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Short Communication

Plasma chemical method of extending the apples shelf life

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The efficiency of using ozone and plasma chemical technology to reduce the concentration of ethylene impurities to extend the shelf life of apples has been studied. The ozone concentration was measured by sensors located in the experimental box. The ethylene concentration was measured with an ICA56 meter (in the experimental box) and monitored by sampling from the circulation lines of both boxes. The ICA56 meter use electrochemical sensor with ethylene resolution 0.2 ppm. This sensor have cross sensitivities for CO (40%), ethanol (72%), CO_2 (0%), H_2S (220%) and its reason use control method of measuring ethylene. Control samples were analyzed with a Thermo Scientific Trace 1310 gas chromatograph with a flame ionization detector. The chromatograph was pre-calibrated with calibration gas mixtures with ethylene content of 10 and 100 ppm. It has been shown that Gala, McIntosh and Jonathan apples are stored several times better when the air in which apples are stored is treated with a plasma-chemical system. After 40 days of storage in the control box, the weight of apples acceptable for consumption (absence of rot and mold) was for varieties Gala – 3.3 kg (31%), Jonathan – 2.1 kg (15.6%), McIntosh – 2 kg (20%). In the experimental boxing varieties Gala – 12.1 kg (66.4%), Jonathan – 10.2 kg (59.3%), McIntosh – 9.3 kg (52.5%). Thus, the combined plasma-ozone method of air treatment of stored apples has shown high efficiency and has prospects for use.

Keywords: plasma treatment, barrierless plasma chemical reactor, ethylene

1 Introduction

Apples, like many other fruits, generate ethylene during storage, which is a growth hormone for many fruits and vegetables, and, accordingly, accelerates the processes of further ripening and then spoilage (Crocker et al., 1935). Existing fruit storage technologies use sorption or catalytic methods to reduce the concentration of ethylene, as well as the technology of storage in modified gaseous media to reduce the intensity of "respiration", and hence the amount of ethylene (Golden, 2014). All these methods have significant disadvantages. Thus, storage in special gaseous media significantly increases the requirements for storage, catalytic and sorption methods are sensitive to impurities of other gases and water vapor in the air and are often insufficiently predicted in conditions of rapid changes in environmental factors. The task of reducing the ethylene concentration is also difficult due to the small concentrations (0.1–32 ppm) (Nakatsuka et al., 1998; Dong et al., 2002; Concello et al., 2005) and the large volumes of air to be treated. As shown in (Golota, Kudin et al., 2018), low-temperature plasma of barrierless gas discharge can be used to reduce the concentration of ethylene impurities in the air circulating in the sea container. Although the use of ozonation as a separate technology for controlling the content of biological contamination and mold suppression is already a well-established technology used in industrial vegetable storage facilities (Golota, Taran et al., 2018), but a significant number of fruits are sensitive to ozone, which is a by-product of plasma chemical reactors, which can have both positive (mold suppression (Taran et al., 2019; Skog et al., 2001)) and negative (spoilage of products and loss of attractive appearance) effect for processed and stored fruits. Commonly, the quality degradation, discolouration, loss of moisture, loss of firmness, microbial load increase, and loss of nutrients and flavor occur in the

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fresh-cut product after minimal processing (Bagheri et al., 2020). With the known advantages of ozone treatment methods, the effectiveness of combined plasma-ozone methods remains unknown (Miller et al., 2013). Recently, the number of works in which the use of low-temperature plasma for treatment of fruits and vegetables is being investigated has been increasing (Ma et al., 2017; Bagheri et al., 2020). Therefore, the aim of the work is to study the effect of plasma chemical treatment of air in the volume where apples are stored on the extension of shelf life of apples.

2 Material and methods

Gala, McIntosh and Jonathan apples were selected for an experimental study of the effectiveness of the use of the plasma chemical method of air treatment to extend the shelf life of apples. To conduct the experiment, apples of all the above varieties were divided into two batches, which were placed in separate boxes. In the first experimental box, the circulating air was treated in a plasma chemical system. In the second there was a control batch, and also air circulated in a closed circle.

The air in the boxes was forcibly circulated by air pumps at a speed of 4 l min^{-1}. Air flow was stable and regular. The air speed was 2.4 m min^{-1}. The volume of the experimental box was 582 liters, of which 120 liters it's apples and containers volume, and the volume of the control box was 190 liters, of which 72 liters it's volume of apples and containers. The total weight of apples in the experimental box was 53.1 kg, of which Gala – 18.2 kg, McIntosh – 17.7 kg and Jonathan – 17.2 kg. The total weight of apples in the control box was 34 kg, of which Gala – 10.6 kg, McIntosh – 10 kg and Jonathan – 13.5 kg. The ozone concentration, as well as air temperature and moisture content were measured by sensors located in the experimental box. The ethylene concentration was measured with an ICA56 meter (in the experimental box) and monitored by sampling from the circulation lines of both boxes. The ICA56 meter use electrochemical sensor with ethylene resolution 0,2 ppm. This sensor have cross sensitivities for CO (40%), ethanol (72%), CO_2 (0%), H_2S (220%) and its reason use control method of measuring ethylene. Control samples were analyzed with a Thermo Scientific Trace 1310 gas chromatograph with a flame ionization detector. The chromatograph was pre-calibrated with calibration gas mixtures with ethylene content of 10 and 100 ppm. The flame ionization detector can measure organic substance concentration at very low (10^{-13} g s^{-1}) and very high levels, having a linear response range of 10^7 g s^{-1}. The energy consumption of plasma chemistry system was 4 W*h. The detailed description of the barrierless plasma chemical reactor used for gas treatment in experimental box is presented in (Golota et al., 2003). The studies were performed at a temperature of 18–20 °C. The ozone concentration was maintained at 5 ppm by regulating the discharge power of the plasma-chemical barrierless reactor.

3 Results and discussion

On Figure 1 is shown a graph of the increase in the concentration of ethylene in the air of the experimental box from time to time in the circulation of air in a closed circuit without starting the plasma chemical system.

According to formula 1, the specific ethylene emission can be estimated, it's mass of ethylene emitted by apples per kilogram:

$$f = \frac{c \times V}{m} \tag{1}$$

where:
c – change in the concentration of ethylene in the air; *V* – free volume in the box (total volume minus the volume occupied by apples and containers); *m* – mass of apples in a box. For the experimental box, without switch on plasma chemical system, the specific ethylene emission of is 0.02349 mg h^{-1} · kg. On Figure 2 is shown a graph of the increase in the concentration of ethylene in the air of the control box over time.

According to formula 1, the specific ethylene emission can be estimated, its mass of ethylene emitted by apples per kilogram. For the experimental box, the specific ethylene emission is 0.0236 mg h^{-1} · kg. Thus, the specific ethylene emissions close for both boxes, when in experimental box plasma chemical system switch of. On Figure 3 is shown graphs of the dependence of the concentration of ethylene and ozone in the experimental box. Measurements were performed for 40 days.

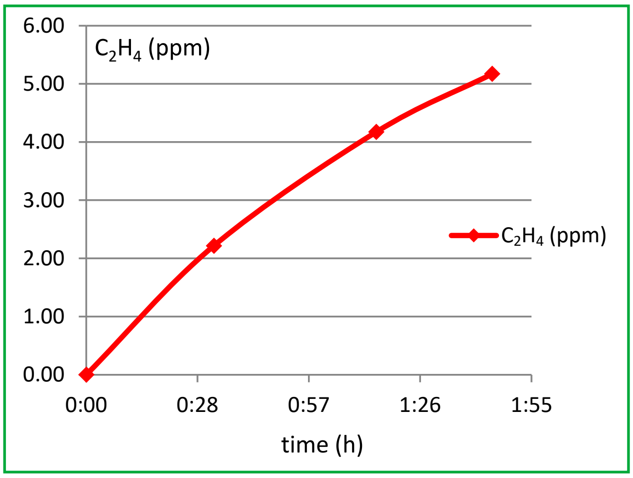

Figure 1 The dependence of ethylene concentration in the air of experimental box

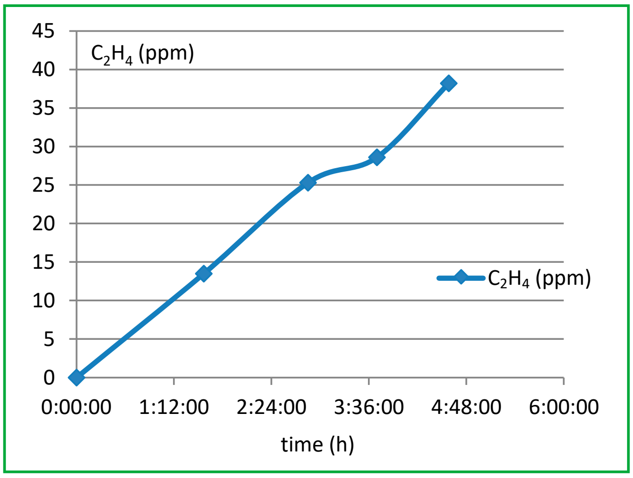

Figure 2 The dependence of ethylene concentration in the air of the control box

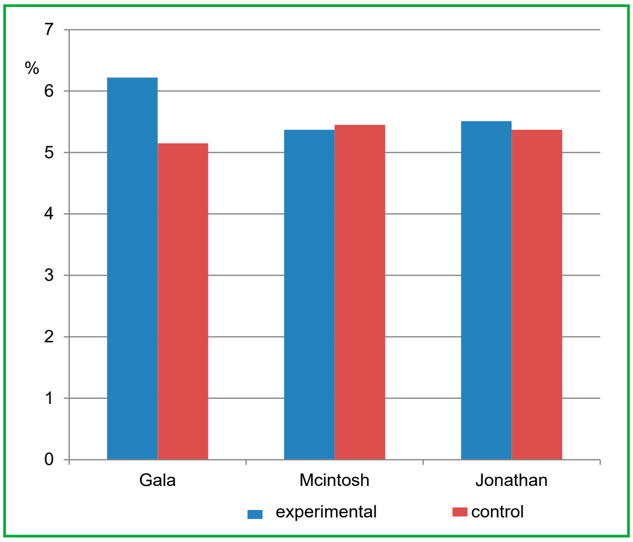

Figure 4 The total weight loss of apples in control and experimental boxes

It is seen that after the inclusion of the plasma chemical system there was a decrease in the concentration of ethylene in the air of the experimental box and an increase in the concentration of ozone.

On the Figure 4 is shown a diagram of total weight loss in the control and experimental batches of apples.

The diagram shows that for both the control and plasma chemical systems, the total weight loss is almost at the same level. After 40 days of storage in the control box, the weight of apples acceptable for consumption (absence of rot and mold) was for varieties Gala – 3.3 kg (31%), Jonathan – 2.1 kg (15.6%), McIntosh – 2 kg (20%). In the experimental boxing varieties Gala – 12.1 kg (66.4%), Jonathan – 10.2 kg (59.3%), McIntosh – 9.3 kg (52.5%).

On Figure 5 is shown a diagram comparing the relative weight of apples that haven't spoiled in the control and experimental boxes.

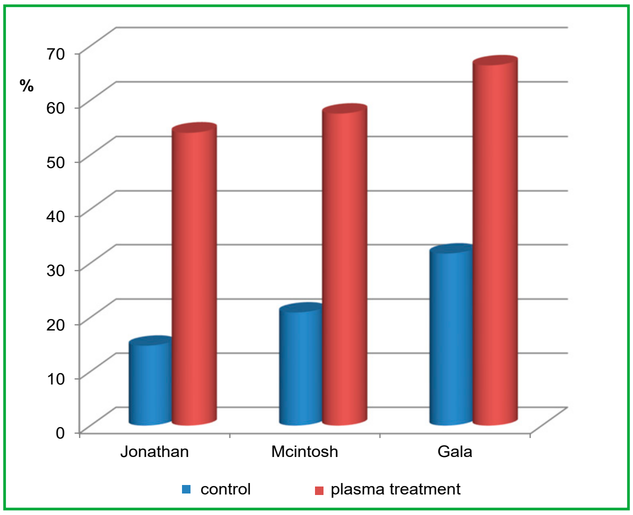

Figure 5 The relative weight of apples that haven't spoiled in control and experimental boxes

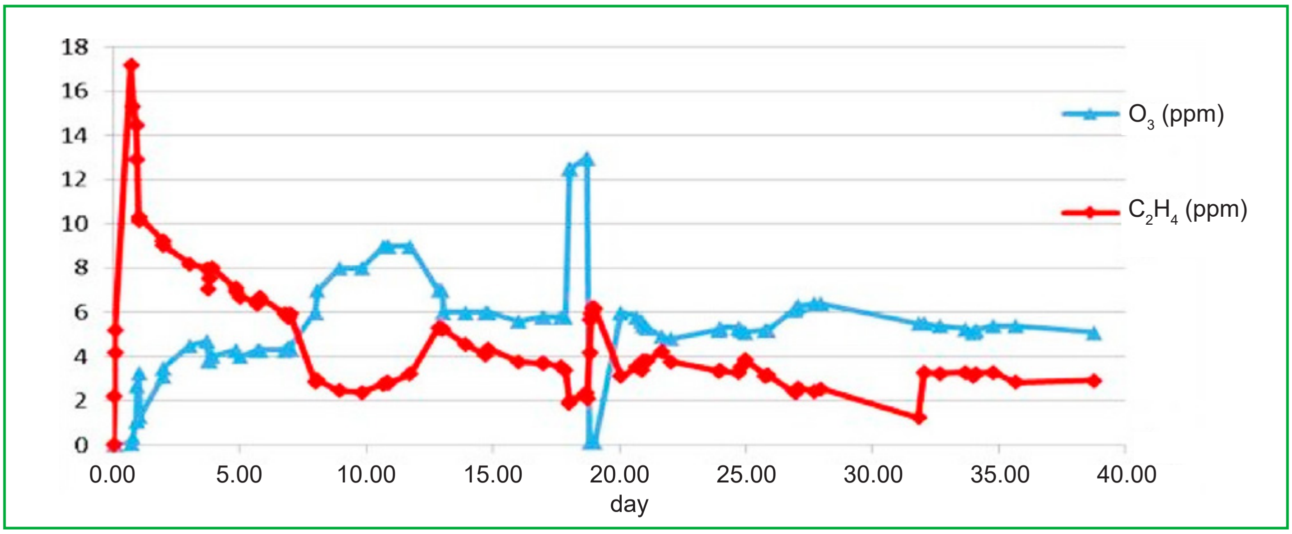

Figure 3 The dependence of ethylene and ozone concentration in the experimental box on time

It can be seen that the use of a plasma chemical system that reduces the concentration of ethylene and at the same time maintains the concentration of ozone at several ppm, can reduce the amount of spoiled products several times.

4 Conclusions

The efficiency of using plasma chemical technology to reduce the concentration of ethylene impurities to extend the shelf life of apples has been studied. It was shown that in the presence of barrierless plasma chemical system treatment, the weight of Gala, McIntosh and Jonathan apples that didn't spoil for 40 days at room temperature was 2–4 times greater than in the control. Thus, the plasma-chemical method of extending the shelf life of apples showed high efficiency and has prospects for use.

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