Effect of Magnetic Field Technology on Preservation Quality of Fresh-cut Apple

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Abstract [**Objectives**] The paper was to study the effect of magnetic field technology on physicochemical properties of fresh-cut apple during storage. [**Methods**] Using fresh-cut apples as materials, magnetic field assisted refrigeration and conventional refrigeration control groups were set up, and the preservation effects of magnetic field assisted refrigeration on fresh-cut apples were tested by measuring the changes of microorganisms and physicochemical indicators. In this experiment, the conditions of magnetic field assisted refrigeration group was set as follows: temperature 4 ℃, magnetic field intensity 5 mT, static magnetic field, and storage for 6 d. [**Results**] At 6 d post storage, the weight loss rate, total number of colonies and total number of fungi of fresh-cut apples increased; the L^* value and hardness showed a downward trend; the soluble solid content first increased and then decreased; and the total acid decreased first and then increased. The above indicators in magnetic field assisted refrigeration group changed more gently than that in conventional refrigeration group. Compared with conventional assisted refrigeration, the weight loss rate of fresh-cut apples treated by magnetic field combined with 4 ℃ refrigeration was reduced by 68.00%; the hardness was increased by 12.23%; the total number of colonies and total number of fungi were reduced by 64.15% and 37.50%; and the L^* value did not change much. High content of soluble solids and total acid was maintained. [**Conclusions**] Magnetic field assisted refrigeration delays quality deterioration of fresh-cut apples during storage, prolongs shelf life, and further improves their edible quality and commodity value.

Key words Fresh-cut apples, Magnetic field, Preservation

1 Introduction

Apple, belonging to *Malus*, Maloideae, Rosaceae, has been planted for more than two thousand years, and cultivars such as red Fuji, Golden Delicious and Ralls apple are common in life. Apple is nutritious, rich in minerals and vitamins, and contains calcium, phosphorus, iron and other elements[1]. It has the functions of whitening and moisturizing skin, calming and hypnosis, lowering blood lipid and cleaning mouth. Besides, apple is a low-calorie fruit, and malic acid can metabolize heat and prevent body obesity, so it is a fruit that people often eat[2]. Fresh-cut apple, also known as light processing apple, is a ready-to-eat product that has received grading, cleaning, disinfection, drainage, peeling (coring), cutting, color protection, packaging and other procedures of fresh apple for consumers. It gradually becomes popular among consumers because of the advantages of high quality and freshness, convenience and high edible rate[3].

Fresh-cut fruit originated in the United States in the 1950s and gradually opened up the market in China in the 1990s. Different from traditional food processing, fresh-cut fruit has higher technical requirements. Compared with ordinary fruits, fresh-cut fruit has a shorter shelf life, and a series of physiological and biochemical reactions and quality changes will occur in the process of operation, storage, transportation and sales. Fresh-cut processing involves cutting the tissue of fresh agricultural products, which leads to the destruction of major tissues and the release of tissue-related substances, the destruction of original protection system, the accelerated aging process of fruits and vegetables, and the deterioration of quality[4-5].

In order to prolong the shelf life of fresh-cut fruits and vegetables, fresh-cut fruit and vegetable preservation technology has become a hot spot. However, due to the late development of fresh-cut fruit and vegetable industry in China, influenced by traditional ideas and marketing conditions, current fresh-cut fruit and vegetable industry does not occupy the market on a large scale, and fresh-cut fruit and vegetable preservation technology needs to be further expanded[6-7]. The main factor affecting the quality of fresh-cut apple is microorganism, so the most important thing to prolong the shelf life of fresh-cut apple is to inhibit the growth of microorganisms. At present, there are studies on fresh-cut apple preservation technology, such as the high oxygen technology mentioned by Day[8]. High oxygen treatment will weaken respiration and inhibit microbial growth and reproduction, and further reduce ethylene synthesis and affect the activity of polyphenol oxidase, thus slowing down the browning of tissues[9]. Fresh-cut apple can be preserved by using grapefruit essential oil microcapsules[10], and soaking fresh-cut apple in essential oil microcapsule solution can well inhibit the browning reaction during storage, maintain its hardness and high content of ascorbic acid and total phenol, and

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reduce the influence of essential oil odor on apple taste, thereby improving its storage quality. In addition, common preservation technologies such as coating technology[11], modified atmosphere packaging[12] and radiation treatment[13] are also conducive to the preservation of fresh-cut apples.

Although various preservation technologies emerge in an endless stream and have certain preservation effects, the ensuing environmental pollution and food safety problems are also emerging[14]. Therefore, development of a green and safe preservation technology has become an important research direction of fresh-cut apple preservation. The preservation technology of magnetic field combined with low temperature[15], as a new fresh-cut fruit and vegetable preservation technology, has therefore attracted more and more attention. The technology is mainly based on the magnetic properties of the organism itself and the influence of external magnetic field on internal tissue activity of food, to inhibit the growth of rot pathogens and delay other physiological metabolic reactions, thereby maintaining the original quality of food. Zhang Xiaoying *et al.*[16] found that low temperature combined with static magnetic field had a significant impact on physicochemical indicators of fresh strawberries during storage, which could reduce the decay rate and respiration rate, *etc.* Wang Ying *et al.*[17] summarized the relationship of static magnetic field, alternating magnetic field and pulsed magnetic field with food preservation, and the influence on fruits and vegetables, milk, bacteria and fungi under different magnetic field conditions. Zhang Wujie *et al.*[18] found that magnetic field had little sensory effect on apples and pears, while increasing magnetic field intensity significantly increased the content of Vc in fruits and vegetables, and concluded that magnetic field could protect the nutrients in fruits and vegetables.

This study mainly aimed at quality reduction of fresh-cut apples during storage, and the method of magnetic field assisted refrigeration was adopted. As other conditions were completely consistent, refrigerator assisted refrigeration group was used as the control to study the changes in physicochemical properties of fresh-cut apples during storage, and to determine whether magnetic field combined with low temperature storage could delay quality deterioration of fresh-cut apples. Moreover, it would provide some experimental basis for industrialization of magnetic field refrigeration technology of fruits and vegetables.

2 Materials and methods

2.1 Materials

2.1.1 Raw materials and reagents. Fuji apples: apples of uniform maturity and size without mechanical damage; PP food storage container 360 type (specification: bottom diameter 7.5 cm, mouth diameter 12 cm, height 5 cm); potato-glucose-agar medium (BR, Beijing Land Bridge Technology Co., Ltd.); plate counting agar medium (BR, Beijing Aobox Biotechnology Co., Ltd.); sodium hydroxide (AR, Tianjin Damao Chemical Reagent Factory); potassium hydrogen phthalate (AR, Tianjin Beichen District Fangzheng Reagent Factory); sodium chloride (AR, Tianjin Fuyu Fine Chemical Co., Ltd.).

2.1.2 Instruments and equipments. S210pH meter: Toledo Instrument (Shanghai) Co., Ltd.; TD15k-1 electronic balance: Tianjin Tianma Hengji Instrument Co., Ltd.; YXQ-LS-100A vertical pressure steam sterilizer: Shanghai Boxun Industrial Co., Ltd.; BSC-15 constant temperature humidity chamber: Medical Equipment Factory of Shanghai Boxun Industrial Co., Ltd.; DRP-781 electric thermostatic incubator: Hubei Huangshi Medical Device Factory; SW-CJ-2FD clean bench: Sujing Group Suzhou Antai Air Technology Co., Ltd.; CM-5 colorimeter: Konica Minolta, Japan; TA – XT Plus C texture analyzer: Stable Micro Systems, UK; 79-1 (heating) magnetic stirrer: Tianjin Saidelisi Experimental Analytical Instrument Factory; 820109110063 Abbe refractometer: Shanghai Precision Scientific Instrument Co., Ltd.; BCD-571WDEMU1 refrigerator: Qingdao Haier Co., Ltd.; MFI-T1 magnetic field catalytic high-low temperature test chamber: Induce+ (Wuxi) Induction Technology Co., Ltd.; DGG-9070B electric constant temperature blast drying oven: Shanghai Senxin Experimental Instrument Co., Ltd.

2.2 Methods

2.2.1 Raw-material handling. Two groups were designed in the test: magnetic field assisted refrigeration group (M-C) and conventional refrigeration group (C). Each group had three parallel tests. The 2 mL centrifuge tube and pipette tips were sterilized at 121 ℃ for 20 min before use. Stainless steel knife, 100 – 1 000 μL pipette, cutting board and PP plastic crisper were pretreated by UV sterilization for 15 min. The conditions of magnetic field refrigeration test chamber were: magnetic field mode, static magnetic field; magnetic field intensity, 5 mT; refrigeration temperature, 4 ℃. The refrigerator-assisted refrigeration group was used as the control, and the refrigeration temperature was 4 ℃.

Apples were soaked in sodium hypochlorite solution (2 mL/kg) for 10 min and rinsed with running water. After removing the peel (core) in aseptic conditions, the pulp was cut into small blocks of uniform size, and then divided into 28 pieces and packaged into PP crisper with 1% Vc water color protection, each of which was about 50 g, and numbered. The packaged apples were kept fresh at 4 ℃ in the refrigerator and magnetic field equipment (static magnetic field intensity 5 mT), and the indicators were detected on the 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} d of storage. Three parallel tests were set in each group, with refrigerator preservation as the control.

2.2.2 Detection of indicators. (i) Detection of weight loss rate. Using the weighing method, two boxes of fresh-cut apples were taken out from magnetic field and refrigerator and weighed, and the data were recorded. Then, they were put back into the magnetic field and refrigerator for continuous detection for 6 d to compare the changes and calculate the weight loss rate.

$$\text{Weight loss rate} = (m_0 - m_1)/m_0 \times 100\%$$

where m_0 represents the mass of fresh-cut apple blocks before storage, g; m_1 represents the mass of fresh-cut apple blocks at the time of measurement, g.

(ii) Detection of microorganisms. Microorganisms were detected referring to GB 4789.2-2016 and GB4789.15-2016 with slight modification. Ultra-clean workbench was sterilized by ultraviolet for 15 min. Two copies of fresh-cut apples taken from refrigerator and magnetic field were put into the ultra-clean workbench, 10 g of which were cut into small blocks and put into 90 mL of normal saline (0.85%) for 10-fold series dilution. For detection of bacteria, 1 mL of liquid was absorbed with pipette and added into sterile petri dish, and then 15 – 20 mL of plate counting agar medium was poured and mixed, two plates for each dilution. After solidification of agar, the plate was turned over and cultured at (36 ±1) ℃ for (48 ±2) h. For detection of fungi, 1 mL of liquid was absorbed with pipette and added into sterile petri dish, and then 15 – 20 mL potato-glucose-agar medium was mixed, two plates for each dilution. After solidification of agar, the plate was turned over and cultured in an incubator at (28 ±1) ℃. The results of culture were constantly observed and recorded until the 5th day, and the results were expressed by l CFU/g.

(iii) Detection of color. Standard colorimetric plate was used for calibration. L^* value (brightness, reflecting brightness of color), a^* value (a-axis value in Hunter scale, positive value is in red, negative value is in green), b^* value (b-axis value in Hunter scale, positive value is in yellow, negative value is in blue) in CIE-Lab table color system were measured with colorimeter. Three fresh-cut apple blocks were selected for each treatment group and detected by colorimeter. Each block was detected at three different points and set as three parallel groups, and the results were repeatedly measured for 3 times and averaged for data analysis. ΔE^* indicated color difference. The greater the value of ΔE^*, the greater the color difference; conversely, the smaller the value of ΔE^*, the smaller the measurement color difference.

(iv) Detection of texture. TA-XT plus texture analyzer was used to analyze the texture of samples, and P/2 column probe was selected. First, the depth of probe inserted into fresh-cut apple blocks was set, and then the texture analyzer was calibrated. Each treatment group selected 3 blocks of fresh-cut apple, to determine the hardness, brittleness and compactness. Each block was detected at 3 different points and set as 3 parallel groups, and the results were averaged after 3 repetitions. The data were processed and finally analyzed.

(v) Detection of soluble solid. Fresh-cut apple blocks in each treatment group were squeezed juice, and then the concentration of soluble solid was detected by Abbe refractometer. Three parallel groups were set. The results were repeatedly measured for 3 times and averaged for data analysis.

(vi) Detection of total acid. After pH meter was corrected, 5 mL of apple juice was added with water to 50 mL and titrated with standard sodium hydroxide solution (0.1 mol/L). Magnetic stirrer was turned on to stir till titration end point when pH meter reading was 8.2. The amount of sodium hydroxide solution consumed was read out, and three parallel tests were conducted. The average value was calculated according to the total acid calculation formula, and the absolute difference of the final measured results should not exceed 10% of the arithmetic mean value.

2.2.3 Data processing and analysis. Excel software was used for plotting, and SPSS Statistics 20.0 software was used for variance analysis.

3 Results and analysis

3.1 Effect of magnetic field preservation on weight loss rate of fresh-cut apple Weight loss rate can reflect the status of juice loss of fresh-cut apple to some extent. Table 1 shows the change in weight loss rate of fresh-cut apples with storage time under the condition of refrigerator and magnetic field preservation at low temperature. Data analysis showed that the weight loss rate of fresh-cut apples increased with the prolongation of time under two different storage conditions, probably because fresh-cut processing technology destroyed the tissue structure of apples, and accelerated the tissue metabolism and the loss of nutrients and water. The weight loss rate of magnetic field assisted refrigeration group was lower than that of conventional refrigeration group. At 6 d post storage, the weight loss rate of magnetic field assisted refrigeration group was 0.08%, which was only 32% of that of refrigerator assisted refrigeration group, indicating that magnetic field assisted preservation can effectively reduce the loss rate of juice. But generally speaking, when fresh-cut apples were stored for 6 d, the change in weight loss rate was not obvious, probably attributed to the cultivar and texture of apples. Red Fuji apple has tight texture that microorganisms are not easy to enter and decompose nutrients, and the water loss is slow, resulting in small changes of weight loss rate.

Table 1 Changes in weight loss rate of fresh-cut apples with storage time under refrigerator and magnetic field preservation %

Group	Storage time//d						
	0	1	2	3	4	5	6
C	0.00 ±0.00	0.02 ±0.00	0.23 ±0.01	0.23 ±0.01	0.25 ±0.01	0.25 ±0.00	0.25 ±0.00
M-C	0.00 ±0.00	0.06 ±0.03	0.07 ±0.02	0.07 ±0.01	0.07 ±0.00	0.08 ±0.01	0.08 ±0.01

Note: C. Refrigerator assisted refrigeration group; M-C. Magnetic field assisted refrigeration group. The same in Figs. 1-6.

3.2 Effect of magnetic field preservation on hardness of fresh-cut apple The changes in hardness of fresh-cut apple with storage time under different storage conditions are shown in Fig. 1. As shown in Fig. 1, the hardness of fresh-cut apples in both refrigerator assisted refrigeration group and magnetic field assisted refrigeration group showed an overall trend of first increasing and then decreasing, rapidly decreasing after reaching the highest point, and then flattening out within 4 – 6 d. The hardness in refrigerator group reached the highest point of 174.29 on the 2nd d, while that in magnetic field group reached the highest point of 174.74 on the 3rd d. The reason may be that apples are respiratory climacteric fruits, and the hardness increases to the maximum before climacteric period, resulting in fully mature fruits, increased respiratory intensity, and soft fruits. Then it changed gently, probably because low temperature inhibited the respiration intensity of fresh-cut apples and reduced the loss of water. After storage for 6 d, the hardness in magnetic field group was significantly higher than that in refrigerator group. The results indicate that compared with common refrigerator, magnetic field can preserve nutrients by inhibiting the reproduction of microorganisms, reducing the respiration, slowing down the rate of decomposition of tissue structure, delaying the softening of fruits to a certain extent, and delaying the rapid loss of water, which is conducive to later utilization.

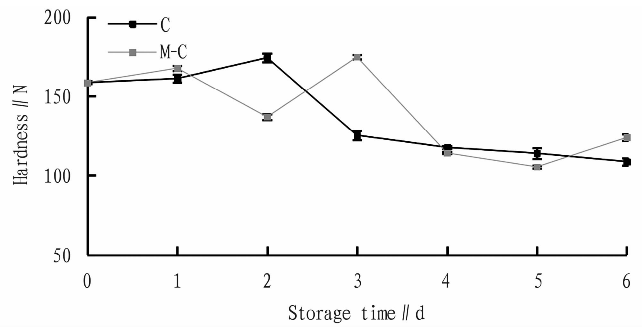

Fig. 1 Changes in hardness of fresh-cut apple under different storage conditions

3.3 Effect of magnetic field preservation on color of fresh-cut apple Colorimeter can reflect the change in color of fresh-cut apples. Fig. 2 reflects the change in L^* value of fresh-cut apples along with storage time, and L^* value represents brightness. It can be seen from Fig. 2 that the L^* value of refrigerator assisted refrigeration group and magnetic field assisted refrigeration group showed a downward trend as a whole, because polyphenol oxidase, an enzyme that mainly exists in apples to change color, caused browning reaction of apples from bright yellow to yellow brown. From the perspective of daily changes, L^* value of magnetic field group was higher than that of refrigerator group, indicating that the browning intensity of magnetic field group was lower than that of refrigerator group, and magnetic field had a certain effect of passivating enzyme activity. However, after 6 d of storage, although there was a decline but the trend was not obvious under both conditions. The main reason was that apple blocks used Vc color protection, and Vc color retention agent can reduce o-quinone produced by polyphenol oxidase to dihydroxyphenol substance, thus effectively slowing down the speed of apple browning. Therefore, in order to slow down the browning speed and extend the shelf life when fresh-cut apple is kept fresh, Vc color protection treatment can be used.

3.4 Effect of magnetic field preservation on total acid of fresh-cut apple Fig. 3 shows the changes in total acid of fresh-cut apples with storage time under different storage conditions. Apples contain a variety of acids, but the most important one is malic acid, which can be used to calculate the changes in total acid of apples under different storage conditions. As shown in Fig. 3, the minimum total acid value of fresh-cut apples appeared after storage for 2 d, which was 0.831 in refrigerator group and 0.963 in magnetic field group. Subsequently, it showed an upward trend, and the difference between the 2nd and 5th d was the most significant. The total acid under refrigerator storage condition was higher than that under magnetic field. The decrease of total acid on the 2nd d may be due to the increase of acid consumption during storage with the loss of water and the enhancement of aging respiration of fresh-cut apples. With the consumption of energy storage substances, the energy required for respiration could not be provided. Therefore, fresh cut apples underwent anaerobic respiration and produced lactic acid. At the same time, fresh-cut apples were decomposed by microorganisms and produced yeast, which led to the rise of total acid. The reason for the relatively low total acid of magnetic field was that magnetic field had certain inhibitory effect on microorganisms, which would inhibit their growth and reproduction.

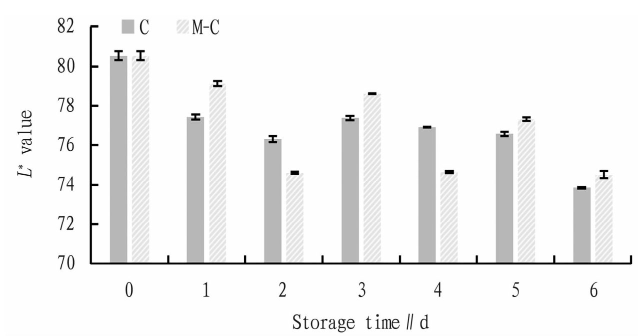

Fig. 2 Changes in L^* value of fresh-cut apple under different storage conditions

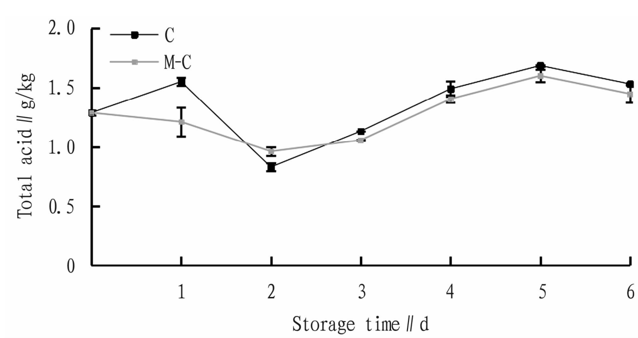

Fig. 3 Changes in total acid of fresh-cut apple under different storage conditions

3.5 Effect of magnetic field preservation on soluble solid of fresh-cut apple Fig. 4 shows the changes in soluble solid content of fresh-cut apples with storage time under different storage conditions. As shown in Fig. 4, the soluble solid content in magnetic field group and refrigerator group did not change much in the first 5 d, showing a gentle upward trend, while the soluble solid content in magnetic field group was significantly lower than that in refrigerator group. The reason may be related to the weight loss rate, which was higher in refrigerator group than in magnetic field group. With the loss of water, soluble solid in apples was concentrated, leading to increased content. After 5 d, the soluble solid content in both groups decreased significantly, probably because with the extension of storage time, microorganisms prolifically consumed nutrients and decomposed soluble solid, thus reducing the soluble solid content.

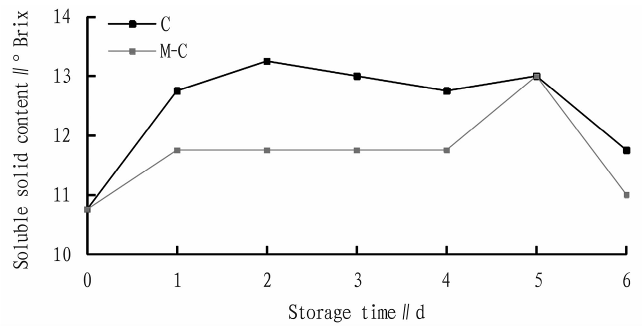

Fig. 4 Changes in soluble solid in fresh-cut apple under different storage conditions

3.6 Effect of magnetic field preservation on microorganisms in fresh-cut apple Figs. 5 – 6 reflect the changes in microbial quantity with storage time under different storage conditions. As shown in Fig. 5, the total number of colonies in refrigerator assisted refrigeration group was higher than that in magnetic field assisted refrigeration group during the same storage time, which became more obvious in the later stage, indicating that magnetic field could inhibit the growth of microorganisms. On the whole, the total number of colonies in magnetic field group showed an increasing trend but a decreasing trend after the 2nd d. As shown in Fig. 6, the total number of fungi in magnetic field group also decreased from the 2nd d, because magnetic field had a hysteresis effect.

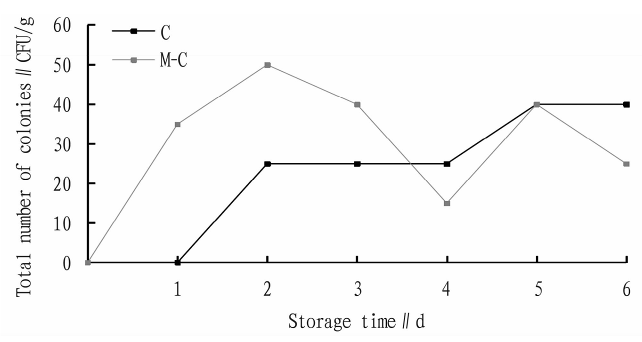

Fig. 5 Changes in total number of colonies in fresh-cut apple under different storage conditions

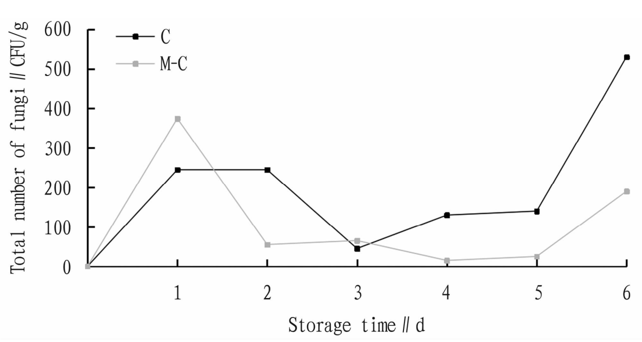

Fig. 6 Changes in total number of fungi in fresh-cut apple under different storage conditions

The antifungal effect of magnetic field was not obvious in the early stage, but became more obvious in the later stage, and the preservation effect of magnetic field was better. When fresh-cut apples were stored for 6 d, the highest number of colonies in either magnetic field assisted refrigeration group or refrigerator assisted refrigeration group only reached a small number of 10^2. The reason may be related to Vc color protection solution, and the use of Vc color protection on fresh-cut apples also have antifungal effect.

4 Conclusions

The effect of magnetic field assisted refrigeration on fresh-cut apple was studied by measuring the changes of microbiological and physicochemical indicators. The results showed that the weight loss rate, total number of colonies, and total number of fungi showed an increasing trend during the storage; the L^* value and hardness showed a decreasing trend; the soluble solid content first increased and then decreased; and the total acid first decreased and then increased. During the same storage time, the above indicators changed more gently under magnetic field assisted refrigeration conditions than that under conventional assisted refrigeration conditions, and the quality was relatively better. After storage for 6 d, the weight loss rate, hardness, L^* value, total acid, soluble solid content, total number of colonies and total number of fungi in magnetic field assisted refrigeration group were 0.08%, 123.90, 76.5, 1.45 g/kg, 11.00° Brix, 190 and 25 CFU/g, respectively. The storage quality of magnetic field assisted refrigeration group was obviously better than that of conventional assisted refrigeration group. Magnetic field assisted refrigeration group treatment could effectively improve preservation quality and prolong shelf life.

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member martyrs, and inherit the spirit of patriotism[4]. Through living and studying in the countryside, students can feel the hardship of agricultural production and development, strengthen self-education, firm ideals and beliefs, and enhance their love and perseverance for their profession. In the third place, teachers can guide students to participate in China International College Students' "Internet +" Innovation and Entrepreneurship Competition, the National College Students' Innovation and Entrepreneurship Training Project, and the "Youth Red Dream Tour" project, so that students take advantage of their professional knowledge, combine red culture, independently go out of campus, explore and innovate in practice, accordingly Zunyi red culture leads the green development of rural areas and promotes rural revitalization.

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ting variables, enhance the prediction, help people to solve realistic problems in future. In addition to collecting, analyzing and supplying the information, the more profound value of library is to provide future information through virtual simulation, build a massive "future information research database" which make library a "development think tank research center" and will be an imporant value orientation of library. Only if a library has relatively complete information, historical inheritance and expansion, it will be a key link between reality and future (metaverse), which is also its irreplaceable uniqueness. In the age of "data", library will carry this responsibility, and rebuild people's confidence on future development.

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