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EFFECT OF PLASMA CHEMICAL OXIDATION OF ETHYLENE IMPURITIES ON THE EFFICIENCY OF KIWIFRUIT STORAGE

M.O. Yegorov, G.V. Taran, O.O. Zamuriev, P.O. Opalev
National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine
E-mail: zamuriev84@gmail.com

The effectiveness of plasma chemical technology in reducing the concentration of ethylene impurities in order to extend the shelf life of kiwifruit has been studied. Ethylene and mold were controlled by plasma treatment, which slowed the ripening of kiwifruit and significantly inhibited rotting. When storing kiwifruit using the plasma chemical system, the level of ethylene was twice lower than that measured in the control batch. Also, the level of ethylene practically did not change during the entire period of the experiment, since the ethylene released from the fruit was quickly oxidized by ozone. Air treatment of kiwifruit storage environment resulted in the fact that ripening mechanism was delayed and the loss of fruits during their further transportation and storage was almost completely prevented. Thus, high efficiency of plasma-chemical method for extending kiwifruit shelf life was shown as well as the prospects of its application. Storage period can be doubled while preserving the subtle aroma of fruits. The effectiveness of plasma chemical technology in reducing the concentration of ethylene impurities in order to extend the shelf life of kiwifruit has been studied. High efficiency of plasma-chemical method for extending kiwifruit shelf life was shown as well as the prospects of its application. Storage period can be doubled while preserving the subtle aroma of fruits.

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INTRODUCTION

Fruit growing becomes increasingly important in today's world. Fresh fruits are the main source of vitamins and minerals that are most essential for normal body functioning [1]. The range of fruits is expanded due to their import from tropical countries [2]. Kiwifruit is one of the last cultivated tropical fruits. Kiwifruit was not a well-known fruit until the end of the 20th century. Nowadays, it is a species that is recognized all over the world, and its production and consumption are increased year by year [3]. Kiwifruits are of high nutritional value as they contain a large amount of vitamin C, B1, B2, E, PP, as well as fiber, folic acid, potassium, magnesium, iron, phosphorus and calcium, flavonoids, minerals, carotenoids, phenolic compounds, enzymes, many of which are antioxidants [4, 5]. Due to this fact and high adaptability of kiwifruit, there is an increased demand for this fruit [6, 7]. The main exporters of kiwifruit are only three countries, which means that the fruit is grown far away from the consumer and its transportation takes a long time [8, 9]. The production and consumption of kiwifruit keeps growing and currently amounts to more than 4 thousand tons every year in the world [10].

However, the post-harvest loss of biomass is common not only for other fruits and vegetables, but also for kiwifruit, and amounts from 15 to 35% of all grown products [11]. One of the main reasons for such loss is product diseases which occur in the post-harvest period and are caused by microorganisms on the surface of vegetables in the amount of $10^5…10^7$ of their species (Escherichia coli, saprophytes, proteus, cocci, sarcins, actinomycetes, molds, yeasts, etc.). This results in rapid spoilage of fruits and toxin formation in them [12 - 14]. At low temperatures, the loss of fruits because of bacterial and, especially, fungal diseases causing various rots also remains significant [15 - 17].

The number of microorganisms in individual fruits depends on many factors, among which the main ones are temperature, gas composition of the environment, relative humidity, biological characteristics of fruits, presence and type of microorganisms on the surface of the fruit [18, 19]. Ethylene, which affects the ripening process, plays an important role in the metabolism of kiwifruit during storage [20, 21]. Kiwi is very sensitive to ethylene [22]. Its accumulation results in the formation of toxic metabolic products in large quantities, poisoning and subsequent rotting of the fruits [23]. Almost all the respiration energy (more than 90...96%) is released in the form of heat, which should be saved to extend the shelf life [24]. Therefore, it is extremely relevant to study the methods for controlling the reduction of biomass loss from phytopathogens, decrease in respiration intensity, as well as slowing down the ripening due to ethylene oxidation during the storage of fruits and vegetables.

The existing technologies are either unstable or require a significant amount of additional equipment and significant financial and energy investments, which negate the positive effect of their use [25, 26].

In accordance with previous experimental results, the systems based on barrierless plasma-chemical reactors (PCR) allow reducing equilibrium ethylene concentration in air by more than 10 times [26, 27]. At the same time, the fruits are not contaminated with harmful impurities and retain their nutritional and organoleptic properties [28].

The goal of the study is to determine the effectiveness of using plasma chemical technology for reducing ethylene concentration to extend the kiwifruit shelf life. The main tasks of the study are: to expand the available knowledge and show the effectiveness of plasma-chemical technology for reducing ethylene concentration in air to preserve consumer properties of kiwi fruits.

METHODS AND MATERIALS

The Hayward variety of kiwifruit was selected for experimental study. This variety is the most preferred by producers and consumers due to its excellent flavor, high nutrition, yield and long shelf life [29]. The fruits were divided into two batches of 14 kg each, which were placed in separate 65-liter boxes, 30 liters of which are the volume of kiwifruits (Fig. 1).

Fig. 1. Experimental stand for studying the effect of ethylene plasma-chemical oxidation on the efficiency of kiwifruit storage

In Fig. 2,a structural diagram for the experimental stand on the development of a technological process for increasing the shelf life of kiwifruit is shown. In the first experimental box, circulating air was treated in a plasma-chemical system (see Fig. 2,a). In the second experimental box, there was a control batch, where the air also circulated in a closed circuit (see Fig. 2,b).

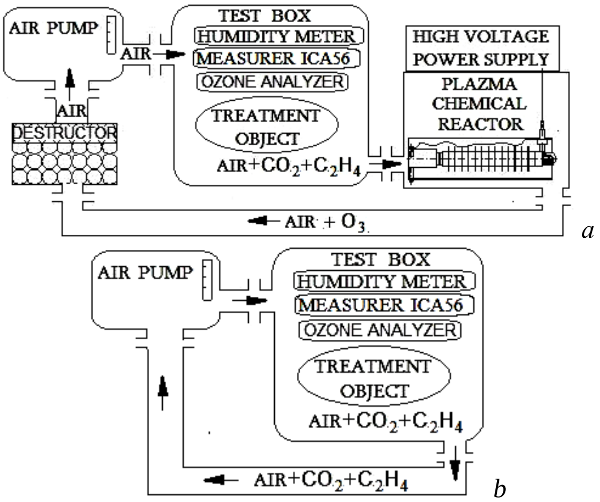

Fig. 2. Structural diagram of the experimental stand for air treatment in the plasma chemical system (a) and control box (b) during kiwifruit storage

The air in the boxes was forcibly circulated with the help of air compressors at a rate of 1 l/min. The air flow was steady and regular. The air speed was 2.4 m/min. Ozone concentration, as well as air temperature and moisture content, were measured by sensors located in the experimental boxes. Ethylene concentration was measured using the ICA56 analyzer and monitored by sampling from the circulation lines of both boxes. In ICA56 ethylene analyzer, electrochemical sensor with ethylene resolution of 0.2 ppm is used. This sensor has a cross-sensitivity to CO (40%), ethanol (72%), CO_2 (0%), H_2C (220%). Therefore, a control method for measuring ethylene is used. Control samples were analyzed using a Thermo Scientific Trace 1310 gas chromatograph with a flame ionization detector. The chromatograph was pre-calibrated using calibration gas mixtures with ethylene content of 10 and 100 ppm. The flame ionization detector can measure the concentration of organic substance at extremely low (10…13 g/s) and high levels, having a linear response range of 107 g/s. Power consumption of the plasma chemical system was 4 W·h. A barrierless plasma-chemical reactor (PCR) designed and manufactured at the Institute of Plasma Electronics and New Methods of Acceleration on the basis of Kharkiv Institute of Physics and Technology was used for gas treatment in the experimental box. Research was conducted at 10…15°C. Ozone concentration was maintained at the level of 5 ppm. The treatment period was 7 weeks.

Every week, fruit condition was visually controlled and 5 fruits of worst condition were picked from each box. Sugar content of these fruits was measured in accordance with the Brix scale using a Walcom REF 103/113 portable reflectometer. Hardness was measured in accordance with the Shore scale using a HT-6510 hardness tester. Total mass was measured with Sencor SKS 5305 (Fig. 3).

Fig. 3. Devices for measuring the parameters of kiwifruits

RESULTS

As a result of experimental studies, no visible growth of pathogens was detected on kiwifruit samples stored in a box with circulating air treated in a plasma chemical reactor (Fig. 4,a). The growth of pathogens was noticeable on the control samples stored in a container with circulating air (see Fig. 4,b). Morphological observation of the pathogenic microflora showed that it may belong to the species Penicilliumexpansum. From this, it can be concluded that the plasma chemical system disinfected the storage atmosphere and, thus, can play an important role in extending the shelf life of kiwifruit. It was previously shown that the products of plasma chemical reactions effectively suppressed the growth of pathogenic microflora [14, 15].

a *b*

Fig. 4. Comparison of kiwifruit from the experimental box (a) and control box (b)

The process of kiwifruit ripening was also monitored in accordance with the Brix and Shore scale. The data below show that kiwifruits remained more unripe in the container with air treated by the plasma chemical system (Table 1) in comparison with the control container (Table 2).

Table 1

The degree of kiwifruit ripeness in the control container, 7 weeks of storage

Treatment	**Storage, weeks**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Brix, %	7	9	10	12	14	14	13
Shore, unit	22	19	15	10	6	4	2

Table 2

Degree of kiwifruit ripeness in the container with air treated by the plasma chemical system, 7 weeks of storage

Treatment	**Storage, weeks**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Brix, %	6	6	7	9	10	11	11
Shore, unit	25	24	24	23	22	22	22

The total weight of fruits was also measured in the treated and control box. The measurement results were used to calculate the fruit loss during storage. The results are presented in the graph (Fig. 5).

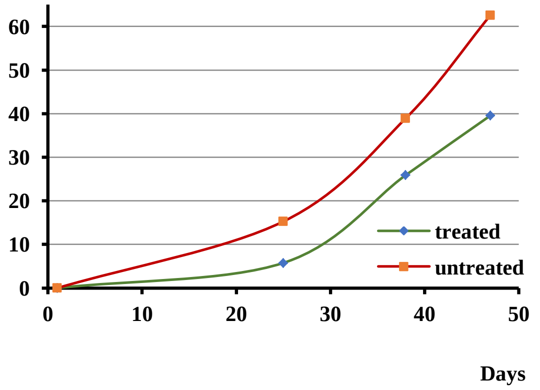

Fig. 5. Dependence of biomass loss in the treated and control experimental boxes on storage period

As can be seen from the graph, fruit loss in the treated box is about 40% after 7 weeks of storage under suboptimal conditions T=10…20°C, RH=85…100%, and more than 63% in the control box.

In the next photo, kiwifruits after 7 weeks of treatment are demonstrated (Fig. 6).

a *b*

Fig. 6. Kiwifruit in the container with air treated by the plasma chemical system for 7 weeks (a) and control container (b)

It is shown that there is a lot of rot on kiwifruits from the control box, while there is no rot in the experimental box.

In the graphs (Fig. 7), the measuring results on the dependence of humidity and temperature parameters (a), ozone concentration (b) and carbon dioxide (c) in experimental containers are presented for the control batch and the batch with air treated by the plasma chemical reactor.

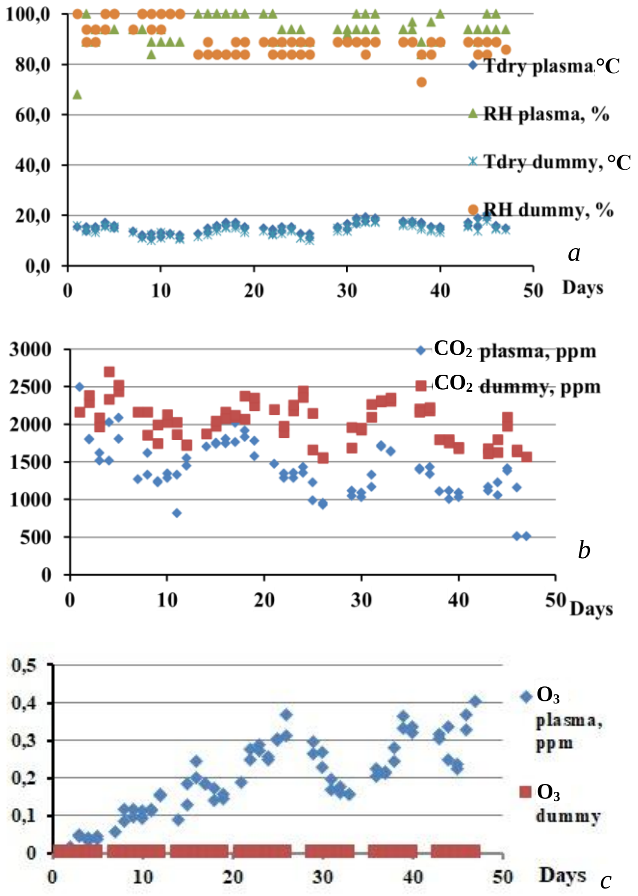

Fig. 7. Dependence of humidity and temperature (a), ozone concentration (b), and carbon dioxide (c) in experimental containers for the control batch and the batch with air treated by the plasma chemical reactor

It can be seen from the graphs that during the entire storage period, humidity, temperature, O_3 and CO_2 concentrations almost did not change in both experimental containers.

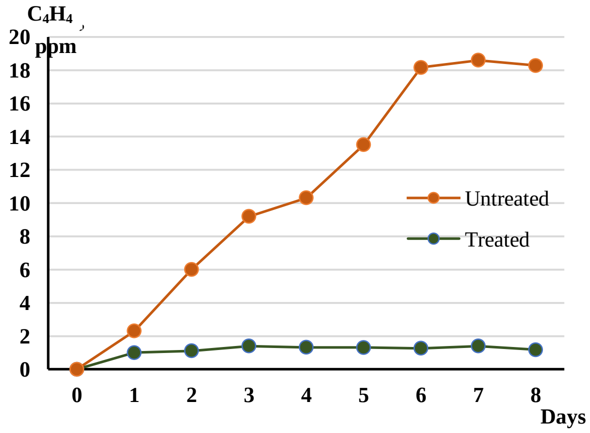

Fig. 8. Dependence of ethylene level in the control and experimental containers on the storage period

Experimental studies on ethylene control (C_2H_4) during kiwifruit storage were conducted. In Fig. 8, the dependence of ethylene level in the control and experimental containers is shown.

It was shown that ethylene level in the control container increased for six days and then it stopped changing. In the experimental container, the level of ethylene was almost twice lower than that measured in the control container and almost did not change during the entire experimental period. Thus, kiwifruit ripened more slowly in the container with treated air in comparison with the control container.

CONCLUSIONS

The effectiveness of plasma chemical technology in reducing ethylene concentration to extend the shelf life of kiwifruit was studied.

Ethylene and mold are controlled by plasma treatment, due to which the ripening of kiwifruit is slowed down and rotting is significantly inhibited. This is confirmed by the data on glucose concentration and fruit firmness measurement. Treated kiwifruit were of almost the same firmness by day 22, whereas untreated kiwifruit became soft (firmness under 2 pounds) starting after the first week.

It was shown that after 7 weeks of storage under suboptimal conditions (T=10…15°C, RH=85…100%), product loss in the experimental container was about 40%, and in the control container, it was more than 63%.

Ethylene level was twice lower than that measured in the control batch and almost did not change during the entire experimental period, since the ethylene released from the fruit was quickly oxidized by ozone.

Air treatment of the environment for kiwifruit storage results in a delayed ripening mechanism and almost completely prevents the loss of fruits and vegetables during their further transportation and storage.

Thus, the plasma-chemical method of extending the shelf life of kiwi has shown high efficiency and has prospects for application. The duration of storage can be doubled on average while preserving the subtle aroma of fruits.

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ДОСЛІДЖЕННЯ ВПЛИВУ ПЛАЗМОХІМІЧНОГО ОКИСЛЕННЯ ДОМІШКИ ЕТИЛЕНУ НА ЕФЕКТИВНІСТЬ ЗБЕРІГАННЯ ПЛОДІВ КІВІ

М.О. Єгоров, Г.В. Таран, О.О. Замурієв, П.О. Опалев

Вивчено ефективність використання плазмохімічної технології для зниження концентрації домішок етилену з метою продовження терміну зберігання ківі. Плазмова обробка контролює етилен і цвіль, що уповільнює дозрівання ківі і значно пригнічує гниття. При зберіганні ківі рівень етилену при використанні плазмохімічної системи на 2 порядки нижчий за той, що вимірювався у контрольній партії і практично не змінювався весь період експерименту, оскільки етилен, що виділяється із фруктів, швидко окислюється озоном. Обробка повітря середовища, в якому зберігається ківі, призводить до затримки механізму їхнього дозрівання й практично повністю запобігає втраті плодоовочевої продукції при її подальшому транспортуванні й зберіганні. Таким чином, плазмохімічний метод подовження терміну зберігання ківі показав високу ефективність і має перспективи до застосування. Тривалість зберігання можна збільшити в середньому вдвічі з одночасним збереженням тонкого аромату фруктів.