Effect of Magnetic Field Assisted Freezing on Freezing Characteristics and Storage Quality of Fruits and Vegetables

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Master Directory

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2 Experimental System Design

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4 Experimental Study on Fruit and Vegetable storage and Analyze

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Project Background and Content

- Project background
- Research Status at Home and Abroad
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- Significance

Project Background

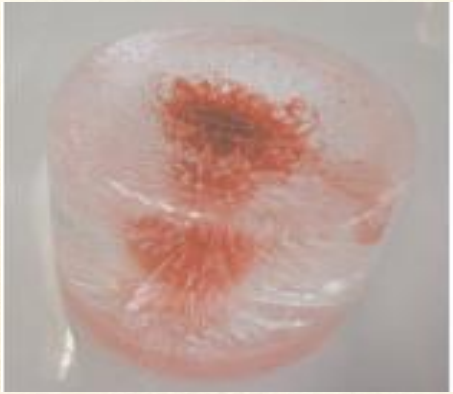
Project Background

Stage1	Stage2	Stage3	Stage4
Traditional Low Temperature Freezing	Quick Freezing	Magnetic Field Assisted Freezing	To be Continued…

Domestic and foreign Related research

Since 2000, Japan ABI company Limited, has introduced a freezing system called Cell Survival System (CAS), which uses a static magnetic field and an oscillating magnetic field. The magnetic field generator can be used to generate a uniform magnetic field distributed in the quick-freezer, which can produce foods and food materials that are fresh and taste good. Figures a and b show images taken by microscopy. We can clearly see the difference in tissue displayed after quick freezing and simple quick freezing under CAS system. Tissues that have been assisted by magnetic fields can contribute to a more even distribution.

(a)



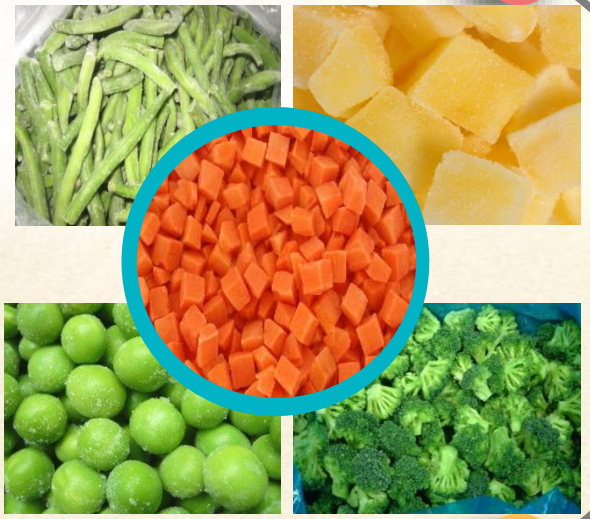
(b)

Frozen picture of red food chromatin aqueous solution

Domestic and foreign Related research

- Fatemeh Javani Jouni and others' research found that with the increase of exposure time of bone marrow stem cells under the static magnetic field of 4mt ,it significantly promoted the expression of pluripotency genes ,indicating that this magnetic field plays a role in promoting.
- Tagami M and others use a mixed magnetic field for droplet suspension freezing experiments for the first time. When the strength of magnetic field reaches 17.9T,we can observe that the droplet suddenly changes from transparent to opaque. This temperature is the undercooling temperature.
- Wang P. explored the effects of different forms (DC and AC) and size (4.6Gs, 9.2Gs, 18Gs, 36Gs, 72Gs) on the shape and size of ice crystals during the phase transformation of fruit and vegetable cells and the effect of freezing methods on cell morphology and size. The results show that the supercooling degree increases with the increase of the magnetic field strength in the experimental range, and the cell ice crystal tends to be atomized and sanded during the magnetic field assisted freezing process.
- Zhao H. and Zhou Z. of Shandong Univ. conducted a series of exploration work on the freezing process of aqueous solution and food in the weak magnetic field (here, the magnetic field is less than 100Gs), pointing out that the magnetic field can reduce the degree of supercooling degree of water and aqueous solution. The water holding capacity and flavor retention of the freezing process of food materials such as pork and carp are beneficial.

Research Contents



1

Taking tap water, potatoes, carrots, beans, peas, broccoli as experimental samples， exploring the effect of different magnetic field strengths in the experimental range on the freezing characteristics of fruits and vegetables， obtaining a quick freezing curve， comparing the correlation and difference between tap water and other fruits and vegetables， the comparing comment include phase change time, phase transition temperature, freezing time et al.

2

The quick-frozen fruits and vegetables are stored in a freezer at the temperature below -18℃ for a storage period of 70 days. The fruit and vegetable indicators are measured in a 10-day cycle, and the state image of the fruit and vegetable cells is observed through a microscope, contrasting from macroscopic and microscopic aspects. Analyse and compare the effects of different magnetic field strengths on the storage quality of fruits and vegetables .

Research Significance

Research significance

Numerous studies have shown that magnetic fields can act directly on water by positioning, vibration or rotation to promote supercooling. However, there are still many doubts about the true impact of magnetic freezing and the underlying mechanisms involved. The wide range of magnetic field strengths makes people fail to grasp the law of action and conduct a profound analysis.

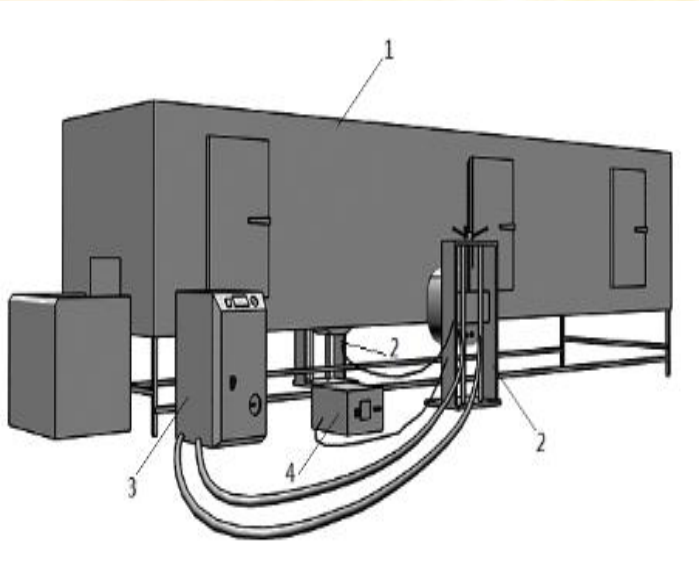
1. Having practical applicability
2. Having obvious advantages
3. Having great research prospects and value

Design of Magnetic Field Aided Freezing Experiment System

- Introduction to the experimental system
- Magnetic field position correlation calculation
- Relationship between supply air temperature, wind speed, equivalent diameter of fruits and vegetables and pre-cooling time
- Magnetic field distribution

Introduction to the experimental system

Diagram of experimental equipment



Schematic diagram of experimental system device

1—Quick-freezing machine，2—Magnetic field generator，3—Cooling water circulator，4— DC power supply

Magnetic field position correlation calculation

Table2-1 Experimental sample related parameters

sample parameters	carrots	potatoes	beans	peas	broccoli
Dimension	1cm×1cm×1cm		Approximate size：17cm×1.2cm×0.4cm	The radius is about: 0.35cm	Flower ball with a stem length of 2 cm and a diameter of 3 cm
Physical model	Three-dimensional tablet			Sphere	Short cylinder
Density (kg/m^3)	1013	1052	915	1250	1100
Thermal conductivity (W/(m·K))	0.456	0.526	0.428	0.5874	0.758
Specific heat Capacity (J/(kg·K))	3390	2928	3300	3900	4000

Magnetic field position correlation calculation

In this experiment, the freezing process of food is an unsteady cooling process. For the non-steady state problem, we need to grasp two criterion numbers: Bi-number and Fourier number.

Generalized heat transfer model：
$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = q_s T$$

Initial conditions:
$$T(x, y, 0) = T_0$$

Third type of boundary condition：
$$-\lambda \left(\frac{\partial T}{\partial n}\right)_w = h(T_w - T_f)$$

Tablet type：
$$\frac{\theta(\eta, \tau)}{\theta_0} = \frac{2 \sin \mu_1}{\mu_1 + \sin \mu_1 \cos \mu_1} \exp(-\mu_1^2 F_o) \cos(\mu_1 \eta)$$

Cylindrical：
$$\frac{\theta(\eta, \tau)}{\theta_0} = \frac{2}{\mu_1} \frac{J_1(\mu_1)}{J_0^2(\mu_1) + J_1^2(\mu_1)} \exp(-\mu_1^2 F_o) J_0(\mu_1 \eta)$$

Ball：
$$\frac{\theta(\eta, \tau)}{\theta_0} = \frac{2(\sin \mu_1 - \mu_1 \cos \mu_1)}{\mu_1 - \sin \mu_1} \exp(-\mu_1^2 F_o) \frac{\sin(\mu_1 \eta)}{\mu_1 \eta}$$

Magnetic field position correlation calculation

Approximate fitting formula

$$\mu_1^2 = (a + \frac{b}{Bi})^{-1} \qquad A = a + b(1 - e^{-cBi}) \qquad B = \frac{a + cBi}{1 + bBi} \qquad J_0 = a + bx + cx^2$$

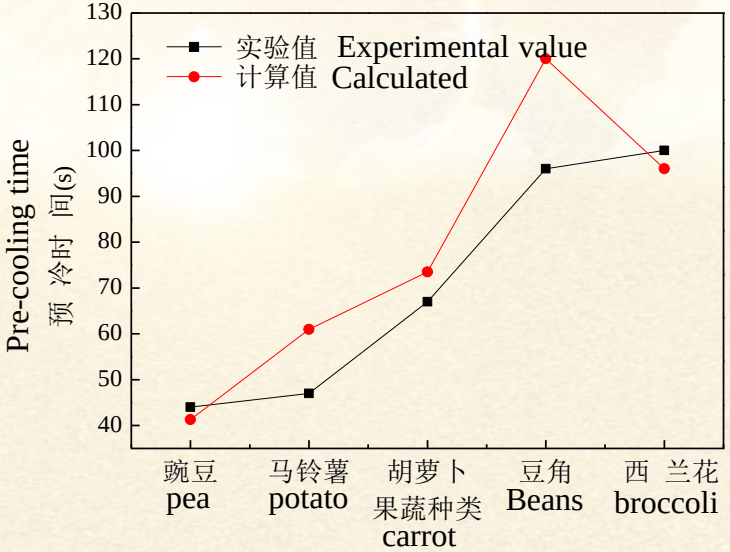
Table 2-2 Constants

Geometric shape / Calculated amount		flat	cylinder	ball
Eigenvalues μ_1	a	0.4022	0.1700	0.0988
	b	0.9188	0.4349	0.2779
Coefficient A	a	1.0101	1.0042	1.0003
	b	0.2575	0.5877	0.9858
	c	0.4271	0.4038	0.3191
Coefficient B	a	1.0063	1.0173	1.0295
	b	0.5475	0.5983	0.6481
	c	0.3483	0.2574	0.1953

Magnetic field position correlation calculation

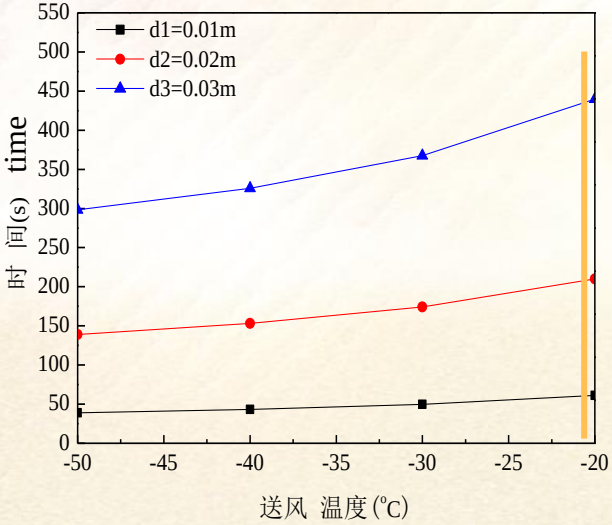
The magnetic field occurrence position of the five kinds of fruits and vegetables can be calculated from the entrance of the quick-freezer

Potato: 1.64m;
carrot: 1.98m;
beans: 3.25m;
peas: 1.11m;
broccoli: 2.9m.

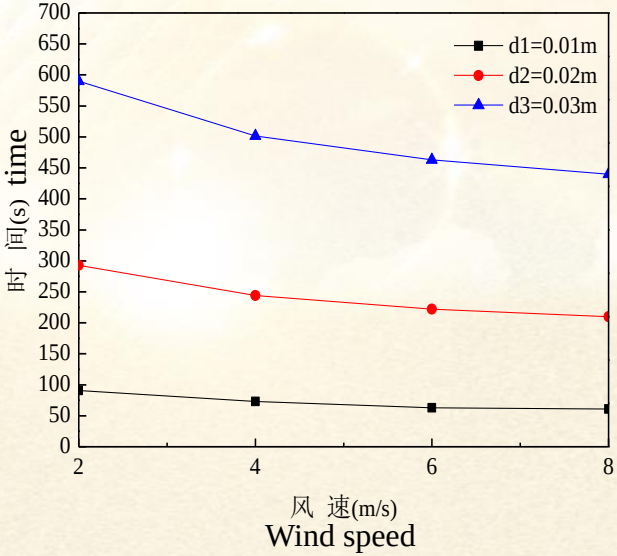


Comparison of freezing curves of different fruits and vegetables

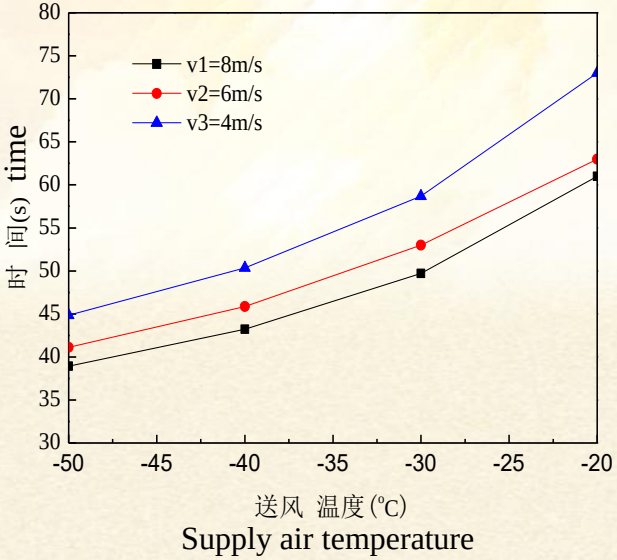
Relationship between supply air temperature, wind speed, equivalent diameter of fruits and vegetables and pre-cooling time



Relationship between pre-cooling time and supply air temperature and equivalent diameter (wind speed v=8m/s)

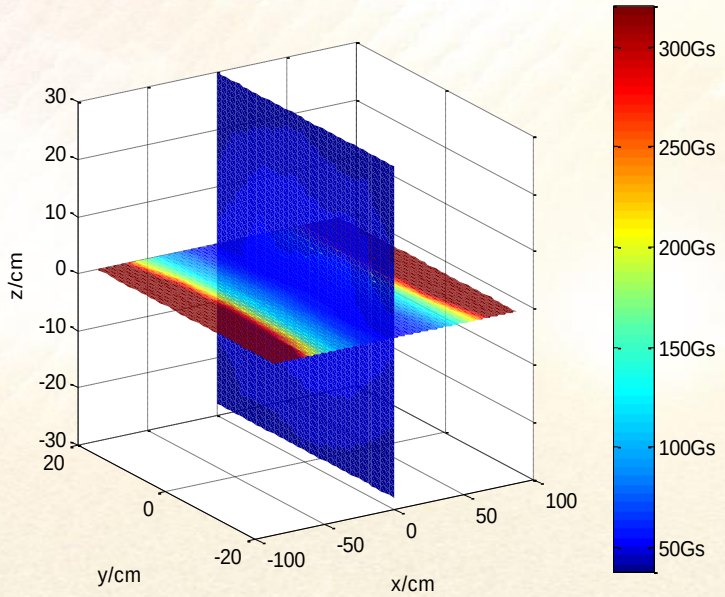


Relationship between pre-cooling time and supply air temperature and wind speed (equivalent diameter d = 0.01m)

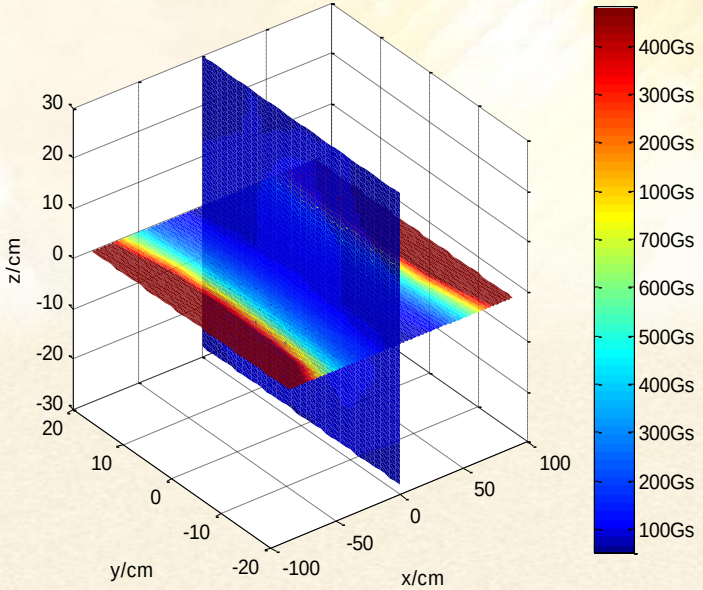


Relationship between pre-cooling time and wind speed and equivalent diameter (supply air temperature T=-20° C)

Magnetic field distribution



Magnetic field distribution at a central magnetic field strength of 4.6 Gs

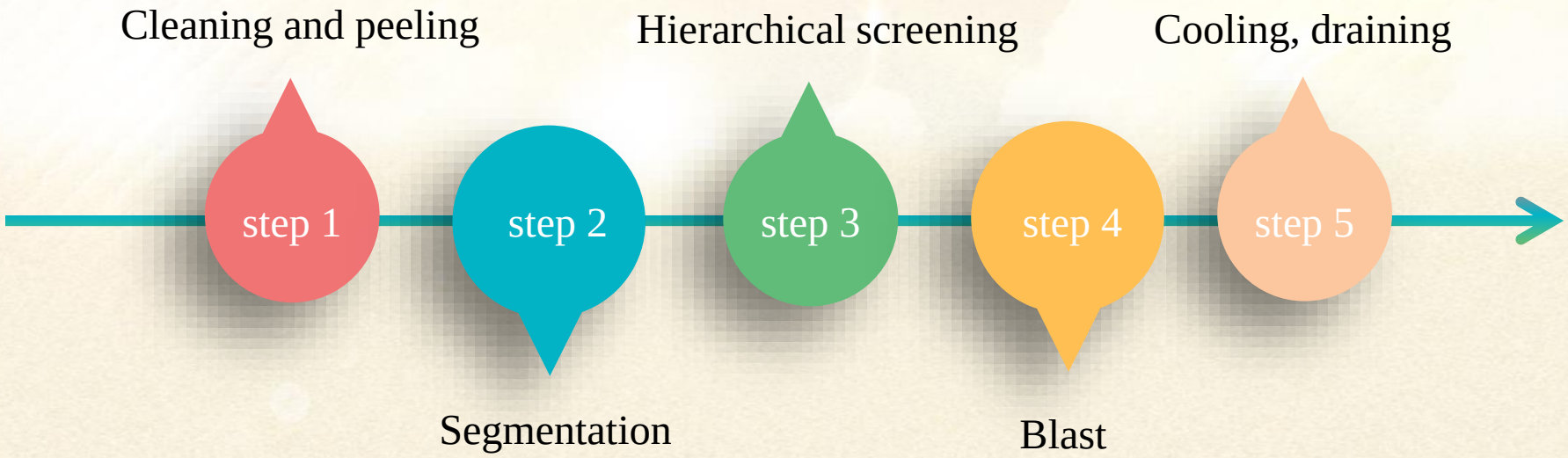


Magnetic field distribution at a central magnetic field strength of 9.2 Gs

Experiment and Analysis of Magnetic Field on Freezing Process of Water and Fruits and Vegetables

- Quick freezing pretreatment
- Freeze curve and analysis
- Effect of magnetic field on fruit and vegetable cells during storage

Quick freezing pretreatment



Freeze curve and analysis

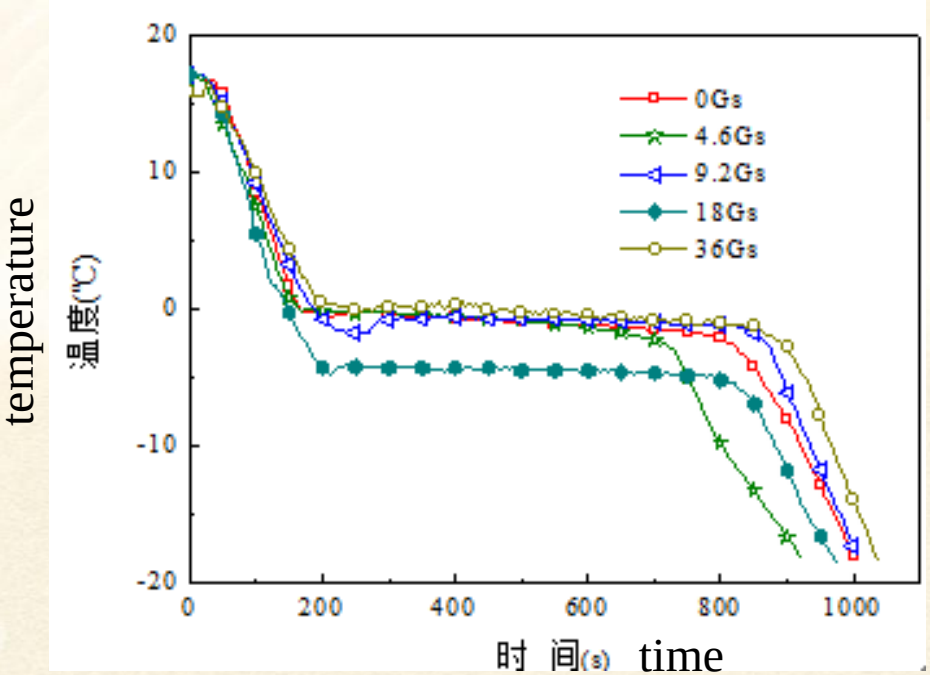


Figure 3-1 Curve of freezing process of water under different magnetic field strengths

Freeze curve and analysis

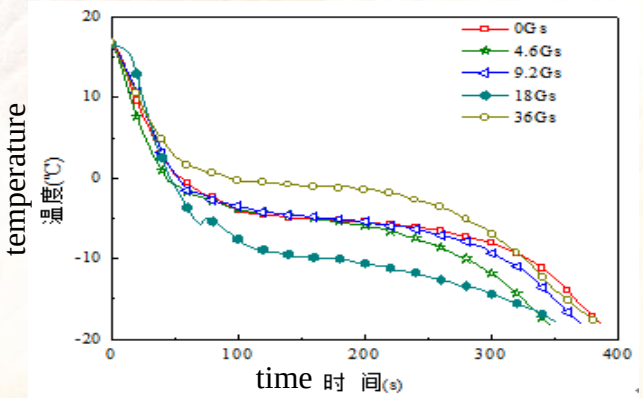


Figure 3-2 The freezing process curve of carrots under different magnetic field strengths

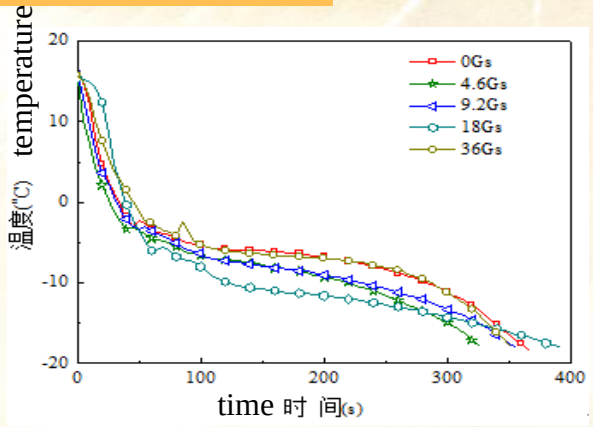


Figure 3-3 Frozen process curve of potato under different magnetic field strengths

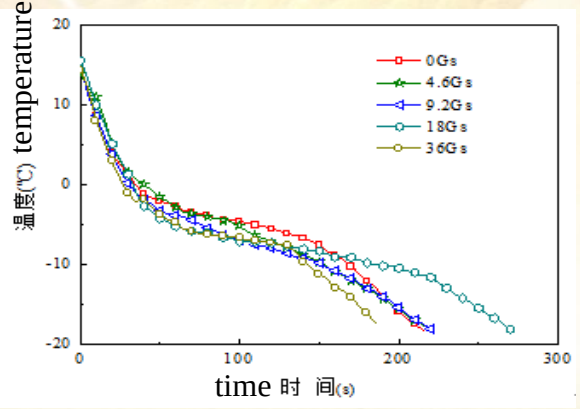


Figure 3-6 Frozen process curve of peas under different magnetic field strengths

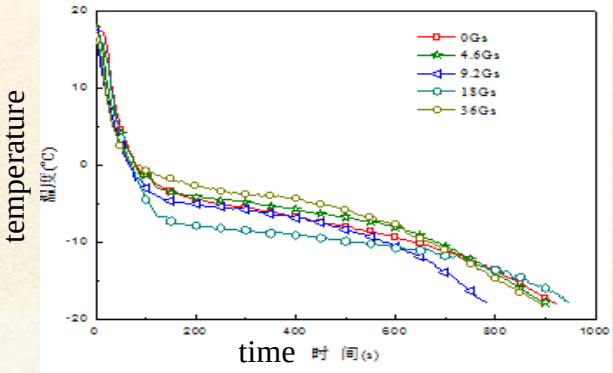


Figure 3-4 Frozen process curve of beans under different magnetic field strengths

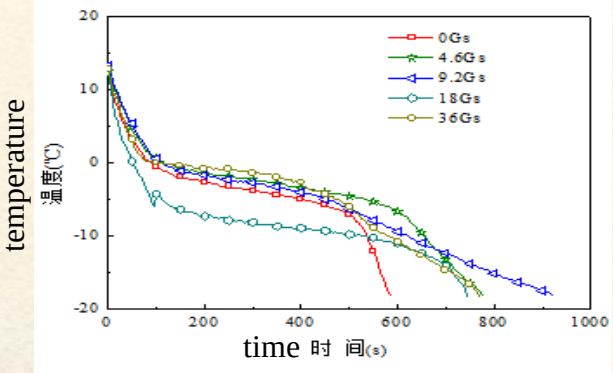


Figure 3-5 Frozen process curve of broccoli under different magnetic field strengths

Experimental study and analysis of fruit and vegetable storage

- Experimental results and analysis of physical and chemical indicators during storage of fruits and vegetables
- Results and analysis of cell changes during storage of fruits and vegetables

Carrot storage experiment results and analysis

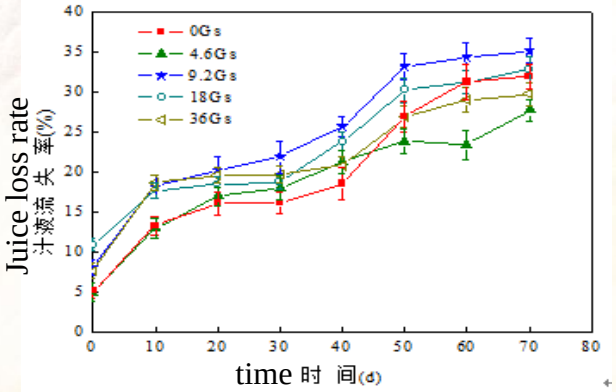


Figure 4-1 Changes in juice loss rate during carrot storage

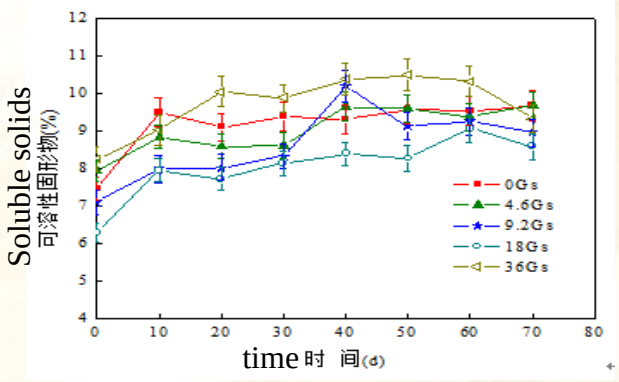


Figure 4-2 Changes in soluble solids during storage of carrots

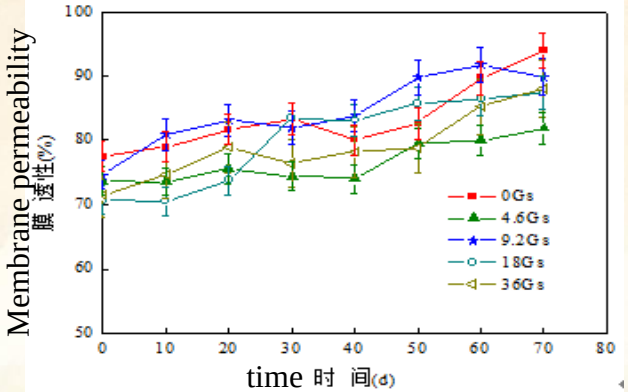


Figure 4-3 Changes in membrane permeability during storage of carrots

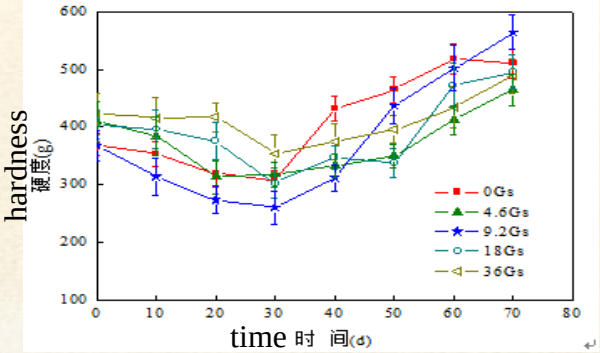


Figure 4-4 Change in hardness during storage of carrots

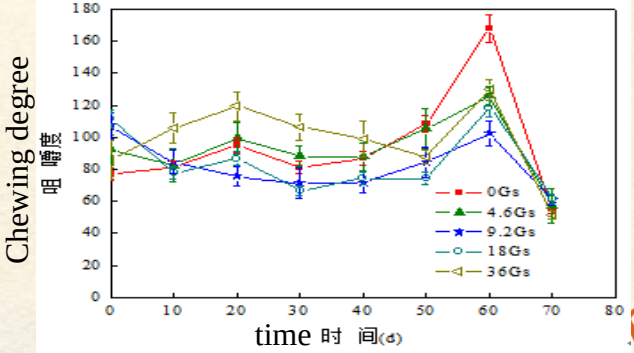


Figure 4-5 Changes in chewing degree during carrot storage

Results and analysis of pea storage experiment

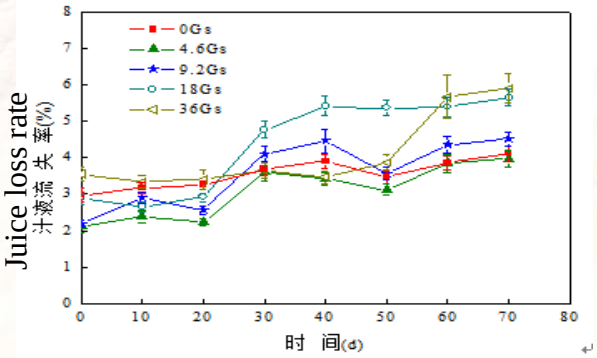


Figure 4-11 Changes in juice loss rate during pea storage

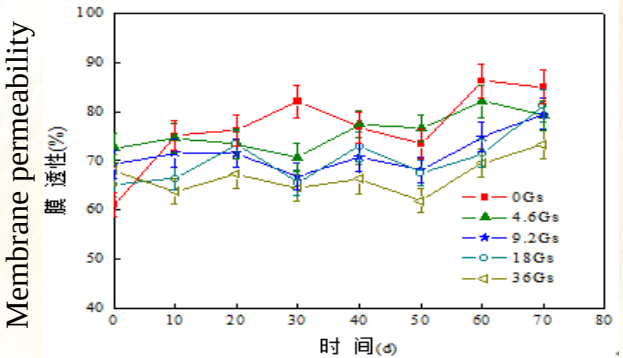


Figure 4-12 Membrane permeability change during pea storage

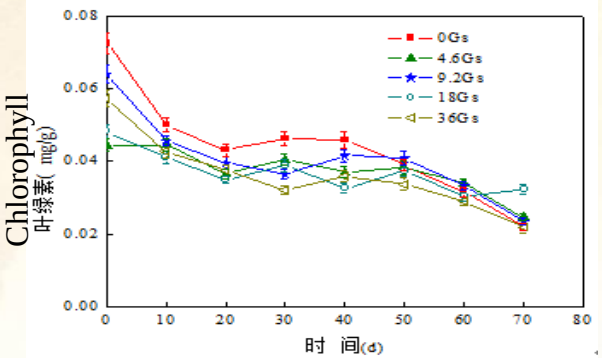


Figure 4-13 Chlorophyll changes during pea storage

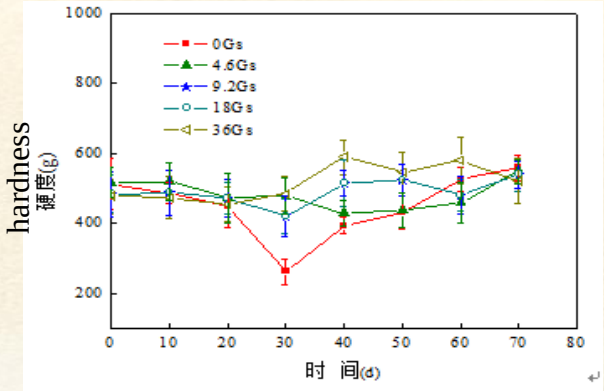


Figure 4-14 Change in hardness during storage of peas

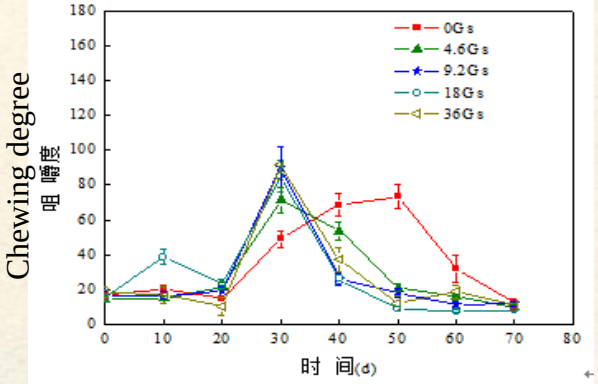


Figure 4-15 Changes in chewing degree during pea storage

Bean storage experiment results and analysis

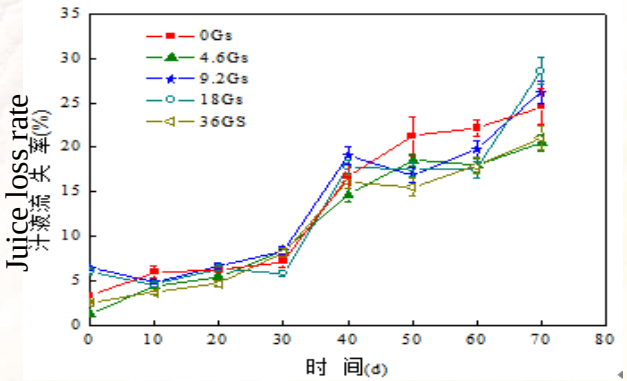


Figure 4-16 Changes in juice loss rate during bean storage

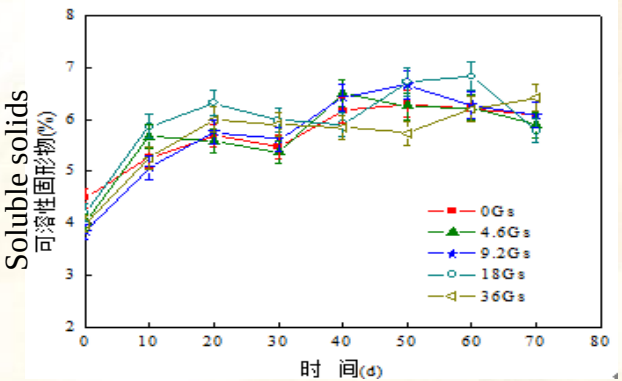


Figure 4-17 Changes in soluble solids during storage of beans

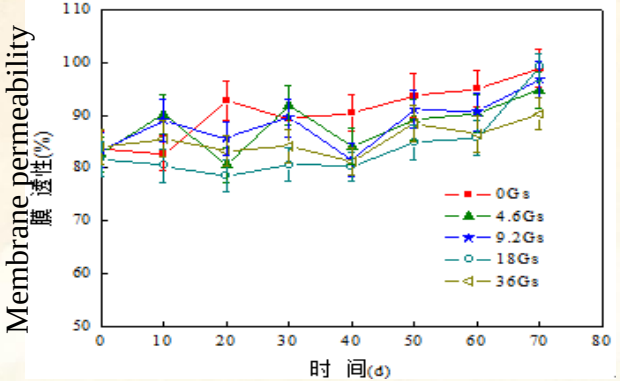


Figure 4-18 Changes in cell membrane permeability during storage of beans

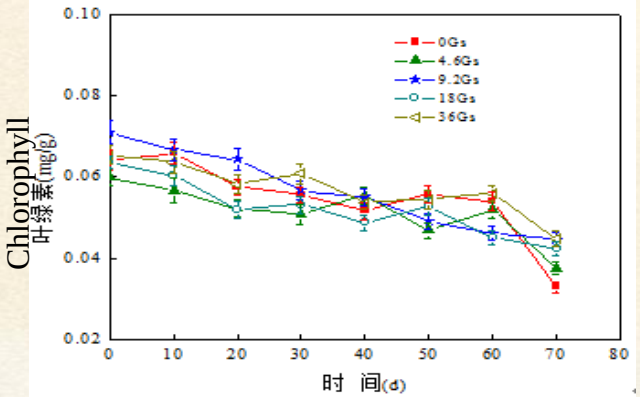


Figure 4-19 Chlorophyll changes during storage of beans

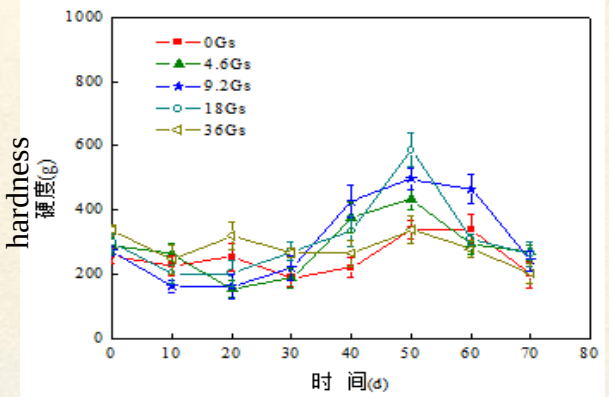


Figure 4-20 Change in hardness during storage of beans

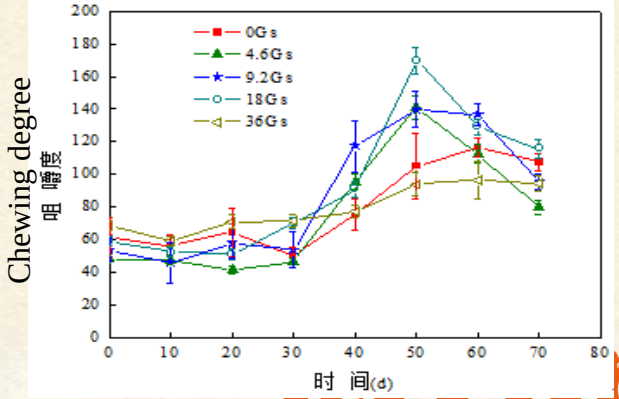


Figure 4-21 Change in chewing degree during storage of beans

Results and analysis of broccoli storage experiment

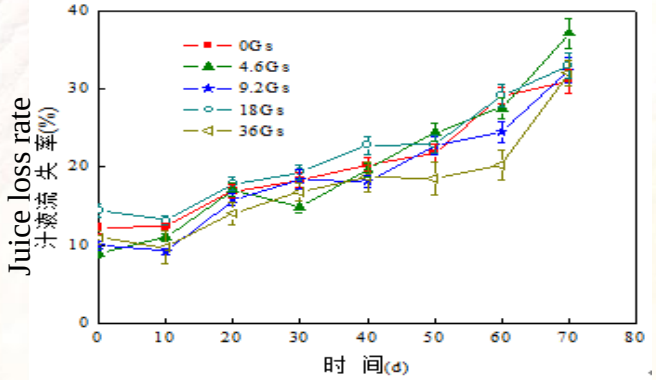


Figure 4-22 Changes in juice loss rate during broccoli storage

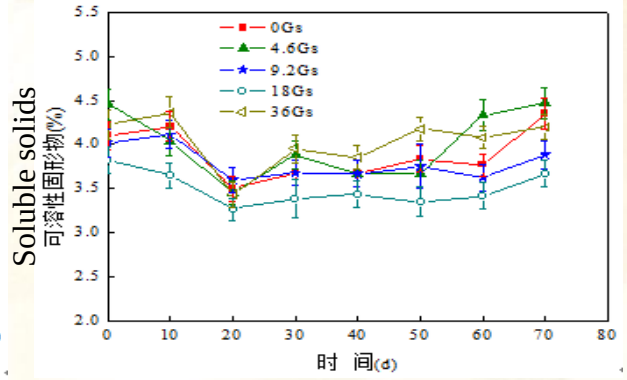


Figure 4-23 Changes in soluble solids during storage of broccoli

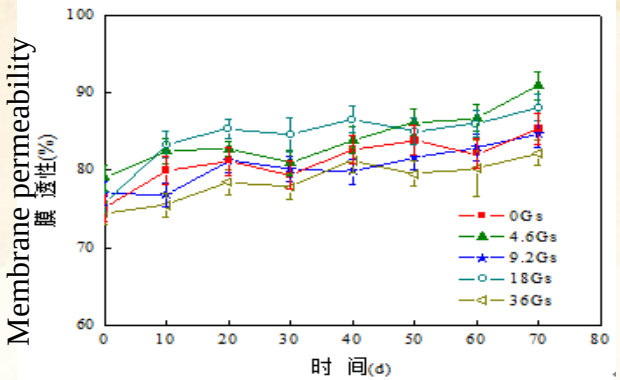


Figure 4-24 Membrane permeability change during broccoli storage

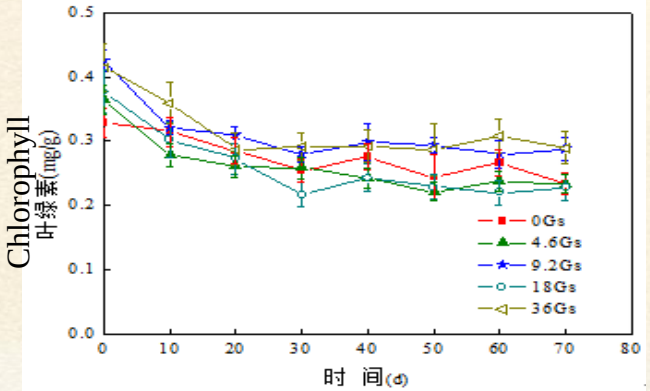


Figure 4-25 Chlorophyll changes during broccoli storage

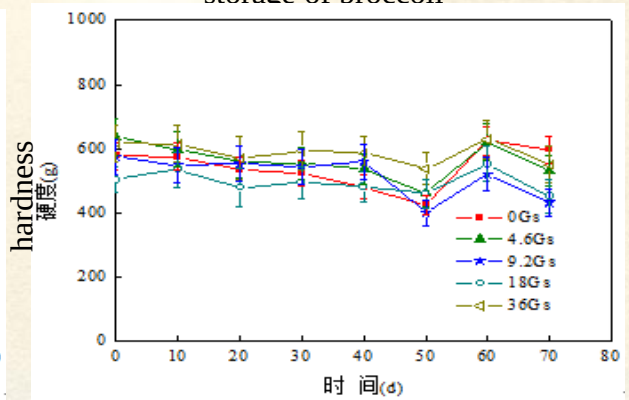


Figure 4-26 Hardness change during broccoli storage

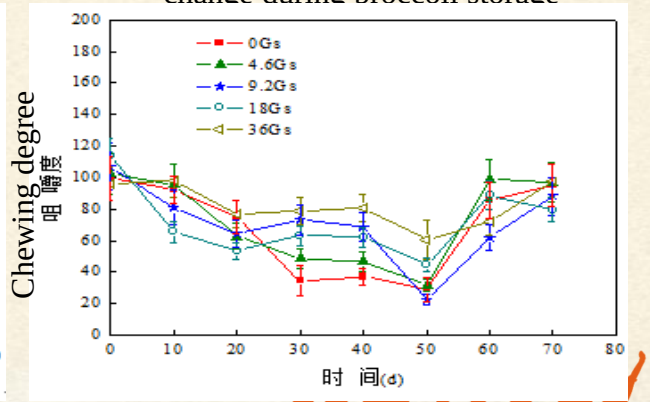


Figure 4-27 Change in chewing degree during broccoli storage

Potato storage experiment results and analysis

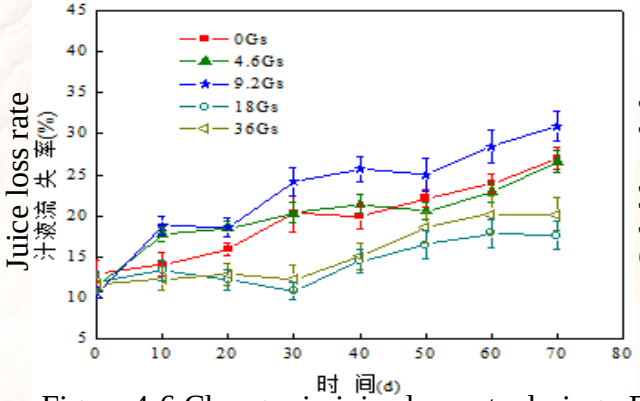


Figure 4-6 Changes in juice loss rate during potato storage

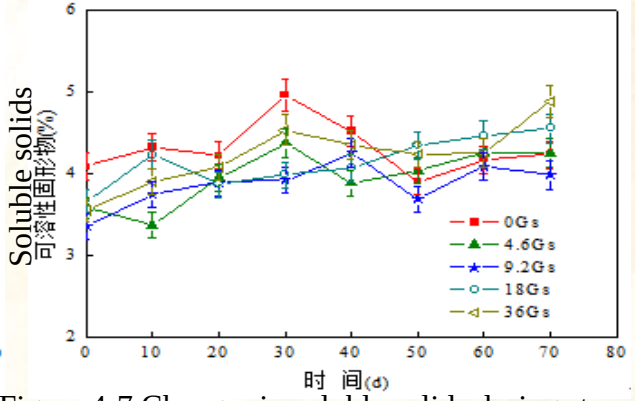


Figure 4-7 Changes in soluble solids during storage of potatoes

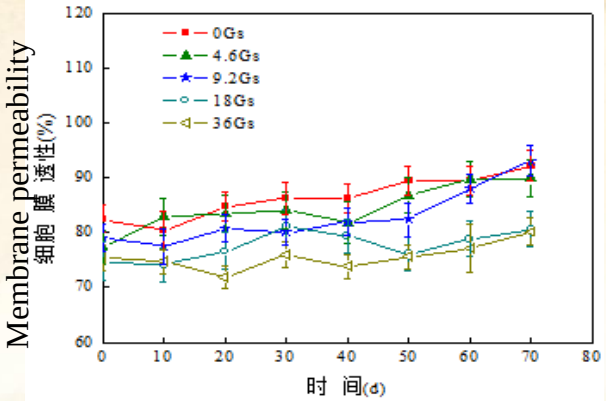


Figure 4-8 Changes in membrane permeability during storage of potatoes

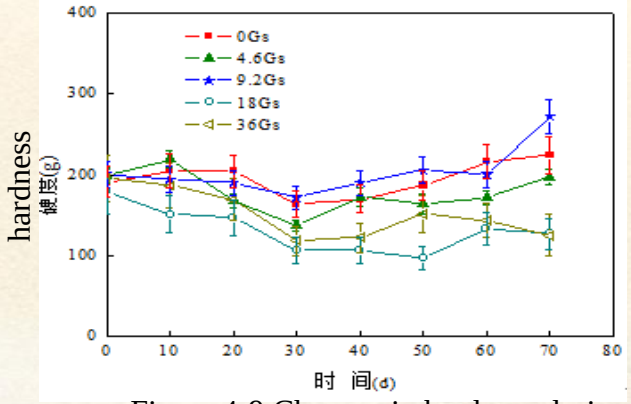


Figure 4-9 Changes in hardness during storage of potatoes

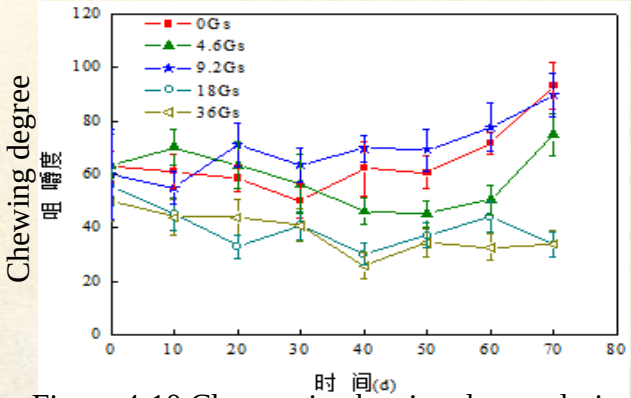


Figure 4-10 Changes in chewing degree during storage of potatoes

Effects of different magnetic field strengths on freezing of fruits and vegetables during storage

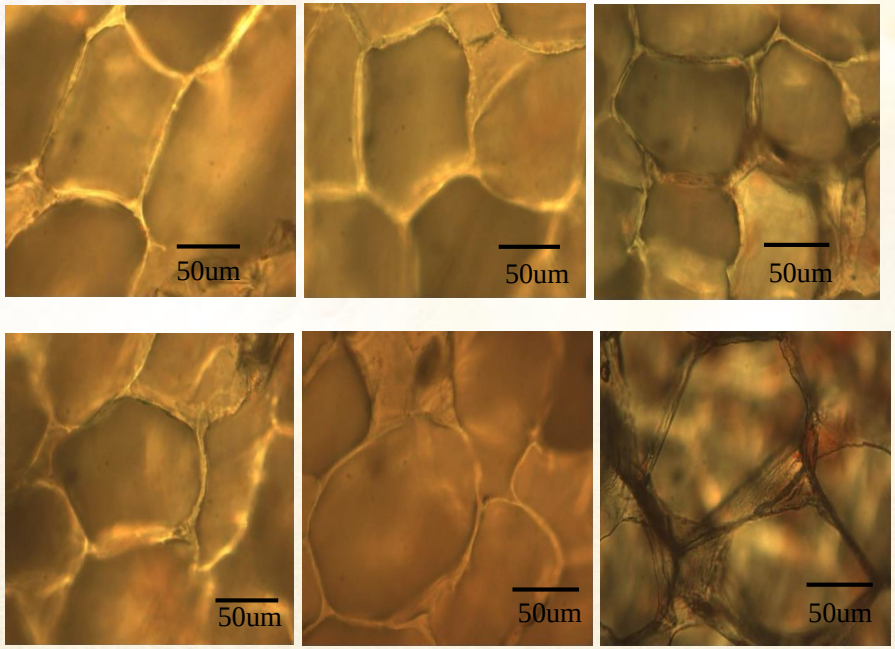


Figure 4-28 Cell morphology of carrots on day 0 of storage

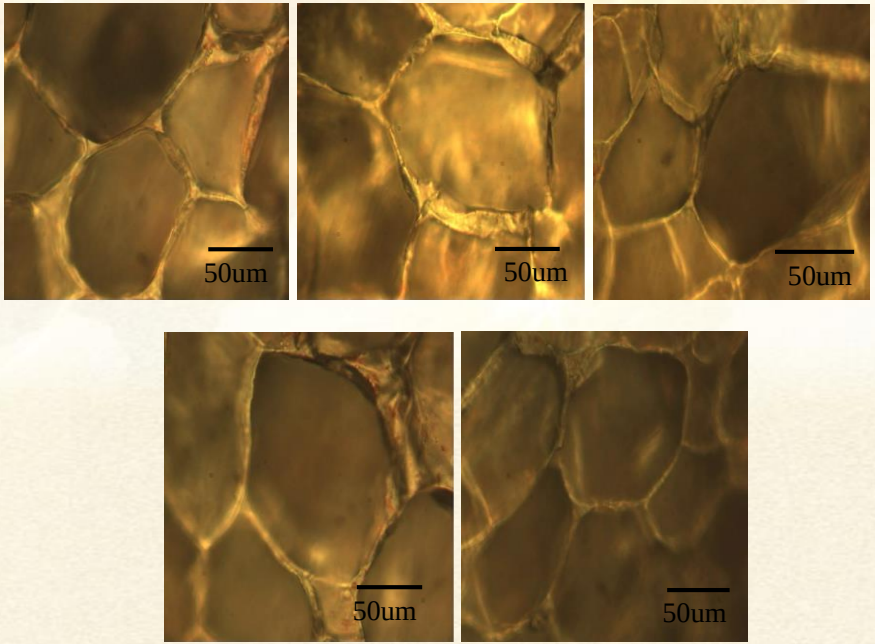


Figure 4-29 Cell morphology of carrots on the 20th day of storage

Effects of different magnetic field strengths on freezing of fruits and vegetables during storage

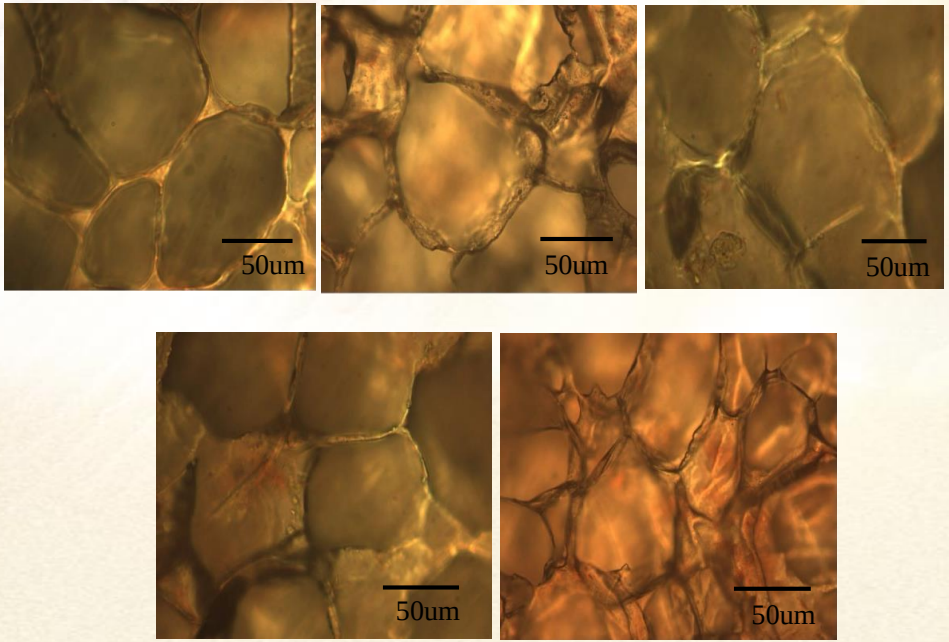


Figure 4-30 Cell morphology of carrots on the 40th day of storage

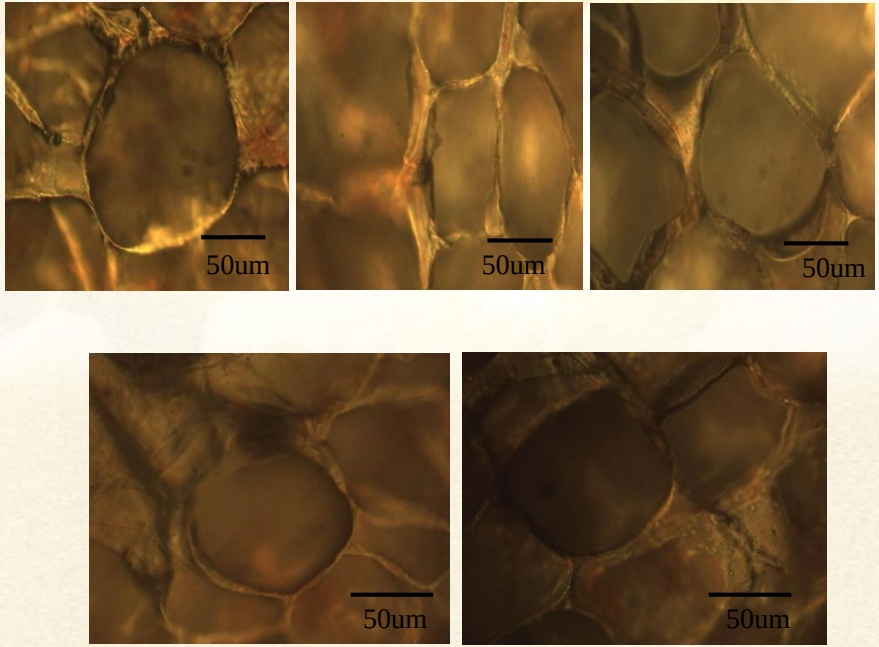


Figure 4-31 Cell morphology of carrots on the 60th day of storage

Effects of different magnetic field strengths on freezing of fruits and vegetables during storage

In view of the above-mentioned changes in the cells, we quantify them. Different cell states represent different stages. According to the previous research basis, quantitative processing is adopted to explain the problem more intuitively. Therefore, the dimensionless parameter "cell" is proposed. The concept of shrinkage rate, namely: R_c

$$R_c = \frac{S_s}{S}$$

among them, s- the total area of the cell image within the field of view,

s_s -the area occupied by the shrunken cells in the visual field image

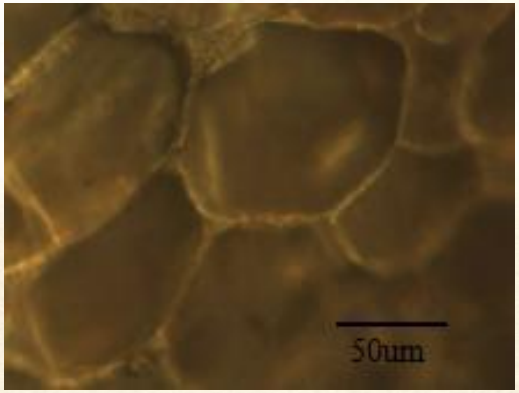
Table 4-1 Cell quantitation conversion method

Cell grade	A	B	C	D
Cell state	Relatively full	Partial juice loss	Overall flat state / retain a certain fullness but wrinkles	Severe drain and blurred cell contour
Shrinkage coefficient C_i	Within 20%	20%~50%	50%~85%	85%~100%

$$S_j = S_i \times C_i$$

$$S_s = \sum_{1}^{n} S_j \quad i = (A, B, C, D)$$

Effects of different magnetic field strengths on freezing of fruits and vegetables during storage



(A) Level one

(B) Level two

(C) Level three

(D) Level four

Effects of different magnetic field strengths on freezing of fruits and vegetables during storage

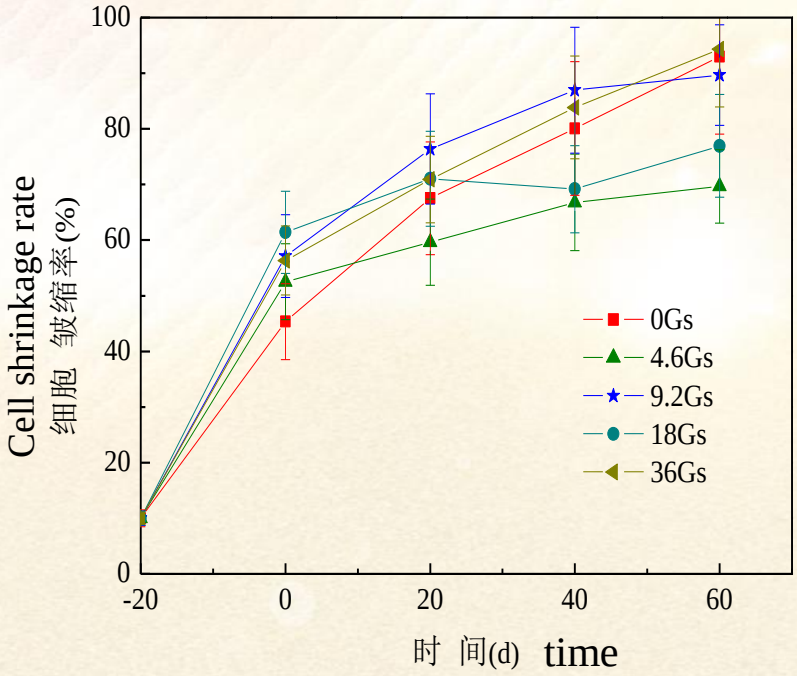


Figure 4-37 Cell shrinkage rate during carrot storage

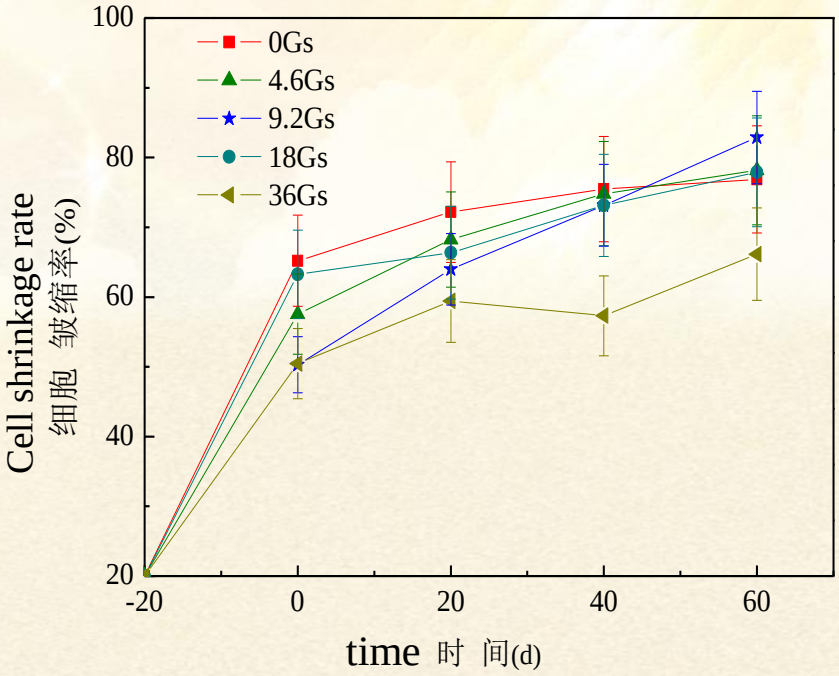


Figure 4-38 Cell shrinkage rate during broccoli storage

Conclusion

Conclusion

The auxiliary freezing effect of different intensity DC magnetic fields on fruits and vegetables showed extreme value, and showed similar freezing rules with water to different extents. Compared with water, the composition of fruits and vegetables is much more complicated, and the differences between different types of fruits and vegetables are also large, which will cause the difference of magnetic fields. In this experiment, the difference in peas was more obvious, and the uniformity of the freezing characteristics of carrots, potatoes, beans, broccoli and water was higher.

The magnetic field freezes the water and mainly affects the hydrogen bonding of the water molecules. By weakening and enhancing the stability of the hydrogen bonds between the molecular clusters, the phase transition time can be affected. Macroscopically, it is the influence of heat conduction, convection heat transfer and latent heat of phase change during the freezing process. The composition of fruits and vegetables is complex and the composition is quite different. Therefore, the magnetic field freezing characteristics of each fruit and vegetable are not universal.

Conclusion

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In the process of storage of fruits and vegetables, in terms of carrots and peas, the comprehensive storage quality of 4.6Gs is superior, and compared with the freezing curve, the phase change time of fruits and vegetables is positively correlated with the change of juice loss rate. For beans and broccoli, 36Gs has a significant effect on the overall storage quality, which can maintain the nutritional quality of fruits and vegetables as a whole. For potato, 36Gs is the best in juice loss rate, soluble solids and cell membrane permeability, but The storage hardness and chewing degree are always kept to a minimum.

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In the analysis of the changes in the characteristics of fruits and vegetables during storage, the "cell shrinkage rate" index was proposed. After the cell pattern was classified by Photoshop, the value of the cell shrinkage rate R_c was obtained by using imagej conversion. The above conclusions were further verified.

THANKS