STUDY ON THE EFFECTS OF MOISTURE CONTENT ON THE COMPRESSIVE MECHANICAL PROPERTIES OF SWEET POTATO ROOTS
/
含水率对甘薯块根压缩力学特性的影响研究

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ABSTRACT
To investigate the effects of moisture content on the compressive mechanical properties of sweet potato roots, this study used three sweet potato varieties (Zishu, Hongyao, and Xiguahong) cultivated in the Tianjin region as experimental materials. Experiments were conducted between October 8, 2025, and January 8, 2026, in a laboratory environment maintained at 20°C ± 2°C and 50% ± 5% relative humidity. The test employed a moisture content measurement method based on storage duration, measuring moisture content every 10 days. Simultaneously, compressive mechanical property tests were performed using an INSTRON 3344 series universal material testing machine under conditions of a 10 mm/min loading speed and a maximum pressure of 1500 N. The maximum rupture force, maximum deformation, and elastic modulus of sweet potatoes at different moisture contents were determined. Data analysis was conducted using Design-Expert 13 software. The results indicated that the variation patterns of moisture content were similar across the different sweet potato varieties. The moisture content decreased rapidly during the initial storage period, showed a brief increase in the middle stage, and then continued to decline at a slower rate in the later stage. Moisture content significantly affected the compressive mechanical properties of sweet potatoes. As the moisture content decreased, the elastic modulus and maximum rupture force increased, while the maximum deformation decreased.

摘 要
为探究水分含量对甘薯块根压缩力学特性的影响，本研究以天津地区种植的紫薯、红瑶、西瓜红三个甘薯品种为试验材料，于 2025 年 10 月 8 日至 2026 年 1 月 8 日，在温度保持为 20℃±2℃、相对湿度保持为 50%±5% 的实验室环境中开展试验。本试验采用基于贮藏时长的水分含量测定方法，每 10 天测定一次甘薯水分含量；同时使用英斯特朗 3344 系列万能材料试验机，在加载速率 10 毫米 / 分钟、最大压力 1500 牛的试验条件下开展压缩力学特性测试，测定不同水分含量下甘薯的最大断裂力、最大变形量及弹性模量，并采用 Design-Expert 13 软件对试验数据进行分析。试验结果表明，不同甘薯品种的水分含量变化规律具有一致性：贮藏初期水分含量快速下降，贮藏中期出现短暂上升，贮藏后期则以较慢速率持续降低。水分含量对甘薯的压缩力学特性存在显著影响，随着水分含量的降低，甘薯的弹性模量和最大断裂力呈上升趋势，而最大变形量呈下降趋势。

INTRODUCTION
Sweet potato is an important food crop, rich in nutrients such as protein, carotenoids, flavonoids, anthocyanins, various vitamins, and minerals (*Alam M.K., 2020; Khatun T., 2025*). The physical and mechanical property parameters of sweet potato roots serve as crucial theoretical basis for the design of related machinery and are essential parameters for establishing models when studying the interaction mechanisms between sweet potatoes, soil, and machinery using numerical simulation methods (*Zhao Ping, 2024*). Furthermore, the compressive characteristics of sweet potatoes are also a theoretical guide for designing machinery used in storage, transportation, and processing. Since moisture content significantly influences compressive mechanical properties, studying the compressive mechanical properties of sweet potatoes at different moisture levels is of great importance. Additionally, the deep processing methods for sweet potatoes are closely related to their moisture content.

Different moisture levels determine the most suitable processing techniques; for instance, slicing, juicing, and mashing are more appropriate at high moisture content, while baking, frying, and grinding into flour are better suited for lower moisture content. Therefore, investigating the variation pattern of sweet potato moisture content during storage is particularly important, providing references for selecting preservation methods, processing techniques, and optimal timing.

Currently, researchers domestically and internationally have conducted studies on the relationship between the compressive mechanical properties of root and tuber crops and moisture content. Foreign scholar studied the relationship between the mechanical properties and moisture content of cassava roots, measuring the mechanical response of cassava roots under compression and other loads at different moisture contents and analyzing the effect of moisture content on mechanical indicators such as hardness and elastic modulus (*Bo M.W. et al, 2016*). *Agboola et al, (2024*), experimentally studied the mechanical properties of sugarcane stalks, analyzing compressive strength, Young's modulus, and other mechanical performance indicators based on compression tests conducted at different growth stages and among different varieties. *Bulan R et al, (2020),* investigated the relationship between moisture content and mechanical properties of arecanut fruits by measuring various engineering properties of fresh arecanut fruits at three different moisture levels. Their findings revealed that a reduction in moisture content led to increases in most dimensional, frictional and compressive indicators, while sphericity, thousand-fruit mass and bulk density decreased. *Teshome A et al, (2025),* measured grain size, thousand-kernel weight, bulk density, angle of repose, friction coefficient and other indicators under multiple moisture contents and conducted statistical analyses. The results demonstrated that rising moisture content enlarged grain dimensions, thousand-kernel weight, angle of repose and friction coefficient yet lowered bulk density, with significant disparities in grain properties across treatments, indicating that differentiated seeding equipment should be matched for wheat varieties with varying cultivars and moisture contents. Domestic researcher conducted tests on the mechanical physical characteristics of sweet potato tubers at harvest, demonstrating that sweet potato tubers can be considered isotropic materials (*Shen Haiyang, 2020*). An overview of these studies reveals that relatively little attention has been paid to the patterns of moisture content variation and its specific effects on compressive mechanical properties. *Zhang Lingzhi et al, (2025)*, explored the variation laws of moisture content in various plant organs, grain starch content, and membrane puncture properties at different grain positions during ripening. They verified that the grain dehydration rate had an extremely significant positive correlation with the moisture contents of stalks and cobs. When the grain moisture content fell below 25%, the yield load and elastic modulus at the side and top positions of grains in the desiccant treatment group were superior to those in the natural dehydration group. *Cui Qingliang et al, (2022),* measured the tensile, bending, shear and dynamic cutting mechanical properties of buckwheat stalks, analyzed the influences of moisture content, stalk height above ground and cutting parameters. The results revealed that buckwheat stalks with higher moisture content exhibited greater tensile and cutting-related indicators yet weaker bending performance; the overall mechanical strength of stalks declined with the increase of height above ground. Cutting speed and blade bevel angle had significant effects on cutting stress and cutting energy consumption, and the optimal ranges of cutting parameters were put forward.

However, reviewing literature on crops similar to sweet potatoes, conducted block experiments on cassava stems and determined stem mechanical parameters, finding that the moisture content at different growth locations significantly affected the maximum compression load, indicating a significant influence of moisture content on compressive mechanical properties (*Wang Wei, 2017*). *Wang Juxia, (2024*), through completely randomized compression mechanical property tests on mung bean seeds, found that under the same loading speed, seed moisture content significantly affected the yield load and apparent elastic modulus of the seeds. Based on the above analysis, this paper aims to study the effect of moisture content on the compressive mechanical properties of sweet potato roots.

MATERIALS AND METHODS

Test Materials

This experiment was conducted in a sweet potato test field established through cooperation between Shenyang Agricultural University and Yuelong Town, Tianjin. Three cultivated sweet potato varieties, namely Zishu, Hongyao, and Xiguahong, were used as experimental materials. Manual harvesting took place on October 8, 2024 (*Liao J., 2025*).

Thirty tubers of each variety were selected based on uniform size, absence of damage, pests, and diseases, ensuring consistent maturity. After harvest, The length, width, and thickness of the fresh sweet potatoes for each variety were measured using a vernier caliper, and tubers of similar size and shape were selected, labeled, and stored, as shown in Figure 1. All test sweet potatoes were stored in the Agricultural Product Processing and Storage Laboratory of Shenyang Agricultural University from October 8, 2025, to January 8, 2026, totaling 3 months.

Fig. 1 - Sweet potato samples used for the experiment

Test Equipment and Instruments

The test equipment included a 101-type electric drum drying oven (Tianjin Tonglixinda Instrument Factory), an INSTRON 3344 series universal material testing machine (INSTRON, USA), an electronic balance (precision 0.01 g), a vernier caliper (measurement range 0-300 mm, accuracy 0.02 mm), plastic bags, and labels. The universal testing machine was used to test the compressive mechanical properties of sweet potatoes at different moisture contents. It can display compression load, displacement, speed, and test curves in real-time. The electronic balance and the 101 electric drum drying oven were used to determine the moisture content of the sweet potatoes. The vernier caliper was used to measure the diameter and thickness of the sweet potato samples.

Fig. 2 - Universal material physical testing machine

Fig. 3 - Electric drum drying oven

Experimental Procedure

Detailed elaboration of the adopted test method and its advantages over conventional laboratory testing methods

The integrated storage-stage moisture monitoring combined with uniaxial compression test adopted in this work is a customized composite testing scheme for fresh tuber crops. Conventional single standard laboratory analysis methods are divided into two independent tests: one-time destructive drying for moisture measurement and separated compression tests on randomly sampled tuber blocks, which have two obvious defects: first, the moisture sample and mechanical sample are taken from different sweet potato individuals, leading to inconsistent actual moisture levels between mechanical test specimens and measured moisture data; second, traditional instant dehydration treatment will destroy the original internal tissue structure of fresh sweet potatoes and cannot reflect the natural tissue state of tubers during actual storage.

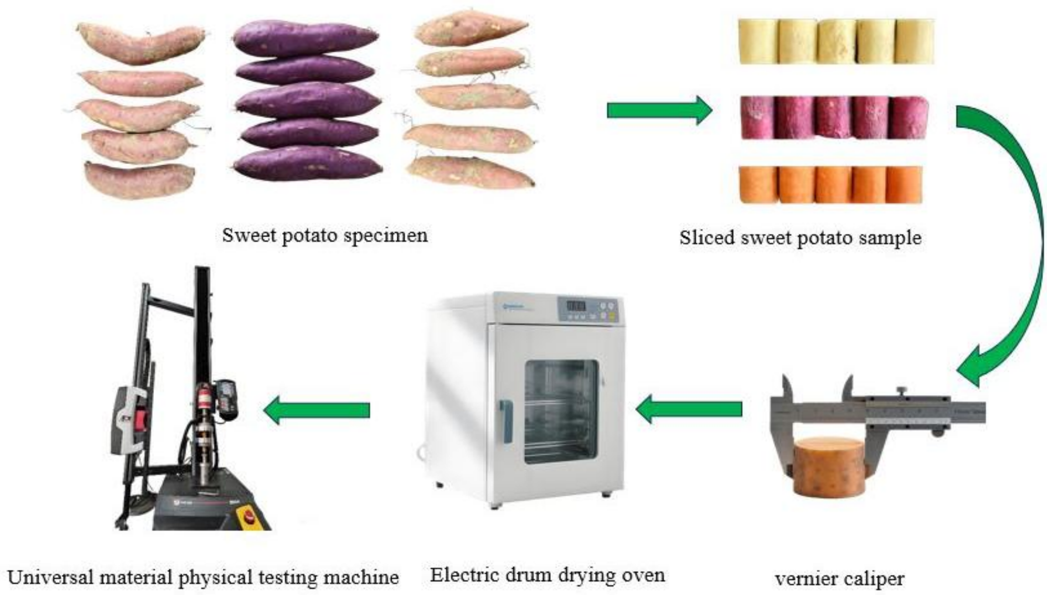


Fig. 4 - Test Procedure

The present testing method synchronously completes moisture tracking and compression measurement on the same batch of sweet potato tubers under natural storage environment, without artificial forced dehydration before mechanical testing. Cylindrical samples are cut from the same intact tuber for moisture detection and compression loading respectively, which ensures the complete consistency of tissue state and moisture background of test specimens. Besides, continuous 90-day periodic sampling avoids the error caused by discrete single-point sampling in short-term static tests. Compared with vacuum drying independent mechanical test and rapid oven drying mechanical test, this method can truly restore the natural water migration and tissue hardening law of sweet potato during postharvest storage, and the data correlation between moisture and mechanical indicators is higher, which is more suitable for exploring the continuous variation law of mechanical properties of fresh root crops with moisture content.

Sample repetition setting for guaranteeing test accuracy

Sweet potatoes were cut into cylindrical pieces approximately 15 mm thick using a sampling tool. The slices were made flat, avoiding cracks or unevenness, as shown in Figure 4. The universal testing machine was turned on and preheated for 10-15 minutes to ensure instrument stability. Test machine parameters were set: loading speed at 10 mm/min, maximum pressure set to 1500 N based on expected compression degree. The cut sweet potato sample was placed on the compression platform of the testing machine, ensuring it was centered, as shown in Figure 5. The testing machine was started, applying pressure to the sample at the set loading speed, and the deformation under different pressures was recorded. The deformation of the sample was observed, and any anomalies were recorded. Changes in the moisture content of sweet potatoes during storage are affected by temperature and humidity (*Guo Lianghu, 2020*). Therefore, environmental temperature and humidity were kept stable to avoid affecting the experimental results. Experiments were conducted in a laboratory environment maintained at 20°C ± 2°C and 50% ± 5% relative humidity. For each sweet potato variety under every single storage time/moisture level, 5 parallel tuber individuals were selected, and 3 cylindrical specimens were cut from each tuber for repeated compression tests; a total of 15 replicate compression samples were measured per treatment group. Meanwhile, 5 parallel thin slice samples were prepared for moisture content measurement at each test node. Multi-layer repetition design (individual tuber repetition + specimen repetition) can eliminate random errors caused by individual differences of sweet potato tubers, cutting thickness deviation and instrument micro-fluctuation, effectively improving the stability and reproducibility of test data.

The above steps were repeated for multiple sweet potato samples to ensure the repeatability and accuracy of the results. Based on the recorded pressure and deformation data, the elastic modulus of the sweet potato samples was calculated. The elastic modulus is an indicator reflecting the material's ability to resist deformation (*Long Che, 2024*).

Fig. 5 - Sweet potato samples placed on the testing machine platform

Fig. 6 - Cylindrical samples of sliced sweet potatoes

Test Design and Methods

To study the effect of moisture content on the compressive mechanical properties of sweet potatoes, this test adopted a moisture content testing method based on storage time. After harvest, the first moisture content determination and compression mechanical test were conducted; the second test was performed after 10 days; the third after 20 days; the fourth after 30 days; the fifth after 40 days; continuing this pattern, moisture content was tested every 10 days, resulting in 10 measurements over a total of 90 days. Through these tests, the variation patterns of moisture content with storage time for the three sweet potato varieties were obtained.

There are many methods for measuring moisture content; currently, internationally common methods include vacuum drying and convection oven drying (*Ge Naijun, 2025; Chen Siyu, 2025*). Based on available laboratory conditions and referencing GB/T 12078-2008, the convection oven drying method and mass weighing method were used to determine the moisture content of sweet potatoes. First, 10 samples were prepared for each sweet potato variety, cut into thin slices of similar thickness, and numbered separately. The weight of the samples was measured and the initial weight recorded. They were evenly placed on trays and in a convection oven at 100°C, dried for 0, 1, 2, 3, and 4 hours respectively. During the drying process, at specified times, samples of the three varieties were taken out, weighed, and the data recorded. If the weight no longer changed, it signified the end of drying; samples not meeting the specified drying standard were returned to the convection oven for continued drying.

$$x = \frac{m_1 + m_2}{m_1} \tag{1}$$

where: x is the moisture content of the crop, m_1 is the mass of the sample in grams, m_2 is the mass of the sample dried to constant weight in grams.

The procedure for testing the compressive properties of sweet potatoes was as follows: the loading speed was fixed at 10 mm/min, and the loading direction was vertical (*Ruan B., 2024*). Samples from the three sweet potato varieties were compressed at their natural moisture content levels after different storage periods to obtain the maximum rupture force, maximum deformation, and elastic modulus. The influence of moisture content on compressive mechanical properties was then studied through static load mechanical performance analysis. For each of the three sweet potato varieties tested, five replicate tests were conducted at the same moisture content level. For each of the three sweet potato varieties tested, five independent intact tubers were selected at the same moisture content level, and three cylindrical test pieces were cut from each tuber for compression test, forming 15 repeated test replicates for one treatment to reduce random test error. Data were statistically analyzed, and the mean and variance were calculated. During the test, a rigid plate was used as the loading device (*Barnett M.R., 2004*). The test sweet potato sample was placed in the center of the platen, and the upper platen was adjusted so that it did not contact the sweet potato. Entering the test program control interface, the control parameters were selected in the method settings, including a loading rate of 10 mm/min, an upper load limit of 1500 N, an upper displacement limit of 25 mm, an upper load drop percentage of 20%, and an upper load drop value of 10 N. In the test interface, the steps were followed by clicking load zero, reset extensometer, start, and finish sequentially. To reduce test error, each test was repeated five times under the same conditions, and the average value was taken finally.

This paper selected sweet potato moisture content as the experimental factor. The maximum rupture force at sample fracture, maximum deformation, and elastic modulus were used as test indicators. A three-factor, three-level experimental design was implemented, and response surface analysis was conducted to explore the interaction between these three factors and their effect on moisture content. The factor levels are shown in Table 1:

Table 1

Factor level table

Factor	level		
	-1	0	1
A（N）	300	390	480
B（mm）	5	7.5	10
C（MPa）	3	4.5	6

Note: A denotes maximum breaking force, B denotes maximum deformation, and C denotes elastic modulus.

To explore the interactive effects of the three factors on moisture content, simulation analyses were performed for each model sequentially. The data obtained from the simulation process were integrated, and the monitoring results are shown in Table 2.

Table 2

Orthogonal experimental design of moisture content

Test Number	A Maximum breaking force / N	B Maximum deformation / mm	C Modulus of elasticity / MPa	Y_1- Moisture content （%）
1	390	5	3	71.5
2	390	10	6	72.5
3	390	7.5	4.5	75.3
4	390	10	3	74.2
5	390	5	6	74.1
6	480	7.5	3	73.3
7	390	7.5	4.5	75.0
8	300	5	4.5	72.1
9	480	7.5	6	74.3
10	480	10	4.5	74.1
11	390	7.5	4.5	75.3
12	390	7.5	4.5	75.1
13	300	7.5	6	73.1
14	300	10	4.5	73.8
15	300	7.5	3	73.2
16	480	5	4.5	74.0
17	390	7.5	4.5	75.2

Based on Design-Expert 13 software, data were analyzed to perform significance tests and analysis of variance (ANOVA) for the mean Y_1 moisture content regression equation.

RESULTS AND DISCUSSION

Variation Pattern of Moisture Content in Different Varieties

The moisture content measurement results for the three varieties from 0 to 3 months after harvest were collected and analyzed, as shown in Figure 6. It can be observed that the moisture content of the three sweet potato varieties at harvest reached 74%-76%, but as storage time increased, the moisture content showed a decreasing trend: during the first 0-30 days of storage, the moisture content decreased rapidly; around 45 days, the decreasing trend slowed down further, reaching about 72%-74%. At 60 days of storage, the Zishu variety had the lowest moisture content and tended to stabilize. Starting from day 50, the moisture content of the Hongyao, Xiguahong, and Zishu varieties also slightly increased. Taking Xiguahong as an example, the moisture content of freshly harvested tubers initially reached 74.8%; after 20 days, it decreased to 74.3%, a drop of about 0.5%. The moisture content on day 90 was 72.7%, and the data stabilized. For different sweet potato varieties, their moisture content also differed. Overall, despite the different varieties, the variation pattern of moisture content in sweet potato tubers was similar. In the initial storage period, the moisture content decreased relatively quickly.

This is because physiological activities within the sweet potato continue after harvest, and respiration consumes a certain amount of water. The moisture content showed a brief increasing trend in the middle stage, possibly due to high humidity in the storage environment and poor ventilation, causing the sweet potato surface to absorb moisture from the air, leading to an increase in its moisture content. Microbial metabolic activities can also produce water, causing local increases in moisture content. However, this increase is temporary. As storage time increases, the moisture content of sweet potatoes continues to decrease, but the rate of decrease gradually slows down. Considering that sweet potatoes contain starch, sugars, and other carbohydrates besides water, it is certain that the tubers are not fully mature immediately after harvest, the skin is still tender, the cork layer has not formed, the water content is high, and they are prone to peeling. At this stage, sweet potatoes have sufficient moisture and a relatively soft texture, making them suitable for direct processing into mashed or pulped sweet potato for fillings in pastries. They can also be used to make sweet potato beverages or processed into ready-to-eat products such as steamed or roasted fresh sweet potato products.

Through compression mechanical tests, the compressive mechanical properties of different sweet potato varieties at various moisture contents were obtained (Table 3).

Table 3

The values of compressive mechanical properties under different moisture contents

Variety	Moisture content /%	Maximum breaking force / N	Maximum deformation / mm	Modulus of elasticity / MPa
Xiguahong	74.8	302.45	6.10	4.85
	74.3	389.54	9.45	4.11
	73.8	460.75	7.35	5.70
	73.3	487.68	10.45	5.33
	73.1	517.68	7.40	5.25
	72.8	562.25	17.50	3.92
	72.9	540.59	8.30	5.81
	73.0	506.61	13.05	3.26
	72.8	480.55	7.25	5.01
	72.7	473.50	8.52	4.71
Hongyao	75.3	299.85	6.32	4.19
	74.6	370.57	5.90	5.04
	74.0	424.75	10.21	4.15
	73.5	484.65	8.25	4.82
	73.4	494.35	7.45	5.68
	73.5	477.28	8.85	5.08
	73.7	457.92	6.54	5.42
	73.6	436.05	7.25	4.35
	73.5	427.52	8.65	4.11
	73.5	415.28	8.14	4.48
Zishu	74.3	344.69	4.85	5.44
	73.8	408.45	7.65	4.71
	73.4	464.15	6.35	6.22
	73.1	514.74	8.71	5.32
	72.9	542.72	6.45	7.04
	73.1	560.31	5.32	7.87
	73.2	542.56	5.21	7.18
	73.1	521.15	6.23	7.89
	73.0	506.45	7.15	6.38
	73.0	495.51	6.45	6.11

The rupture force of sweet potato primarily refers to the maximum value of the external load sustained by the sweet potato at the point of rupture. From Table 3, it can be seen that as the moisture content decreases, the compressive load that the sweet potato can withstand increases. The moisture content of all varieties was above 70% at the initial harvest stage. During the first 20 days of natural storage, the moisture content decreased rapidly. For example, for Hongyao, the maximum rupture force increased from 299.85 N to 370.57 N. Then, after about 50 days of storage, the change in maximum rupture force tended to stabilize. With further increase in storage time, around 90 days, when the moisture content was lower, the rupture force showed a subsequent decrease in some cases.

The elastic modulus of sweet potato is a measure of its resistance to deformation. A larger elastic modulus indicates that a greater external load pressure is required to cause elastic deformation. From the experimental data in Table 3, it can be observed that the modulus for the three varieties increased as the moisture content decreased. However, after 50 days, the trend of change in the elastic modulus was similar for the three varieties, with Zishu having the highest elastic modulus, followed by Xiguahong, and Hongyao having the smallest. A higher elastic modulus value indicates better firmness of the tuber. Analysis suggests that after the moisture content decreases, the elastic viscosity of the sweet potato decreases, and the density increases. The sweet potato becomes closer to a rigid body, is less prone to deformation under pressure, and possesses a certain load-bearing capacity.

The compressive deformation of sweet potato refers to its deformation under external compressive load, specifically the maximum displacement at the fracture point. From the experimental data in Table 3, it can be seen that as the moisture content decreases, the deformation tends to decrease, and the trend of change is consistent across different varieties. For example, for the Hongyao variety, the change in sweet potato deformation with moisture content is shown in Figure 7 (Note: Referenced but not provided in original text).

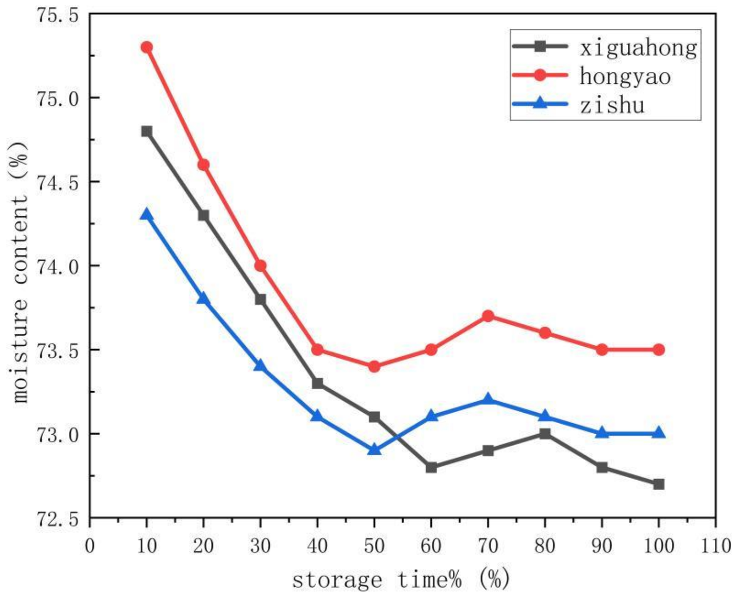


Fig. 7 - The variation law of moisture content of sweet potatoes with storage time

When the moisture content decreased from 75.3% to 73.5%, the deformation showed a decreasing trend, but overall, the decrease was relatively slow. After 50 days of storage, when the moisture content dropped to around 73.4%, the change in deformation was small. Other varieties exhibited their own characteristics, but the overall trend was consistent. As storage time increases and moisture content gradually decreases, the internal tissue of the sweet potato becomes more compact. Additionally, increased maturity and hardness enhance its ability to resist external loads, resulting in reduced deformation. At this stage, the moisture content is moderate, and the texture has a certain toughness, making it suitable for producing sweet potato dried strips by natural air-drying or oven-drying to remove some moisture while retaining flavor. They can also be processed into sweet potato flour through dehydration and grinding, which can be used for thickening or making pastries.

Based on Design-Expert 13 software, the significance of the regression equation and the analysis of variance for the mean Y_1 moisture content are shown in Table 4. Due to space limitations, this paper only presents the analysis for one sweet potato variety, Hongyao.

Table 4

Significance and analysis of variance of mean regression equation

Source	Sum of Squared Deviations	degree of freedom	Mean Square	F-value	p-value	Significance
Model	20.83	9	2.31	70.28	<0.0001	**
A	1.53	1	1.53	46.50	0.0002	**
B	1.05	1	1.05	31.92	0.0008	**
C	0.41	1	0.40	12.30	0.009	**
AB	0.64	1	0.64	19.44	0.003	**
AC	0.30	1	0.30	9.19	0.019	*
BC	4.62	1	4.62	140.386	<0.0001	**
A2	1.72	1	1.72	52.37	0.0002	**
B2	4.55	1	4.55	138.30	<0.0001	**
C2	4.77	1	4.78	145.03	<0.0001	**
residual	0.2305	7	0.03			
Missing item	0.1625	3	0.05	3.186	0.146	ns
Pure error	0.0680	4	0.02			
total	21.05	16				

Note: P < 0.01 indicates highly significant results, denoted by **; P < 0.05 indicates significant results, denoted by *; P > 0.05 indicates non-significant results, denoted by ns.

According to the table data, the significance test result for the model (p-value less than 0.0001) indicates that the model is statistically highly significant. Simultaneously, the p-value for the lack of fit is 0.146, indicating that the lack of fit is not significant. The fit statistic R_1^2 = 0.9891, indicating a high degree of fit for the regression model. The regression equation for moisture content is given by Equation 2:

$$Y_1=75.18+0.4375^*A+0.3625^*B+0.225^*C-0.4^*AB+0.275^*AC-1.07^*BC-0.64^*A^2-1.04^*B^2-1.06^*C^2 \tag{2}$$

where: Y_1: Moisture content of crop. A: Maximum rupture force. B: Maximum deformation. C: Elastic modulus. AB, AC, BC: Interaction terms of two factors. A^2, B^2, C^2: Quadratic terms of each single factor.

The response surfaces showing the interactive effects of the three factors on Y_1 moisture content are shown in Figure 8:

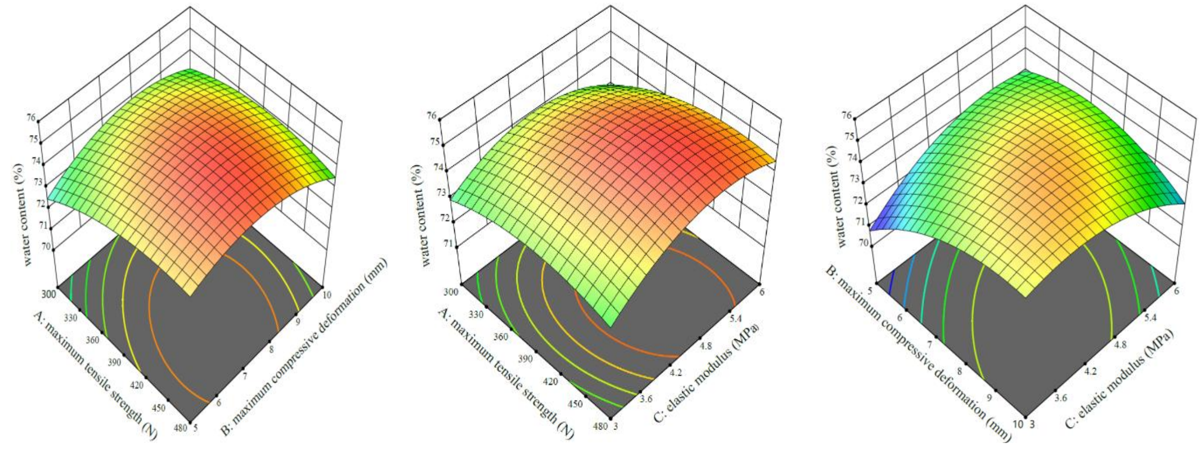
(a) Response surface of maximum rupture force (A) and maximum deformation (B) on sweet potato moisture content;

(b) Response surface of maximum rupture force (A) and elastic modulus (C) on sweet potato moisture content;

(c) Response surface of maximum deformation (B) and elastic modulus (C) on sweet potato moisture content.

Fig. 8 - Three-dimensional response surface plots showing the interactive effects between every two mechanical indicators (maximum rupture force, maximum deformation, elastic modulus) on the moisture content of Hongyao sweet potato tubers. Each subfigure corresponds to the coupling effect of two independent mechanical factors on the moisture content response value, while the third factor is fixed at the zero central level (A =390 N, B =7.5 mm, C =4.5 MPa). The vertical axis of each 3D surface represents the predicted moisture content; the two horizontal axes represent the two selected mechanical indicators respectively. The gradient change of surface height intuitively reflects the changing trend of moisture content under different factor combinations. The curved shape of the response surface demonstrates that there exists obvious nonlinear interaction between every pair of mechanical indicators, consistent with the significance results of AB, AC and BC interaction terms in ANOVA table. The surface shows an overall rising trend first and then falling, which is caused by the negative quadratic terms of A, B and C in the regression equation. The BC coupling surface has the steepest curvature, indicating that the interaction between maximum deformation and

elastic modulus exerts the most prominent influence on sweet potato moisture content, which matches the extremely significant p-value of BC item (p$<$0.0001) in the analysis of variance.



（a） A and B （b） A and C （c） B and C

Fig. 8 - Response surfaces of test factors to the effects of soil disturbance

CONCLUSIONS

Through moisture content tests and mechanical property tests on different sweet potato varieties from the Tianjin region, this study investigated the effect of moisture content on the mechanical properties of sweet potato roots and their variation patterns. The influence of moisture content on the maximum rupture force, maximum deformation, and elastic modulus for three sweet potato varieties was analyzed. The main conclusions are as follows:

The moisture content of three sweet potato varieties was studied over 3 months post-harvest. The variation pattern of moisture content was similar across different sweet potato varieties. During the initial storage period, the moisture content decreased rapidly, showed a brief increase in the middle stage, and continued to decrease in the later period.

Moisture content had a highly significant effect on the mechanical properties of sweet potatoes, including the maximum rupture force, maximum deformation, and elastic modulus. The elastic modulus and maximum rupture force increased with decreasing moisture content, while the maximum deformation decreased with decreasing moisture content.

In the early storage period, when sweet potatoes have high moisture content, they are suitable for direct processing into mash or pulp for use as fillings in pastries. They can also be used to make sweet potato beverages or processed into ready-to-eat products like steamed or roasted fresh sweet potatoes. In the later storage period, when the moisture content is moderate and the texture has a certain toughness, they are suitable for making sweet potato dried strips by natural air-drying or oven-drying to remove partial moisture while retaining flavor. They can also be processed into sweet potato flour through dehydration and grinding, which can be used for thickening or making pastries.

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