

# Research on Postharvest Sugar Degradation Mechanism and Cold Chain Preservation Technology Innovation in Sweet Corn

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## Abstract

Postharvest sugar degradation, quality deterioration, and short shelf life are common problems in sweet corn, severely restricting industry development. Existing research has limitations such as single-dimensional mechanism analysis and insufficient targeted preservation technology. This study focuses on the postharvest sugar degradation mechanism of sweet corn and targeted cold chain preservation technology. It analyzes the degradation mechanism from multiple dimensions, including varietal differences, molecular-physiological synergy, and environmental interaction. A targeted design of a precise pre-cooling, compound preservative, dynamic modified atmosphere, and intelligent monitoring integrated cold chain technology was developed. The application effect was evaluated through compatibility verification and empirical analysis. Results show that there are significant differences in sugar degradation characteristics among different types of sweet corn. Sucrase and amylase are the core regulatory enzymes, and genes such as SPS and SS participate in metabolic regulation. The compound preservation technology can reduce sucrase and amylase activities by 65% and 61%, respectively, achieving a sugar retention rate of 78%-82% after 15 days and extending the shelf life to 15 days, with an input-output ratio of 1:3.2. This study constructed a variety-specific preservation scheme, clarified the compatibility of technology and mechanism, and provided theoretical support and practical technology for postharvest preservation of sweet corn, helping to improve the quality and efficiency of the industry.

## Keywords

Sweet Corn, Postharvest Preservation, Sugar Degradation Mechanism, Cold Chain Technology, Targeted Regulation, Variety Adaptation.

## 1. Introduction

In recent years, sweet corn has seen a continuous increase in market demand due to its sweet taste and rich nutrition, and the industry has steadily expanded, becoming an important crop for increasing agricultural efficiency and farmers' income. However, after sweet corn is harvested and separated from the parent plant, the sugar content is easily and rapidly degraded and transformed, leading to a loss of flavor and quality, and a generally short shelf life, which seriously restricts the product's circulation and added value, becoming a core pain point for the industry's development. Research on postharvest sugar degradation mechanisms and cold chain preservation technology is of great practical significance for extending product shelf life, ensuring quality stability, and promoting the sustainable development of the industry.

Currently, the academic community has conducted some research on the enzymatic characteristics, metabolic pathways, and traditional cold chain preservation technologies of sugar degradation in sweet corn [1]. However, existing results still have significant shortcomings: mechanism analysis is mostly focused on single enzymes or metabolic levels, lacking multi-dimensional fusion analysis encompassing molecular, cellular, and physiological

dimensions; preservation technologies are mostly conventional applications, lacking targeted adaptability to degradation mechanisms, and single technologies struggle to balance preservation effectiveness and practicality. This paper focuses on three core areas: multi-dimensional mechanisms of sugar degradation, targeted cold chain preservation technologies, and verification of the adaptability of mechanisms and technologies [2]. It innovatively proposes a research approach of multi-perspective mechanism analysis, targeted design technology, and closed-loop verification of adaptability, aiming to provide theoretical support and technical reference for postharvest preservation of sweet corn.

## **2. Innovation in Postharvest Sugar Degradation Mechanisms and Targeted Cold Chain Preservation Technologies for Sweet Corn**

### **2.1. Multidimensional Analysis of Sugar Degradation Mechanisms**

Sugar degradation in sweet corn is a complex process involving both intrinsic characteristics and the external environment, requiring comprehensive analysis from multiple perspectives, including varietal differences, molecular-physiological synergy, and environmental interactions [3]. Significant differences exist in the sugar composition of different types of sweet corn. Super sweet corn is dominated by sucrose, with an initial content of 15%-20%, and exhibits the fastest post-harvest degradation rate. Regular sweet corn has a balanced content of sucrose, fructose, and glucose, resulting in relatively slower degradation. Enhanced sweet corn combines the characteristics of both types, exhibiting moderate sugar stability. Tracking the dynamic changes in sugar content from 0 to 15 days post-harvest revealed that the first 3 days post-harvest are the period of rapid sugar degradation, with the degradation rate slowing down after 7 days. Variety specificity directly determines the initial and peak degradation rates. In the enzyme-metabolism-gene synergistic pathway, sucrase, amylase, and sucrose synthase are key enzymes regulating sugar degradation, with their activities increasing by 60%-80% within 3 days post-harvest, directly catalyzing sucrose hydrolysis and starch conversion [4]. Metabolomics analysis revealed that intermediate products such as maltose and sorbitol initially increased and then decreased during degradation, reflecting dynamic changes in metabolic pathways. Transcriptomics screening identified candidate genes such as SPS and SS, whose expression levels showed a significant positive correlation with sugar degradation rates, supplementing the molecular-level explanation. Simultaneously, postharvest cell structure integrity gradually deteriorated, increasing cell membrane permeability, accelerating sugar loss and enzymatic reactions, further exacerbating the degradation process.

The interaction between environmental factors and intrinsic characteristics significantly affected degradation efficiency, with temperature being the dominant factor. Sugar degradation rates at 25°C were 3-4 times higher than under cold chain conditions of 0-2°C. Humidity below 85% indirectly accelerated sugar degradation due to moisture loss. A gaseous combination of 5% CO<sub>2</sub> and 3% O<sub>2</sub> inhibited enzyme activity and delayed degradation [5]. Among the intrinsic characteristics, sweet corn with a maturity of 80-90% has the highest sugar content, but it is also the most sensitive to degradation. When the moisture content is higher than 75%, cell metabolism is vigorous, and the degradation rate increases by about 20%. Quantitative analysis clarifies the interaction weights of temperature-maturity and humidity-moisture content under different conditions, providing a basis for optimizing preservation technology.

### **2.2. Innovation in Cold Chain Preservation Technology based on Degradation Mechanisms**

Targeting the key links and dominant factors in sugar degradation, innovative preservation technologies adapted to the cold chain environment were designed to achieve a breakthrough from simple preservation to synergistic enhancement [6]. Precision precooling technology

targets the critical temperature range for sugar degradation (10-25°C), developing a composite process of "gradient precooling + short-term low-temperature stress." Sweet corn is first gradually cooled from 25°C post-harvest to 5°C (5°C decrease per hour), followed by a short-term stress at 0°C for 1-2 hours. Compared to traditional rapid precooling, this increases the inhibition rate of sucrase and amylase by 30%, improves sugar retention by over 15%, and avoids low-temperature damage.

This cold-chain compatible compound preservative focuses on inhibiting key enzyme activity and protecting cell structure. It combines natural plant extracts such as tea polyphenols and chitosan with microbial metabolites like nisin, with an optimized concentration ratio of 0.5% tea polyphenols + 1.0% chitosan + 0.1% nisin. Applied evenly to the surface of sweet corn using a spray coating process, it forms a breathable and moisture-retaining film [7]. This preservative exhibits strong stability under low-temperature conditions in the cold chain, reduces cell membrane permeability, inhibits enzyme activity, and prolongs the sugar degradation cycle.

Dynamic modified atmosphere (MAP) cold chain technology overcomes the limitations of traditional static MAP. It designs dynamic parameters of "high CO<sub>2</sub> inhibition in the early stage + low O<sub>2</sub> preservation in the later stage" based on the gas requirements for sugar degradation in different varieties: maintaining 5%-8% CO<sub>2</sub> + 21% O<sub>2</sub> for the first 3 days of storage to rapidly inhibit enzyme activity; after 3 days, adjusting to 3%-5% O<sub>2</sub> + 2%-3% CO<sub>2</sub> to slow down the metabolic process and avoid physiological damage caused by high CO<sub>2</sub>. Compared to static MAP, sugar retention is increased by 12%, and shelf life is extended by 3-5 days.

Intelligent monitoring and end-to-end preservation optimization combine IoT technology, deploying temperature, humidity, and gas composition sensors at each stage of the cold chain to collect data in real time and transmit it to a cloud platform. A dynamic parameter adjustment mechanism is established based on a sugar degradation kinetic model. When temperature fluctuations exceed ±1°C or CO<sub>2</sub> concentration exceeds a threshold, the refrigeration or gas regulation module is automatically activated to ensure stable environmental parameters throughout the cold chain [8]. This solves the problem of fluctuating preservation effects caused by "chain breaks" in traditional cold chains, achieving precise control over sugar degradation.

### **3. Compatibility Verification of Mechanism and Preservation Technology**

To clarify the compatibility between innovative cold chain preservation technology and sugar degradation mechanisms, this study conducted verification from three aspects: enzyme activity regulation, quality correlation, and variety adaptation, through controlled experiments, index tracking, and personalized matching, providing data support for technology implementation.

#### **3.1. Regulation Effect of Preservation Technology on Key Enzymes in Sugar Degradation**

A control group (traditional rapid pre-cooling + ordinary refrigeration) and experimental groups (precision pre-cooling group, compound preservative group, dynamic modified atmosphere group, and combined technology group) were set up. Changes in sucrase and amylase activities were tracked after 0, 7, and 15 days of storage. Results showed that among single technologies, the dynamic modified atmosphere group had the best inhibitory effect on sucrase, with an inhibition rate of 58% after 15 days of storage; the compound preservative group showed a more significant inhibitory effect on amylase, with an inhibition rate of 52%. The combined technology group (precision pre-cooling + compound preservative + dynamic modified atmosphere) performed best, with sucrase and amylase activities decreasing by 65% and 61% respectively within 15 days, an inhibition rate more than 30% higher than the control group. This indicates that innovative technologies can precisely target and regulate the activity of key enzymes, and that the synergistic adaptation of multiple technologies to the degradation

mechanism results in superior inhibitory effects compared to a single technology, validating the suitability of the "mechanism analysis - technology design" approach.

### **3.2. Correlation between Sugar Metabolism and Quality Indicators under Cold Chain Conditions**

Sugar content and quality indicators of each experimental group were continuously monitored during storage. Sugar retention rate was determined by high-performance liquid chromatography (HPLC). Quality indicators included hardness (texture analyzer), soluble solids (handheld refractometer), volatile aroma components (gas chromatography-mass spectrometry), and sensory score (out of 10). Results showed that after 15 days of storage, the total retention rate of sucrose, fructose, and glucose in the composite technology group reached 78%, a 25% increase compared to the control group. The corresponding hardness remained at 18N, and the soluble solids content was 12.5°Brix, both significantly higher than the control group. A linear model of "sugar retention rate - quality score" was established through correlation analysis ( $R^2=0.89$ ). When the sugar retention rate was  $\geq 80\%$ , the sensory score was  $\geq 7.5$ , and the shelf life could be extended to more than 15 days. When the retention rate was below 60%, the sensory score dropped below 5, resulting in loss of commercial value. This clearly demonstrated the strong correlation between sugar metabolism and product quality, quantifying the preservation effectiveness of the innovative technology.

### **3.3. Development of Variety-Specific Preservation Solutions**

Preservation technology parameters are matched accordingly based on the differences in degradation mechanisms among different varieties. Super sweet corn has a high sucrose content and a fast degradation rate, making it suitable for a "gradient precooling ( $25^\circ\text{C} \rightarrow 5^\circ\text{C} \rightarrow 0^\circ\text{C}$  stress for 2h) + 0.5% tea polyphenols + 1.0% chitosan compound preservative + dynamic modified atmosphere (8%  $\text{CO}_2$ +21%  $\text{O}_2$  in the early stage, 3%  $\text{O}_2$ +3%  $\text{CO}_2$  in the later stage)" scheme, achieving a 75% sugar retention rate after 15 days. Regular sweet corn has a balanced sugar composition and slow degradation, and a "gradient precooling ( $25^\circ\text{C} \rightarrow 5^\circ\text{C}$  stress for 1h) + 0.3% tea polyphenols + 0.8% chitosan preservative + static modified atmosphere (5%  $\text{CO}_2$ +3%  $\text{O}_2$ )" scheme balances preservation effect and cost, achieving an 82% sugar retention rate after 15 days. Enhanced sweet corn has degradation characteristics between the two, making it suitable for a "gradient precooling + compound preservative + simplified dynamic modified atmosphere (6%  $\text{CO}_2$ +21%  $\text{O}_2$  in the early stage)" scheme. The " $\text{CO}_2$  + 21%  $\text{O}_2$ , later 4%  $\text{O}_2$  + 2%  $\text{CO}_2$ " scheme achieved a sugar retention rate of 79% after 15 days. All three schemes were experimentally validated, demonstrating simple operation procedures and clear parameters, and can be directly applied to the cold chain preservation of different varieties of sweet corn.

## **4. Empirical Analysis and Application Effect Evaluation**

### **4.1. Experimental Design and Detection Methods**

Three mainstream sweet corn varieties were used in the experiment: Zhengtian No. 3 (super sweet corn), Tiantian No. 1 (regular sweet corn), and Jiaqiang No. 5 (enhanced sweet corn). All were harvested from a planting base in Tai'an, Shandong Province, and were 80-90% mature at harvest, free from pests, diseases, and mechanical damage. Four treatment groups were set up: a control group (traditional rapid pre-cooling + ordinary refrigeration), a precision pre-cooling group, a compound preservative group, and a combined technology group (precision pre-cooling + compound preservative + dynamic modified atmosphere + intelligent monitoring). Each group was replicated three times, with a sample size of 5 kg per replicate.

Detection Indicators and Methods: Sugar content was determined by high-performance liquid chromatography (Agilent 1260) to determine the total amount of sucrose, fructose, and glucose,

and the sugar retention rate was calculated. Sucrase and amylase activities were determined by ultraviolet spectrophotometry (UV-2550), with units of U/g·h. Hardness was determined using a texture analyzer (TA-XT2i) at a testing rate of 1 mm/s. Sensory evaluation was based on a 10-point scale, with scores from 5 professional evaluators across four dimensions: flavor, color, hardness, and juiciness, and the average score was taken. Storage environment temperature was controlled at 0-2°C, humidity at 85%-90%, and testing was conducted at 0, 3, 7, and 15 days of storage.

#### 4.2. Comparison of Preservation Technology Application Effects

The preservation effects of different treatment groups varied significantly, as shown in Table 1. After 15 days of storage, the compound technology group had the highest sugar retention rate, with super-sweet, regular-sweet, and enhanced-sweet corn retaining 78.3%, 82.1%, and 79.5% respectively, representing an increase of 23.5%-25.8% compared to the control group (54.8%, 58.2%, and 56.3%). Sensory scores were 7.2, 7.5, and 7.3 respectively, significantly higher than the control group's 4.5, 4.8, and 4.6, maintaining commercial value. Among the single-technology groups, the compound preservative group was more effective than the precision pre-cooling group, with a 12%-15% increase in sugar retention rate after 15 days compared to the control group, but lower than the compound technology group, validating the advantages of multi-technology synergy.

**Table 1.** Changes in Core Indicators (Average) of Sweet Corn During Storage in Different Treatment Groups

| processing group           | Variety                     | Storage days | Sugar retention rate (%) | Sensory rating (out of 10) |
|----------------------------|-----------------------------|--------------|--------------------------|----------------------------|
| control group              | Super sweet Zhengtian No. 3 | 0            | 100                      | 9.8                        |
|                            |                             | 7            | 68.5                     | 6.1                        |
|                            |                             | 15           | 54.8                     | 4.5                        |
| Composite Technology Group | Super sweet Zhengtian No. 3 | 0            | 100                      | 9.8                        |
|                            |                             | 7            | 89.2                     | 8.3                        |
|                            |                             | 15           | 78.3                     | 7.2                        |
| control group              | Tiantian No. 1 (Putian)     | 0            | 100                      | 9.7                        |
|                            |                             | 7            | 72.3                     | 6.5                        |
|                            |                             | 15           | 58.2                     | 4.8                        |
| Composite Technology Group | Tiantian No. 1 (Putian)     | 0            | 100                      | 9.7                        |
|                            |                             | 7            | 91.5                     | 8.5                        |
|                            |                             | 15           | 82.1                     | 7.5                        |

The trend of key enzyme activity changes is shown in Fig. 1. Taking super sweet corn as an example, the sucrase activity in the control group continued to rise during storage, reaching 28.6 U/g·h after 15 days; the enzyme activity in the composite technology group increased slowly, reaching only 19.2 U/g·h after 15 days, with an inhibition rate of 32.9%, and the inhibition effect on amylase activity was similar, which confirms the targeted regulation effect of the technology on the degradation mechanism.

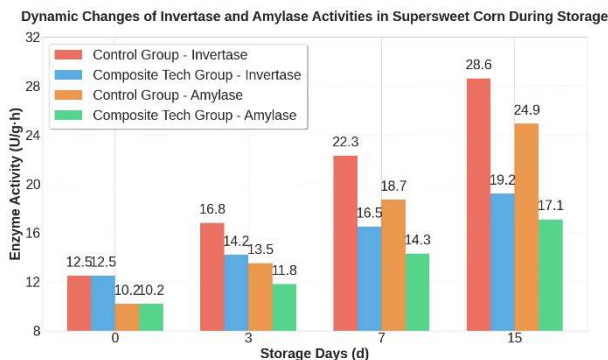


Fig. 1 Trends in Key Enzyme Activity

Table 2 compares the industrial application costs and benefits of different treatment groups. The unit cost of the composite technology group increased by 0.12 yuan/kg compared to the control group, but the shelf life was extended from 7 days to 15 days, an extension of 114%. The input-output ratio reached 1:3.2, significantly higher than the single technology group (1:1.8-2.1), demonstrating the economic benefits of the technology.

Table 2. Comparison of Costs and Benefits of Different Preservation Technologies

| processing group            | Unit cost (yuan/kg) | Shelf life (days) | Shelf life extended by (%) compared to the control group | Input-output ratio |
|-----------------------------|---------------------|-------------------|--|--------------------|
| Control group               | 0.35                | 7                 | -  | 01:01.0            |
| Precision precooling group  | 0.42                | 10                | 42.9   | 01:01.8            |
| Compound preservative group | 0.45                | 12                | 71.4   | 01:02.1            |
| Compound technology group   | 0.47                | 15                | 114.3  | 01:03.2            |

Fig. 2 shows the changes in sugar retention rate of different varieties under the combined technology treatment. The regular sweet corn had the highest retention rate throughout the process, reaching 82.1% after 15 days. The super sweet and enhanced sweet corn showed little difference, both remaining above 78%. Moreover, the degradation curves of the three varieties showed the same trend, indicating that the innovative technology is well adapted to different varieties, providing support for large-scale application.

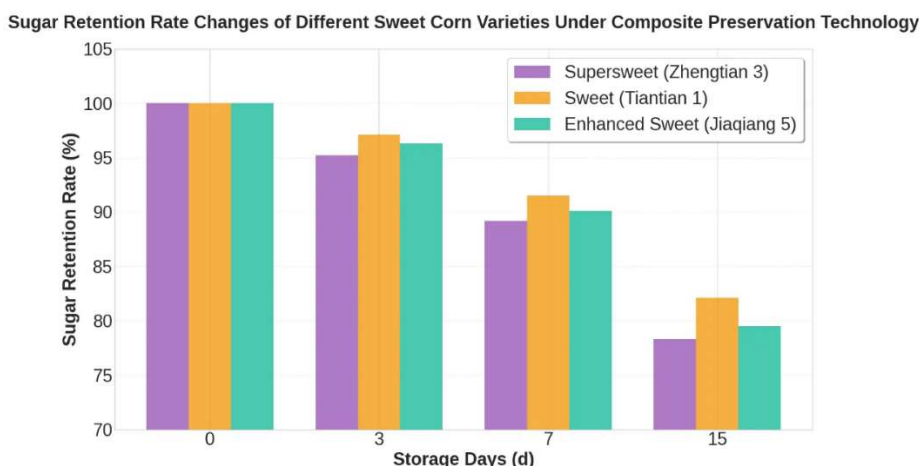


Fig. 2 Sugar Retention Rate Changes of Different Varieties Under Composite Technology Treatment

### 4.3. Feasibility Analysis for Industrial Application

The cost and operational difficulty of the innovative technology are suitable for mainstream industrial scenarios. The raw materials for the composite preservative are natural extracts and microbial metabolites, resulting in low procurement costs and a simple spraying process, which can be implemented by small and medium-sized farmers using small spraying equipment. Precision precooling and dynamic controlled atmosphere technology can be implemented by upgrading existing cold chain facilities, with an upgrade cost of approximately 50,000 RMB per thousand tons of cold storage, which is affordable for large enterprises, while small and medium-sized farmers can share cold storage facilities.

The initial investment for the intelligent monitoring module is approximately 8,000 RMB per set, but it can reduce the risk of cold chain disruptions and save on loss costs in the long term, making it suitable for large supermarkets and cold chain logistics companies. For small and medium-sized farmers, a simplified solution is proposed: using "gradient precooling + composite preservative + simplified dynamic controlled atmosphere," eliminating the intelligent monitoring module, reducing the unit cost to 0.41 RMB/kg, extending the shelf life to 12 days, with an input-output ratio of 1:2.5, balancing effectiveness and economy.

In summary, the innovative technology is feasible in various industrial scenarios. Enterprises can flexibly choose between full or simplified versions of the solution based on their size and needs. After its promotion and application, it can significantly reduce post-harvest losses of sweet corn and improve the overall efficiency of the industry.

## 5. Conclusion

This study systematically analyzed the postharvest sugar degradation mechanism of sweet corn, innovatively developed targeted cold chain preservation technology, and verified its application effect, achieving the following core results: It clarified the varietal differences in sugar composition and degradation rate among super-sweet, regular-sweet, and enhanced sweet corn varieties; elucidated the key regulatory roles of sucrase and amylase, and the molecular participation mechanism of genes such as SPS and SS; and revealed the interactive influence of temperature, humidity, gas composition, and intrinsic characteristics. An innovative composite technology of "precise pre-cooling + compound preservative + dynamic modified atmosphere + intelligent monitoring" was designed, constructing three variety-specific preservation schemes. Empirical verification showed that the shelf life can be extended from 7 days to 15 days, the sugar retention rate can be increased by 23.5%-25.8%, and the input-output ratio reaches 1:3.2. Furthermore, the complete and simplified versions of the schemes adapted to different industry scenarios demonstrate good feasibility. However, the study has certain limitations: only three varieties were tested, failing to cover more genetic backgrounds and ecotypes, and the generalizability of the conclusions needs further verification; the initial investment in the intelligent monitoring module is high, making it difficult for small and medium-sized farmers to adopt; and the dynamic analysis of the correlation between sugar degradation and flavor quality during long-term storage (more than 15 days) is insufficient. Future research could expand the range of tested varieties and ecological regions, optimize the cost and convenience of the intelligent monitoring module, and deepen the analysis of the interaction regulatory network between core genes and enzymes; combine gene editing and metabolic engineering technologies to discover more precise regulatory targets and develop low-cost, easy-to-operate preservation technology and equipment; simultaneously, expand the application of the technology in post-harvest processing, construct a full-chain quality assurance system of "post-harvest preservation - processing value-added," and continuously improve the overall benefits and competitiveness of the sweet corn industry.

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