UDC 635.36:631.563
DOI: 10.15587/1729-4061.2024.298641

# DETERMINING THE EFFECT OF TREATMENT WITH ANTIMICROBIAL SUBSTANCES BEFORE STORAGE ON THE PRESERVATION OF LEMONS

***The problem solved is to determine safer and more effective technologies for post-harvest processing of fruits. To achieve the goal, lemon fruits (of different degrees of wilting) were cut crosswise, each piece was treated with miramistin and decasan in concentrations of 0.1 %, 0.3 %, and 0.5 %. The samples were placed on agar blocks with pure cultures of pathogens and placed in wet Petri dishes, kept at a temperature of 25 °C in a thermostat for 6–10 days; the experiment was repeated three times. The research aimed to establish the concentration of antimicrobial drugs for treating lemons; determine the weight loss of lemon fruits depending on the storage temperature. The object of the study is the process of preserving the quality of lemon fruits during post-harvest treatment with antiseptics during cold storage.***

***It is proposed to treat lemon fruits with miramistin and decasan in concentrations of 0.3 % and 0.5 % in order to inhibit the development of blue and green mold during storage. Damage to turgor fruits is two times less than that of weakly wilted ones. At a storage temperature of 10 °C, fruits are stored for 40–45 days. At the same time, daily losses are 0.49 %. Lowering the storage temperature to 4 °C extends the storage period to 90–100 days, with a daily mass loss of 0.08 %. A curvilinear correlation dependence of the second order of weight loss of lemon fruits on the duration of storage was established ($R^2$=0.9758–0.9903).***

***Treatment with antiseptics makes it possible to implement environmentally friendly solutions that will make it possible to exclude chemically synthesized fungicides and preserve the natural properties of fresh citrus fruits after harvesting, as well as extend their shelf life. In the development of new, low-cost, environmentally friendly, and affordable technologies, this is an important technique***

***Keywords: lemon fruits, pathogens, storage temperature, miramistin, decasan, antimicrobial substances***

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*Received date 25.12.2023*
*Accepted date 15.02.2024*
*Published date 28.02.2024*

***How to Cite:*** *Pusik, L., Pusik, V., Bondarenko, V., Kyriukhina, N., Terokhina, L., Ketskalo, V., Kondratenko, S., Voitsekhivskyi, V. (2024). Determining the effect of treatment with antimicrobial substances before storage on the preservation of lemons. Eastern-European Journal of Enterprise Technologies, 1 (11 (127)), 64–72. doi: https://doi.org/10.15587/1729-4061.2024.298641*

## 1. Introduction

According to its properties, the value of citrus fruits is comprehensive – a dietary and vitamin product with medicinal properties. Vitamin C in citrus fruits does not lose its properties even during heat treatment. Citrus crops are very common in subtropical and tropical zones, but the fruits of the latter have worse properties. The largest areas of citrus are in Brazil and the USA. The largest areas in the USA are occupied by citrus plantations – in California (dry subtropics) and Florida (humid subtropics). The largest exporter of oranges is Spain, the USA, Israel, Morocco, and South Africa. In the Mediterranean, Italy takes first place. Especially the island of Sicily – large plantations of lemons [1, 2]. The main supplier countries of lemons on the European market are Turkey, Spain, Greece, and Italy. Firms engaged in the supply and trade of citrus fruits try to sell them as soon as possible (2–3 weeks) since they deteriorate quickly and do not withstand the storage periods specified in the literature.

Affected by diseases is the main factor in the deterioration of the preservation of lemons. The most common and serious diseases are brown rot (*Phytophthora*), Alternaria rot (*Alternaria tenuis Nees.*), gray rot (*Botrytis cinerea*), anthracnose (*Colletotrichum gloeosporioides Penz.*), green mold (*Penicillium digitatum Sacc.*), blue mold (*P. italicum Weh.*). Infestation with green and blue molds causes the greatest losses during storage and sale of fruits [3].

It is possible to inhibit the reproduction of phytopathogens by treating fruits with antiseptics. During transportation, storage, and sale, the development of microorganisms accelerates the withering of fruits. In the trade network, 20–40 % of the fruits are sold withered to varying degrees. This indicates that it is not known with what reserve of potential fruit is imported. To reduce losses, suppliers treat fruits with fungicides. At the same time, consumer concern about the presence of fungicide residues in fruits is growing: the consumer wants ecologically clean products.

Researchers are trying to find safer and more effective alternative strategies to devise adequate technologies for post-harvest processing of fruits. Scientific research on this topic is important. New, environmentally friendly solutions could make it possible to eliminate chemically synthesized fungicides, which are used to preserve the natural properties of fresh citrus fruits after harvesting and extend their shelf life. The results of such studies are needed in practice because the further development of safe methods and technologies of post-harvest processing to preserve the quality of freshly harvested citrus fruits will allow obtaining a product with high added value and the possibility of entering distant markets [4]. The essence of the problem is to get rid of microbial insemination of fruits after harvesting by treating them with antimicrobial agents. It is important not only to reduce the weight loss of fruits during storage but also to significantly extend the duration of consumption of lemon fruits.

## 2. Literature review and problem statement

Fresh fruits are perishable products. In order to maintain quality and reduce losses and waste during their path from the field to the consumer, it is necessary to create conditions that inhibit the physiological processes occurring in living organisms. There is a need for coordinated actions of manufacturers, warehouse operators, processors, and retailers. According to estimates from the Food and Agricultural Organization of the United Nations (FAO), 32 % (by weight) of all food produced in the world was lost or thrown away [5].

Indicators of fresh fruit (appearance, turgor, taste, and nutritional value) were traditional quality criteria, but product safety (chemical, toxicological, and microbiological) is becoming increasingly important for all participants in the supply chain: from the farm to consumers. Fresh fruit is eaten raw or after minimal processing, and contamination by foodborne pathogens can pose a risk of foodborne disease outbreaks [6]. *Listeria monocytogenes*, *Salmonella enteritidis*, and *Escherichia coli* O157:H7 and O104:H4 are the main pathogens contributing to outbreaks of foodborne illness with fresh produce [7].

Microbial contamination leading to spoilage and post-harvest loss can occur at any stage of the farm-to-consumer supply chain. Therefore, post-harvest processing is important for minimizing microbiological spoilage and reducing the risk of infection with pathogens [8].

Various post-harvest physical, chemical and gas treatments can be applied to preserve the quality of fresh products with high nutritional value and compliance with fresh product safety standards. These post-harvest treatments are usually combined with proper storage temperature control.

The closest approach to the proposed technique is to treat the surface of the fruit with disinfectants used to sterilize the fruit, reducing the initial high level of inoculum present on the fruit. Chlorine solutions are modern products used in packaging plants. Cleaning is usually achieved by spraying solutions of sodium hypochlorite (100–150 parts per million) and washing the brushes followed by rinsing with potable water [9]. However, this method has some downsides due to the constant adjustment of available chlorine and control of the pH of the solution for proper treatment. Moreover, compounds that emit chlorine can form toxic products.

An alternative to chemical treatment of harvested fruits is heat treatment. The processing technology involves hot water immersion (HWD), heating with saturated steam, hot dry air treatment, and hot water rinsing (HWR) with brushing [10].

The favorable effects of these heat treatments are the reduction of hypothermia and the slowing down of ripening processes due to thermal inactivation of degradation enzymes [11], the level of critical insect infestations and the onset of fungal decay [10]. Heat treatments can be short-term (up to 1 hour) or long-term (up to 4 days). Heat treatment was applied to potatoes, tomatoes, carrots, and strawberries; to preserve the color of asparagus, broccoli, green beans, kiwi, celery, and lettuce; to prevent the appearance of an overripe melon aroma; for longevity of grapes, plums, bean sprouts and peaches [12]. However, most studies have been conducted on subjects such as strawberries, lettuce, broccoli, asparagus, etc., which have delicate covering tissues. The issue of heat treatment of citrus fruits remains unresolved. It should be noted that steam heat treatment was developed primarily for insect control, while hot dry air was used for both fungal and insect control. Water is the preferred medium for most applications because it is a more efficient heat transfer medium than air. Hot water treatment (HWT) needs to be optimized in terms of temperature and duration to guarantee gentle and stress-free treatment to fully preserve product quality, in addition to effective sanitation.

Early-harvest satsuma mandarins were hot showered (HWT) at 65 °C for 10 s on an industrial scale in a packing house, and then stored at 5 °C for 3 weeks and at 18 °C for 3 weeks [13]. It has been established that processing contributes to the preservation of pH, titrated acidity, the content of soluble substances, reduction of loss of mass, hardness, and color of the skin. In heat-treated fruits, compared to untreated fruits, the development of various types of rot was lower. Organoleptic evaluation showed that HWT significantly improved the appearance of fruits, making them cleaner and glossier. The results showed that HWT can be applied to satsuma mandarin as an effective pretreatment to maintain postharvest quality during storage and marketing. The research did not take into account the turgor state of fruits, as well as the species composition of pathogens of citrus fruits. In addition, the fruits were stored for 3 weeks at temperatures of 5 °C and 18 °C. It should be noted that at a storage temperature of 18 °C, the intensity of respiration increases sharply and, as a result, the loss of fruit mass, as well as the rapid development of microflora, part of which is not washed away by water.

Studies have been conducted on the effectiveness of hot water immersion (HWD) and leaf extracts of *Cistus creticus L. subsp. creticus* on the preservation of fresh oranges of the Valencia variety. Preservation of weight, appearance and density of fruits, reduction of titrated acidity content, increase of ascorbic acid content, reduction of respiration intensity of orange fruits, prevention of pathogenic rot were established [14]. Controversial questions arise, which has a greater effect on the preservation of oranges immersed in hot water or the strong antibacterial properties of the leaves of *Cistus creticus L. subsp. creticus*, which inhibit the growth of bacteria that cause Lyme disease. Undoubtedly, this treatment has a number of advantages, including relative ease of use, short processing time, reliable monitoring of fruit and water temperature. However, no further study of the temperature regime of preservation of oranges was conducted. Issues related to the arrangement of premises for heat treatment at small enterprises remained unresolved.

Treatment with hot water (from 37 to 55 °C) from 30 s to 3 min. can improve the post-harvest quality of spinach, lettuce [15], apples [16], tangerines, and other fruits [17].

In addition, water treatment washes off spores from the surface of the fruit. Hot water is a better energy carrier than air and provides a comparable reduction in fungal spoilage. Blue mold on grapefruit, caused by *Penicillium sp.*, is controlled by immersing the fruit in hot water for 2 minutes at 50 °C [10]. It should be noted that, in addition to blue mold on the surface of lemon fruits, the most common and serious diseases are brown rot (*Phytophthora*), Alternaria rot (*Alternaria tenuis Nees.*), gray rot (*Botrytis cinerea*), anthracnose (*Colletotrichum gloeosporioides Penz.*), green mold (*Penicillium digitatum Sacc.*), blue mold (*P. italicum Weh.*), which can withstand different water temperatures and treatment times. Such processing of products increases the cost of products.

Cold water cleaning in combination with brushing and short HWR of bell pepper, apple, melon, sweet corn, kumquat, and grapefruit fruits improves their quality [12]. It is believed that covering cracks and wounds with wax accelerates the formation of antifungal substances in them after heating [16]. But a waxy coating may indicate treatment with fungicides, which prevent the appearance of mold, but are dangerous for the human body.

The combination of *Bacillus amyloliquefaciens* HF-01, sodium bicarbonate, and hot water inhibits the development of citrus rot and improves their preservation [17]. It can be noted that *Bacillus amyloliquefaciens* is a type of bacteria of the genus *Bacillus*, which is the most promising probiotic, the action of which is associated with the synthesis of antimicrobial substances. The drawback of the cited research is the unresolved issue of the effect of heat treatment on the species composition of pathogens, as well as on the degree of fruit wilting.

In Germany, HWD is used when storing organic apples. Fruits were immersed in water at 20 and 56 °C for 3 minutes. Processing fruits after several days of storage in the refrigerator or immediately after opening the long-term storage chamber with a controlled atmosphere (CA) provides new opportunities for extending their further shelf life [18]. However, excessive heat during immersion easily causes heat stress and physiological disorders that manifest only after several weeks of cold storage. For further development of HWD technology, a method of early detection of physiological disorders is desirable. Since apples release volatile organic compounds (VOCs) in response to stress and ripening, VOC profiling can be a useful tool to detect immediate heat stress and latent physiological disorders.

In [19], data on the effect of post-harvest treatment of Newhall orange fruits with hot air flow (HAF) on their preservation, fruit loss from rotting, and natural weight loss are given. Fruits were treated with air at a temperature of 37 °C for 36 hours, 48 and 60 hours. A 48-hour treatment based on percent fruit rot and weight loss was determined to be optimal, and further studies were conducted with this treatment. After processing, the fruits were cooled for 12 hours at a temperature of 10...12 °C, individually wrapped in film and stored at a temperature of 6±0.5 °C and a relative humidity of 85–90 % for 120 days. HAF treatment significantly inhibited the content of malondialdehyde, the intensity of respiration of orange fruits after 45 days of storage. The activity of peroxidase enzymes increased after 60 days of storage, while the activity of polyphenol oxidase enzyme increased throughout the storage period. The results showed that the activity of these enzymes is closely related to respiratory activity and can be enhanced by the flow of hot air. HAF treatment maintained a high content of soluble solids, total sugar, and vitamin C in the fruits.

However, the treatment requires heating the air to a temperature of 37 °C for 36 hours, 48 and 60 hours, and maintaining a high relative humidity of 85–95 %. After processing, the fruit must be gradually cooled to storage temperature to prevent condensation. However, the adoption of this technology by fruit growers is difficult due to high costs of electricity, water, and the need for additional labor during the peak harvest period.

Therefore, the above studies were conducted to explore the possibility of using hot water treatment (HWT) as an environmentally safe method to preserve the quality of fruits and vegetables during post-harvest storage and sale. However, the duration of the development of microorganisms on the surface of fruits of different degrees of attachment to post-harvest processing (HWT) was neglected. In addition, long-term heat treatments can intensify the development of pathogens, so it is important to determine a safe period of heat treatment. There is an unresolved issue of the effect of heat treatment on the species composition of pathogens, as well as on the degree of fruit wilting.

In view of this, devising environmentally-friendly and easy-to-implement lemon storage technology with the use of antimicrobial drugs is an essential task. It should be noted that antimicrobial drugs have different degrees of antimicrobial and antifungal action. Determining what concentration of antiseptics effectively inhibits the development of pathogens on lemon fruits remains an unsolved problem. Storage temperature is crucial for successful storage. During transportation and storage in the retail network, lemons are kept at temperatures between 4 °C and 10 °C. Fluctuations within these limits affect fruit weight loss differently. So, under the conditions of today's wide range of fruits, this is an unsolved part of the scientific problem, which is interesting from a scientific and practical point of view.

## 3. The aim and objectives of the study

The purpose of our study is to determine the preservation of lemon fruits depending on the treatment with antimicrobial drugs before storage and the extent of wilting. This will make it possible to extend the duration of their consumption.

To achieve the goal, the following tasks were solved:

– to investigate the development of microorganisms depending on the treatment with antiseptics and the extent of wilting of lemon fruits;

– to determine the concentration of antimicrobial drugs for processing lemons;

– to determine the weight loss of lemon fruits depending on the storage temperature.

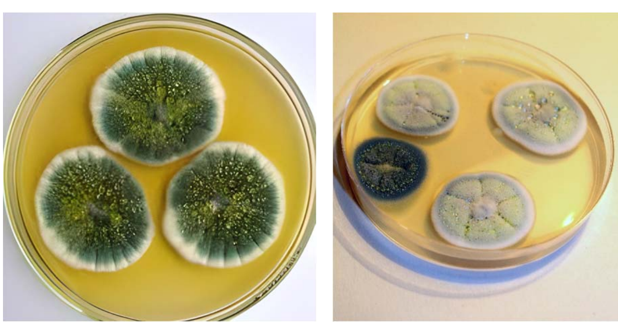
## 4. The study materials and methods

The object of our study is the process of preserving the quality of lemon fruits during post-harvest treatment with antiseptics at cold storage.

The subject of the study is the effect of antiseptics on the stability of lemon fruits.

The research was conducted with lemon fruits that came to Ukraine from Turkey. The working hypothesis of the study is based on the assumption of the possibility of using antiseptics to increase the resistance of lemon fruits to disease deterioration during storage.

The research assumes that the most common causative agents of diseases are *Penicilium italicum* and *Penicilium digitatum* – causative agents of blue and green mold (Fig. 1).



*a* *b*

Fig. 1. Damage to lemon fruits from pathogens: *a* – green mold; *b* – blue mold

Lemon fruits (of different degrees of wilting) were cut crosswise, each particle was treated with miramistin and decasan in concentrations of 0.1 %, 0.3 %, and 0.5 %. The samples were artificially infected by placing them on agar blocks with pure cultures of pathogens in Petri dishes and kept at a temperature of 25 °C in a thermostat for 6–10 days. Observations on studying the effect of drugs on the development of diseases on lemon fruits were carried out every two days. The experiment was repeated three times.

Studies to determine the effect of antiseptics on the shelf life of lemons were conducted on turgor (T) and wilted (W) fruits.

The effect of Miramistin and Decasan was determined on two pathogens – *Penicillium italicum* and *Penicillium digitatum*.

Miramistin is a drug effective against gram-positive bacteria (*Staphylococcus spp., Streptococcus spp., Streptococcus pneumoniae*, etc.) and gram-negative bacteria (*Pseudomonas aeruginosa, Escherichia coli, Klebsiella spp.*, etc.). It has an antifungal effect on ascomycetes of the genera *Aspergillus* and *Pénicillium*, yeast fungi (*Rhodotorula rubra*, *Torulopsis gabrata*, etc.), and yeast-like fungi (*Candida albicans, Candida tropicalis, Candida krusei* [20].

Decasan is a drug that has antimicrobial and antifungal effects, concentrates on the cytoplasmic membrane of a microbial cell, and binds to the phosphatidic groups of membrane lipids, disrupting the permeability of the cytoplasmic membrane of microorganisms. Decasan has a pronounced bactericidal effect on staphylococci, streptococci, diphtheria and pneumococci, capsular bacteria and fungicidal effect on yeast, yeast-like fungi, virucidal effect on viruses [21].

Lemon samples were stored in cardboard boxes with small holes on two sides at temperatures of 4 °C and 10 °C, relative humidity of 85–95 %. Observations on the study of mass loss depending on the storage temperature were carried out every 10 days.

The data reported in our paper are the average value from three measurements. Statistical analysis was performed using Microsoft Excel 2007 (USA). Differences were considered statistically significant at the $\alpha$=0.05 significance level.

## 5. Results of studies on the preservation of fruits depending on the treatment with antiseptics, the extent of wilting, and the storage temperature

**5. 1. Development of microorganisms depending on treatment with antiseptics and degree of wilting of lemon fruits**

It was established that the intensity of development of *Penicillium Italicum*, *Penicillium digitatum* depends on the turgor state of lemon fruits (Fig. 2). Rings of blue mold appear, first of all, in places of damage to the peel. They are separated from healthy tissue by a white powdery strip with a rim of wet tissue on the outside of the damaged peel ring. The peel in the affected areas softens, as a result of which depressed spots are formed, which are later covered with white mycelium with a blue tint. During storage, the disease is easily transmitted to healthy fruits, as well as to flabby, underdeveloped ones. At the initial stage of development of green mold, the lesion resembles blue mold. With further development, the pulp softens a lot and becomes bitter. The disease develops in places of mechanical damage and spreads quickly by contact. In contrast to blue mold, in green mold, a white, sticky, wide band forms around the affected part of the peel (wrapping paper easily sticks to it).

After two days and until the end of the study, a significant difference in the distribution of *P. italicum* on fruits with different turgor status is visible (Fig. 3). On the second and fourth day of research, the disease developed on slightly and severely wilted fruits 1.5–2.8 and 1.2–1.5 times faster, respectively, than on turgor fruits. Only at the end of the experiment, the significant difference in the development of the disease on turgor and wilted fruits became less noticeable due to the loss of immunity first.

*a* *b*

Fig. 2. Damage to lemon fruits: *a* — blue mold; *b* — green mold

On the second and fourth day of research, the fruits treated with miramistin, compared to the control, restrained the development of the disease 2–3 times better, and on the sixth day, when the damage to the control samples reached 95–100 %.

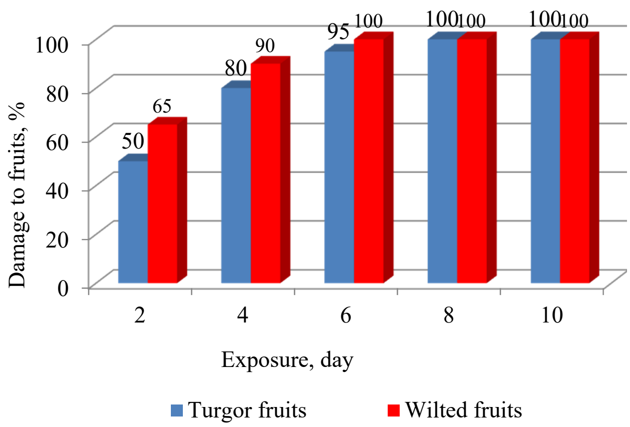



Fig. 3. Damage to lemon fruits by mold fungi depending on the turgor state

The action of decasan on pathogens of blue and green mold is similar. Already on the second day, a significant difference (more than twice) between the control and experimental samples is noticeable.

A somewhat similar situation was observed on samples artificially infected with *P. digitatum*. The development of the disease began especially quickly in severely wilted fruits – after four days they were affected by mold by 90 %, and after six days – by 100 % (Fig. 4).

*a* *b*

Fig. 4. Fruits damaged by blue mold depending on the turgor state: *a* — turgor; *b* — wilted

Thus, the resistance of fruits to damage by green and blue molds depends significantly on their turgor state. The development of diseases on turgor fruits occurred more slowly than on slightly and severely wilted ones.

**5. 2. Results of research into the concentration of antimicrobial drugs for treating lemons**

The effect of miramistin on slowing down the development of green mold was not significant. All samples were almost equally affected by the disease. A significant delay of the disease (up to 50 %) was observed only for two days, although miramistin (0.3 %) prevented the development of the disease even on the fourth day (in turgor fruits (Table 1).

Table 1

Damage to lemon fruits by mold fungi depending on the turgor state and treatment with miramistin, %

| Miramistin concentration, % | Fruit condition | Damage to lemons at exposure, days | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 |
| *Penicillium italicum* | | | | | | |
| Unprocessed (control) | Turgor | 50 | 80 | 95 | 100 | 100 |
| | Wilted | 65 | 90 | 100 | 100 | 100 |
| 0.1 | Turgor | 30 | 40 | 70 | 80 | 95 |
| | Wilted | 35 | 50 | 80 | 100 | 100 |
| 0.3 | Turgor | 25 | 35 | 40 | 70 | 85 |
| | Wilted | 30 | 40 | 60 | 90 | 100 |
| 0.5 | Turgor | 15 | 30 | 40 | 55 | 80 |
| | Wilted | 20 | 35 | 50 | 70 | 95 |
| *Penicillium digitatum* | | | | | | |
| Unprocessed (control) | Turgor | 50 | 60 | 100 | 100 | 100 |
| | Wilted | 65 | 90 | 100 | 100 | 100 |
| 0.1 | Turgor | 50 | 75 | 95 | 100 | 100 |
| | Wilted | 55 | 80 | 100 | 100 | 100 |
| 0.3 | Turgor | 45 | 65 | 90 | 100 | 100 |
| | Wilted | 50 | 55 | 95 | 100 | 100 |
| 0.5 | Turgor | 40 | 60 | 80 | 100 | 100 |
| | Wilted | 45 | 70 | 85 | 100 | 100 |
| $LSD_{05}$ | | 2 | 2 | 2 | 2 | 2 |

Pathogens on the eighth day affected only up to 50 % of the fruits at the drug concentration of 0.3 % and 0.5 % (except for samples withered and treated with decasan 0.3 %). Decasan at a concentration of 0.5 % was especially good at delaying the development of diseases (Table 2).

The influence of miramistin and decasan (in concentrations of 0.3 % and 0.5 %) on the delay in the development of blue and green mold during storage in optimal conditions for the development of the disease is significant. What was established within four and eight days, respectively, was quite significant, the rate of damage was almost halved.

Table 2

Damage to lemon fruits by mold fungi depending on the turgor state and treatment with decasan, %

| Decasan concentration, % | Condition of fruits | Damage to lemons at exposure, days | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 |
| *Penicillium italicum* | | | | | | |
| Unprocessed (control) | Turgor | 50 | 80 | 100 | 100 | 100 |
| | Wilted | 65 | 90 | 100 | 100 | 100 |
| 0.1 | Turgor | 30 | 45 | 85 | 100 | 100 |
| | Wilted | 30 | 50 | 100 | 100 | 100 |
| 0.3 | Turgor | 20 | 30 | 40 | 50 | 100 |
| | Wilted | 30 | 40 | 50 | 65 | 100 |
| 0.5 | Turgor | 15 | 20 | 25 | 35 | 100 |
| | Wilted | 25 | 40 | 45 | 55 | 100 |
| *Penicillium digitatum* | | | | | | |
| Unprocessed (control) | Turgor | 30 | 60 | 90 | 100 | 100 |
| | Wilted | 45 | 80 | 95 | 100 | 100 |
| 0.1 | Turgor | 15 | 30 | 50 | 60 | 80 |
| | Wilted | 20 | 40 | 75 | 90 | 100 |
| 0.3 | Turgor | 10 | 25 | 30 | 45 | 80 |
| | Wilted | 15 | 35 | 40 | 45 | 80 |
| 0.5 | Turgor | 5 | 10 | 15 | 20 | 50 |
| | Wilted | 10 | 20 | 30 | 40 | 65 |
| $LSD_{05}$ | | 2 | 2 | 2 | 2 | 2 |

**5. 3. Weight loss of lemon fruits depending on storage temperature**

Research has established that the weight loss of lemon fruits is correlated with the storage temperature. At a storage temperature of 10 °C, fruits are stored for up to 70 days with a daily loss of 0.49 % (Fig. 5). Lowering the storage temperature to 4 °C extends the storage time to 120–130 days, with a daily mass loss of 0.08 %.

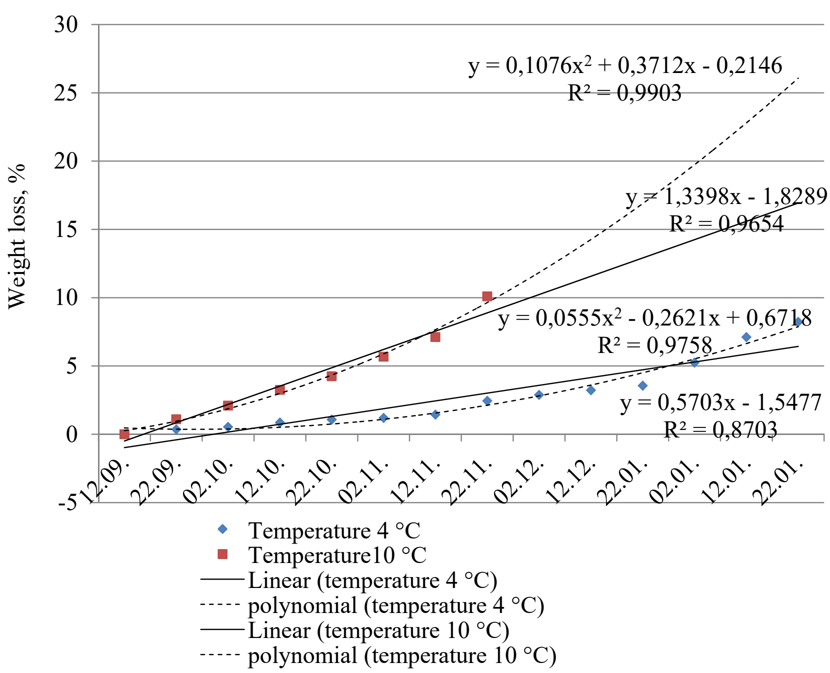



Fig. 5. The dynamics of weight loss of lemon fruits depending on the storage temperature, %

It is possible to predict fruit weight loss during storage using regression analysis. It was established that the loss of mass depending on the duration of storage is described by the regression equation given in Table 3.

Table 3

Mass loss regression equation as a function of storage duration

| Storage temperature | Regression equation of linear dependence | $R^2$ | Regression equation of curvilinear dependence | $R^2$ |
|---|---|---|---|---|
| 4 °C | Y=0.5703x–1.5477 | 0.8703 | Y =0.1076x2+ +0.3712x–0.2146 | 0.9903 |
| 10 °C | Y=1.3398x–1.8289 | 0.9654 | Y =0.555x2– –0.2621x+0.6718 | 0.9758 |

Comparing $R^2$ of the linear and curvilinear dependence of weight loss depending on the duration of storage, it is possible to assert a second-order curvilinear correlation dependence of weight loss of lemon fruits on the duration of storage ($R^2$=0.9758–0.9903). Deviations of individual observations from the trend line are unaccounted for random fluctuations.

**6. Discussion of results of investigating the preservation of fruits depending on the treatment with antiseptics, the extent of wilting, and the storage temperature**

It should be noted that experimental data corroborated that the development of mold fungi depends on the turgor state of the fruits and the storage temperature. Damage to fruits of turgor was 45 % (two times less) than weakly wilted ones on the fourth day. Therefore, if the fruit tissues are turgor, diseases develop more slowly compared to wilted ones. But over time, in turgor fruits affected by pathogens, in connection with the loss of immunity, the development of diseases occurs more intensively (Tables 1, 2).

Fruits treated with miramistin at a concentration of 0.3 % and 0.5 % quite successfully restrained the development of the disease (up to 60 %). The intensity of mold growth increased from 7 % on the second day to 14 % on the tenth day of the study. Data in Table 1 indicate that miramistin better inhibited the development of *P. digitatum*. It was established that the share of the influence of the Miramistin drug concentration on damage to lemon fruits by green and blue molds during storage was 50–86 %. At the same time, the extent of wilting of fruits on their damage by these diseases affected 3–15 %, gradually decreasing until the tenth day. The share of the influence of the concentration of the decasan drug on the degree of damage to lemon fruits was 85–60 %, the degree of fruit susceptibility to disease damage varied from 20 to 7 %, the characteristics of the response of pathogens to the drug were 2–7 %. Decasan was more effective against *Penicillium italicum* (Table 2). Thus, it has been theoretically proven that the intensity of the development of phytopathogenic microorganisms depends on the extent of wilting of lemon fruits and the concentration of the antiseptic.

Low-quality post-harvest processing of fruits leads to loss of quality, the occurrence of physiological disorders, and the development of microorganisms. These losses can be minimized by low-temperature storage.

It was established that the minimum weight loss of lemons occurs during storage at a temperature of 4 °C. Under such conditions, the duration of storage of lemons is 90–100 days (Fig. 4). Similar studies claim that increasing the storage temperature to 8 °C contributes to an increase in fruit weight loss. The optimal storage temperature for tangerines is 5±0.5 °C. Under such conditions, mass loss is minimal, and the duration of storage increases [22, 23].

Other studies have established that tangerines retain good quality under normal conditions for 15–30 days. To extend the storage time, researchers recommend storing tangerines at a temperature of 5...8 °C and high relative humidity (90–95 %) [24, 25].

In a number of EU countries (Switzerland, Austria, the Czech Republic, Finland), microbial preparations have become a complementary component of organic technology [26, 27].

Adaptability of citrus fruits growing in subtropical regions to a gradual temperature regime reduces the time of their adaptation to reduced storage temperatures. This allows citrus fruits from subtropical regions to be stored at relatively lower temperatures than tropical fruits. This contributes to the reduction of losses due to water evaporation, respiration and reduces damage to fruits by microorganisms, i. e., increases the yield of marketable products, increases their shelf life. In contrast to [28], in which the use of Trichodermin was proposed against the causative agents of verticillosis, celery, eggplant; fusarium wilt of watermelons, rhizoctoniosis of potatoes, as well as for the destruction of damage by various types of rot, [29] it is proposed to use yeast. Antagonistic yeasts as safe and effective alternatives for disease treatment. 15 strains demonstrated biocontrol potential against green mold on Olinda oranges. *Pichia galeiformis* was found to have the best antagonistic activity against *P. digitatum* during 6 days of storage at 25 °C and good antagonistic activity during 29 days at 4 °C.

The possibility to store citrus fruits at low temperatures by hardening them during the growing period can be explained by the fact that cell membranes do not harden, and membrane enzymes do not change the speed of their reactions. This is confirmed by the experience of differentiated storage of winter and summer harvest citrus fruits at different temperatures in the USA [30].

It has been established that the loss of fruit mass depends on the duration of storage. It is possible to predict the end of fruit storage duration by regression analysis of research results. A trend line was used to analyze (estimate) regression analysis errors. Under the conditions of classical linear multiple regression, the coefficient ($R$) takes a value from 0 to 1. It is believed that the closer the coefficient is to 1, the better the model is. The coefficient of determination ($R^2$) is used as one of the metrics to judge the fidelity of the model. The accuracy of the regression analysis is determined by the value of $R^2$. According to the results of the study, $R^2$=0.8703–0.9654 was determined based on the linear dependence of fruit weight loss depending on the duration of storage. More reliable is the curvilinear correlation dependence of the second order of weight loss of lemon fruits $R^2$=0.9758–0.9903.

A limitation of the study was that only *Penicillium italicum* and *Penicillium digitatum* were investigated, as the most common. However, lemon fruits are affected by brown rot (*Phytophthora*), Alternaria rot *(Alternaria tenuis Nees.*), gray rot (*Botrytis cinerea*). Further studies may take into account the above pathogens. Fruit weight loss depends on the packaging method. Therefore, further research may be aimed at studying the preservation of fruits under different types of packaging.

## 7. Conclusions

1. The effect of miramistin and decasan in concentrations of 0.3 % and 0.5 % on delaying the development of blue and green mold during storage under optimal conditions for the development of the disease for four and eight days is reduced by half. It was established that the share of influence of the concentration of Miramistin on the damage of lemon fruits by green and blue mold during storage was 50–86 %, of the drug Decasan – 85–60 %.

2. The development of mold fungi depends on the turgor state of the fruits and the storage temperature. The damage to turgor fruits was 45 % (two times less) than that of weakly wilted ones. At the same time, the extent of wilting of fruits affected their damage by these diseases by 3–15 %, gradually decreasing until the tenth day.

It was established that the degree of wilting of fruits to damage by diseases varied from 20 to 7 %, the peculiarities of the reaction of pathogens to the drug were 2–7 %. Decasan was more effective against *Penicillium italicum*.

3. Fruit weight loss correlates with storage temperature. At a storage temperature of 10 °C, fruits are stored for 40–45 days. At the same time, the mass loss is 22.0±0.21 %, the daily loss is 0.49 %. Lowering the storage temperature to 4 °C extends the storage period to 90–100 days, with a daily mass loss of 0.08 %. A curvilinear correlation dependence of the second order for the weight loss of lemon fruits on the duration of storage was established ($R^2$=0.9758–0.9903).

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

## Funding

The study was conducted without financial support.

## Data availability

All data are available in the main text of the manuscript.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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