Proceedings of the 2nd International Conference on Modern Medicine and Global Health
DOI: 10.54254/2753-8818/35/20240929

# Effect of magnetic field-assisted cryogenic storage technology on food quality

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**Abstract.** With the rapid development of society, the eating quality of cryopreserved food has long failed to meet people's needs. However, in recent years, one of the physical preservation technologies—magnetic field which is used in the field of low-temperature food storage, as it is safe, non-polluting, and greatly improves food quality. Magnetic fields maintain and improve food quality by regulating the freezing process, reducing enzyme activity, and killing microorganisms. The paper reviews the mechanism of magnetic field-assisted low-temperature storage technology and its effects on water molecules, enzyme activities, and microbial counts in different foodstuffs through literature at home and abroad. The study summarizes the fact that there are only a small number of studies on pasta products. The experimental design is subject to the interference of other factors with the results of the experiments. It also includes prospects for future research that magnetic field-assisted cryogenic storage technology can greatly reduce the probability of fresh food due to improper low-temperature storage and lead to corruption and deterioration to protect the original nutritional value and economic value of fresh food.

**Keywords:** Magnetic field, cryogenic storage, food quality, frozen food.

## 1. Introduction

With the rapid development of society, there have been many domestic food quality and safety problems in China. For example, the Master Kang Laotan pickled cabbage incident on 15 March 2022 [1] raised national concerns about the quality of processed foods such as instant noodles. The extremely high production of fresh food in China can contribute considerable economic value, but because China's technology in the field of fresh food preservation is not yet perfect, resulting in nearly 30% of fresh food due to various factors corruption and deterioration, loss of economic value [2].

The promotion of preservation technology and freshness is the focus of people's attention. In the past, people would add large amounts of salt and sugar to foods to prolong storage such as cured meats, canned goods, etc. At present, three food preservation technologies are in China: biological preservation, chemical preservation, and physical preservation. Biological preservation and chemical preservation are in the food residue additives. These additives will produce some harm to the human body, therefore, physical preservation technology with its green, non-polluting characteristics stands out, in the large-scale industrialization of the application.

Nowadays, in a fast-paced world, the demand for many frozen fresh foods is satisfied by low-temperature storage technology in physical preservation. However, a single low-temperature

DOI: 10.54254/2753-8818/35/20240929

storage process can damage certain food quality and cannot meet the nutritional needs of consumers. However, according to current research by national scholars, the food quality of frozen fresh food can be improved by combining the physical treatment process with low-temperature storage technology, which includes ultra-high pressure, ultrasonic waves, magnetic fields, etc. Among them, the magnetic field preservation technology has been proven in several studies to change the size of the ice crystals formed by altering the structure of water molecules, thus improving the quality of foods stored at low temperatures. The combination of magnetic field and low-temperature storage technology is called magnetic field-assisted cryogenic storage technology. The principle is to add an external magnetic field around the food in a low-temperature (frozen or refrigerated) environment to change the internal molecular state of the food and make up for the shortcomings of only using a single low-temperature storage technology, which leads to the quality of the food produced by the damage. Magnetic field through the induced current effect, oscillation effect, Lorentz force effect, ionization effect, etc. change the characteristics and movement state of the charged particles in the cell, thus changing the internal components during the food in the freezing process [3] such as making the phase transition phase of the water molecules more homogeneous and controlling the size of the formation of the ice crystals and the distribution of the location, to minimize the damage brought by the ice crystals to the internal tissues of the food. Song [4] and others found that the DC magnetic field frozen onion cells formed thin and scale-like ice crystals, thus avoiding the destruction of the cell structure, to maintain the nutrition and moisture of fruits and vegetables. Choi [5] and others found that electromagnetic resonance freezing can be better to improve the water retention rate of beef, which in turn reduces the beef thawing process of the loss so that the consumer can be more accepting. Magnetic field-assisted cryogenic storage technology is conducive to maintaining the nutritional composition of food, slowing down the degradation of food sensory properties, making up for the single low-temperature storage technology that brings great damage to the quality of food, and becoming a new technology to improve the quality of frozen fresh food. Magnetic field-assisted cryogenic storage technology involves changing the structure of water molecules in different food categories to optimize the cooling and freezing processes, change enzyme activity, reduce or even inhibit the growth of microorganisms, and other ways to improve the quality of fresh food.

In this paper, the mechanism of magnetic field-assisted cryogenic storage technology and its effects on moisture, enzyme activity, and microbial growth and development in different foodstuffs will be reviewed by combining the relevant research progress at home and abroad, and the shortcomings in the application process will be summarized as well as the outlook of its prospects.

## 2. Mechanism of magnetic field-assisted cryogenic storage technology

### *2.1. Influence of magnetic fields in freezing technology*

Water itself has a magnetic field, and during cold storage, the water molecules of food products are subjected to changes in many physicochemical properties, such as surface tension, viscosity, refractive index, dielectric constant, and the structure and number of hydrogen bonds under the effect of an external magnetic field [6]. Cai [7] and others found that the viscosity increases, the speed of movement slows down, and more hydrogen bonds are formed making the size of water clusters larger under a fixed magnetic field, and the surface tension of water molecules decreases. Niu [8] and others found that ammonia water decreases the viscosity to a greater extent and the coefficient of thermal conductivity increases under the condition of the longer magnetization time and the greater the intensity of the magnetization. Wang [9] and others found that the friction coefficient of water decreases with the increase of the magnetic field strength under the effect of the static magnetic field, while the difference in the friction coefficient may be due to the weak influence of the Lorentz force of the magnetic field on the hydrogen bonds between water molecules. It can be seen that the magnetization time and the strength of the magnetic field are also important factors affecting the physicochemical properties of water molecules. The magnetic field affects the properties of hydrogen

DOI: 10.54254/2753-8818/35/20240929

bonding through the Lorentz force effect, which in turn affects the chemical structure of water molecules, leading to deviations from the normal physicochemical properties of water.

*2.2. Influence of magnetic fields on the freezing process*

Studies at home and abroad have shown that the magnetic field reduces the degree of supercooling of food in the freezing process, shortens the phase transition time, prolongs the nucleation time, breaks up the large molecular water clusters to produce small ice crystals that are uniformly distributed, and inhibits the growth of the ice crystal nuclei, which results in a reduction in the mechanical damage produced by the water molecules (Figure. 1) [6]. Shan and others [10] found that under the effect of an external magnetic field, the probability of directional movement of water molecules and ions increases, which leads to an increase in the probability of collision among molecules, a more uniform temperature, and a greater thermal conductivity, thus shortening the phase transition time, while the resulting crystals become smaller and mist-like in shape. The liquid effluent from the crystallization process is reduced, thus better maintaining the properties of the cells. It can be seen that the magnetic field shortens the crystallization time of the water molecule freezing process and obtains more uniform and fine ice crystals, thus reducing the mechanical damage of ice crystals on the internal tissues of the foodstuffs and safeguarding the quality of the foodstuffs.

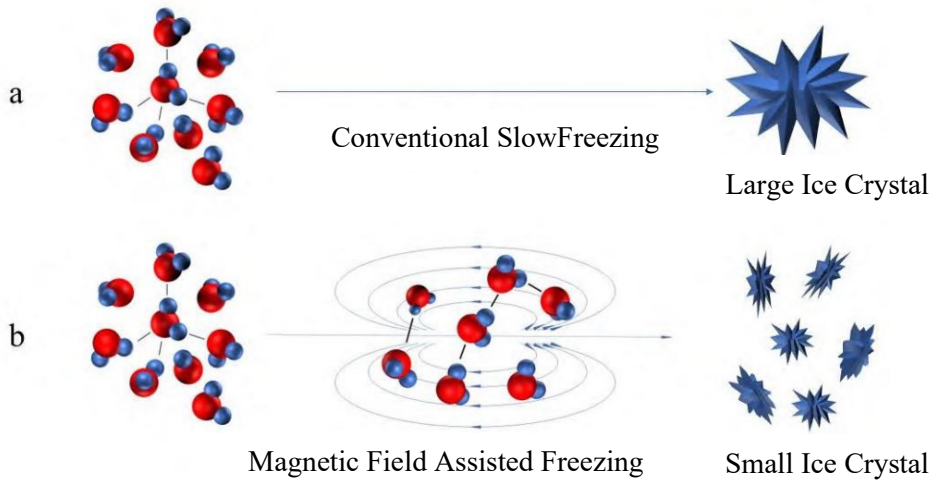


**Figure 1.** Effect of magnetic field on the freezing process of water [6].

*2.3. Effects of magnetic fields on refrigeration technology*

Food a long time in the storage process, distributed on the food surface of a variety of microorganisms and internal enzymes will hurt it. Although cold storage cannot make the food internal ice crystals, it rarely maintains the quality of the food in a relatively short period. Magnetic field-assisted cold storage technology can inhibit the growth of microorganisms, and reduce enzyme activity to maintain the original food quality while extending the freshness of food.

*2.3.1. Effects of magnetic fields on microorganisms.* Microorganisms in food are metabolized during growth and development to form products that are harmful to the quality of the food. Magnetic fields can kill microorganisms in cells by rupturing cell membranes through an oscillatory effect [11]. The contamination is caused by direct contact between the electrodes. The sterilized material can also be greatly reduced by magnetic perforation and the effect of electromagnetic wave sterilization [12]. Microorganisms in food are one of the main factors leading to food spoilage. With the aid of a magnetic field can effectively kill microorganisms and control microorganisms within a reasonable range to ensure the quality of food consumption.

DOI: 10.54254/2753-8818/35/20240929

*2.3.2. Effect of magnetic fields on enzyme activities.* Enzymes are one of the main factors in the spoilage of food due to special chemical properties, and catalysis. Magnetic fields can be used to prolong the shelf life of food by destroying the hydrogen bonds between water molecules, thus preventing the maintenance of the conformations of proteases bound to water [6], and controlling the enzyme activity and the occurrence of the associated physiochemical reactions.

## 3. Effect of magnetic field-assisted cryogenic storage technology on meat foods

### *3.1. Effects of water molecules on meat foods*

Meat products are one of the main sources of protein for human beings. However, a large number of meat products in the world undergo spoilage every day, which is mostly due to ice crystals during the storage phase of meat products that cause great mechanical damage to the meat tissues. During the defrosting and rewarming process, the melting of ice crystals results in a large amount of nutrients being taken away, which greatly reduces the quality of the meat. Magnetic field-assisted cryogenic storage technology maintains the food quality of meat products by shortening the phase-changing time of the meat and making the crystals smaller and more evenly distributed, thus reducing the damage to the meat tissues caused by the freezing process. Pan [13] found that under the conditions of alternating magnetic field-assisted refrigeration, the juice loss rate of grass carp fillets and beef was less than that of conventional refrigeration, which guaranteed the nutritional value and economic benefits of grass carp fillets and beef. Lin [14] and others found that a static magnetic field could prolong the freshness of beef for 6 days by making it last for 14 days in a sub-cooled state without ice nucleation while decreasing the loss of dripping. Okuda [15] and others found that the number of ice holes in mackerel decreased and the percentage of interstitial area increased under conditions of oscillating magnetic field freezing, which in turn inhibited tissue damage in mackerel. It can be seen that the magnetic field-assisted low-temperature storage technology can reduce the irreversible damage of ice nucleation on meat tissues and reduce the loss of juice and nutrients, thus improving the quality of meat products.

### *3.2. Effects of Microorganisms on products meat products*

There are also a large number of microorganisms in meat products, which produce metabolic wastes that reduce the quality of meat products during their growth and development, and the presence of an external magnetic field can minimize the risk of microorganisms to the quality of the food by inhibiting the growth of the microorganisms. Pan's [13] research showed that the addition of an alternating magnetic field inhibited microbial multiplication, delayed spoilage, and prolonged shelf life in refrigerated grass carp fillets and beef compared to conventional refrigeration. Patricia [16] and others found that microbial content in fresh beef was suppressed under pulsed magnetic field conditions.

## 4. Effect of magnetic field-assisted cryogenic storage technology on fruit and vegetable foods

### *4.1. Effects of water molecules on fruit and vegetable foods*

Fresh fruits and vegetables can provide people with great nutritional value. Fruits and vegetables in low-temperature storage will also carry out cellular respiration, transpiration, and other life activities, which are easy to cause corruption and deterioration, thus losing economic value. Fruits and vegetables are rich in moisture, which can form large ice crystals during the freezing process, causing mechanical damage to the cellular structure of fruits and vegetables. However, magnetic fields can inhibit the occurrence of this process. The study of Zhao [17] showed that magnetic fields can inhibit the diffusion properties of water molecules during the storage of fruits and vegetables, thus reducing the dry consumption of fruits and vegetables, and at the same time, compared with continuous and intermittent electromagnetic treatment, low-intensity alternating magnetic fields can increase the degree of sub-cooling of grapes, decrease the latent heat of phase transition, thus reducing the chances of crystallization and consequently reducing the freezing damage. Zhang [18] and others found that the

DOI: 10.54254/2753-8818/35/20240929

cucumber's initial nucleation temperature and freezing point temperature were reduced under the action of a pulsed magnetic field, and the tempering time and phase transition time were shortened. Jiang [19] and others found that the addition of an external magnetic field shortened the phase transition time, maintained the ratio of free and bound water at a good level, and reduced the number of broccoli cell ruptures in broccoli in a frozen environment. It can be seen that magnetic fields can guarantee a certain period of freshness and economic value for frozen fruits and vegetables, which satisfy people's needs.

### *4.2. Effects on enzyme activities on fruit and vegetable foods*

Under refrigerated conditions, the enzymes in fruits and vegetables can accelerate the process of their spoilage and deterioration; however, magnetic fields can slow down this process. Zhao [17] found that the metal ions inside polyphenol oxidase undergo regular vibration due to the external magnetic field, which leads to the breakage of chemical bonds, thus reducing the enzyme activity, and because polyphenol oxidase activity is related to the tissue browning that occurs in the late stage of fruits and vegetables. So, the magnetic field reduces the degree of tissue browning in the late stages of fruits and vegetables. Zhao [20] and others found that, compared to a single cold-water shock treatment, the peroxidase and superoxide dismutase activities were increased by a static magnetic field, which led to a decrease in malondialdehyde content and thus maintained the freshness quality of cucumber. Qian [21] and others found that a pulsed magnetic field reduced the activities of peroxidase, pectin methyl esterase, and polyphenol oxidase, which led to a decrease in ascorbic acid and maintained the quality of apple juice at a high level.

### *4.3. Effects of microorganisms on fruit and vegetable foods*

Liquid fruit and vegetable products are highly susceptible to spoilage due to the presence of microorganisms, which reduces their organoleptic quality, and magnetic fields can be a good way to slow down this deterioration process. Ma [22] and others found that a high-intensity pulsed magnetic field can effectively meet the demanding requirements of watermelon juice with low-acid heat sensitivity to the sterilization conditions, and the pulsed strong magnetic field kills microorganisms deep into the food through strong penetration ability, maintaining the original flavor characteristics of watermelon juice. Wang [23] found that the effect of the pulsed strong magnetic field can produce different degrees of damage to the bacterial bodies of Escherichia coli, Staphylococcus aureus, Salmonella, etc. in apple juice, to regulate the distribution of the bacterial flora of apple juice, and then reduce the degree of contamination of the finished product of apple juice.

## 5. Impact of magnetic field-assisted cryogenic storage techniques on flour products

### *5.1. Effect of water molecules on flour products*

Flour products are an important source of carbohydrates for the human body. Frozen flour products can be consumed through simple heating, which brings great convenience to the contemporary fast-paced life. However, flour products are very different from fresh ones after thawing and re-steaming processes. In recent years, magnetic fields have gradually been applied to preserve the quality of flour products. Zhou [24] found that the magnetic field lowered the freezing point and phase transition time of the dough, leading to the formation of a large number of small, uniformly distributed ice crystals, which reduced the damage and quality loss of the dough caused by freezing. Besides, the transition of non-freezable water to freezable water in the dough was inhibited under the action of the magnetic field, which reduced the recrystallization of the ice and reduced the damage of the ice crystals to the gluten protein reticulum structure. Therefore, magnetic fields can improve the food quality of frozen flour products and then improve the organoleptic properties after re-steaming.

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### *5.2. Influence of microorganisms on flour products*

Flour products such as steamed buns and bread contain a large number of yeasts. The ice crystals produced during the freezing process will inhibit the activity of beneficial microorganisms such as yeasts, while the magnetic field can help these microorganisms maintain their original functional properties in the freezing environment. Zhou [24] found that the magnetic field can not only inhibit the adverse effects of ice crystals on yeast but also inhibit yeast inactivation, which in turn maintains the gas production of flour products and safeguards the food quality of flour products.

## 6. Impact of magnetic field-assisted cryogenic storage technology on dairy products

### *6.1. Effect on enzyme activity in dairy products*

Milk and other dairy products are beneficial to human growth and development, but even at low temperatures, enzymes in milk can catalyze spoilage of the milk itself. However magnetic fields can reduce the loss of nutritional and economic value of milk. Chen [25] and others found that the pulsed strong magnetic field has a strong passivation effect on the catalase enzyme in milk, which reduces the catalase enzyme activity, thus prolonging the shelf-life of milk as well as improving the organoleptic quality of milk.

### *6.2. Effects of microorganisms on dairy products*

Spoilage of dairy products is often also because microorganisms produce a large number of metabolic wastes inside them, which can be killed by magnetic fields to maintain dairy product quality. Guo [26] and others found that under conditions of high-intensity pulsed magnetic fields, the total number of colonies of milk was significantly reduced, and under optimal treatment conditions, the milk was even commercially sterile.

## 7. Conclusion

This paper reviews the domestic and international research on the progress of magnetic field-assisted cryogenic storage technology in improving and maintaining the quality of food and analyses the effects of this technology on the quality of food by adjusting the crystal size and distribution of water molecules in the freezing process of different kinds of food, which is used to reduce the mechanical damage of ice crystals on the internal part of the food, decreasing the activity of enzymes to slow down the spoilage of the food on both the surface and the internal part of the food, and killing the microorganisms to reduce the influence made by harmful metabolic wastes on food. Magnetic fields are effective in improving the quality of different foods at low temperatures and have great potential in the field of food preservation and processing, and their use in industrial production could better meet the supply needs of preserved fresh foods. However, the existing research does not cover most of the food types, such as research scholars are mostly focused on analyzing meat products and fruit and vegetable products, and less research on flour products. Secondly, there are certain shortcomings, such as the application of magnetic fields in the process of cooling and freezing. The external environmental factors to the experimental process will produce a certain degree of interference, which will lead to the results of the experiments not being compared, and even preventing contradictions between other researchers. Therefore, it is possible to improve the persuasive power of the magnetic field which can promote the quality of cryogenically stored foods by first clarifying the criteria for the formulation of various parameters, and then conducting experiments to minimize interference and reduce experimental errors. The large-scale industrial application of magnetic field-assisted cryogenic storage technology can improve people's nutritional and sensory needs for frozen fresh food and reduce the loss of economic value of fresh food due to spoilage, which is of great help to human health and the world's economic gain.

DOI: 10.54254/2753-8818/35/20240929

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