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Research Article

Hot-Air Drying Characteristics of Sea Cucumber (*Apostichopus japonicus*) and Its Rehydration Properties

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Drying is one of the most common methods for processing and preserving sea cucumber. Based on the research of pretreatment and drying process, this paper develops a dried sea cucumber product that can be quickly rehydrated in only 8 hours. By setting the pretreatment at heated water temperature of 80°C and the drying temperature from 30°C to 60°C, the fitting model is found by comparing empirical formulas and artificial neural networks. The ANN-based model was demonstrated to fit the experimental data for the adequate drying of sea cucumber. Following the increased drying temperature, the drying time was decreased and the rehydration ratio was increased. The sensory evaluation and texture properties dried at 40°C and 50°C were much better than those dried at 30°C and 60°C. Microstructure of rehydrated dried sample showed that increasing the temperature leads to the increase of fiber pore space, and the rehydration rate increases. The results of drying time and the rehydration properties of sea cucumber showed that 50°C is the best drying condition for hot-air drying of sea cucumber. The developed rapid rehydration dried sea cucumber can effectively simplify the rehydration time and steps of the dried sea cucumber and improve the quality of the sea cucumber, and it is considered to be a good technology for drying the sea cucumber and making a fast rehydration dried sea cucumber that can be further used for value-added product.

1. Introduction

Sea cucumber (*Apostichopus japonicus*) is one of the most commercially valuable seafood products. In China, total production of sea cucumber has reached more than 171700 tons in 2019 [1]. It is very important to maintain the sea cucumber quality during food processing. In response to a variety of environmental and mechanical factors, sea cucumber vomits intestinal constituents and easily autolyzes. This can lead to severe deterioration in sea cucumber quality during handling and storage, consequently causing heavy economic losses [2]. From the quality and economic aspect, drying is normally used as the essential step for processing sea cucumber. It is reported that over 80% of the fresh sea cucumbers all over the world are processed to dehydrated product [3]. However, the quality of dried sea cucumbers is uneven, and it is also very cumbersome to rehydrate. The rehydration process requires multiple cooking and soaking, and it takes a lot of time. If it is not handled well, it will be difficult to chew or become soft.

Drying is one of the traditional methods for food preservation with its complex process [4]. Hot-air drying is the most widely used drying method at present, and it is widely used in drying sea cucumbers. It does not require high equipment and operating technology, is easy to operate, and has low cost. The production process is controllable and easy to industrialize [5]. Hot-air drying is still the most commonly used processing method in factories. However, hot-air drying also reduced the texture, color, and flavor of sea cucumbers [6–8]. Taking all attributes into consideration in terms of quality and economic purposes, drying is a requisite for sea cucumber processing. To the best of our knowledge, there are few reports on the effects of hot-air drying method on the quality of sea cucumbers.

Geng et al. [9] used traditional methods to study the rehydration of dried sea cucumbers and used non-invasive NMR and MRI methods to monitor the rehydration of dried sea cucumbers. The results indicated that the proper presoaking and rehydration time was 24 and 96 h, the rehydration ratio was 11.58, and texture profile analysis (TPA) parameters of hardness, chewiness, and rehydration ratio showed good correlations. Traditional dried sea cucumbers contain inedible parts, including sand, oral tentacles, and calcareous ring which are needed to be removed while rehydration. However, this makes it cumbersome to soak the dried sea cucumber. For example, the specific steps of rehydration are as follows: firstly, soak the sea cucumbers in water for 24–48 hours; secondly, remove inedible parts; thirdly, boil with water at 100°C for 2 h; at last, regain water at 4°C for 48–72 h. As mentioned before, the traditional rehydration steps are complicated and time consuming. In order to simplify the complex rehydration steps, traditional trying processing steps were changed in this study, and the non-edible part of sea cucumber was moved before drying, which makes rehydration steps become simple and fast. The dried sea cucumbers need to be soaked with water at 80°C for 8 h when rehydrating.

The main purpose of the current study was to examine the quality changes of sea cucumber using hot-air drying process. No research endeavours are yet executed for analysis of quality of sea cucumber using ANN. The rehydration rate, organoleptic attribute, texture properties, and the microstructure of rehydrated dried sea cucumbers were studied. The specific objectives are to (1) explore effects of different hot-air drying conditions or parameters on quality of sea cucumber; (2) analyze the correlation between empirical formulas and artificial neural network fitting model; and (3) provide more insights into the relationship of physicochemical properties and the quality changes of sea cucumber.

2. Materials and Methods

2.1. Materials. The sea cucumbers (*Stichopus japonicas*) were procured from local company in Dalian, Liaoning, China. The company provided the body walls of sea cucumber where it was already degutted, boiled, and salted [10]. The initial weight of the samples was 14.69 ± 1.66 g.

2.2. Experimental Methods. The boiled and salted sea cucumbers contained high amount of salt, so in order to remove it, they were soaked in water for 24 h by changing water every 8 h. The sea cucumber was cut from the abdomen, then the oral tentacles and calcareous ring of the sea cucumber mouth were removed, and the sea cucumber was cleaned. It was heated in tap water at 80°C for 3 h. The processed samples were placed on the hexagon bamboo placemat. They were put into the drying oven (Blue pard, PH-070A, Shanghai Yiheng Instrument Co., Ltd., Shanghai, China) to dry. The experiments were conducted at drying temperatures of 30, 40, 50, and 60°C. Constant velocity of oven use was 3 m/s. Mass changes of the samples were measured every 10 min at the first 2 h, every 20 min at the second 2 h, every 30 min for 4–8 h, every 1 h for 8–16 h, and every 2 h for the rest of times. Samples were weighted by a digital balance, and the results were recorded. The drying process was conducted until the mass changes of the samples were less than 0.01 g between each hour [11]. In this stage, moisture of samples was measured again and considered as equilibrium moisture. All experiments were performed in triplicates.

2.3. Moisture Content (MC). MC of the samples during drying process was calculated by the following equation which was the definition employed by some other authors in the literature [12–14]:

$$MC = \frac{M - M_d}{M_d} \times 100, \tag{1}$$

where MC is the moisture content (%, dry basis), M is the mass of samples (g), and M_d is the mass of dry matter.

2.4. Moisture Ratio (MR). MR was another parameter related to MC that was calculated from the data acquired for its later analysis. Measured weights were converted to MR by the following equation:

$$MR = \frac{MC - MC_e}{MC_0 - MC_e}, \tag{2}$$

where MR was the moisture ratio (dimensionless), MC was the moisture content (%, dry basis), MC_0 was initial moisture content (%), and MC_e was equilibrium moisture content (%). In this study, MC_e was numerically estimated as the final MC at the conclusion of the drying experiment [15].

2.5. Rehydration Ratio (RR). Each batch of the dried samples was weighed with a digital balance and then immersed into food-packaging bags containing 200 ml distilled water. The water was heated to 80°C. The bags were sealed after placing the dried samples into the packaging bags. The food-packaging bags were placed into a water bath (HWS24, Shanghai Yiheng Instrument Co., Ltd., Shanghai, China) which was maintained at a constant temperature at 80°C for 8 h. Then, the samples were removed from the food-packaging bags and weighed precisely. Each experiment was performed in triplicate. The rehydration ratio (RR) was expressed as follows [16]:

$$RR = \frac{W_r}{W_d}, \tag{3}$$

where W_r is the weight after rehydration (g) and W_d is the weight before rehydration (g).

2.6. Sensory Evaluation. The quantitative descriptive analysis (QDA) method was proposed as descriptive analysis method for rehydrated dried sea cucumber. Ten panelists were selected from a large pool of candidates according to their ability to discriminate differences in sensory properties among sea cucumber [17]. Table 1 shows the QDA method description words and definitions of sea cucumber. Panelists were free to develop their own approach to scoring, using the 10 cm line. The endpoints for each scale were weak (like extremely soft, extremely light) and strong (like extremely hard, extremely dark) [18].

2.7. Texture Properties. The textural properties of the rehydrated dried sea cucumbers were measured using a texture analyzer (TA.XT Plus, Stable Micro Systems Co., Oxford, UK). The texture profile analysis (TPA) test samples were cut into 1 cm × 1 cm portions. The TPA test was equipped with a 50 mm diameter cylindrical probe (P/50).The pretest speed, test speed, and posttest speed were 2, 1, and 1 mm/sec, respectively, trigger force was 5 g, deformation rate was 75%, and pause time between compression cycles was 5 sec [20].

2.8. Scanning Electron Microscopy (SEM). Prior to SEM observations, the rehydrated samples were lyophilized for 12 h in order to stabilize the structure. The specimen fragments were then glued to the holder and sputter-coated with gold, and we examined the inner structure and photographed it using a scanning electron microscope (JSM-7800F, JEOL Ltd., Tokyo, Japan) at an accelerating voltage of 1 kV. The magnification was 1000 [21].

2.9. Artificial Neural Network (ANN). An ANN-based system equipped with adaptive learning capability was used to predict the biomass MC as a function of the time horizon considering different drying process conditions and using the acquired and preprocessed data. Neurons are believed to be the basic units of neural networks, whose topological structure diagram is shown in Figure 1(a), in which the input of neuron unit is denoted by (x_1,x_2,. . ., x_m), where m is the dimension of the input vector, and the inner product of the input units and weight vector (w1, w2,. . ., w_m) plus a threshold value is $\sum_{i=1}^{m} x_i w_i + b$, and the output of the neuron after transformation by activation function *f*() is $y = f\left(\sum_{i=1}^{m} x_i w_i + b\right)$.The ANNs with hidden layers were developed and tested, which have been the most widely used type.

The ANN in this article is a kind of hierarchical model of typical multilayer networks with three layers including input layer, one single hidden layer, and output layer. As shown in Figure 1(b), from a structural point of view, this ANN is with full connection between layer and layer and with no mutual connection between same layer neurons. The number of neurons of the input layer and the output layer is, respectively, determined by the dimension of the input and output variables utilized in the model. In this study, analysis data were randomly divided for the drying process into three parts: the first part was used to train the network and consisted of approximately 70% of the total data points. The second part was used to validate the network and consisted of approximately 15% of the samples. The remaining 15% were used as experimental inputs [22, 23]. The determination of the number of neurons in the hidden layer is always empirically chosen. The mean squared error (MSE) of the trained ANN is used as loss function in this ANN. In order to evaluate the efficacy of the ANN model more objectively, 100 repetitions of the simulations for each number of hidden neurons are performed. The activation function utilized in the hidden layer is the tan–sigmoid function ((4)) and a linear function for the output layer:

$$\tan - sigmoid(k; x) = \tanh(kx) = \frac{e^{kx} - e^{-kx}}{e^{kx} + e^{-kx}}, \; k \in R, \; k > 0. \quad (4)$$

ANN training was performed by applying the back-propagation method employing the Levenberg–Marquardt algorithm [16]. The minimum value of the gradient was set to10^{-4}, being a stop criterion when the gradient falls under it. Furthermore, the initial value of μ was set to 10^{-3}, the factor of increment and decrement of μ during the factor ($ß$) was set to 10, and the maximum value of μ was set to 0.01, according to the nomenclature of Hagan and Menhaj [24].

2.10. Empirical Formulas. Moreover, some mathematical empirical formulas often used in the literature for describing drying processes are demonstrated in Table 2, which are applied to simulate the drying processes of the first experiment. Finally, the MC prediction error was computed for each experiment using coefficient of determination (R^2) as primary criterion and four statistical parameters. The parameters were root mean square error (RMSE) [25], chi square (CS), residual sum square (RSS), correlation coefficient (ρ) [26], and relative percentage deviation (RPD) [27]. The values of R^2 were one of the primary criteria for selecting the best model and can be used to test linear relationship between experimental and model predicted values [28]. Statistical parameters may be computed from the following mathematical equations.-where N is the total number of observations, p is number of factors in the mathematical model, and $MR_{exp}(i)$ and $MR_{pre\ d}(i)$ are the experimental and predicted moisture ratios at any observation *i*. In non-linear regression, RSS is the important parameter and ideal value is zero [32]. Relative percentage deviation compares the absolute differences between the predicted moisture content and the experimental moisture content throughout the drying process. The relative percent errors below 10 % indicate very good fit [33, 34]. RMSE and CS compare the differences between the model predicted values of moisture ratios to the experimental moisture ratios. The values of the RMSE and CS are always positive. Lower values indicate the closeness of experimental value with predicted value and goodness of fit [27, 35].

Table 1: Sensory description words and definitions of sea cucumber [17, 19].

Texture index	Definition
Color	Through the visual organs to perceive light sensation
Fishy smell	Through the olfactory organs to perceive smell
Salty	Through the taste organs to perceive smell
Hardness	The force to attain a given deformation, such as force to compress between molars
Cohesiveness	The amount to which sample deforms rather than crumbles, cracks, or breaks
Springiness	The degree to which sample returns to original shape
Fracturability	The force with which the sample breaks
Chewiness	The force to chew the food to swallow

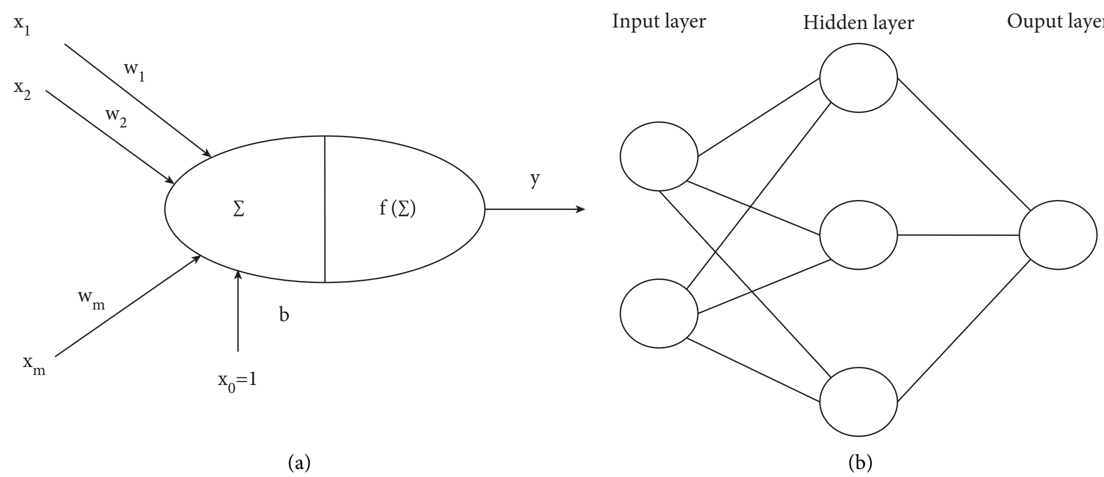

Figure 1: Artificial neural network topology structure. (a) Signal-flow graph of a perceptron, where ($x_1, x_2,\ldots, x_m$) are the inputs; ($w_1, w_2,\ldots, w_m$) are the weights; b is the bias; v is the linear combination of the inputs, weights, and bias ($v = \sum_{i=1}^{R} x_i w_i + b$); f() is the activation function; and $y = f(v)$ is the output. (b) Example of a three-layer multilayer perceptron with two inputs, one output, and three neurons in the hidden layer.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pred}(i) - MR_{\exp}(i)\right)^2}{N}},$$

$$CS = \frac{\sum_{i=1}^{N}\left(MR_{pred}(i) - MR_{\exp}(i)\right)^2}{N - p},$$

$$RSS = \sum_{i=1}^{N}\left(MR_{pred}(i) - MR_{\exp}(i)\right)^2, \quad (5)$$

$$PRD = \frac{100}{N}\cdot\sum_{i=1}^{N}\left|\frac{MR_{pred}(i) - MR_{\exp}(i)}{MR_{\exp}(i)}\right|,$$

$$\rho(\%) = \left(1 - \frac{\sum_{i=1}^{N}\left[MR_{\exp}(i) - MR_{pred}(i)\right]^2}{\sum_{i=1}^{N}\left[MR_{\exp}(i)\right]^2}\right)\cdot 100,$$

2.11. Statistical Method. All the tests were conducted with three replicates. Data were presented as mean ± standard deviation (SD). The statistical analysis was performed by using SPSS 19.0 software (SPSS Inc., Chicago, IL, USA). The SNK (Student–Newman–Keuls) method was used to determine difference in the means, and statistical significance was identified at $P < 0.05$.

3. Results and Discussion

3.1. Drying Characteristics. We use the ANN-based model and three empirical equations, respectively, to fit the drying process. The results obtained from the experiments are given in Figure 2 and Table 3. Figure 2 shows that when the temperature was 30°C, the drying time was 46 h. When the temperature was 50°C and 60°C, the drying time was reduced to 38 h and 32 h. According to the drying temperature and time curve, drying time was reduced with an increase in the temperature. Comparable results were also conveyed by Mariani et al. [36].

As shown in Figure 2, though the middle of Lewis model evidently diverge from the drying process, either of Page model and Lewis model basically fit the drying process. Only the end of Hend model and Pab model matched the drying process, which has very big deviation with other parts of the two models. The ANN-based model with 5 hidden layer neurons was used to fit the whole drying process, and the fitting degree was better than the other three drying empirical equations.

Dimensionless MR was regressed against the drying time according to the thin layer drying models presented in Table 3. Comparing the various statistical parameters of various models in the wake of the temperature rising

Table 2: Definition of the drying empirical equations used in this article.

Name	Equation	Linear formula after processing	Reference
Newton	MR = exp (-kt)	ln(MR) = -kt	Lewis (1921) [29]
Page	MR = exp (−ktN)	ln (-ln (MR)) = lnk + N∗lnt	Page (1949) [30]
Henderson-Pabis (Hend and Pab)	MR = a∗exp (-kt)	ln (MR) = lna-kt	Henderson and Pabis (1961) [31]

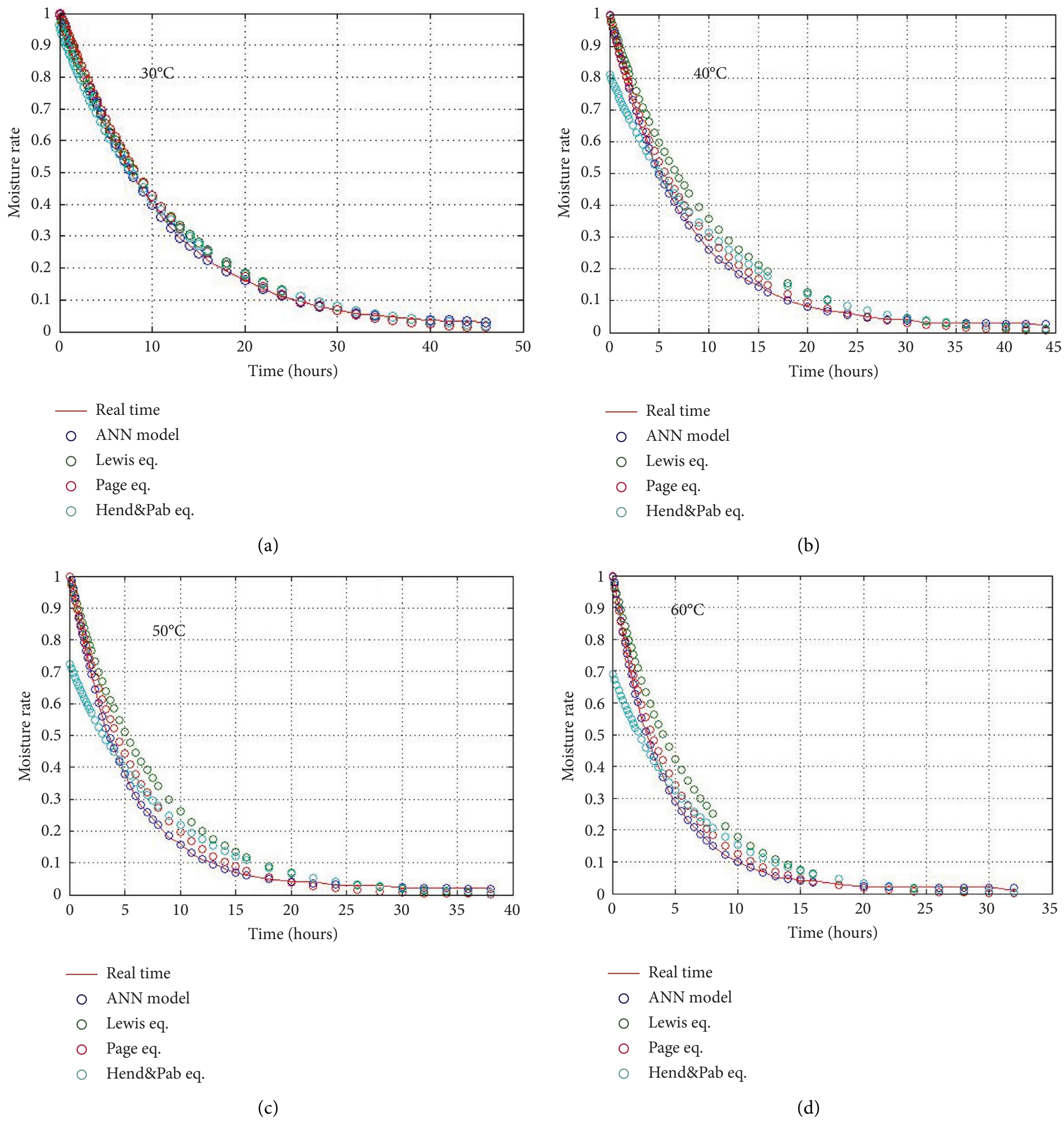

Figure 2: Experiment results for four drying tests under different temperatures. Color representation: Lewis (green), Page (red), Hend and Pab (blue), and ANN model (black).

more, the value of ρ [26] for the same model was going down, and the values of PRD, CS, RSS, and RMSE [27] for the same model were going up. Comparing with the different models, the ANN-based model was better than the Page, Lewis, and Hend and Pab models from the valves of ρ, PRD, CS, RSS, and RMSE.

3.2. Rehydration Ratio (RR). Rehydration is considered as one of the important quality attributes used to characterize quality of dried food [37]. Dried sea cucumbers need to be rehydrated before eating. The rehydration ratio increased from 10.14 ± 0.92 g/g to 12.63 ± 1.15 g/g as drying temperature increased from 30°C to 60°C (Figure 3). This was in

Table 3: The estimated values of statistical parameters and model at different drying conditions.

Equation/model		RMSE	ρ	RSS	CS	PRD	a	k	N
Lewis	30	0.2885	99.9861	0.0876	0.0018	0.5577	—	0.0846	—
	40	2.3363	98.8191	5.2475	0.1116	0.1796	—	0.1031	—
	50	2.8474	97.4897	8.0973	0.1840	0.1320	—	0.1337	—
	60	2.9274	96.6324	8.1954	0.1999	0.1315	—	0.1716	—
Page	30	0.2957	99.9854	0.0921	0.0018	0.5531	—	0.0752	1.0530
	40	0.5864	99.9256	0.3306	0.0070	0.3110	—	0.1319	0.9614
	50	0.9818	99.7016	0.9627	0.0219	0.2112	—	0.1633	0.9987
	60	0.7786	99.7618	0.5797	0.0141	0.2688	—	0.2313	0.9563
Hend and Pab	30	0.7047	99.9171	0.5229	0.0109	0.5412	0.9599	0.0831	—
	40	2.1766	98.9750	4.5546	0.0969	0.2501	0.8107	0.0951	—
	50	2.9112	97.3759	8.4644	0.1924	0.1932	0.7234	0.1189	—
	60	2.9388	96.6062	8.2593	0.2014	0.2231	0.6893	0.1509	—
ANN-based model	30	0.0043	100	1.9645e-05	4.0928e-07	6.2032	—	—	—
	40	0.0030	100.000	8.4212e-06	1.7918e-07	1.5976	—	—	—
	50	0.0028	100.000	7.9627e-06	1.8097e-07	2.3417	—	—	—
	60	0.0029	100.000	7.8793e-06	1.9218e-07	1.3001	—	—	—

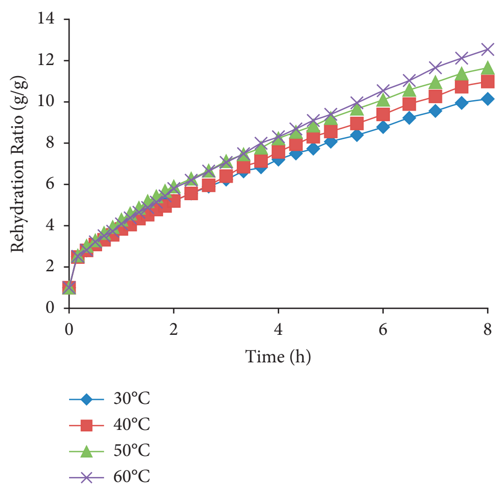

Figure 3: Rehydration ratio of sea cucumber at different drying temperatures.

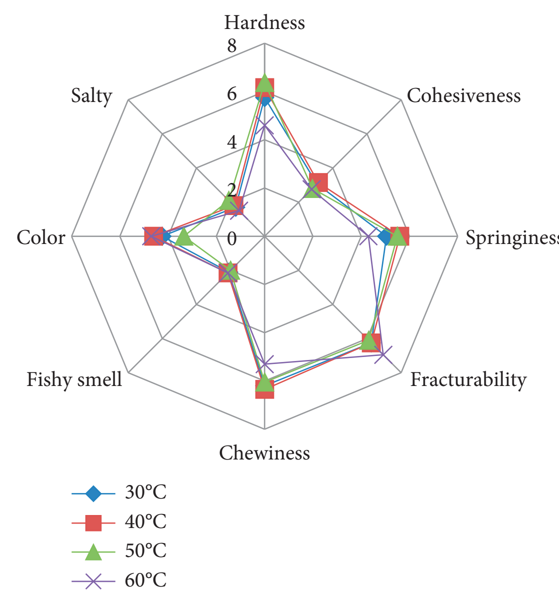

Figure 4: Spider web plot for the sensory evaluation of rehydrated sea cucumber with different properties.

accordance with previous studies. Li et al. [25] obtained similar result for onion. It claimed that the rehydration ratio showed an increasing trend with the increase of drying temperature. Most samples dried at high drying temperature caused highly porous and loose structure.

3.3. Sensory Evaluation. For rehydrated sea cucumber, there were several important properties such as color, smell, hardness, springiness, and so on [38]. Figure 4 shows the results of the sensory evaluation. There were significant differences in hardness, springiness, and chewiness among different drying temperatures. The sensory scores of the three indicators of hardness, springiness, and chewiness at 60°C were significantly lower than those at the other three temperatures, which may be caused by the gradual denaturation and degradation of sea cucumber body wall collagen at 60°C. Comparable results were also conveyed by Jiang et al. [39]. Although the sensory score of springiness at 30°C was higher than that at 60°C, it was also significantly lower than that at the other two drying temperatures. There were no significant differences in color, fishy smell, salty, cohesiveness, and fracturability among different drying temperatures. These four indexes of the products achieved the high standard of good quality. According to the results, rehydrated sea cucumber was influenced mostly by texture. The sensory evaluation of drying temperature 40°C and 50°C was the best.

3.4. Texture Properties. Table 4 shows the result of TPA parameters (hardness, chewiness, cohesiveness, springiness, and resilience) of rehydrated sea cucumber at different drying temperatures. The indexes of rehydrated sea cucumber dried at 60°C were worse than those at the other three temperatures, except that cohesiveness had no difference. The hardness of the rehydrated sea cucumber was the highest under the drying condition of 50°C. There were

Table 4: Influence of drying temperatures on the texture properties of dried sea cucumber.

	30°C	40°C	50°C	60°C
Hardness (TP)/g	3505.20 ± 251.26^{ab}	3862.80 ± 936.11^{bc}	4379.56 ± 718.95^{c}	3057.98 ± 680.55^{a}
Springiness (TP)	0.92 ± 0.02^{b}	0.92 ± 0.04^{b}	0.92 ± 0.04^{b}	0.85 ± 0.02^{a}
Cohesiveness (TP)	0.70 ± 0.05^{a}	0.62 ± 0.15^{a}	0.70 ± 0.12^{a}	0.58 ± 0.09^{a}
Chewiness (TP)	2206.52 ± 285.48^{a}	3128.88 ± 1072.56^{b}	3329.23 ± 1071.16^{b}	2031.57 ± 775.98^{a}
Resilience (TP)	0.55 ± 0.05^{b}	0.53 ± 0.14^{b}	0.56 ± 0.12^{b}	0.43 ± 0.10^{a}

Mean ± standard error. Different letters in the same row represented the significant differences between different groups ($P < 0.05$), and there was no significant difference between groups that contained at least one identical letter.

Table 5: Relationship between sensory evaluation and texture properties.

	Hardness	Cohesiveness	Springiness	Fracturability	Chewiness
Hardness (TP)	0.379*	0.135	0.420**	−0.265	0.146
Springiness (TP)	0.438**	0.239	0.403**	−0.302	0.206
Cohesiveness (TP)	0.265	0.205	0.313*	−0.193	0.145
Chewiness (TP)	0.325*	0.226	0.436**	−0.220	0.111
Resilience (TP)	0.255	0.232	0.320*	−0.177	0.189

*Significant correlation at 0.05 level (bilateral). **Significant correlation at 0.01 level (bilateral).

many similarities between the trend of various indicators of texture properties and the trend of sensory evaluation. Conclusion can be drawn by analyzing the correlation between texture properties and sensory evaluation indicators (Table 5). The springiness index of the texture analyzer significantly ($P < 0.01$) showed the rehydration state of dried sea cucumbers. It showed that the springiness index set by the texture analyzer can well express the springiness of rehydrated sea cucumbers. In addition, the hardness index of the texture analyzer also significantly ($P < 0.05$) showed the rehydration state of dried sea cucumbers. The other indicators of the texture analyzer had no correlation with the sensory evaluation indicators. Therefore, improving the texture analyzer profile, method, and probe in order to obtain a more accurate evaluation of rehydrated dried sea cucumbers could be considered.

3.5. Scanning Electron Microscopy (SEM). The fibers in the body wall of fresh sea cucumbers are thin and long, and the distribution of fibers has a certain directionality. The collagen fibers are evenly distributed and the structure is neat and orderly [40]. Figure 5 shows the SEM images of rehydrated sea cucumber obtained using different drying temperatures. The collagen fibers in the sea cucumber did not possess specific directions (Figure 5). This means that after the drying and rehydration process, the fiber arrangement was altered. Most of the collagen fibers were broken, forming a reticulation structure, which made the rehydrated sea cucumbers have a unique texture. As the drying temperature increases, collagen fibers are folded together, and the destruction and aggregation of collagen fibers become more obvious, which is consistent with the trend of texture properties. When the drying temperature is 60°C, the fibers can no longer be distinguished, and the fibers not only aggregate but also show clump and other phenomena. The results in this part reveal the relationship between drying temperature of the sea cucumber and the pore size of collagen fibrin. The pore size of rehydrated sea cucumber increased with the rise of drying temperature, that is, due to rupture of cell wall at high temperature. The result was consistent with the study by Paola et al. [41], which found that the pore size of eggplant slabs becomes larger when the drying temperature increased from 40°C to 60°C. This is because the higher temperature causes greater damage to the microstructure. This implies that increased temperatures not only reduced the processing time of drying but also changed the structures of sea cucumber.

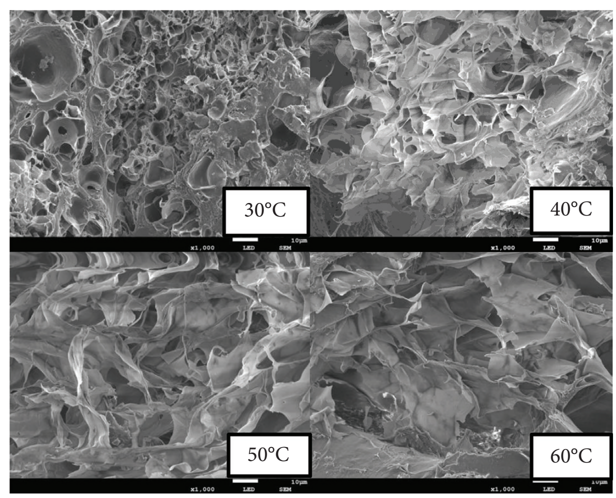

Figure 5: SEM images of rehydrated sea cucumber under different drying temperatures (1000×).

4. Conclusions

The ANN-based model can fit the experimental data for the drying of sea cucumber better than empirical equations. With the increase of drying temperature, the drying rate increases and the drying time shortens. The rehydration ratio was increased with the increased temperature. In summary, sea cucumber dried at 50°C had less drying time and better rehydration capacity, sensory quality, texture quality, and microstructure observation than the other drying temperatures. Above all, hot-air drying at 50°C was suggested as the best drying condition for sea cucumber in this study.

Data Availability

The data generated or analyzed during this study are included within this article. The data used can be acquired from the first author (67118948@qq.com) upon request.

Conflicts of Interest

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

Authors' Contributions

Pengfei Jiang and Wengang Jin contributed equally to this work. Pengfei Jiang and Wengang Jin conducted investigation, wrote the original draft, and performed plot analysis. Yan Liu, Na Sun, Kaiyue Zhu, and Zhijie Bao performed partial analysis, visualization, and language check. Xiuping Dong reviewed and edited the manuscript, supervised the work, and acquired funding.

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