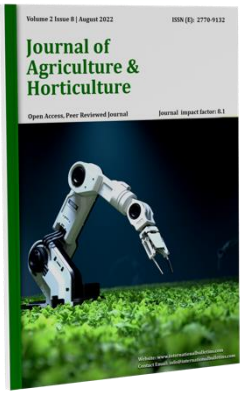

LEMON FRUIT STORAGE TECHNOLOGIES AND THEIR EFFECTIVENESS

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Abstract.
This article analyzes the morphological and physiological characteristics of lemon fruit, the factors affecting its storage process, storage methods, and modern technologies. The results of an experiment on changes in the quality indicators of lemons under various temperature and humidity conditions are also presented.

Keywords: Lemon, storage, temperature, relative humidity, citrus, processing, vitamin, preservation

Introduction. Lemon (Citrus limon) is one of the most important commercial fruits among citrus fruits. It is distinguished by its high nutritional value, especially its richness in vitamin C (ascorbic acid), organic acids, essential oils and flavonoids. Lemon fruits are not only consumed fresh, but are also widely used in the production of canned goods, juices, marmalades, medicines and cosmetics.

The volume of lemon cultivation in the world is increasing every year, and its export potential is also high, making it one of the most economically profitable crops. In Uzbekistan, lemon growing has also developed in recent years due to structural reforms, large lemon farms are being established, and new local and foreign varieties are being introduced.

At the same time, the issues of long-term storage, transportation and delivery of lemon fruits to the consumer while maintaining their quality are quite relevant. Lemon fruits, as a product that undergoes rapid physiological changes and is sensitive to humidity and temperature, require storage in special conditions. If fruits are not provided with sufficient technical and technological measures during storage, significant losses are observed in their appearance, taste characteristics, and chemical composition.

Therefore, an in-depth study of the biological properties of lemon fruits, analysis of the main factors in the storage process, and development of effective storage technologies are important scientific and practical tasks in this area.

A number of agrobiological and technological problems are observed during the storage of lemon fruits, which negatively affect their appearance, taste, chemical composition, and marketability. To eliminate these problems, it is first necessary to study their causes and mechanisms in depth.

1. Water loss (transpiration):

During storage, the evaporation of moisture through the skin of lemon fruits is a physiological natural process. However, low humidity and high temperature in the storage environment accelerate this process. As a result, the fruit mass decreases by 5–15%, the skin hardens and acquires a sparsely cracked structure. This reduces its attractiveness to consumers and leads to illegal product losses.

2. Physiological aging and biochemical changes:

During storage, carbon-containing substances decompose in lemon fruits through respiration and ethylene production. This process causes fruit ripening, aging, and at the same time a decrease in the content of vitamin C. In particular, if temperature control is not maintained, the loss of ascorbic acid can reach 20–40%.

3. Microbial contamination:

One of the most common problems observed in lemon fruits during storage is mycosis. In particular, fungi of the Penicillium digitatum (green mold) and Botrytis cinerea (gray mold) types can spread contagiously during storage. These pathogens are mainly spread through mechanically damaged fruits during transportation. A humid environment and insufficient air circulation create favorable conditions for their growth.

4. Gas environment and ethylene effect:

When lemon fruits are stored in close proximity to products that produce ethylene, which is highly sensitive, the physiological aging process is significantly accelerated. Ethylene is a hormone that causes ripening in citrus fruits, causing discoloration of lemon fruits, breakdown of pigments on the skin surface and softening of fruit segments.

5. Mechanical damage during storage:

Since the skin of lemon fruits is thin and sensitive, they are easily damaged during storage and transportation. Such damaged fruits serve as an "entry gate" for microorganisms and increase the risk of infection.

The process of long-term storage of lemon fruits should be organized in accordance with their biochemical, physiological and morphological characteristics. The main goal of storage is to preserve the mass, components and appearance of the product for consumption for as long as possible. This can only be achieved by coordinating various factors. These factors include:

1. Temperature:

Temperature is one of the most important regulatory factors in the storage of lemons. The right temperature conditions slow down the respiration process, reducing biochemical changes and microbiological activity. Scientific studies show that the optimal temperature for lemons is from +8°C to +10°C. At this temperature, respiratory activity decreases by up to 50%, and the overall shelf life of the fruit can be extended by 6–8 weeks.

At the same time, when the temperature is too low (less than 4°C), lemons experience physiological stress, which results in cell damage and darkening of the skin surface and water loss in the inner segments. This condition is called “chilling injury”.

2. Relative humidity:

Lemons are among the products that lose moisture quickly through transpiration. Therefore, the relative humidity in the storage environment should be maintained at 85–90%. In conditions of low humidity, the skin of the fruit dries out, shrinks in size, pigmentation is damaged, and the appearance deteriorates. Also, the loss of water in the juicy part inside the fruit segments negatively affects the taste.

To prevent food products from spoiling, air circulation and humidity control air compression systems are used.

3. Gas composition (modified atmosphere):

Although citrus fruits do not produce ethylene, they are very sensitive to ethylene gas in the external environment. Therefore, it is advisable to use modified atmosphere (MAS) technologies for their storage.

A typical modified atmosphere is composed of:

- CO_2 (carbon dioxide): 3–5%
- O_2 (oxygen): 2–3%
- N_2 (nitrogen): balancing gas

This environment slows down the respiration process and reduces the activity of ethylene-sensitive enzymes in the fruit. This slows down the ripening and biochemical aging processes of the fruit.

4. Ethylene concentration:

Ethylene is a phytohormone that initiates the ripening process in many fruits. Although endogenous ethylene is low in citrus fruits, ethylene from an external source (e.g., fruits such as bananas, apples, tomatoes) breaks down carotenoids in citrus fruits and causes discoloration, softening, and changes in taste.

Therefore, it is recommended to store lemons separately from ethylene-producing products, to ensure regular ventilation and, if necessary, to treat with 1-Methylcyclopropene (1-MCP).

5. Exposure to light and ultraviolet rays:

During storage, lemons should be protected from direct light and ultraviolet rays. These rays cause the breakdown of skin pigments, a decrease in vitamin C content and a deterioration in appearance. Therefore, lemons should be stored in a specially shaded and moisture-balanced environment.

Table 1

Important factors in lemon storage

Factor	Standard value	Impact
Temperature	+8...+10°C	Slows down physiological activity
Relative humidity	85–90%	Reduces evaporation
Ethylene gas	Less than 0.1 ppm	Prevents premature aging
Gas environment	CO_2: 3-5%, O_2: 2-3%	Inhibits the growth of microbes

Various modern technologies have been developed and implemented to improve the shelf life of lemons, maintain their quality for a long time, and reduce losses. These technologies not only preserve the appearance and composition of the fruit, but also ensure its competitiveness in the market. The main technologies considered effective for lemons are listed below:

1. Storage in refrigerated chambers (mechanical cooling):

Mechanical cooling is the most common traditional method of storing lemon fruits. In this method, the temperature is maintained at +8...+10°C and the relative humidity is 85–90%.

Advantages:

• Respiration and biochemical processes are slowed down.
• Vitamin C and organic acids in the fruit are well preserved.
• The activity of microorganisms is reduced.

Limitations:

• Drying and discoloration of the skin may occur during long-term storage.
• A special control system is required due to its sensitivity to temperature changes.

2. Modified atmosphere storage (MAS):

MAS technology reduces the respiratory activity of the fruit by artificially changing the composition of gases in the storage environment - carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2). Favorable atmosphere for citrus fruits:

• CO_2: 3–5%
• O_2: 2–3%
• N_2: balance supplement

Advantages:

• The ripening process is slowed down.

• Water loss and ethylene effect are reduced.
• The incidence of rotting is reduced, and the shelf life can be increased by up to 2 times.
Limitations:
• Equipment and systems require high investment.
• Regular monitoring of the gas composition is necessary.
3. Treatment with 1-Methylcyclopropene (1-MCP):
1-MCP is a substance that binds to ethylene receptors and blocks the sensitivity of the fruit to ethylene. This substance slows down the ripening, softening and aging processes in citrus fruits.
Advantages:
• • Reduces the effect of ethylene by 70–90%.
• • Delays color and flavor changes in fruits.
• • May extend shelf life by 2–3 weeks.
Limitations:
• • Effective only on fruits close to maturity.
• • Requires systematic application and precise dosage.
4. Surface coating with paraffin oil or wax:
• In this method, a thin layer of paraffin oil (wax) is applied to the skin of lemon fruits. This layer reduces water evaporation through the skin and limits the entry of microorganisms.
Advantages:
• • Transpiration is reduced by 30–50%.
• • Appearance and gloss are maintained.
• • A protective barrier is created.
Limitations:
• • If poor-quality material is used, taste and odor may be impaired.
• • It must be sufficiently clean and meet high sanitary requirements for use.
5. Disinfection with ozonated air:
• In storage chambers, low concentrations of ozone (O_3) are released into the air and used to destroy bacteria and fungi.
Advantages:
• • Microorganisms on the surface of the fruit are killed.
• • Freshness and cleanliness are maintained.
Limitations:
• • The amount of ozone must be carefully dosed (otherwise, skin burns will occur).
• • The chamber must be completely hermetic.
Research results.
In studies conducted in the Tashkent region in 2024–2025, the effectiveness of storing lemon fruits in different conditions was studied. During the experiment, lemon fruits were stored for 60 days using four different technologies: in natural conditions, in a refrigerated chamber, in a modified atmosphere (MAS), and in refrigerated conditions treated with 1-MCP.
During the experiment, the following main indicators were analyzed:
• • water loss (%),
• • rotting (%),
• • appearance and taste (organoleptic evaluation, on a 100-point scale),
• • vitamin C retention rate (%).

Table 2

Results of storage of lemon fruits under different conditions (after 60 days)

№	Storage method	Water loss (%)	Decay status (%)	Organoleptic evaluation (out of 100)	Vitamin C retention (%)
1	In natural conditions	14.8	18.3	67.2	56.4
2	In the refrigerated chamber	6.5	3.7	89.4	81.2
3	In a modified atmosphere (MAS)	4.2	2.1	93.8	86.7
4	1-MCP + Cooling	3.1	1.2	96.5	90.5

Water loss is one of the main indicators of the mass preservation of lemon fruits, and almost 15% of water loss was observed in the sample stored in natural conditions. In other methods, this indicator was much lower, and the best result was recorded in fruits treated with 1-MCP (3.1%).

State of decay - the spread of mycosis diseases depends on the temperature, humidity and air circulation in the storage environment. Cooling, especially MAS and 1-MCP technologies, dramatically reduced the incidence of decay. While the degree of decay in natural conditions was 18.3%, in the sample stored with 1-MCP this indicator was 1.2%.

Organoleptic evaluation - the quality of appearance, gloss, smell and taste was evaluated. Lemons stored in cooled and innovative methods received high scores (90+), while the sample stored in natural conditions was rated as low in quality.

Preservation of vitamin C - the most valuable component of lemon fruits - ascorbic acid. If in natural conditions more than half of this vitamin is lost, then in 1-MCP and MAS technology this substance is preserved up to 85-90%.

According to the results of the conducted studies, the following conclusions were drawn. Lemon fruits are among the biologically active, moisture and temperature-sensitive products. Their shelf life is closely related to various external factors - temperature, humidity, atmospheric gas composition and the influence of ethylene. In natural conditions, lemon fruits are subject to high water loss and rotting. This leads to a decrease in fruit quality, economic losses and a decrease in market competitiveness. It has been confirmed that storage in refrigerated chambers, especially with treatment with 1-MCP and in a modified atmosphere, is effective in significantly extending the shelf life of lemon fruits, preserving organoleptic characteristics and maintaining a high level of vitamin C content. Auxiliary methods such as paraffinization and ozonation can play an important role in protecting lemon fruits from microbiological damage, but they must be used with caution and in compliance with sanitary requirements.

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