 \\ 0.4 & 0.1 & 0.3 & 0.2 & 0.1 \\ 0 & 0.1 & 0.4 & 0.4 & 0.2 \end{bmatrix},$$

$$R_7 = \begin{bmatrix} 0.2 & 0.2 & 0.3 & 0.3 & 0.1 \\ 0.2 & 0.1 & 0.5 & 0.2 & 0.1 \\ 0.1 & 0.1 & 0.2 & 0.4 & 0.3 \end{bmatrix},$$

$$R_8 = \begin{bmatrix} 0.1 & 0.4 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.4 & 0.3 & 0.3 & 0 \\ 0.2 & 0.1 & 0.2 & 0.5 & 0.1 \end{bmatrix},$$

$$R_9 = \begin{bmatrix} 0.3 & 0.4 & 0.2 & 0.2 & 0 \\ 0.4 & 0.3 & 0.2 & 0.2 & 0 \\ 0.4 & 0.4 & 0.2 & 0.0 & 1 \end{bmatrix},$$

$$R_{10} = \begin{bmatrix} 0.1 & 0.5 & 0.3 & 0.1 & 0.1 \\ 0.4 & 0.1 & 0.3 & 0.2 & 0.1 \\ 0.1 & 0.5 & 0.2 & 0.3 & 0.1 \end{bmatrix},$$

$$R_{11} = \begin{bmatrix} 0.1 & 0.5 & 0.3 & 0.2 & 0 \\ 0.4 & 0.2 & 0.3 & 0.1 & 0.1 \\ 0.5 & 0.3 & 0.1 & 0.1 & 0.1 \end{bmatrix},$$

$$R_{12} = \begin{vmatrix} 0.1 & 0.3 & 0.3 & 0.2 & 0 \\ 0.3 & 0.2 & 0.3 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.1 \end{vmatrix},$$

$$R_{13} = \begin{vmatrix} 0.1 & 0.3 & 0.4 & 0.3 & 0 \\ 0.2 & 0.3 & 0.5 & 0.1 & 0 \\ 0 & 0.1 & 0.2 & 0.6 & 0.2 \end{vmatrix},$$

$$R_{14} = \begin{vmatrix} 0.1 & 0.5 & 0.2 & 0.3 & 0 \\ 0.2 & 0.7 & 0.1 & 0.1 & 0 \\ 0 & 0.2 & 0.4 & 0.5 & 0 \end{vmatrix},$$

$$R_{15} = \begin{vmatrix} 0.3 & 0.3 & 0.4 & 0.1 & 0 \\ 0.4 & 0.3 & 0.3 & 0.1 & 0 \\ 0.4 & 0.4 & 0.3 & 0 & 0 \end{vmatrix},$$

$$R_{16} = \begin{vmatrix} 0.2 & 0.3 & 0.3 & 0.1 & 0.2 \\ 0.5 & 0.3 & 0.2 & 0.1 & 0 \\ 0.1 & 0.5 & 0.3 & 0.2 & 0 \end{vmatrix},$$

$$R_{17} = \begin{vmatrix} 0.1 & 0.2 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.5 & 0.1 & 0.2 & 0 \\ 0.2 & 0.4 & 0.2 & 0.3 & 0 \end{vmatrix},$$

$$R_{18} = \begin{vmatrix} 0.1 & 0.4 & 0.4 & 0.2 & 0 \\ 0.3 & 0.3 & 0.3 & 0.2 & 0 \\ 0.3 & 0.2 & 0.4 & 0.1 & 0.1 \end{vmatrix},$$

$$R_{19} = \begin{vmatrix} 0.1 & 0.4 & 0.4 & 0.1 & 0.1 \\ 0.5 & 0.1 & 0.3 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.2 & 0.5 & 0.2 \end{vmatrix},$$

$$R_{20} = \begin{vmatrix} 0.1 & 0.4 & 0.4 & 0.1 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.3 & 0 \\ 0.1 & 0.2 & 0.4 & 0.2 & 0.2 \end{vmatrix},$$

$$R_{21} = \begin{vmatrix} 0.2 & 0.4 & 0.3 & 0 & 0.2 \\ 0.5 & 0.3 & 0.2 & 0.1 & 0 \\ 0.3 & 0.4 & 0.2 & 0.2 & 0 \end{vmatrix},$$

$$R_{22} = \begin{vmatrix} 0.1 & 0.4 & 0.2 & 0.3 & 0.1 \\ 0.4 & 0.2 & 0.3 & 0 & 0.2 \\ 0.1 & 0.3 & 0.4 & 0.2 & 0.1 \end{vmatrix},$$

$$R_{23} = \begin{vmatrix} 0.1 & 0.3 & 0.2 & 0.4 & 0.1 \\ 0.4 & 0.3 & 0.1 & 0.2 & 0.1 \\ 0.5 & 0.3 & 0.1 & 0.2 & 0.1 \end{vmatrix},$$

$$R_{24} = \begin{vmatrix} 0.2 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0.3 & 0.1 & 0.4 & 0 & 0.2 \\ 0.1 & 0.1 & 0.2 & 0.5 & 0.1 \end{vmatrix},$$

TABLE 3: Membership grades of different evaluation indices.

	u_1	u_2	u_3
Expert 1	0.53	0.51	0.27
Expert 2	0.46	0.41	0.32
Expert 3	0.39	0.49	0.28
Expert 4	0.54	0.37	0.33
Expert 5	0.47	0.44	0.29

TABLE 4: Normalization results of the membership grade.

	u_1	u_2	u_3
Expert 1	0.405	0.389	0.206
Expert 2	0.387	0.345	0.268
Expert 3	0.336	0.422	0.241
Expert 4	0.435	0.298	0.267
Expert 5	0.392	0.366	0.242
Average value	0.391	0.364	0.245

$$R_{25} = \begin{vmatrix} 0.1 & 0.3 & 0.2 & 0.2 & 0.1 \\ 0.2 & 0.4 & 0.3 & 0.2 & 0 \\ 0.2 & 0.2 & 0 & 0.5 & 0.2 \end{vmatrix},$$

$$R_{26} = \begin{vmatrix} 0.2 & 0.4 & 0.2 & 0.2 & 0.1 \\ 0.4 & 0.3 & 0.3 & 0.1 & 0 \\ 0.2 & 0.2 & 0.3 & 0.4 & 0 \end{vmatrix},$$

$$R_{27} = \begin{vmatrix} 0.1 & 0.4 & 0.3 & 0.2 & 0.1 \\ 0.4 & 0.1 & 0.4 & 0 & 0.2 \\ 0.1 & 0.5 & 0.2 & 0.1 & 0.2 \end{vmatrix},$$

$$R_{28} = \begin{vmatrix} 0.1 & 0.3 & 0.5 & 0.1 & 0.1 \\ 0.4 & 0.1 & 0.4 & 0.2 & 0 \\ 0.1 & 0.5 & 0.2 & 0.2 & 0.1 \end{vmatrix},$$

$$R_{29} = \begin{vmatrix} 0.2 & 0.2 & 0.4 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0 & 0.2 \\ 0.1 & 0.4 & 0.4 & 0.1 & 0.1 \end{vmatrix},$$

$$R_{30} = \begin{vmatrix} 0.1 & 0.2 & 0.6 & 0.2 & 0 \\ 0.2 & 0.1 & 0.5 & 0.1 & 0.2 \\ 0.3 & 0.2 & 0.3 & 0.2 & 0.1 \end{vmatrix}.$$

(4)

3.2.2. *Fuzzy Weight Vector of Evaluation Index.* The membership grades of different evaluation indices were given by professional teachers, as shown in Table 3. The normalized results are shown in Table 4.

As can be seen from Table 4, the weight vector in the fuzzy comprehensive evaluation was $a = (0.391, 0.364, 0.245)$.

TABLE 5: Vote distributions of sensory evaluation of sample 1.

Index set	Evaluation set				
	v_1	v_2	v_3	v_4	v_5
u_1	1 (c_{11})	2 (c_{12})	3 (c_{13})	4 (c_{14})	1 (c_{15})
u_2	1 (c_{21})	3 (c_{22})	4 (c_{23})	1 (c_{24})	2 (c_{25})
u_3	0 (c_{33})	1 (c_{32})	1 (c_{33})	3 (c_{34})	6 (c_{35})

Note. C_{ij} ($i = 1, 2, 3; j = 1, 2, 3, 4, 5$) was the number of votes for the i factor as the j grade. Springiness was u_1 , hardness was u_2 , and smell was u_3 .

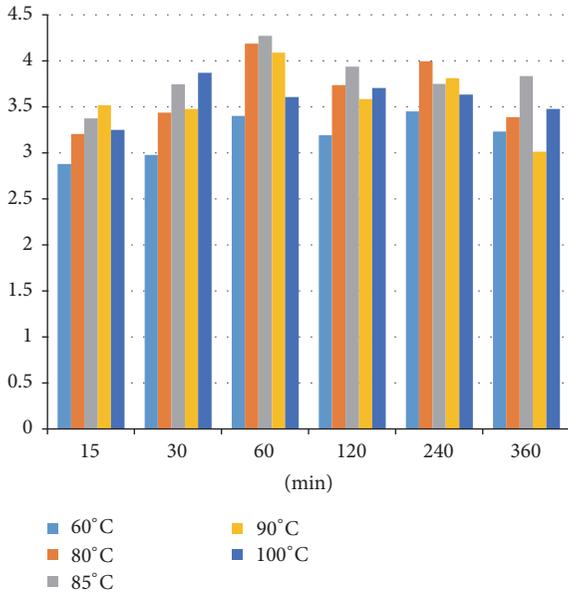


FIGURE 7: Comprehensive evaluation for the scores of abalone meat.

3.2.3. Fuzzy Transformation and Comprehensive Evaluation Results. The comprehensive evaluation results for sample 1 are as follows:

$$\begin{aligned}
 b_1 &= a \cdot R_1 = (a_1, a_2, a_3) \begin{vmatrix} 0.1 & 0.2 & 0.3 & 0.4 & 0.1 \\ 0.1 & 0.3 & 0.4 & 0.1 & 0.2 \\ 0 & 0.1 & 0.1 & 0.3 & 0.6 \end{vmatrix} \\
 &= (0.391, 0.364, 0.245) \begin{vmatrix} 0.1 & 0.2 & 0.3 & 0.4 & 0.1 \\ 0.1 & 0.3 & 0.4 & 0.1 & 0.2 \\ 0 & 0.1 & 0.1 & 0.3 & 0.6 \end{vmatrix} \quad (5) \\
 &= (0.0755, 0.2119, 0.2874, 0.2663, 0.2589).
 \end{aligned}$$

The results for the other samples are shown in Table 6.

Furthermore, we could attain sensory scores (A) corresponding to different heating conditions. The higher the sensory score, the higher the quality level. Specifically, a score of 2~3 was poor, 3~4 was average, and 4~5 was excellent. The results are shown in Figure 7.

Although the sensory evaluation scores for samples 9, 15, and 18 were, respectively, 4.19, 4.27, and 4.09, which are extremely excellent, most samples scored at the general level. However, sample 1 was the worst. Therefore, sample 9 can

TABLE 6: Fuzzy synthesis evaluation result.

SN	Fuzzy synthesis evaluation result
1	$b_1 = (0.0755, 0.2119, 0.2874, 0.2663, 0.2589)$
2	$b_2 = (0.0728, 0.1901, 0.351, 0.3153, 0.1708)$
3	$b_3 = (0.1847, 0.2537, 0.2755, 0.2517, 0.1344)$
4	$b_4 = (0.1119, 0.2119, 0.3364, 0.3371, 0.1027)$
5	$b_5 = (0.1119, 0.3146, 0.3337, 0.2908, 0.049)$
6	$b_6 = (0.2238, 0.1, 0.3245, 0.2881, 0.1636)$
7	$b_7 = (0.1755, 0.1391, 0.3483, 0.2881, 0.149)$
8	$b_8 = (0.1245, 0.3265, 0.2755, 0.3099, 0.0636)$
9	$b_9 = (0.3609, 0.3636, 0.2, 0.151, 0.0245)$
10	$b_{10} = (0.2092, 0.3544, 0.2755, 0.1854, 0.0755)$
11	$b_{11} = (0.3072, 0.3418, 0.251, 0.1391, 0.0609)$
12	$b_{12} = (0.1728, 0.2146, 0.3391, 0.2735, 0.1)$
13	$b_{13} = (0.1119, 0.251, 0.3874, 0.3007, 0.049)$
14	$b_{14} = (0.1119, 0.4993, 0.2126, 0.2762, 0)$
15	$b_{15} = (0.3609, 0.3245, 0.3391, 0.0755, 0)$
16	$b_{16} = (0.2847, 0.349, 0.2636, 0.1245, 0.0782)$
17	$b_{17} = (0.1973, 0.3582, 0.2809, 0.2245, 0.0391)$
18	$b_{18} = (0.2218, 0.3146, 0.3636, 0.1755, 0.0245)$
19	$b_{19} = (0.2456, 0.2173, 0.3146, 0.198, 0.1245)$
20	$b_{20} = (0.1364, 0.2782, 0.4, 0.1973, 0.0881)$
21	$b_{21} = (0.3337, 0.3636, 0.2391, 0.0854, 0.0782)$
22	$b_{22} = (0.2092, 0.3027, 0.2854, 0.1663, 0.1364)$
23	$b_{23} = (0.3027, 0.3, 0.1391, 0.2782, 0.1)$
24	$b_{24} = (0.2119, 0.1, 0.2728, 0.2789, 0.1755)$
25	$b_{25} = (0.1609, 0.3119, 0.1874, 0.2735, 0.0881)$
26	$b_{26} = (0.2728, 0.3146, 0.2609, 0.2126, 0.0391)$
27	$b_{27} = (0.2092, 0.3153, 0.3119, 0.1027, 0.1609)$
28	$b_{28} = (0.2092, 0.2762, 0.3901, 0.1609, 0.0636)$
29	$b_{29} = (0.2119, 0.2854, 0.3636, 0.1027, 0.1364)$
30	$b_{30} = (0.1854, 0.1636, 0.4901, 0.1636, 0.0973)$

be determined optimally, showing 85°C for 1 hour, which represents the optimal processing scheme.

3.3. Analysis of Predictive Texture Model

3.3.1. Determining the Hidden Layer Nodes. Although the number of neurons in the hidden layer has a great impact on the accuracy of the prediction model, difficulties are inherent in determining the numbers of hidden neurons. Through the experimental comparison of neural network prediction

TABLE 7: Comparison of BP neural network model predictions with actual results.

S/N	Sensory index	Sensory results	Predictive results	Error/%
1	Springiness	1.93	1.85	4.15
	Hardness	2.38	2.61	9.66
	Smell	4.21	3.84	8.79
2	Springiness	2.83	2.72	3.89
	Hardness	3.29	3.16	3.95
	Smell	3.07	2.79	9.12
3	Springiness	2.43	2.27	6.58
	Hardness	2.79	2.97	6.45
	Smell	1.66	1.47	11.45
4	Springiness	2.82	2.57	8.87
	Hardness	3.4	3.21	5.59
	Smell	2.94	2.65	9.86
5	Springiness	2.38	2.12	10.92
	Hardness	2.32	2.29	1.29
	Smell	3.21	3.4	5.92
6	Springiness	2.97	2.79	6.06
	Hardness	2.25	2.16	4.00
	Smell	2.67	2.77	3.75
7	Springiness	4.11	3.84	6.57
	Hardness	2.67	2.27	14.98
	Smell	1.79	2.02	12.85
8	Springiness	2.76	2.61	5.43
	Hardness	3.2	3.01	5.94
	Smell	2.11	2.32	9.95
9	Springiness	4.73	4.38	7.40
	Hardness	2.55	2.74	7.45
	Smell	3.73	3.86	3.49
10	Springiness	2.83	2.71	4.24
	Hardness	2.24	2.39	6.70
	Smell	4.41	3.92	11.11
11	Springiness	3.21	3.28	2.18
	Hardness	1.82	1.78	2.20
	Smell	2.53	2.21	12.65
12	Springiness	2.24	2.19	2.23
	Hardness	3.85	3.74	2.86
	Smell	1.19	1.32	10.92
Average error/%				6.93

results, it can be shown that the number of hidden layer nodes was 17.

3.3.2. Validation of Predictive Texture Model. The BP neural network was used to predict the sensory evaluation data of abalone meat. The results show little difference between the predicted and measured values, with the average error of calculation being relatively small. The prediction results varied for different samples, as did those for different texture parameters of the same sample.

Based on the data in Table 7, the maximum error was 14.98%, the minimum was 1.29%, and the average was 6.93%. These results demonstrate that the established BP neural

network has a good prediction effect and the advantages of high prediction efficiency. Thus TPA texture parameters can be used to predict human sensory evaluation results via the BP neural network model.

4. Conclusion

(1) The texture and sensory characteristics of abalone meat were analyzed under different heat treatments. A significant decline in hardness occurred at a shorter heat time (<60 min), which may have increased the sensory score. Heat treatment for an extended period (>120 min), meanwhile, resulted in no significant change in the hardness and sensory score. The

heat treatment time (<120 min) potentially led to a significant decline in springiness and chewiness. Thereafter, a longer heating time (>120 min) had little effect on springiness and chewiness, which tended to be stable. An appropriate increase in the heating temperature might result in a lower level of hardness and chewiness; a significantly low level of hardness, springiness, and chewiness was observed in boiled samples. The increase and decrease of heating time were associated with the change of chewiness to a very small degree. Moreover, a low level of chewiness could be obtained at 60°C. The heating condition of 60°C was abnormal compared to the higher temperature heating conditions, which could have been a result of changes in chemical forces.

(2) A sensory evaluation of abalone meat was conducted using fuzzy mathematics, which is beneficial for avoiding interference from subjective factors and obtaining fair results. A suitable temperature and time for the preparation of abalone meat should be around 85°C for 60 min, at which condition the evaluation score was 4.27, higher than at other temperatures and times; the springiness and resilience were maintained at a high level, and the hardness and chewiness were moderate.

(3) The method of using the BP neural network was introduced to predict sensory evaluation parameters of sensory hardness, springiness, and smell, based on the TPA parameters of the texture analyzer test. The results showed that the average error of the prediction model could reach 6.93%. To sum up, this method offers great advantages and application prospects because of its simplicity, handling convenience, and high accuracy.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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