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Quality changes of Pleurotus eryngii during vacuum frying

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Quick and accurate determination of oil content is extremely important to control the oil content of vacuum fried fruit and vegetable chips. This article uses fresh Pleurotus eryngii as raw materials to explore the influence of different vacuum frying times (0–14 min) on the moisture distribution, oil changes and quality of Pleurotus eryngii strips. The results show that as the frying time increases, the lateral relaxation time required for the taro strips to drop from the highest point of the signal amplitude to smooth becomes shorter and shorter, and the decay rate becomes faster and faster, that is, when the frying time is 14 minutes, The attenuation curvature and velocity are the largest. The oil content and brittleness of Pleurotus eryngii strips are significantly increased ($P < 0.05$); the water content is significantly reduced ($P < 0.05$); the hardness first decreases and then increases ($P < 0.05$); the brightness L value does not change much, and the color is not Significant change ($P > 0.05$). At the same time, low-field NMR shows that the high-degree-of-freedom water in the pleurotus eryngii strips migrates to the low-degree-of-freedom water during the vacuum frying process. Among them, the free water in the pleurotus eryngii strips has a large degree of freedom. It has been removed, resulting in poor mobility and increased inability to flow. Part of the free water migrates to the semi-bound water, and most of the semi-bound water migrates outward as free water and then is removed. From this, all peaks are gradually removed. Moving to the left, the total peak area decreases. During the frying process, the T_2 relaxation time of Pleurotus eryngii strips all shifted to the left, the total peak area is continuously reduced, the water content is getting less and less, the fat content is getting higher and higher, and the fat content distributed in the edge shell is always higher than Other locations. Low-field nuclear magnetic resonance technology can provide a fast, accurate, and non-destructive method for detecting moisture and grease for the vacuum-fried fruit and vegetable chips. As the frying time increases, the inner contour of the MRI image of Pleurotus eryngii strips gradually becomes blurred, the brightness gradually decreases, the volume shrinks, the less water, and the image interior is close to the background color (blue), indicating that the sample has reached the end of drying; and The grease content is distributed in the edge shell layer higher than other positions. Therefore, the water is continuously removed, the oil signal becomes stronger and stronger, and the oil content of the sample becomes higher and higher.*

Key words: *Pleurotus eryngii; vacuum frying; quality; low-field nuclear magnetism; T_2 relaxation time.*

Зміна якості Pleurotus eryngii в процесі вакуумної сушки

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Швидке, точне визначення вмісту жиру в фруктових та овочевих чіпсах при вакуумному сушіння має надзвичайне значення. Сировиною для дослідження обрано свіжий Pleurotus eryngii. В статті вивчали вплив тривалості вакуумного сушіння (0–14 хв) на розподіл вологи, зміну вмісту жиру та якість слайсів Pleurotus eryngii. В результаті досліджень встановлено, що із збільшенням часу обжарювання до 14 хв час латеральної релаксації, необхідний для падіння слайсів з найвищої точки стає коротшим, а швидкість

*затухання – більшою. Коли час обжарювання становить 4 хв, крива та швидкість затухання є найбільшими. Вміст жиру та крихкість слайсів Pleurotus eryngii значно збільшуються (P < 0,05); вміст води значно знижується (P < 0,05); твердість спочатку зменшується, а потім збільшується (P < 0,05); значення яскравості L * та колір змінюються не суттєво (P > 0,05). Однак, в процесі вакуумної сушки ЯМР в низькому полі показує, що вода з високим ступенем свободи в слайсах Pleurotus eryngii мігрує у воду з низьким ступенем свободи. Більша частина води мігрує назовні та видаляється. В результаті піки поступово прибираються. Під час сушіння час релаксації T_2 слайсів Pleurotus eryngii зміцується вліво, загальна площа піків постійно зменшується, вміст вологи знижується, вміст жиру рівномірно збільшується. Вміст жиру в поверхневих шарах більший, ніж в середніх. Технологія ядерного магнітного резонатора з низьким полем може забезпечити швидкий, точний і якісний метод визначення вологи та жиру висушених у вакуумі фруктових та овочевих слайсів. Зі збільшенням часу обжарювання внутрішній контур МРТ-зображення слайсів Pleurotus eryngii поступово стає розмитим, яскравість та об'єм зменшуються, а внутрішня частина по кольору наближається до кольору фону (синій). Це вказує на закінчення процесу сушіння. Отже, волога неперервно видаляється, сигнал жиру стає все сильнішим, а отже його вміст зростає.*

Ключові слова: *Pleurotus eryngii, вакуумна сушка, якість, ядерний магнетизм низького поля, T_2 час релаксації.*

Introduction

Pleurotus eryngii is named for its aroma of almonds and taste like abalone (Huang et al., 2015; Li et al., 2016; Shi et al., 2018; Li et al., 2020). Pleurotus eryngii has thick flesh and crisp texture. It is a new species of rare edible fungus developed and cultivated over the years with the same medicine and food (Wu et al., 2020). Pleurotus eryngii is rich in nutrition, rich in protein, carbohydrates, vitamins, amino acids and minerals such as calcium, magnesium, copper, zinc, etc. It can lower blood fat, antioxidant, lower cholesterol, promote gastrointestinal function, enhance body immunity, and prevent heart Vascular diseases and other effects (Cao et al., 2016; Liu et al., 2020).

Pleurotus eryngii has a relatively high water content and a relatively crisp tissue structure. At room temperature, pleurotus eryngii is prone to decay and browning, which brings great losses to production and transportation. Therefore, it is important to maintain the original product characteristics by adopting appropriate treatment methods. It seems particularly important (Jia et al., 2017; Samilyk et al., 2020). At present, vacuum frying technology has been widely used in the processing of fruit and vegetable products (Zhang, 2013; Yang et al., 2018), but so far there has been no research report on drying Pleurotus eryngii using vacuum frying method. According to its characteristics, this experiment uses Pleurotus eryngii strips as raw materials, using nuclear magnetic resonance analysis technology and its imaging technology to explain and detect the fluidity of moisture and oil in the process of vacuum frying pleurotus eryngii from a microscopic point of view. The distribution status of water and oil, qualitatively and quantitatively describe the internal oil and moisture change law of the material during the drying process; analyze the internal oil and water status and distribution changes of Pleurotus eryngii strips during the frying process under different frying time conditions In order to provide a theoretical basis for the deep processing of Pleurotus eryngii.

Material and methods

Materials and reagents: Pleurotus eryngii (Choose fresh and plump Pleurotus eryngii of similar size and without damage, provided by Hezhou Baijiafu Supermarket); Palm oil (purchased from Baijiafu Supermarket in Hezhou City); Petroleum ether (30–60 °C boiling range).

Test equipment: Vacuum frying dryer (VF-40C type, Zhongshan Weijia Vacuum Machinery Factory); Moisture Analyzer (Model MX-50, Guangzhou A&D Instrument Co., Ltd.); Crude fat analyzer (Model SCF-06, Shanghai Xinjia Electronics Co., Ltd.); NMR imaging analyzer (NMI20 type, Suzhou (Shanghai) Newmai Electronic Technology Co., Ltd.); Physical property tester (S-081 British SMS company); Drying box (PH-070A type, Shanghai Yiheng Scientific Instrument Co., Ltd.); Color difference meter (CR-400 type, Konica Minolta (China) Investment Co., Ltd.); Electronic balance (Sartorius Scientific Instruments (Beijing) Co., Ltd.); Ultra-thin induction cooker (Zhejiang Supor Co., Ltd.).

Test method:

1. Process flow. Raw material → washing → cutting into strips → blanching → draining → vacuum frying → degreasing → packaging → finished product.

2. Operating points. Raw material: Select pleurotus eryngii without mold or mechanical damage. Washing: Rinse pleurotus eryngii with clean water 2~3 times. Cut strips: Cut into strips of 6mm × 6mm × 40mm. Blanching: Blanch the cut pleurotus eryngii strips in boiling water at 100 °C for 3 minutes. Drain: Drain the water on the surface of the Pleurotus eryngii strips. Vacuum frying: Vacuum frying at a frying temperature of 90 °C. Deoiling: oiling time is 15s, deoiling time is 3min.

3. Acquisition and inversion of T2. When the measuring temperature range is 31.99–32.01 ℃, collect the samples every 2 minutes, place them in the NMR tube and put them in the center of the magnet coil, first use the FID sequence to obtain the center frequency of the sample, and then use the CPMG pulse sequence to measure the transverse direction in the sample The relaxation time is T2, and the signal is collected three times for each sample, and the results are averaged. The sequence parameters are set as: main frequency SF1 = 23 MHz, offset frequency O1 = 416765.87 KHz, waiting time TW = 3000 ms, 90° pulse time P90 = 10 μs, 180° pulse time P180 = 20 μs, sampling points TD = 150000, The accumulation times are 8 times, the echo time TE = 0.300 ms, the echo times NECH = 5,000, and the inversion iteration times are 100,000.

4. NMR imaging experiment and parameter setting. Use the SE pulse sequence in the NMR imaging software to perform imaging experiments on the samples, and place the Pleurotus eryngii strips in the center of the RF coil at the center of the permanent magnetic field for signal acquisition. The imaging parameters are set to: main frequency SF1 = 18 MHz, offset frequency O1 =

159.609 131 kHz, number of sampling points TD = 256, sampling frequency SW = 20 kHz, sampling time DW = 50 μs, total signal sampling time ACQ = 12.8 ms, Receiver dead time DT2 = 1.4 ms, analog gain RG1 = 20 dB, digital gain DRG1 = 3 dB, layer selection direction GsliceY = 1, phase encoding direction GphaseZ = 1, frequency encoding direction GreadX = 1, 90° pulse width P1 = 1 200 μs, 180° pulse width P2 = 1 200 μs, 90° pulse amplitude RFA1 = 3 %, 180° pulse amplitude RFA2 = 6 %, radio frequency pulse shape RFSH1 is 5sinc256, number of repetitive sampling NS = 4, accumulation number RP1count = 4. The phase encoding step RP2count = 128.

5. Measuring method of moisture content. The moisture content of Pleurotus eryngii was measured by using the MB90 rapid moisture analyzer. The average initial moisture content of Pleurotus eryngii strips was 86.79 %. The moisture content of the dry base of Pleurotus eryngii is calculated according to formula (1):

$$M = \frac{W}{1 - W} \qquad (1)$$

In the formula:

M-the dry basis moisture content of the pleurotus eryngii fried to time t, g/g;

W-the wet basis moisture content of the pleurotus eryngii fried to the time t, g/g (Wu et al., 2020).

6. Determination method of color. The color of Pleurotus eryngii strips was measured by a color-color difference meter. The working conditions were: a color measurement spot with a diameter of 10mm, a standard ceramic white board, and an international lighting association CIE L*a*b* uniform color space color system, L* The value varies from 0 to 100, 0 means black, 100 means white; a* value means the value from red to green, 100 is red, -80 is green; b* value means the value from yellow to blue; 100 is Yellow, -80 is blue (Zhang et al., 2019); the standard whiteboard of the instrument L*(brightness) = 94.75, a*(redness) = 0.28, b*(yellowness) = 3; repeat the measurement for each sample 3 times, take average value.\

$$\Delta E = \sqrt{(L - L^*)^2 + (a - a^*)^2 + (b - b^*)^2} \qquad (2)$$

In the formula, ΔE is the difference between the sample and the white board. The larger the value, the greater the difference from the white board, which can better reflect the color change.

7. Determination of brittleness and hardness. The brittleness and hardness of Pleurotus eryngii were measured by TA.XT PLUS physical property tester. Using the P2 probe, the speed before the test is 1mm/s, the test speed is 1mm/s, the speed after the test is 10mm/s, and the puncture distance is 5mm. The brittleness of this test is expressed by the number of peaks produced by the test. The greater the number of peaks, the better the brittleness of the product. On the contrary, the brittleness of the product is worse. The hardness value is equal to the peak force in the curve, that is, the maximum force required for the sample to break, in “g”. The higher the value, the harder the product (Bi et al., 2010).

8. Determination of oil content. The determination of oil content refers to the method specified in GB 5009.6-2016, and is determined by Soxhlet extraction.

9. Data Analysis. SPSS 19.0 software was used for the analysis and processing of test data, and a, b, c, d, f, g, and h were used to represent significant differences at the $P < 0.05$ level. Each test was repeated three times, and the results were expressed as the mean ± SD.

Results and discussions. Low-field NMR test results of vacuum frying of Pleurotus eryngii. The influence of CPMG sequence attenuation characteristics during vacuum frying of Pleurotus eryngii. Under the condition of a frying temperature of 90 °C and a particle size of 6mm × 6mm × 40 mm, the T2 attenuation curve of Pleurotus eryngii strips at different frying times is shown in Fig. 1 below.

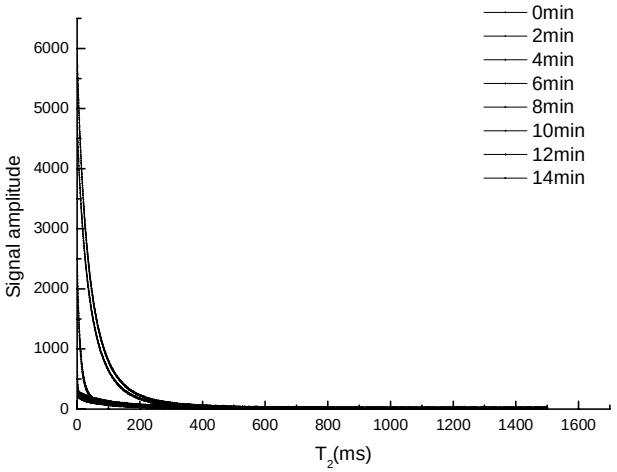

Fig. 1. Decay curve of Pleurotus eryngii strips

The signal data of the horizontal relaxation time of Pleurotus eryngii under different frying times is collected through the echo peak point diagram of the CPMG sequence. The state and content of water and oil content in Pleurotus eryngii will directly affect the attenuation trend of the CPMG sequence, so different CPMGs The attenuation curve can indicate that there is a certain difference in the state and content of the internal water content and oil content of Pleurotus eryngii. It can be seen from Fig.1 that the curvature trend of the attenuation curve of the CPMG sequence is the same. With the extension of the frying time, the horizontal relaxation time required for the Pleurotus eryngii strips to drop from the highest point of the signal amplitude to the flatness becomes shorter and shorter. The decay rate is faster. However, the attenuation curve of the CPMG sequence can only see the relative change trend of the overall water content, oil content and fluidity of the Pleurotus eryngii strips. The state and distribution of the internal water and oil cannot be obtained. Therefore, the CPMG is calculated by the Fourier formula. The signal is converted into a spectral signal, which can better reflect the internal moisture state and distribution of Pleurotus eryngii strips and the T2 relaxation spectrum of the oil distribution (Xie et al., 2014; Dong et al., 2018).

Change of T2 inversion spectrum of fresh Pleurotus eryngii with relaxation time. Under the condition of frying temperature of 90 ℃ and grain size of 6 mm × 6 mm × 40 mm, the T2 inversion spectrum of fresh Pleurotus eryngii strips is shown in Fig. 2 below.

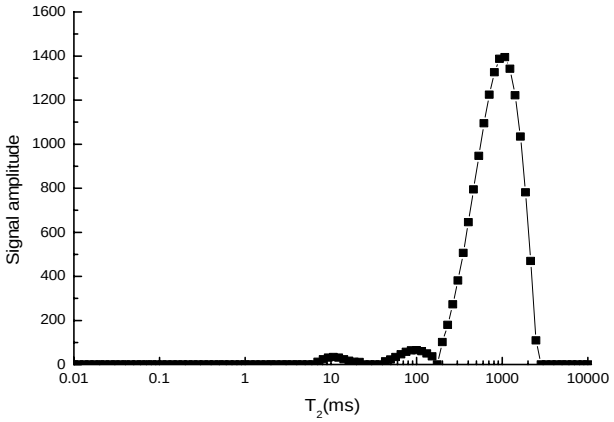

Fig. 2. T2 inversion spectrum of fresh Pleurotus eryngii

The transverse relaxation time T2 refers to the time required for the H proton spin nucleus to reach the transverse thermal equilibrium in the system after the external magnetic field is stimulated by the radio frequency pulse. The larger the T2, the stronger the fluidity of the water. The low-field NMR technology can be used. Study the changes, distribution and migration of water content and state of Pleurotus eryngii during vacuum frying process (Xie, 2014). As shown in Fig. 2, the NMR T2 inversion spectrum of fresh Pleurotus eryngii strips after inversion has three peaks, indicating that there are three different moisture states in the fresh pleurotus eryngii strips, and the three different moisture states are in the T2 inversion spectrum. The corresponding transverse relaxation time T2 ranges in Pleurotus eryngii are bound water T21 (7.05~21.54 ms), non-flowing water T22 (43.29~151.99 ms), free water T23 (200.92~2477.08 ms), indicating that the content of Pleurotus eryngii is the least It is bound water, followed by water that is not easy to flow, and free water (Pan, 2019).

Change of T2 inversion spectrum with frying time during vacuum frying of Pleurotus eryngii strips. Under the condition that the frying temperature is 90 ℃ and the grain size is 6 mm × 6 mm × 40 mm, the T2 inversion spectrum of Pleurotus eryngii strips at different frying time is shown in Fig. 3 below.

As shown in Fig. 3, the T2 inversion map of Pleurotus eryngii strips at different frying times has 1 to 4 peaks. During the entire frying process, with the extension of frying time, the T2 of different states of moisture is equal. Shows a downward trend, and the oil content gradually increases. The entire T2 inversion spectrum showed that all peaks gradually moved to the left, the total area of the peaks decreased, and the peaks merged. This result is consistent with the results of Wang et al. studying fried French fries (Wang et al., 2019). It shows that the high-degree-of-freedom water in the pleurotus eryngii strips migrates to the low-degree-of-freeness water during the vacuum frying process. Among them, the free water in the pleurotus eryngii strips has a large degree of freedom, which has been removed at the early stage of frying, causing it to move. Poor fluidity, increased resistance to fluidity, and part of the free water migrates to semi-bound water. On the other hand, most of the semi-bound water migrates outward and becomes free water and then is removed. As the drying time increases, T22 decreases significantly; and At the same time, part of the bound water with relatively large fluidity migrates to the semi-bound water, making T23 gradually decrease. It can be concluded that all peaks gradually move to the left, and the total peak area decreases. The frying time affects the water migration and moisture migration of Pleurotus eryngii. The oil content has an effect (Li & Li, 2016).

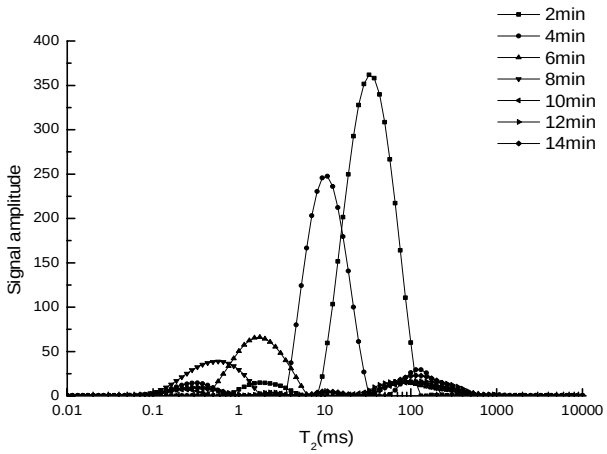

Fig. 3. The variation of T2 inversion spectrum with frying time

T2 inversion spectrum changes of Pleurotus eryngii after different frying time and drying. Under the condition of a frying temperature of 90 ℃ and a size of 6 mm × 6 mm × 40 mm, the T2 inversion spectrum of Pleurotus eryngii strips after drying for different frying times is shown in Fig. 4 below.

According to Fig.4, there is almost no T21 and T22 proton signals, indicating that a large amount of free water and semi-bound water are basically removed, indicating that it is the peak generated by the water molecule signal.

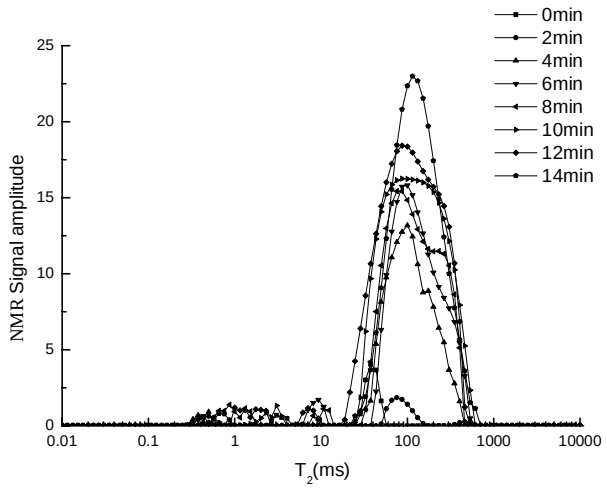

Fig. 4. T2 inversion spectrum of dried Pleurotus eryngii strips

The oil content increases with the extension of the frying time, and the highest oil content is when the frying time is 14 minutes. It is consistent with the results of Chen et al. using low-field nuclear magnetic resonance to measure the water and oil content in fried starch (Chen et al., 2017).

The effect of different frying time on MRI imaging during the process of Pleurotus eryngii. As an important part of modern detection technology, MRI can not only measure the moisture content and distribution of materials with high efficiency, high accuracy and damage-free, but also provide visual information of internal structure intuitively through the clarity and brightness of the image, The MRI image has a clear outline and high brightness, which indicates that the material has high moisture content; the fuzzy image and low brightness indicate that the material has low moisture content.

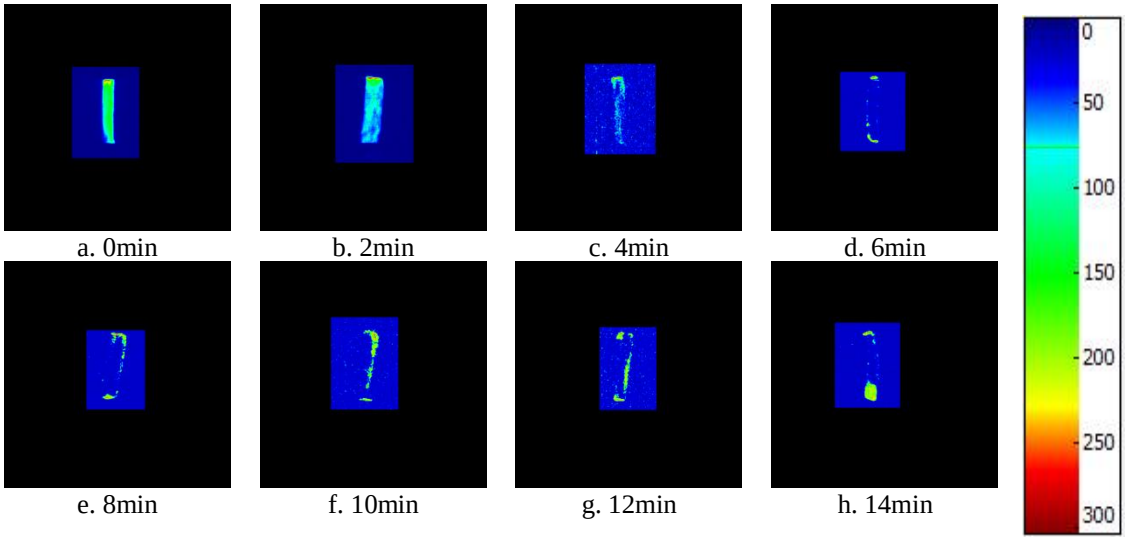

Fig. 5. Hydrogen proton imaging of Pleurotus eryngii strips with drying time

Low-field MRI analysis technology can macroscopically characterize the changes in moisture and the distribution of grease. The NMR image can not only reflect the strength of the oil signal by the difference in color, that is, red means high oil content, blue means low oil content, but also can intuitively characterize the overall oil distribution of fried pleurotus eryngii strips. It can be seen from Fig. 5 that with the extension of the frying time, the inner contour of the MRI image of Pleurotus eryngii strips gradually becomes blurred, the brightness gradually decreases, the volume shrinks, the less water, and the image interior is close to the background color (blue), indicating that the sample has reached The end of drying is reached; and the grease content is distributed in the edge shell layer higher than other positions. Therefore, the water is continuously removed, and the oil signal becomes stronger and stronger, which indicates that as the frying time increases, the oil content of the sample becomes higher and higher (Zhang et al., 2019; Yang et al., 2019).

The effect of different frying time on the quality of Pleurotus eryngii. The length of frying time is one of the most important parameters to control the oil content of fried foods (Li et al., 2017). Therefore, the oil content, water content, color difference, hardness, and crispness of Pleurotus eryngii strips were analyzed, and the results are shown in the following table 1.

Table 1
The effect of different frying time on the quality of Pleurotus eryngii (M ± m)

Frying time, min	Oil content, %	Moisture content, %	Color degree, ΔE	Hardness, g	Brittleness number
0 min	-	86.79 ± 0,77a	3.64 ± 0.19a	161.38 ± 1.85e	-
2 min	8.55 ± 0.26g	59.72 ± 0.68b	25.6 ± 0.35b	36.78 ± 0.51h	-
4 min	9.53 ± 0.08f	44.43 ± 0.29c	25.3 ± 0.30b	38.72 ± 1.40g	-
6 min	10.22 ± 0.18e	23.00 ± 0.44d	25.0 ± 0.45b	86.87 ± 0.75f	-
8 min	13.95 ± 0.58d	16.48 ± 0.28e	24.6 ± 0.59b	673.07 ± 0.29a	10.67 ± 2.08d
10 min	20.60 ± 0.13c	6.62 ± 0.32f	25.5 ± 0.43b	270.10 ± 0.76b	12.33 ± 1.53c
12 min	24.59 ± 0.14b	4.14 ± 0.44g	24.8 ± 0.26b	255.05 ± 0.32c	21.67 ± 0.58b
14 min	26.77 ± 0.25a	3.35 ± 0.21h	25.1 ± 0.16b	231.67 ± 0.61d	26.67 ± 2.08a

Note: The different superscript letters of the data in the same column represent significant differences ($P < 0.05$).

It can be seen from the chart that the oil content of Pleurotus eryngii strips gradually increases with the extension of the frying time. The oil content of 14min is significantly higher than other frying times ($P < 0.05$). Within a certain time range, the oil content is linear with the time It is consistent with Yu Shengshuang's research

results on the vacuum frying technology of lotus seeds (Yu, 2014); with the extension of the frying time, the water content of the Pleurotus eryngii strips will decrease significantly as the vacuum frying time increases ($P < 0.05$), when the frying time is 14min, the water content is reduced to the minimum 3.35 %; as far as the product color is concerned, there is no significant difference with the extension of the frying time; the hardness of the product comes first with the extension of the frying time After rising, there is a downward trend; at 8 min to 14 min, the crispness increases significantly with the extension of the frying time ($P < 0.05$). As the frying process continues, the surface of the sample gradually becomes dry. On the one hand, its hydrophobicity is increased. On the other hand, the evaporation of water leaves many large pores, so that fat can enter the voids. Therefore, the internal fat content is low at the beginning of frying. After the frying and the subsequent cooling stage, the vapor in the pores of the sample begins to condense, and the vapor pressure difference between the inside and outside of the sample allows more surface-adhered fat to enter the inside, which makes the inside contain higher oil content (Yu, 2014).

Conclusion. The moisture content of vacuum-fried Pleurotus eryngii strips decreased with the extension of the frying time, the hardness first increased and then decreased, there was no significant difference in color, but the oil content and crispness increased significantly. Low-field nuclear magnetic resonance and imaging technology studies have found that with the extension of the frying time, the T2 inversion spectrum continues to move to the left, that is, when it reaches 14 minutes, the free water and semi-bound water in the Pleurotus eryngii strips are basically removed, only There is a small amount of bound water that is difficult to remove, and the oil content continues to increase, and the oil content is distributed in the edge shell layer higher than other positions. Therefore, the low-field NMR measurement can predict the change trend of the moisture content and oil content of the vacuum-fried Pleurotus eryngii strips.

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