Review on preservation techniques of edible lily bulbs in China

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ABSTRACT
Chinese sweet lily (Lilium davidii var. unicolor), the only edible lily in the world, has high nutritional value. At present, the application of preservation technology is relatively backward, resulting in a large loss of lily. Therefore, the preservation has become one of the key factors limiting the development of the edible lily bulbs industry. This paper reviews the various application of pretreatment and storage technologies for the preservation of lily bulbs. It is considered that irradiation and proper preservative can be used for pretreatment. Vacuum packaging can be used for short-term storage and transportation. Phase temperature storage could be as a long-term storage mode of lily bulbs.

1. Introduction
Lanzhou lily (Lilium davidii var. unicolor), the only sweet lily that can be used as both medicine and food (Jin et al., 2008), is mainly grown in central Gansu Province. Figure 1 shows the topography and geomorphology of the growing area of Lanzhou lily. It contains abundant nutritional components such as starch, protein, polysaccharides, vitamins and colchicine (W. Li et al., 2020; Y. Li et al., 2020; F. Wang et al., 2018; Zhao et al., 2013). And it has the effects of anti-inflammatory, anti-tumor, anti-oxidation, anti-aging and hypoglycemic (Luo et al., 2012; Munafò & Gianfagna, 2015; Zhu et al., 2014). Lanzhou lily is a very important local cash crop. Bulbs are popular in China, and exported to Korea, Japan and other countries (L. Zhang et al., 2021). However, Lanzhou lily still faces the problem of limited preservation and storage technology. It is a perennial cultivated lily (typically 3 years) with poor adaptability. Problems like severe physiological metabolism and microbial infection could cause the change of bulb quality of lily (Q. H. Shang et al., 2014). Therefore, it is necessary to strengthen the research on the preservation technology of lily bulb.

The current processing process of lily is shown in Figure 2. Lily bulbs are soaked with chemical Preservatives after picking and washing. Then they are treated by traditional methods, such as sand storage and Hoard method. These have some problems such as serious nutrient loss, browning and mildew. To improve the preservation quality of lily bulbs, the first is to delay the loss of nutrients. Low temperature could reduce water loss. At the same time, low temperature can affect gene expression and change enzyme activity to reduce metabolic expenditure. Yu et al. (2022) also confirmed that differentially expressed genes are involved in the metabolic pathways of starch and sucrose in bulbs. This increases the activity of sucrose phosphate synthase and sucrose synthase, leading to starch degradation and sucrose accumulation (Tian et al., 2020). However, low temperature is not an antifungal treatment, which only slows the growth of the fungus. It is identified that pathogens such as Bacillus Safensis, Stenotrophomonas maltophilia and Metschnikowia Pulcherrima in lily bulbs. And some bacteria and fungi, such as Fusarium and Penicillium, have been shown to cause decay (Ling et al., 2019; Shang et al., 2016). The presence of phthalic acids, a endogenous toxin in

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roots, affects the replanting of lily (Z. Wu et al., 2015; Yan et al., 2019). Currently, many new technologies (preservatives, ultrasound and pulsed electric field) can effectively sterilize to reduce the impact of microorganisms on lily bulbs.

Another problem for lily preservation is browning. Enzymatic browning was considered to be the main cause, including polyphenol oxidase (PPO), peroxidase (POD), and Phenystian-lyase (PAL). PPO can oxidize bisphenol to quinone, of which the subsequent reaction leads to the accumulation of melanin. POD can oxidize phenols in the presence of hydrogen peroxide ($H_2O_2$) to produce polymeric brown pigments. PAL can catalyze the deamination of phenylalanine to cinnamic acid, which can synthesize different phenolic compounds. In addition, there are many enzymes that can improve the resilience of fruits and vegetables, such as polygalacturonase (PG) and pectin methylesterase (PME). Analyzing the effects of different techniques and methods on enzyme activity can effectively judge the preservation effect (Mishra et al., 2012; Punia Bangar et al., 2022; Raj et al., 2006; Tinello & Lante, 2018; Toivonen & Brummell, 2008).
This paper concluded the advantages and disadvantages of the preservation techniques and storage methods of lily analyzed from three aspects: nutrient composition, enzyme activity and microorganism. Then the application results of many new preservation technologies and storage methods are discussed. Furthermore, we propose an optimized method for keeping fresh of lily bulbs.

2. Pretreatment technology
The preservation effect can be improved by using pretreatment before storage. The advantages and disadvantages of different pretreatment methods are summarized in Table 1.

2.1. Applied pretreatment technologies

2.1.1. Vacuum treatment
Vacuum precooling is a technology that quickly evaporates water to eliminate heat and achieve longer shelf life (Sun & Zheng, 2006). Vacuum cooling process allows the product to be cooled evenly on the inside without ice forming on the product surface. The pressure and temperature of the cooling process could be controlled quite precisely, which helps to avoid surface icing (McDonald & Sun, 2000).

The large amount of field heat carried by edible lily bulbs can intensify respiration and transpiration. Vacuum precooling can remove field heat in time and effectively inhibit respiration and decay rates (Xie et al., 2015). Meanwhile, studies have found that the cell structure of fruits and vegetables is an important carrier of their contents. The water in fruit and vegetable cells will be partially lost due to evaporation in the process of vacuum precooling, which will lead to changes in their microstructure (He et al., 2004). And it could intensify the oxidation of lily bulbs (C. Zhang, 2018).

The current system of vacuum pre-cooling equipment is complex and expensive, so it is not widely used. In recent years, integrated technologies such as multi-stage vacuum cooling, the combination of vacuum cooling and active packaging, and the combination of water cooling and vacuum drying have received increasing attention (Cheng, 2006; Mittal et al., 2014; Poonlarp & Boonyakiat, 2015).

The technology of vacuum packaging has been widely used in the transport of lily bulbs. Vacuum packaging involves removing the air from the package before sealing. This simple procedure reduces the level of oxygen in the package and limits aerobic growth. Typically, each bag is filled with four uniformly sized lily bulbs and vacuumed to approximately 0.01 MPa. Meanwhile, each vacuum bag is covered with a foam net to avoid crushing (P. Zhang et al., 2021).

Vacuum cooling results in moisture loss. And, the internal structure of the product is damaged as water evaporates. Vacuum technology is widely used because of its convenience. However, its role is limited. It can be combined with other technologies in the future to improve the effect of preservation, such as preservative treatment and electric field treatment.

2.1.2. Preservative treatment
Chemical preservation treatment, such as the use of chlorine as a fruit and vegetable preservation agent, have the advantages of low cost, high efficiency, simple operation, etc (Meireles et al., 2016). However, consumers have gradually lost confidence in the safety of chemical additives due to the increasing number of food safety problems in recent years. At present, many scholars explore the effect of new green preservative (Lagnika et al., 2013).

Gong et al. (2011) found that ClO₂ fumigation can effectively inhibit the browning of lily. It was confirmed that ClO₂ treatment reduced the activity of polyphenol oxidase and

| Table 1. Pretreatment technology for fruits and vegetables. |  |
|-----------------------------------------------------------|---|
| **Preparation technology**                                | **Advantages** | **Disadvantages** |
| Vacuum treatment                                         | - Field heat removal | - Limit to inhibit the growth of microorganisms |
|                                                          | - Effectively reduce respiration rate | - High cost for vacuum precooing equipment |
|                                                          | - Simple operation without professionals | - Water loss |
|                                                          | - Low-cost for vacuum packaging | - Safety risk |
| Preservative treatment                                   | - Low cost | - Undesirable residue |
|                                                          | - Easy to use | - Consider the concentration of preservative |
|                                                          | - Inhibit corruption and pathogenic microorganisms effectively | - Cause mechanical damage easily |
|                                                          | - Delay saccharification at low temperature | - Complicated by difficulty scaling up |
|                                                          | - Assist in other ways of preservation | - High doses may affect product quality |
| Ultrasound treatment                                     | - Inhibit or kill bacteria, mold, pathogens and other pathogenic microorganisms effectively | - Product texture change |
| Radiation treatment                                      | - Can be carried out after packaging | - Cause the loss of vitamins, minerals and other nutrients |
|                                                          | - Inhibition of browning and related enzyme and amylase activities | - Cause cell damage |
|                                                          | - Effective in reducing bacteria and mold | - Less effect on mold growth |
| Thermal process treatment                                | - Reduce aerobic bacteria and mold effectively | - Need to specifically determine the range of electric field intensity |
| Pulsed electric field treatment                          | - Effective elimination of microorganisms | - Equipment expensive |
|                                                          | - Activate defensive enzyme activity (PEM, PG) | - Affect porous integrity |
| High pressure processing                                 | - Microbial inactivation | - High cost |
|                                                          | - Nutrients are not degraded | - Lack of formula information |
| Nanotechnology                                           | - Consistency of processing | - |
inhibited browning. In terms of nutritional quality, ClO₂ treatment can effectively inhibit the reduction of vitamin C (VC) content and delay low temperature saccharification. However, it had no effect on the change of starch content. And some studies have confirmed that the treatment effect of preservatives such as salicylic acid, 1-methylcyclopropene and chitosan is not as obvious as ClO₂ treatment (H. L. Gong et al., 2010; L. Wei et al., 2019).

But different preservatives have different effects. Liu et al. found that ozone treatment could also effectively maintain the content of VC and total sugar, but could not effectively inhibit browning (Y. Liu & Lu, 2008). H. Xu et al. (2021) demonstrated that ozone damages the surface of lily starch and increases particle size. This results in significantly enhanced functionality of lily starch, including thermal properties, gelatinization properties, water solubility, swelling power, gelatinization transparency and in vitro digestion.

NaHS fumigation can increase soluble sugar and ascorbic acid, while decreasing the contents of total phenols and flavonoids. The results showed that NaHS fumigation can stimulate the activities of superoxide dismutase (SOD), catalase and ascorbate peroxidase (APX). At the same time, it can improve appearance by inhibiting the activity of key enzymes involved in anthocyanin synthesis and reducing anthocyanin accumulation (D. Huang et al., 2021; C. Li et al., 2021). Nowadays, more and more natural extractions are studied. Natural essential oils, as a class of fruit and vegetable preservatives, are not only good for anti-mildew but also beneficial to the human body. Essential oils, such as thyme oil and oregano oil, has been shown to inhibit spore germination of Fusarium oxysporum (Bevilacqua et al., 2010; Bounar et al., 2020; Tongnuanchan & Benjakul, 2014).

There are many kinds of preservatives and their effects are extensive. In the future, preservatives can also be used to assist other processing technologies to improve the preservation effect. For example, the preservative is combined with vacuum packaging, air conditioning storage, etc. While paying attention to the fresh-keeping effect, more research should be done on its safety to avoid the safety problems caused by the excessive residue of reagent.

2.1.3. Ultrasound treatment
Ultrasound treatment produces the phenomenon of transient cavitation, which in turn destroys microbial cellular components as a sterilizer. In this phenomenon, the cycling of pressure creates a large number of cavitation bubbles. The subsequent collapse of bubbles and molecular collisions could lead to extreme high temperature and pressure points (5000°C and 50 MPa), destroying cell envelopes and other microbial components. In addition, ultrasound treatment may soften plant tissue and cause mechanical damage to plant slices (Leong et al., 2017; Van Impe et al., 2018).

(F. Li & Zhang, 2019) reported that ultrasonic treatment effectively inhibited or killed bacteria, molds, pathogens and other pathogenic microorganisms, thus extending the safe storage time of lily bulb. At the same time, ultrasound treatment combined with sulfur-free preservatives, ultraviolet radiation and true air packaging can reduce the loss of VC (Y. Wei et al., 2013; Zhou et al., 2013).

Ultrasound treatment has a wide range of treatment effects and obvious application potential. However, there are some limiting factors, such as mechanical damage and nutrient loss. Ultrasound treatment may be considered in combination with other techniques to reduce the loss of nutrients. In addition, the economics of ultrasonic processing, including energy consumption and cost, should also be considered.

2.1.4. Radiation treatment
Radiation treatment (Hernández-Hernández et al., 2019; Urbain, 2012) is a non-thermal processing technique that could sterilize by applying a certain dose of ionizing radiation and non-ionizing radiation. The ionizing radiation included gamma rays, X-rays, accelerated electron beams, etc. And the non-ionizing radiation included ultraviolet light, visible light, infrared, radio waves. In addition, radiation treatment can be applied to packaged foods by eliminating the serious cross-contamination problems that may occur during the production (Qiang, 2003). And it also has a bad effect on the nutritional composition of fruits and vegetables, such as VC (J. Wang & Du, 2005).

Wu et al. (1996) initially clarified that the optimal radiation preservation method for Yixing lily bulbs is a radiation dose of 10 50 Gy from September to February. And the shelf life of fresh lily could be extended 2 4 months by radiation preservation. Huang et al. (2017) observed that appropriate UV-C radiation could inhibit the activity of enzymes (PPO, POD, PAL), especially PAL. It can also slow down the accumulation of malondialdehyde (MDA) content. Huang et al. found that UV-C radiation can effectively inhibit the growth of microorganisms in lily bulbs. The activity of PPO and peroxidase POD decreased by 26% and 18%, respectively, and the total phenol content increased by 13%. On the contrary, the activity of phenylalanine ammonia lyase PAL increased. UV-C treatment decreased the activities of A-amylase, B-amylase and starch phosphorylase, resulting in an increase in starch content, total soluble sugar content and a decrease in reducing sugar content.

At the same time, Forges et al. (2018) found that UV-C irradiation can activate the activity of these defensive enzymes and increase the content of phenolic compounds in fruits and vegetables. It could improve the resistance of fruits and vegetables to botrytis cinerea.

However, radiation preservation technology also has many shortcomings. And the application of radiation preservation technology is also not wide enough. At present, potatoes have been treated with ultraviolet radiation in combination with ultrasonic treatment. The results show that this reduces mass loss and kills bacteria at the same time. At the same time, the technology can use a root vegetable (Steffen et al., 2010). The synergistic effect of using the compound treatment can reduce the dosage of pharmaceuticals and irradiation to minimize the drug residues and irradiation damage, which can both extend the storage period of the product and ensure the safety of its consumption. However, it has some limits, such as high investment cost, high sensitivity of radiation dosage and operation time on product quality and difficult to control the operating conditions (L. Ma et al., 2017).

2.2. Other potential pretreatment technologies of lily bulbs
2.2.1. Thermal process treatment
Thermal process treatment was first mainly used to prevent and control pathogenic infections in fruits and vegetables.
(Xiong et al., 2006). As the research goes on, it has been found that it also performs well in controlling cold damage and maintaining storage quality of fruits and vegetables. The post-harvest heat treatment takes medium temperature generally between 30 and 50°C for a few seconds to several hours (Lurie et al., 1998).

Hirota et al. (1998) found that thermal treatment could reduce flavonol glycosides and flavonols in cooked onion. It also was found that thermal process treatment had an effect on starch morphology. The starch in the potato absorbs water and expands at 50°C, which makes the cells spherical. At 60°C, the integrity of cell membrane and expansion pressure disappear (Gonzalez et al., 2010; Lovegrove et al., 2017; Singh et al., 2016). As for enzyme activity, thermal process treatment can activate pectin methyl esterase activity and inhibit PPO activity at 65°C of potato (Abu-Ghannam & Crowley, 2006; E. Z. Liu & Scanlon, 2007). Zudaire, Viñas, Abadias, Simó, and Aguilo-Aguayo (2018) found that the number of aerobic thermophilic bacteria and molds in onions was significantly reduced after thermal treatment.

However, numerous studies have found that thermal process treatment extensively tends to lead to the loss of vitamins, minerals and other nutrients, resulting in a decrease in the quality of fruits and vegetables (Roselló-Soto et al., 2018). In recent years, many researchers have made significant progress by combining electricity and heat. Different processes, such as galvanic slurry decomposition, ohmic heating and microwave heating will have a huge impact on the food preservation industry.

2.2.2. Pulsed electric field treatment
Pulsed electric field (PEF) treatment is a non-thermal preservation technique. It uses short pulses of 20 kV/cm 100 kV/cm to treat samples. It has the advantages of short treatment time, low treatment temperature and no chemical residue. Compared with heat sterilized samples, samples treated by pulsed electric field contained more stable flavonoids and phenolic acids. The sensory scores of the pulsed electric field treated samples were higher than those of the heat-treated samples (Eliz-Martínez & Martín-Belloso, 2007). Factors affecting the pulsed electric field include field strength, pulse width, frequency, processing time, polarity and temperature used (Odriozola-Serrano et al., 2013; Wiktor et al., 2016).

Currently, electroporation and electroosmosis are considered to be the main mechanisms of microbial inactivation mediated by PEF treatment (Barba et al., 2015). Lebovka et al. (2002) reported that PEF causes swelling loss and cell membrane rupture in potatoes. A method to explain the electroporation has been proposed by using molecular dynamics simulations. Simulations of lipid bilayers confirm that electric fields above 0.5 V/nm can generate electroporation (Vorobiev & Lebovka, 2020).

However, fewer studies have been conducted on the effects of pulsed electric fields on enzymes in fresh fruits and vegetables. López-Gámez et al. (2020) found that PEF treatment (580 J/kg) had no significant effect on antioxidants (PPO and POD) but a significant effect on pectinase activity during carrot storage. The activity of PME immediately increased up to 164%, probably due to cell damage. It results in intracellular material migration that activation of PME activity. However, the activity of PG decreased by about 31%. This phenomenon may be a defense response of plants to PEF-induced stress. These studies suggest that enzyme activities in plants respond differently to PEF. It depends on molecular size, microstructure, and PEF treatment conditions.

It has been shown that PEF could inhibit the growth of yeast in fruit juices, but have less effect on mold growth. There are few studies on the inactivation of mold spores in fruits and vegetables by PEF treatment, but it has been confirmed that PEF treatment can inactivate mold spores in fruit juices (Z. Li et al., 2021).

The key point of PEF treatment is to determine the range of electric field intensity of different fruits and vegetables. Meanwhile, Knorr et al. showed that electric fields can enhance the permeability of cell membranes. If the process of opening cells in an electric field can be reversed, nutrients and other substances can be added to them (Knorr et al., 2001).

2.2.3. High pressure processing
High pressure processing (HPP) is a non-thermal processing technology that uses high pressure of 50-1000 MPa to inactivate bacteria (Castro & Saraiva, 2014; Mújica-Paz et al., 2011). Compared with traditional heat treatment, HPP can better maintain the color and texture of fruits and vegetables. It could also reduce the loss of microbial C and ice crystal damage.

HPP is also effective in inactivating other hazardous microorganisms such as many yeasts, molds, and bacteria responsible for food spoilage (Daher et al., 2017; Yordanov & Angelova, 2010). HPP could decrease PPO activity at pressures and temperatures ranging from 10 to 40°C and 600 to 800 MPa (Roldán-Marín et al., 2009). HPP treatment with 400 MPa/50°C also could improve the antioxidant capacity of onions, Enzyme inactivation by HPP depends largely on the nature of the enzyme (type and source) and processing conditions (pH, food composition, pressure level and temperature). It has been shown that HPP has no negative effect on carotenoid content and their antioxidant activity, such as α-carotene and β-carotene (McInerney et al., 2007).

However, the technology is mostly applied to fruit juices and other applications at present, and less research has been done in fruits and vegetables. The parameters for a particular fruit or vegetable need to be studied in depth. And some scholars believe that HPP cannot inactivate spores. Using a combination of HPP and heat like High Pressure Sterilization (HPS) or Pressure assisted temperature sterilization (PATS) can be a solution (Sharma, 2011). HPP also negatively affects sensory qualities such as color and texture, but is better than heat treatment. Other key challenges identified include Heat transfer problems and resulting in non-uniformity in processing, obtaining reliable reproducible data for process validation, lack of detailed knowledge about the interaction between high pressure, and a number of food constituents, packaging and statutory issues (Rastogi et al., 2007).

2.2.4. Nanotechnology
Nanotechnology (L. Ma et al., 2017) is considered to be one of the frontier technologies of the 21st century. The application of nanotechnology of fruits and vegetables preservation can overcome the shortcomings of traditional preservation technology. At present, the preservation of nano technology mainly includes nano coating and edible coatings (ECs).
Antibacterial nanomaterials can effectively inhibit microbial reproduction and prolong shelf life. Its basic theory is considered to be metal ion dissolution antibacterial mechanism and contact reaction mechanism. Antibacterial metal ions can cross bacterial cell membranes and deform proteins. This can disrupt cellular respiration and metabolism. (Saba & Amini, 2017) reported that nano-ZnO/carboxymethylcellulose-based active envelopes inhibited yeast and mold growth. Nanomaterials can also be combined with other technologies. Xu et al. combined nanotechnology with radiofrequency heating (RFH) and concluded that the combined treatment can effectively reduce the number of bacterial colonies and inhibit microbial growth. J. Xu et al. (2017) reported that a novel photosensitized nanoparticles can effectively inhibit botrytis cinerea.

ECs acts as food packaging. ECs consists of edible and renewable ingredients, thus it can reduce environmental pollution. The preservation effect of ECs can be enhanced by the addition of different bioactive compounds, such as aromatic compounds, essential oils and antioxidants. ECs could slow the browning of fruits and vegetables and reduce microbial growth (Al-Tayyar et al., 2020; Bourtoom, 2008; Janjarasskul & Kroocha, 2010). However, nano preservation technologies for the application of fruits and vegetables are still in the laboratory research stage and are not yet available for large-scale industrial applications. There are many technical problems (W. Liu et al., 2020). For example, nanomaterials may migrate into fruits and vegetables through absorption, dissolution and diffusion during contact with them. But the safety properties of nanomaterials are not yet fully understood. The process of mass production of nano-encapsulated materials also is complex with high technology level investment, and cost-benefit analysis is a concern for future work. Thus, the processing process also needs to be optimized.

3. Storage methods
Storage is a common way to delay the aging of fruits and vegetables. The advantages and disadvantages of different storage are summarized in Table 2.

3.1. Applied storage methods
3.1.1. Low temperature storage
Low temperature storage is widely used in the preservation of fruits and vegetables. Low-temperature storage technology is mainly through the low temperature to reduce the respiratory strength of fruits and vegetables and delay metabolic activities so as to achieve the effect of preservation. At the same time, low temperature storage can also keep the activity of related enzymes to delay senescence and browning (Yu-Fang & Qu-Rong, 2016).

The appropriate temperature for lily bulbs cold storage is generally ~2 °C, and the minimum is not less than ~4°C with a balanced temperature and a better gas flow (X. Wang et al., 2010).

It was found that low temperature can delay the consumption of microbial C and polyphenols in lily. Ma et al. (2018) found that during the low temperature storage at ~2°C, the contents of starch decreased significantly while the contents of soluble sugar and reducing sugar increased gradually. Correlation analysis showed that the activity of total amylase and β-Amylase was negatively correlated with soluble sugar and reducing sugar content, whereas positively correlated with starch content. The β-Amylase is closely related to the degradation of starch into soluble sugar and reducing sugar. Yu et al. (2022) found that the expression of genes related to starch degradation and sucrose synthesis increased while the expression of genes related to sucrose degradation decreased in lily bulbs during cold storage. In addition, starch degradation and sucrose accumulation could improve the edible quality of functional lily bulbs.

C. Zhang (2018) demonstrated that low temperature could inhibit the activity of enzymes (PPO, POD, PAL). At the same time, low temperature maintained low content of MDA and inhibited lipid membrane peroxidation. Tian et al. found that low temperature increased the activity of antioxidant enzymes.

Nevertheless, because of long-term maintenance of low temperature environment, cold storage is expensive and the phenomenon of chilling injuries may also occur (Guan et al., 2016; Ying et al., 2013), since different fruits and vegetables have different low temperature endurance limits.

3.1.2. Phase temperature storage
The temperature fluctuates widely during low-temperature preservation, which will stimulate the organism to accelerate its metabolism. The difference between phase temperature and refrigeration is that the temperature fluctuation value of phase temperature is less, which can control the physiological metabolism of lily bulbs to a lower level.

| Stored method                  | Advantages                                      | Disadvantages                                      |
|--------------------------------|------------------------------------------------|---------------------------------------------------|
| Low temperature storage        | - Affect gene expression to change enzyme       | - Different fruits and vegetables have different   |
|                                |   activity                                      | low temperature tolerance limits                   |
|                                | - Lower respiratory intensity                   | - Potential risk of freezing injury and even       |
|                                | - Inhibiting enzyme activity (PPO, POD, PAL)    | freezing injury                                     |
| Phase temperature storage      | - Low temperature fluctuation                   | - High investment                                  |
| Modified atmosphere storage    | - Lower respiratory rate                        | - High cost                                        |
|                                | - Lower the Browning index                      | - Need specialized technicians                     |
|                                | - Effectively inhibit microbial growth          | - High CO₂ concentration is not conducive to long- |
| Hypobaric storage              | - Inhibit the growth of microorganisms          | - term preservation                                |
|                                | - Inhibiting enzyme activity (PPO, POD, PAL)    | - Different gas formulations for each product type |
| Ice temperature storage        | - Inhibit the growth of gray mold              | - and target microorganism                         |
|                                | - Maintenance nutrient content                  | - Maintain low pressure environment for a long     |
|                                | - Reduce the risk of cold damage               | time                                               |

| Tabla 2. Método de almacenamiento para frutas y verduras. |
Kang et al. (2020) found that a phase temperature storage temperature of \(-0.4 \pm 0.1^\circ C\) was the optimal temperature range for edible lily bulbs. This phase temperature storage condition could maintain the respiratory intensity of edible lily bulbs at a low level and a high reducing sugar content in the early stage of storage, which means that it could slow down the physiological activities. And it also turned out that this phase temperature could produce less ethylene to prolong the dormancy period of edible lily bulbs. Therefore, phase temperature storage could effectively maintain the storage quality of Lanzhou edible lily bulbs with precise temperature control.

Although the optimal and precise temperature range for phase temperature storage of edible lily bulbs has been less studied, controlling the physiological metabolism to a minimum is a topic of interest. At the same time, the combination between phase temperature storage and vacuum packaging may play a better role in preservation.

3.1.3. Modified atmosphere storage

Modified atmosphere storage is a technology to extend the storage time of fruits and vegetables by changing the storage environment (Niemira & Fan, 2012). There are many factors that affect the effect of gas storage, such as different types of fruits and vegetables, storage temperature, storage time and gas composition. For fresh fruits and vegetables, the required air is usually low levels of \(O_2\) and high levels of \(CO_2\) to slow down the rate of breathing. Inert gases including argon (Ar), helium (He), neon (Ne) and xenon can also be used. These gases can be used to reduce microbial growth. Zhang et al. found that modified atmosphere storage delayed the respiratory rate of lily and made the peak respiratory rate appear for 30 days. In addition, MDA content was maintained at a low-level during storage (Char et al., 2012).

Jiang et al. (2022) proved that the combination of plant essential oil and modified atmosphere storage could further improve the preservation effect of lily bulbs. Nano packaging improves antibacterial properties and appearance. Low-oxygen modified atmosphere storage delayed starch hydrolysis and decreased browning index. At the same time, it could also inhibit the activity of respiratory metabolic enzymes.

The equipment for modified atmosphere storage is expensive and requires specialized technicians \(CO_2\) concentration above 10% can effectively inhibit the pathogenic bacteria, but it is not suitable for long-term storage of fruits and vegetables. All these defects limit the commercial application of modified atmosphere storage.

3.2. Other potential storage methods of lily bulbs

3.2.1. Hypobaric storage

Hypobaric storage (Thompson, 2015) refers to the items in the decompression equipment with appropriate low pressure, relative humidity and ventilation rate for a short duration. Depressurization creates a low-oxygen environment and therefore inhibits microbial colonization.

The hypobaric storage can be divided into the short-time hypobaric storage and the long-time hypobaric storage. The short-time hypobaric (\(<48\ h\)) is generally used for postharvest fruits and vegetables pretreatment of fruits and vegetables. Under experimental conditions, the long-time hypobaric storage was 10% 30% longer than gas storage (Zhang, 2018).

Dai et al. (Dai et al., 2021) took the hypobaric storage method to store the shelled yellow sweet bamboo shoots under 55 kPa pressure for 10 days. And the environmental temperature was 6 ± 1°C with 80% to 85% relative humidity. They revealed that it could delay some features such as the browning of the basal section, respiration rate, electrical conductivity, hardness, metaldehyde, cellulose and lignin content. In terms of enzyme activity, this inhibits the activity of PAL, POD, PPO, and cinnamyl alcohol hydrogenase (CAD) enzymes. Hashmi et al. argue that this is a defense mechanism built under low pressure. There are studies that have shown that decompression treatment is beneficial to inhibit the growth of botrytis cinerea of fruits and vegetables.

However, the current decompression storage equipment is very demanding, but also needs to optimize the setting of decompression storage systems, such as vacuum systems, humidification systems, air exchange systems, etc.

3.2.2. Ice temperature storage

Ice temperature (Suzuki & Murata, 1999) is the region of unfrozen temperature from below \(0^\circ C\) to above freezing point, where fruits and vegetables respiration is inhibited. Ice temperature technology is the third generation of new preservation technology after refrigeration and air conditioning. Super ice temperature technology is a new ice temperature technology that has emerged in recent years. It means that the temperature can be successfully maintained in a supercooled state even below the freezing point by regulating the cooling rate (J. Wang et al., 2003). As a result, organisms do not freeze even if the temperature is normally below the freezing point in the field of super ice temperature. However, the super freezing field is extremely unstable, so maintaining stability is the core of this technology (James et al., 2009).

Yang et al. (2021) found that low temperature storage can better preserve the content of ascorbic acid, pectin and cellulose in apricots. It can inhibit the activities of PG and cellulase, whereas increase the activities of peroxidase, cata-

lase, superoxide dismutase and ascorbate peroxidase.

At present, it is necessary to strengthen the research on the internal heat and mass transfer in order to further clarify the mechanism of ice temperature storage. And it is also required to understand microstructural changes of fruits and vegetables. In addition, in order to promote the application and development of ice temperature technology, ice temperature storage should also promote the combination of ice temperature storage with other preservation technologies, such as gas conditioning ice temperature storage.

4. Conclusion

In this paper, the research status of preservation technology and other advanced technologies of lily were reviewed, and their advantages and disadvantages were summarized. It is found that the preservative treatment can effectively disinfect and even delay the aging of fruits and vegetables by affecting the activity of enzymes. And it can combine with other pretreatment technology, such as making up for the fact that vacuum treatment can’t be sterilized. It is also necessary to consider the safe dosage of different preservatives for lily bulbs. Nanotechnology has the advantages of
non-toxicity and high efficiency. Further research is needed to explore the effects of preservation and control costs. The application of pretreatment technologies (ultrasonic treatment and electric field treatment) will be limited due to easy browning of lily bulbs, which is prone to mechanical damage. In terms of storage, phase temperature storage can control the temperature more accurately with low cost. It is considered that irradiation and proper preservative can be used for pretreatment. Vacuum packaging can be used for short-term storage and transportation. Phase temperature storage could be as a long-term storage mode of lily bulbs.

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