



POPULAR ARTICLE

Cold storage technology: extending the shelf life and market value of fruits, vegetables and flowers

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Intricacies of the subject

Fruits, vegetables and flowers are highly perishable agricultural commodities that continue to undergo physiological and biochemical changes after harvest. Respiration, transpiration, moisture loss, enzymatic activity and microbial deterioration gradually reduce freshness, quality and market value. Under normal ambient storage, these processes are strongly influenced by surrounding temperature and humidity, which can result in rapid deterioration, particularly during warm weather. Cold storage provides a controlled environment in which temperature and relative humidity can be maintained according to the requirements of individual commodities. By reducing the rate of respiration and moisture loss, appropriate refrigeration can delay physiological deterioration and extend the marketable life of fresh produce. However, the optimum storage temperature is different for each commodity, and excessively low temperatures may cause chilling injury in sensitive crops. This article explains the importance of cold storage compared with normal storage and discusses its application to selected fruits, vegetables and cut flowers. Examples include apple, mango and grape among fruits; carrot, capsicum and cucumber among vegetables;

and rose, carnation and chrysanthemum among flowers. The article also discusses pre-cooling, packaging, temperature and humidity management, quality preservation, economic benefits, challenges and sustainable cold-storage practices. The available evidence shows that cold storage can significantly improve post-harvest management, reduce deterioration and provide greater flexibility in marketing when the correct commodity-specific conditions are maintained.

Introduction

Fruits, vegetables and flowers are living biological materials even after they are harvested. They continue to respire, lose water and undergo physiological and biochemical changes. These processes gradually affect freshness, firmness, colour, flavour, nutritional quality and appearance. When harvested produce is kept under normal ambient conditions, especially in warm climates, deterioration can occur rapidly because temperature and humidity cannot be effectively controlled. Temperature is one of the most important factors influencing post-harvest deterioration. FAO explains that reducing temperature generally slows respiration, water loss and other metabolic processes, thereby helping to maintain quality



and extend storage life. However, the temperature must be suitable for the particular commodity because some fruits and vegetables are sensitive to chilling injury when exposed to temperatures that are too low (FAO). The purpose of cold storage is therefore not simply to keep agricultural produce cold. Its main purpose is to slow the natural deterioration process while maintaining acceptable quality for a longer period. The effectiveness of the system depends on correct temperature, relative humidity, air circulation, sanitation, packaging and the initial quality of the produce.

Scientific basis of cold storage

After harvest, fruits and vegetables continue to respire. During respiration, stored food reserves are metabolized and energy is released. A higher respiration rate generally means faster physiological ageing and a shorter storage life. Lowering the temperature within the safe range of the commodity reduces the rate of respiration and delays these changes. Cold storage also reduces transpiration and therefore helps control moisture loss. Excessive moisture loss can result in weight reduction, wilting, shrivelling and loss of firmness. Maintaining appropriate relative humidity together with suitable temperature is therefore essential for

preserving freshness. Temperature management can also slow the development of some microorganisms and delay certain biochemical changes. However, refrigeration does not completely prevent microbial spoilage. Produce entering storage must therefore be harvested carefully, sorted, cleaned where appropriate and protected from mechanical injury. This explains the fundamental advantage of cold storage over uncontrolled ambient storage: cold storage controls the environment, whereas normal storage largely depends on the surrounding environment.

Cold storage versus normal storage

The difference between cold storage and normal storage is primarily the level of environmental control. Under ambient storage, temperature may increase significantly during the day and decrease at night, while relative humidity can also fluctuate. These fluctuations can accelerate water loss, respiration and deterioration. In a properly operated cold room, temperature can be maintained close to the recommended range for the stored commodity. Relative humidity and air movement can also be managed to reduce excessive moisture loss without creating conditions that encourage condensation and decay.

Table 1. General comparison of cold storage and normal/ambient storage

Parameter	Cold Storage	Normal / Ambient Storage
Temperature	Controlled according to commodity requirement	Depends mainly on surrounding climate
Relative humidity	Can be controlled	Usually fluctuates
Respiration	Slower under suitable temperature	Generally faster under warm conditions
Moisture loss	Can be reduced	Usually higher
Weight loss	Lower when properly managed	Generally higher
Quality retention	Better	Faster deterioration
Shelf life	Generally longer	Generally shorter
Market flexibility	Greater	Limited
Initial investment	Higher	Lower
Energy requirement	Requires refrigeration	Minimal refrigeration energy



Commodity-specific storage conditions

An important principle in cold storage is that every commodity has its own temperature and humidity requirement. Storing all agricultural products at the same low temperature can result in quality loss rather than quality preservation. For example, apple can tolerate temperatures close to 0°C for long-term

storage, whereas mango requires substantially warmer conditions because it is susceptible to chilling injury. Similarly, carrot can be stored close to 0°C under high relative humidity, while capsicum is generally stored at warmer temperatures around 7–10°C. The following examples provide a simple illustration of this difference.

Table 2. Commodity-specific recommended storage conditions

Commodities	Recommended temperature	Relative humidity	Potential storage period
Apple	-1 to 4°C	90–95%	Several months
Mango	10–13°C depending on maturity/variety	85–90%	Several weeks
Grape	-1 to 0°C	90–95%	Several weeks to months
Carrot	0°C	98–100%	Several months
Capsicum	7–10°C	90–95%	About 2–3 weeks
Rose	0–2°C	High RH	Short-term holding and distribution
Carnation	0–2°C	High RH	Post-harvest storage and marketing
Chrysanthemum	0–2°C	High RH	Short-term storage and transportation

Fruit storage: extending the marketable life of highly perishable produce

Harvested produce often contains field heat accumulated during exposure to sunlight and warm environmental conditions. If this heat is not removed rapidly, respiration continues at a relatively high rate before the produce reaches the desired storage temperature. Pre-cooling is therefore an important step in commercial cold-chain management. Methods such as forced-air cooling and hydrocooling are used for suitable commodities. The objective is to remove field heat quickly and prepare the produce for refrigerated storage. FAO identifies pre-cooling as an important post-harvest operation for maintaining quality in fresh horticultural produce. A cold room should therefore not be viewed as a replacement for all other post-harvest practices. Harvesting, handling, pre-cooling,

packaging, transportation and storage should function as one integrated cold chain.

Packaging and humidity management

Packaging has an important role in refrigerated storage because it can reduce mechanical damage and excessive moisture loss. However, packaging should allow adequate ventilation so that cold air can circulate around the produce. Perforated plastic films, liners, cartons and commodity-specific packaging systems can be used depending on the crop. Excessively sealed packaging may create condensation or restrict cooling, while insufficient packaging may allow excessive moisture loss. The correct combination of packaging, relative humidity and air circulation is therefore important for maintaining quality throughout storage and transportation.



Effect of cold storage on quality and shelf life

The principal quality benefits of cold storage are reduced respiration, lower moisture loss and slower physiological deterioration. These effects help maintain firmness, freshness, appearance and marketability for longer periods. However, cold storage does not stop deterioration completely. Storage life depends on the condition of the produce before storage. Produce that has already suffered bruising, disease or excessive maturity may deteriorate rapidly even inside a cold room. Therefore, the maximum benefit is obtained when high-quality produce is harvested at the correct maturity stage, cooled promptly and stored under suitable conditions.

Modern cold-storage technologies

Modern cold-storage systems are increasingly incorporating digital temperature monitoring, humidity sensors, automated refrigeration controls, improved insulation and energy-efficient refrigeration systems. These technologies allow operators to monitor storage conditions continuously and reduce unnecessary energy consumption. For small and marginal farmers who cannot access conventional refrigerated facilities, low-cost alternatives such as evaporative cooling systems can provide useful post-harvest storage solutions. ICAR-CIAE has demonstrated a low-cost hybrid evaporative cooling-based storage system, showing the potential of decentralized technologies for reducing post-harvest losses.

Economic advantage

The economic value of cold storage comes from more than simply storing produce for a longer period. By slowing deterioration, cold storage can reduce the quantity of produce that becomes unsaleable before reaching the market. It can also provide greater flexibility

in transportation, aggregation and marketing. For highly perishable commodities, farmers may face pressure to sell immediately after harvest because the produce cannot be held for long under ambient conditions. If suitable storage is available, the marketing window can become longer. However, cold storage also involves electricity, maintenance, labour, refrigeration equipment and infrastructure costs. Therefore, the economic benefit depends on the value of the produce saved, storage duration, facility utilization, electricity cost and market price. A proper economic assessment should compare the additional cost of cold storage with the value of reduced post-harvest losses and improved market realization rather than assuming a fixed profit percentage.

Post-harvest management practices for maximum storage life

Cold storage works most effectively when it is integrated with good post-harvest handling. Produce should be harvested carefully, protected from physical damage, sorted and graded before storage. Diseased, bruised or severely damaged produce should be separated because deterioration can spread during storage. Field heat should be removed as early as practical, and produce should be packed using materials suitable for the commodity. The cold room should maintain the appropriate temperature and relative humidity, while sufficient air circulation should be maintained around storage containers. Commodities should also be stored according to compatibility. Different crops have different temperature, humidity and ethylene requirements. FAO recommends avoiding combinations that require incompatible storage conditions. Major challenges in cold storage is the relatively high investment required for construction and refrigeration equipment. Electrically for construction and refrigeration equipment. Electricity consumption and maintenance add to the operating cost.



Conclusion

Cold storage is an important post-harvest technology for extending the marketable life of fruits, vegetables and flowers. Its main advantage over normal ambient storage is the ability to control temperature and create a more suitable environment for slowing respiration, moisture loss and physiological deterioration. The benefits can be seen across a wide range of commodities. Apples and grapes can be maintained for extended periods under low-temperature conditions, while mangoes require warmer temperatures to avoid chilling injury. Carrots can remain marketable for several months under suitable refrigerated and high-humidity conditions, whereas capsicum and cucumber require warmer storage temperatures because of their sensitivity to chilling. Cut flowers such as roses, carnations and chrysanthemums can also benefit from refrigerated handling to slow ageing and maintain freshness during transportation and

marketing. From an economic perspective, cold storage requires greater investment and operating expenditure than normal storage, but it can provide important benefits through reduced post-harvest losses, improved quality, extended marketing periods and greater flexibility in distribution. For farmers who do not have access to conventional refrigerated facilities, low-cost evaporative cooling and other decentralized technologies can provide alternative approaches. Overall, the scientific evidence supports cold storage as an important component of modern post-harvest management. Its greatest value is achieved when refrigeration is combined with proper harvesting, pre-cooling, packaging, sanitation, transportation and market management. The objective should therefore be not merely to store agricultural produce at a low temperature, but to maintain the right temperature and humidity for the right commodity for the required period.

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