IOSUD - "DUNĂREA DE JOS" UNIVERSITY OF GALAŢI

Doctoral School of Fundamental Sciences and Engineering

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PhD THESIS

TECHNOLOGICAL SOLUTIONS FOR EXTENDING THE SHELF LIFE OF SOME FRESH FRUITS AND VEGETABLES

SUMMARY

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CONTENT

I. INTRODUCTION

Fruits and vegetables have always been an important part of human nutrition and the science and medicine confirmed along the years a lot of reasons and advantages for the fruits and vegetables to be consumed, mainly due to the very valuable fibers and micronutrients content [1, 2]. Organizations and authorities like World Health Organization (WHO), Food and Agriculture Organization (FAO) and the European Food Safety Authority (EFSA), but not only, have included the fruits and vegetables intake as a recommendation against risks like cardiovascular diseases and even cancer [3-6].

Consequently, the consumers all over the world are increasingly demanding fresh and healthy food products, including less processed fruits and vegetables, which led to developing new methods and techniques for preservation [3,7-9].

Minimal food processing techniques are non-thermal technologies that guarantee food preservation and compliance with the safety standards while maintaining, as much as possible, the freshness characteristics of fruits and vegetables [3,10]. The main goals for these modern techniques are to prolong the shelf life up to 5-7 days in cold storage at 4℃, without compromising food safety and nutritional and sensory parameters [11].

The commerce with this type of food is continuously growing thanks to the freshness, the attractive appearance and also to the handling efficiency [12]. Their highly valuable content of vitamins, minerals and phytochemicals, necessary for the human healthy diet, makes fruits and vegetables a desirable meal, with no further preparation [7].

Perishable products, like fresh fruits and vegetables, need appropriate handling, suitable preparation and proper storage conditions in order to get the best content and the most nutrients out of them. In order to do so, these products are being essentially processed by sorting, cleaning and washing, peeling or cutting or shredding, decontaminating and packaging. If it's needed when there is no antimicrobial guarantee, refrigeration can be added as a primary step for preservation.

Nowadays consumers are familiar with the regular processing techniques and they are getting more and more interested in lowering the impact of them over the products, and still getting the best quality and nutritional factors. This is why the food industry is under pressure to develop alternative techniques, including pulsed light, UV radiation, ozone, plasma, cold temperature, ultrasounds or new packaging solutions, with low impact on the quality of the fruits and vegetables. Despite the great potential of these methods, we are facing a lack of information regarding the effects and the potential limitations when used in the food industry. The effectiveness of the methods depends on the initial food quality, the contamination factors and the type of process, but also on the desired properties to maintain.

Commonly known, the sulphites were used to prevent the browning effect before 1986, when FDA decided to suspend them due to the health risks for the

consumers [13]. Thereupon, new methods and approaches had to be developed in order to avoid the visual deterioration of the freshly cut fruits or vegetables. Reducing solutions like acids (citric, ascorbic, isoascorbic) [14,15] or thiol-containing aminoacids (N-acetylcysteine, glutathione) [16,17,18,19] were some of the experimentations. Also the calcium treatments were used to maintain the crispness and firmness of the bits of freshly cut fruits.

The surface treatments which involves the immersion of the freshly cut pieces in watery solutions containing antioxidants, antimicrobial agents, calcium salts or functional ingredients (vitamins, minerals) are extensively used to enhance the quality of the minimally processed fruits and vegetables. Nevertheless, the performance of these compounds can be augmented by simply including them in edible coatings. The latest research shows that the comestible coverings can provide essential substances in order to prevent food degradation.

In the current research context, these might be the following specific scientific objectives:

- Investigation of the effects of post-harvest treatments with organic acids (citric, sorbic, benzoic, ascorbic) on physicochemical, biochemical and microbiological changes of fresh fruit during storage under refrigerated conditions;
- Study the effects of post-harvest chemical treatments combined with UV-C irradiation on fruit quality characteristics, bioactive compounds content and antioxidant activity during storage under refrigerated conditions;
- Investigation of the effects of immersion in organic acid solutions (citric, benzoic, sorbic, ascorbic) and acid electrolyzed water on the quality characteristics of freshly cut fruit packed under normal atmospheric conditions during storage under refrigerated conditions;
- Development of active edible coatings incorporating antimicrobial substances (potassium sorbate, sodium benzoate) and anti-browning agents (N-acetyl cysteine, ascorbic acid, citric acid) for maintaining the quality of fresh fruit and vegetables and fresh-cut fruit during storage under refrigerated conditions.

The doctoral thesis is structured in two parts, and 13 chapters, as follows:

I. DOCUMENTARY STUDY, includes three chapters and presents synthesized data from the specialized literature on the post-harvest physiology of fruits and vegetables, the factors that influence their life span and the methods of preserving fresh and freshly cut fruits and vegetables.

II. THE EXPERIMENTAL STUDY includes the results of the research studies carried out throughout the duration of the doctoral internship, and is made up of seven chapters briefly presented below:

CHAPTER 4, entitled "APPLICATION OF POST-HARVEST TREATMENTS WITH ORGANIC ACIDS FOR EXTENDING THE LIFETIME OF BLUEBERRIES", presents the potential of post-harvest immersion in organic acid solutions (citric acid 2%, benzoic acid 0.2% and sorbic acid 0, 2%) in order to preserve the quality of blueberries after harvesting.

CHAPTER 5, entitled "THE EFFECT OF TREATMENTS WITH BENZOIC, SORBIC AND CITRIC ACID ON THE PHYSICO-CHEMICAL AND QUALITY CHARACTERISTICS OF PEACHES DURING REFRIGERATED

STORAGE", presents the study of the effects of post-harvest treatments with organic acids (citric, sorbic and benzoic) on physical-chemical, biochemical and microbiological changes of peaches cv. Redhaven during refrigerated storage.

CHAPTER 6, entitled "THE EFFECT OF SOME SANITATION TREATMENTS ON STRAWBERRY FRUIT QUALITY DURING STORAGE", presents the investigation of the effects of washing treatments with organic acids and acid electrolyzed water on weight loss, firmness, titratable acidity, total content of soluble substances, phenolic compounds and anthocyanins and the DPPH antioxidant activity of strawberry variety "Malvina". The effectiveness of these treatments in reducing strawberry fruit decay was also examined.

CHAPTER 7, entitled "THE EFFECT OF WASHING TREATMENTS WITH ORGANIC ACIDS AND ACID ELECTROLYZED WATER COMBINED WITH UV IRRADIATION ON THE QUALITY OF STRAWBERRY FRUITS DURING STORAGE", presents the study of the effects of postharvest chemical treatments followed by UV-C irradiation on the quality characteristics of strawberry fruits and antioxidant activity of strawberries of cultivar "Malvina". The effectiveness of these treatments in reducing strawberry fruit decay was also examined.

CHAPTER 8, entitled "THE INFLUENCE OF WASHING TREATMENTS BY IMMERSION IN ORGANIC ACIDS AND ACID ELECTROLYZED WATER ON THE QUALITY OF FRESH-CUT APPLES", presents the effects of immersion in organic acid solutions and in acid electrolyzed water on the quality characteristics and the surface microbiota of fresh cut apples from the cultivars 'Florina' and 'Ionathan'.

CHAPTER 9, entitled "EDIBLE PECTIN COATING COMBINED WITH ANTIMICROBIAL AND ANTI-BROWNING AGENT TREATMENTS TO MAINTAIN THE QUALITY OF FRESH-CUT PEARS" presents the study of maintaining the quality of fresh-cut pears during storage at 8℃ using an edible pectin coating combined with chemical treatments containing 0.2% potassium sorbate (PS) or 0.2% sodium benzoate (SB) as antimicrobials and 1% N-acetyl cysteine (N-AC) or 1% ascorbic acid (AA) + 1% citric acid (CA) as anti-browning agents.

CHAPTER 10, entitled "EFFECT OF EDIBLE COATINGS BASED ON POLYSACCHARIDES ON THE QUALITY OF WHITE BUTTON MUSHROOMS (AGARICUS BISPORUS) DURING REFRIGERATED STORAGE", presents the effects of edible coatings based on pectin, chitosan, sodium alginate and carboxymethyl cellulose, individually and/or in combination with N-acetyl cysteine as an anti-browning agent, on the quality of white mushrooms during 14 days of refrigerated storage (4 ± 1℃), measured by weight loss, color change, browning index, degree of opening of the cap, soluble solids content, total phenolic content and DPPH antioxidant activity. The effects of coatings on MDA content, as an indicator of lipid peroxidation, were also evaluated.

CHAPTER 11, FINAL CONCLUSIONS, presents the main conclusions resulting from the experiments.

CHAPTER 12, CONTRIBUTIONS AND PERSPECTIVES FOR FURTHER RESEARCH, describes the main contributions with an impact on the

development of knowledge in the subject covered and the proposed perspectives for further studies.

CHAPTER 13, DISSEMINATION OF THE RESEARCH RESULTS CARRIED OUT ON THE THEME OF THE DOCTORAL THESIS, finally presents the original contributions of the doctoral thesis and how the dissemination of the results obtained in the doctoral thesis was carried out. Thus, the research results were capitalized by the elaboration of 5 scientific articles published in ISI rated journals, one scientific article published in ISI emerging journals, 2 articles published in journals indexed in BDI international databases as well as 5 communications at international scientific events representative for the field of food product engineering.

II. DOCUMENTARY STUDY

CHAPTER 1

POST-HARVEST PHYSIOLOGY OF FRUITS AND VEGETABLES

The losses recorded between the harvest and the consumption of fruits and vegetables are considerable, given the fact that the harvesting methods used, the transport, the storage and the methods of distribution of the products are often inadequate. In order to extend the life of fresh fruits and maintain their state of freshness throughout the storage period, their metabolic activity, structural characteristics and external factors involved in their storage are taken into account.

1.1. HYDRIC ASPECTS

Fruits are made up of cells filled with water in their vacuole, this strong turgidity gives them their characteristic fresh appearance and firmness.

Depending on the storage conditions - temperature, atmospheric humidity, air composition, the fruits can become dehydrated. As a result of excessive dehydration, aging of the products occurs, withering characterized by an unpleasant appearance and a significant loss of mass. Dehydration can also result in the acceleration of senescence, stimulating ethylene synthesis.

1.2. METABOLIC ACTIVITIES

The most representative metabolic activities that need to be taken into account after harvesting are: respiration, ethylene biosynthesis, senescence and oxidation processes.

- **Respiration**

Respiration is the main supplier of energy by which the cell ensures its multiple functions. In the situation where the respiratory activity is disturbed, other phenomena come into action, namely fermentations. They are harmful, they are at the origin of the production of toxic compounds.

- **Ethylene biosynthesis**

Ethylene biosynthesis has an essential role in the physiology of plant organs after their harvest. Ethylene has multiple ill effects, even present in small amounts. It is released in small doses by the cells, in the intercellular spaces and diffuses to the outside of the organs.

- **Oxidation of phenolic compounds**

All browning effects in the case of fruits, regardless of their location, occurs as a result of the oxidation of phenolic compounds. They can occur as a result of mechanical trauma (cuts, injuries, shocks), pathological (attack by saprophytic or parasitic microorganisms), or physiological (different cellular disorders). Plant cells have a high content of phenolic compounds that can easily oxidize, in the presence of oxygen, under the action of some enzymes, the most

relevant of which are polyphenoloxidases and peroxidases. The quinones that are formed in turn oxidize and polymerize resulting in brown compounds, which are responsible for the superficial or deep browning that occurs in various circumstances.

Fruits only turn brown when their tissues are injured or under conditions of a profound disturbance in their physiology. Phenolic compounds are dissolved in the vacuole in healthy cells, while oxidizing enzymes may be located within the cytoplasm.

- **Senescence**

Fruit senescence manifests itself in various ways, including: color change, wilting, tissue degeneration, softening, etc. Post-harvest senescence problems can arise from water deficit, alteration of cellular functioning, ethylene intervention and metabolic disturbances.

CHAPTER 2

FACTORS AFFECTING THE SHELF LIFE OF FRESH AND FRESH-CUT FRUITS AND VEGETABLES

At the time of harvesting, there is a change in the gas balance between oxygen consumption and carbon dioxide production. In this new state, cells are not renewed and gas transfer rates increase, causing metabolic loss and leading the fruit to gradual ripening and eventual senescence. The rate of gas transfer depends on internal and external factors. Internal factors include species, cultivar, and growing condition, while external factors include atmospheric composition (the ratios of O2, CO2, and ethylene), temperature, and other stressors. In addition, fruit pulp contamination can occur from the peel, increasing fruit spoilage, leading to biochemical damage such as browning, off-flavor development and texture degradation, reducing fruit quality and risk to the consumer due to the presence of pathogenic microorganisms [20].

2.1. PRE-HARVEST FACTORS

Pre-harvest factors that affect the quality and post-harvest development of fruits and vegetables include the degree of ripeness, the cultivar or variety, the climate and soil in which the produce was grown, the chemicals applied and the water condition. Within each harvest there is a range of genotypic variation in composition, quality and post-harvest life.

2.2. POST-HARVEST FACTORS

Fruits and vegetables undergo many physiological changes during post-harvest storage including: softening of tissues, increase in sugar level and decrease in organic acid level, chlorophyll degradation accompanied by synthesis of anthocyanins or carotenoids during ripening, production and losses of volatile flavor compounds, the decrease in the content of phenolic compounds and amino acids and the hydrolysis of cellular substances due to respiration.

The type and growth rate of micro-organisms present will be greatly influenced by product temperature, relative humidity, atmosphere and intrinsic factors such as pH, water content and nutrients.

CHAPTER 3

METHODS OF PRESERVING FRESH AND FRESH-CUT FRUITS AND VEGETABLES

Food scientists are involved in the development of new technologies that can improve the quality and quantity of fresh produce in order to meet consumer expectations. Various approaches have been investigated, including surface treatments by coating, modified atmosphere packaging (MAP) to maintain adequate gas concentration around the cut surface, controlled atmosphere to delay fruit softening, chemical treatments, cold storage, gamma irradiation to reduce changes such as microbial growth, drying and discoloration [21].

3.1. USE OF RADIATION

According to several studies, radiation is considered a safe method of preserving fresh fruits and vegetables, it succeeds in destroying the microbial load and therefore extending the marketable period. The safety of fresh fruits and vegetables is thus improved, and radiation can easily be used as a substitute for chemicals [22].

Gamma irradiation has been successfully used as an alternative treatment to increase the shelf life of fresh produce.

Ultraviolet (UV) light refers to a type of non-ionizing radiation with a wavelength between 100 nm and 400 nm, which is usually classified into three types: UV-A (315-400 nm), UV-B (280- 315 nm) and UV-C (100-280 nm) [23]. UV-C irradiation at 254 nm shows maximum germicidal action. The generally recognized mechanism of microbial inactivation of UV is mainly attributed to direct DNA damage in living organisms.

UV induces the formation of DNA photoproducts, such as cyclobutane pyrimidine and pyrimidine 6-4 pyrimidine dimers, which inhibit transcription and replication and ultimately lead to mutagenesis and cell death [24].

Cold plasma (CP) is a novel, non-thermal and environmentally friendly food processing technology with potential applications for food preservation or decontamination. Plasma is described as the fourth state of matter after solid, liquid and gas. Plasma refers to a quasi-neutral ionized gas that consists of particles including photons, free electrons, positive or negative ions, excited or unexcited atoms and molecules [25].

3.2. PRESERVATION WITH ANTISEPTICS

Surface treatments by spraying with antimicrobial agents or by immersing fruit in antimicrobial solutions are widely practiced to prevent microbial growth.

Immersion treatments after peeling and/or cutting reduce both the microbial load and the flushing of tissue fluids, thereby reducing the growth of microorganisms. Organic acids are usually applied by dipping. The antimicrobial effect of adding organic acids to food is to increase the concentration of protons, thereby lowering the external pH.

There are several categories of antimicrobials that can potentially be incorporated into edible films and coatings, including organic acids (acetic, benzoic, lactic, propionic, sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), plant essential oils (OE) (cinnamon, oregano, lemon), nitrites and sulfites, among others [26]. Although their actual mechanisms of action are not well understood, the antibacterial efficacy of organic acids is thought to arise from the fact that protonated acids are membrane soluble and can enter the cytoplasm by simple diffusion.

3.3. USE OF EDIBLE COATINGS

The application of edible coatings is a packaging strategy to extend the shelf life of fresh and freshly cut fruits and vegetables. Edible coatings obtained from natural resources are ecological and able to improve product quality [27]. The use of an edible coating with the desired physical, sensory and microbiological properties for minimally processed fruits and vegetables can reduce harmful changes and consequently extend the shelf life.

3.4. PRESERVATION OF FRESH FRUITS AND VEGETABLES IN A CONTROLLED ATMOSPHERE

Modified atmosphere packaging (MAP) is defined as "the packaging of a perishable product in an atmosphere that has been modified so that its composition is different from that of air". In MAP, the physiology of fresh produce depends on the altered level of gas concentration. Usually, reduced O2 concentration and increased CO2 concentration are used to improve the shelf life of fruits and vegetables [28]. Therefore, MAP successfully extends the post-harvest shelf life of whole and pre-cut fruits and vegetables by reducing their respiration rate, minimizing metabolic activity, delaying enzymatic browning and preserving visual appearance [29,30].

3.5. ACTIVE PACKAGING AND SMART PACKAGING FOR FOOD

Microbial contamination of the food surface represents the majority of the problems that cause food spoilage. The application of chemical preservatives in food can be a problem for food safety; therefore, active packaging plays an important role in extending the shelf life of food by eliminating the direct use of additives. Antimicrobial preservatives added to packaging materials can fulfill the objective of avoiding surface contamination [31].

Antimicrobial food packaging using active packaging is a new preservation method by delaying and slowing down the growth of microorganisms, with the aim of preserving food quality and extending the shelf life of packaged foods [32-36]. In addition to normal packaging functions, active packaging performs additional functions such as antimicrobial and antioxidant activities.

3.6. CONCLUSIONS

The development of new technologies to maintain the quality and extend the shelf life of fresh and freshly cut fruits and vegetables is a major challenge for the food industry and a concern for future research. The use of edible wraps helps maintain the quality and extend the shelf life of fresh-cut fruits and vegetables and other minimally processed fruits and vegetables. In addition, coatings can be used to incorporate active/functional ingredients into fresh cut products.

Future research needs to consider varieties of additional combined applications of physical, chemical and bio-preservation technologies that could allow better maintenance of product characteristics. Meanwhile, consumer acceptance, safety and legal aspects, and commercial availability, such as efficacy, cost-effectiveness, and convenience in handling, should be considered in future studies.

II. EXPERIMENTAL RESULTS

CHAPTER 4

POSTHARVEST ANTIMICROBIAL TREATMENTS WITH ORGANIC ACIDS TO IMPROVE THE SHELF LIFE OF FRESH BLUEBERRIES

4.1. STUDY OPPORTUNITY

The aim of this study was to evaluate the potential of post-harvest immersion in organic acid solutions (2% citric acid, 0.2% benzoic acid and 0.2% sorbic acid) to preserve the quality of blueberries after harvest.

The effects of post-harvest treatments with citric (2%), benzoic (0.2%) and sorbic (0.2%) acids on the physico-chemical, biochemical and microbiological evolution of fresh blueberries stored under refrigerated conditions were investigated.

4.2. MATERIALS AND METHODS

Fruits from the first three batches were immersed for 5 minutes in aqueous solution of 2% citric acid (P1), 0.2% benzoic acid (P2) and 0.2% sorbic acid (P3). Control blueberries were immersed for 5 min in distilled water (M), while the last batch was kept untreated (M0). All blueberry samples were stored at a temperature of 8 ± 1 ·C and relative humidity of 70-75%; also each batch was made in triplicate. Blueberry analysis was performed dynamically every 7 days for the entire 6-week period.

The samples were subjected to the following physicochemical analyses: weight loss, soluble dry matter, total dry matter, titratable acidity, pH, total phenolic content, total flavonoid content and DPPH free radical scavenging activity.

4.3. RESULTS AND DISCUSSIONS

Weight loss of blueberry fruit increased during storage at 8 ·C and 70-75% relative humidity (Figure 4.1). No significant differences in weight loss were found between untreated (M0) and water-immersed (M) blueberries.

The weight loss of control samples (M0 and M) was significantly lower than that recorded in the case of chemically treated samples during the storage period. The main cause of weight loss during storage is the migration of water from the fruit to the surface.

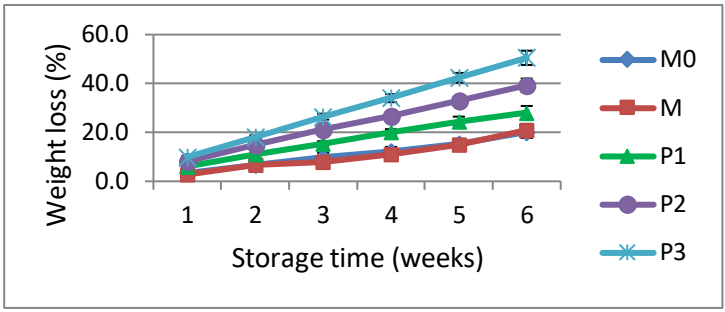


Figure 4.1. Weight loss of blueberries during cold storage in relation to post-harvest treatments with different organic acids

The results obtained after determining the total soluble solids (TSS) content of blueberry fruits subjected to surface treatments with the mentioned acids (samples P1, P2, P3) in relation to the control samples are presented in Figure 4.2. At the end of the storage period, the fruits immersed in organic acids showed a content in total soluble solids significantly higher than in the case of the control groups - M and M0.

The general level of titratable acidity (TA) was found to be around 0.3-0.6 g/100 g (Figure 4.3). The total acidity was relatively stable during the first three weeks of storage, with no significant differences ($P>0.05$) identified between the control samples and the samples subjected to the treatment with organic acids. In the following two weeks, titratable acidity values showed an increase, followed by a decrease in the last week of storage. The control samples presented a significantly lower value of total acidity compared to the treated samples, during the last three weeks of storage.

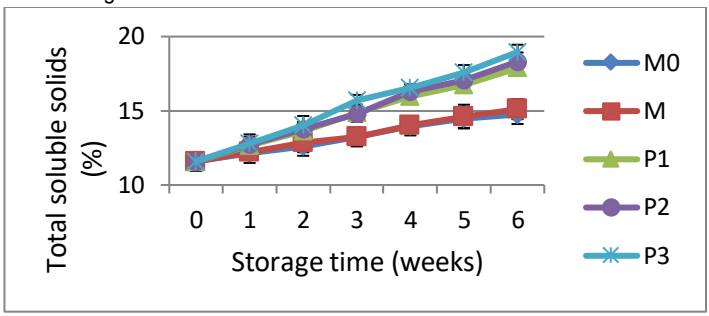


Figure 4.1. Variation of total soluble solids in blueberry fruits during cold storage in relation with post-harvest treatments with different organic acids.

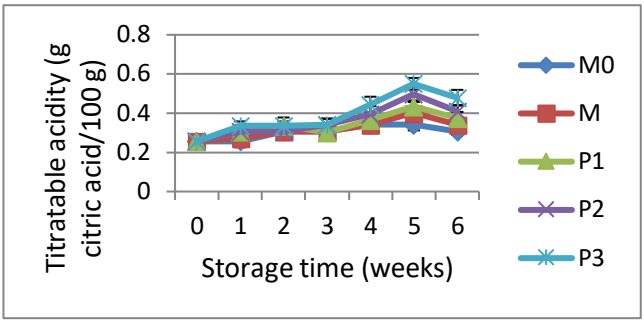


Figure 4.3. Variation of titratable acidity in blueberry fruits during cold storage (8℃) in relation to post-harvest treatments with different organic acids

The variation of the total phenolic compounds content in fruits subjected to different treatments during cold storage is presented in Figure 4.4. Compared to the initial time of storage, the total phenolic content of fruits increased continuously during the first 5 weeks of storage, but decreased thereafter.

The highest total phenolic content was found in the fruits immersed in 0.2% sorbic acid, as a result of the highest moisture loss identified in these fruits during the experiment.

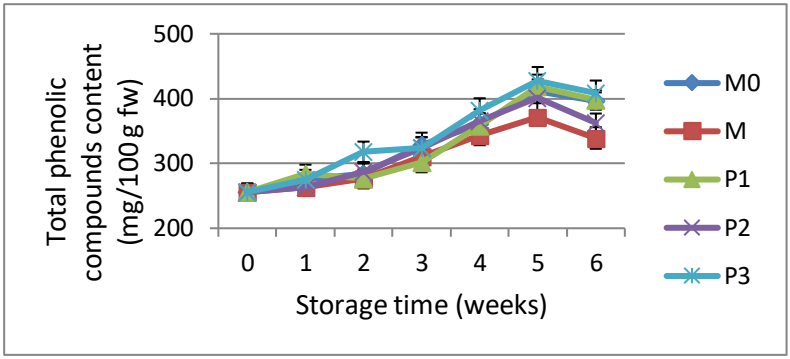


Figure 4.4. Variation of total phenolic compounds content in blueberry fruits during cold storage (8℃) in relation to post-harvest treatments with different organic acids

In all samples, the antioxidant activity increased during the first week, was stable during the following two weeks, and decreased significantly during the last three weeks of storage (Figure 4.5). After six weeks of cold storage, the highest antioxidant activity was found in fruits immersed in 2% citric acid.

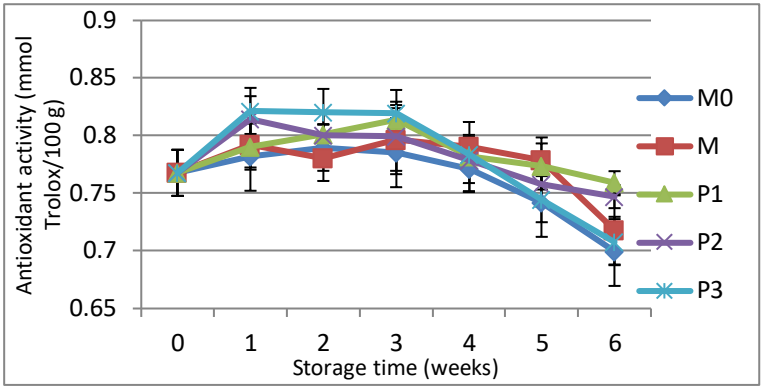


Figure 4.5. Variation of antioxidant activity in blueberry fruits during cold storage (8°C) in relation to post-harvest treatments with different organic acids.

Benzoic acid at 0.2% concentration had a stronger antimicrobial effect compared to 2% citric acid, only 4 CFU/cm² developed from the batch treated with 0.2% benzoic acid after 3 weeks of cold storage. Treatment with 0.2% sorbic acid inhibited all yeasts and bacteria but showed poor activity against Rhizopus mold.

4.4. PARTIAL CONCLUSIONS

After a period of relative stability in the first part of the storage, the titratable acidity started to increase in the next interval, to then decrease towards the end. The samples treated with acids showed a higher titratable acidity than the control samples.

In the case of fruits subjected to treatments with organic acids, the total phenolic content of fruits increased continuously during the first 5 weeks of storage, but decreased thereafter, the highest phenolic content being found in fruits immersed in 0.2% sorbic acid.

The results revealed an increase in antioxidant activity in the first week of refrigeration but also a significant decrease in the last three weeks of storage, the highest antioxidant activity being found in the fruits immersed in 2% citric acid.

The 2% citric acid and 0.2% benzoic acid solutions were found to be the most effective on the samples analyzed, closely followed in effectiveness by the 0.2% sorbic acid solution.

On the long term (42 days), all three types of applied acid treatments had significant antimicrobial effects, with 2% citric acid having the highest efficiency.

CHAPTER 5

EFFECT OF BENZOIC, SORBIC AND CITRIC ACID TREATMENTS ON THE PHYSICOCHEMICAL AND QUALITY CHARACTERISTICS OF PEACH FRUITS DURING COLD STORAGE

5.1. STUDY OPPORTUNITY

The present study was carried out to investigate the effects of post-harvest treatments with organic acids (citric, sorbic and benzoic) on the physicochemical, biochemical and microbiological changes of peaches cv. Redhaven during refrigerated storage.

5.2. MATERIALS AND METHODS

The fruits of the first two batches were immersed for 5 minutes in citric acid solution of concentration 2% (P1) and 0.2% (P2), while the fruits of the next two batches were immersed for 5 minutes in acid solution benzoic acid 0.5% (P3) and respectively sorbic acid solution 0.5% (P4) Control fruits were immersed in water only. The peaches were then allowed to drain for 10 min. For the storage behavior study, fruit samples were analyzed after 0, 7, 14, 21 and 28 days of storage.

5.3. RESULTS AND DISCUSSIONS

Figure 5.1. shows the weight loss of fruits stored at 4-8°C for 28 days, which increased significantly during the 28 days of storage, regardless of the applied treatments. The maximum fruit weight loss was recorded in untreated fruits (13.46%) and the minimum was observed in fruits treated with sorbic acid 0.2% (9.75%), followed by fruits treated with benzoic acid 0, 2% (10.12%).

The results of total soluble substances (TSS) of peach fruits, affected by different treatments are presented in Figure 5.2. The initial fruit TSS was 9.96%. At the end of the storage period, untreated fruits showed significantly higher average TSS than treated fruits. During storage for 28 days, TSS values of peach fruits (M to P4) increased to 13.57, 12.24, 13.08, 12.33 and 12.48%, respectively.

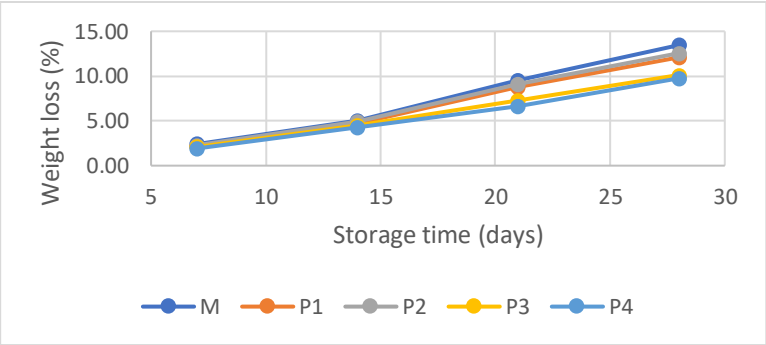


Figure 5.1. Variation of weight loss of peaches during cold storage (5-8°C) in relation to post-harvest treatments with different organic acids: M - fruits immersed in water; P1 - fruits immersed in citric acid 2%; P2 - fruits immersed in citric acid 0.2%; P3 - fruits immersed in 0.5% benzoic acid; P4 - fruits immersed in 0.5% sorbic acid.

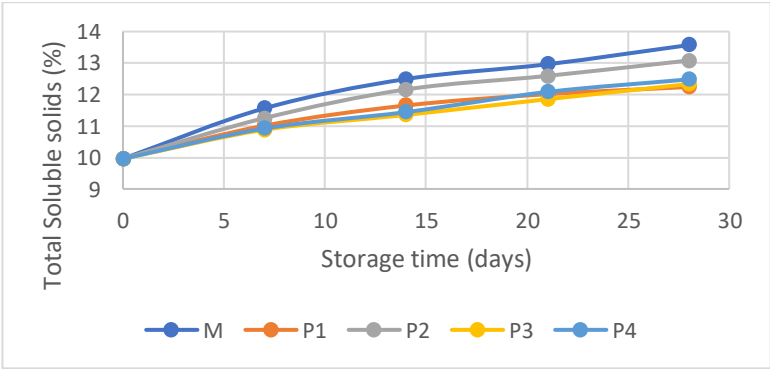


Figure 5.2. The variation of the total content of soluble substances of peaches during cold storage (5-8°C) in relation to the post-harvest treatments with different organic acids: M - fruits immersed in water; P1 - fruits immersed in citric acid 2%; P2 - fruits immersed in citric acid 0.2%; P3 - fruits immersed in 0.5% benzoic acid; P4 - fruits immersed in 0.5% sorbic acid.

Slight increases in titratable acidity were recorded in samples M and P2, probably as a result of higher weight losses correlated with an increase in acid concentration (Figure 5.3).

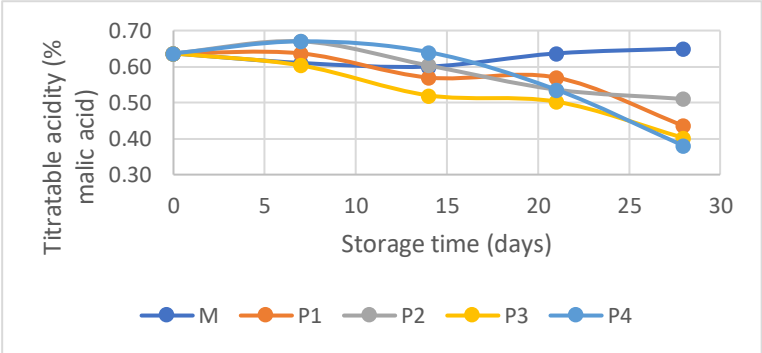


Figure 5.3. Variation of the titratable acidity of peaches during cold storage (5-8oC) in relation to post-harvest treatments with different organic acids: M - fruits immersed in water; P1 - fruits immersed in citric acid 2%; P2 - fruits immersed in citric acid 0.2%; P3 - fruits immersed in 0.5% benzoic acid; P4 - fruits immersed in 0.5% sorbic acid.

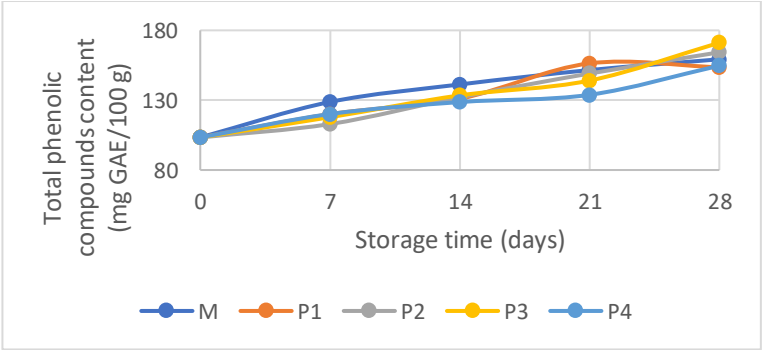


Figure 5.4. Variation of total phenolic compounds content of peaches during cold storage (5-8oC) in relation to post-harvest treatments with different organic acids: M - fruits immersed in water; P1 - fruits immersed in citric acid 2%; P2 - fruits immersed in citric acid 0.2%; P3 - fruits immersed in 0.5% benzoic acid; P4 - fruits immersed in 0.5% sorbic acid.

The phenolic compound content of untreated peaches was 103.36 mg GAE/100 g fresh substance (Figure 5.4.) on day 0. Among the treatments, the highest phenolic content was observed in samples treated with benzoic acid 0.2 %.

At the end of the storage period, the DPPH antioxidant activity ranged from 0.30 to 0.55 mmol TE/100 g, the lowest being determined in the control and the highest in the samples treated with 0.2% benzoic acid.

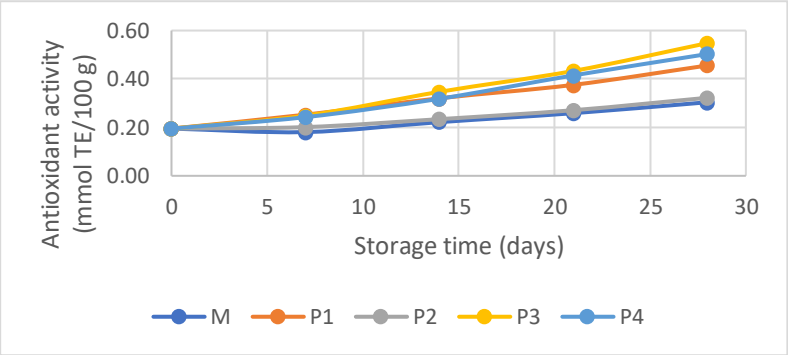


Figure 5.5. Variation of the antioxidant activity of peaches during cold storage (5-8oC) in relation to post-harvest treatments with different organic acids: M - fruits immersed in water; P1 - fruits immersed in citric acid 2%; P2 - fruits immersed in citric acid 0.2%; P3 - fruits immersed in 0.5% benzoic acid; P4 - fruits immersed in 0.5% sorbic acid.

5.4. PARTIAL CONCLUSIONS

The results showed that dipping peaches in citric, benzoic and sorbic acid reduced fruit weight loss during 28 days of cold storage. Titratable acidity decreased while total phenolic content and antioxidant activity generally increased in all samples during storage. The 0.2% benzoic acid treatment was found to be the most effective in maintaining the physicochemical characteristics of peach fruits under refrigerated storage conditions.

The use of preservative organic acids, in combination with the action of low temperature, led to a considerable decrease in the number of microorganisms, as well as to the destruction of the least resistant ones.

CHAPTER 6

EFFECT OF SOME SANITIZING TREATMENTS ON STRAWBERRY FRUIT QUALITY DURING COLD STORAGE

6.1. STUDY OPPORTUNITY

The aim of the present study was to investigate the effects of washing treatments with organic acids and acid electrolysed water on weight loss, firmness, titratable acidity, total soluble matter content, phenolic and anthocyanin compounds and DPPH antioxidant activity of the strawberry cultivar 'Malvina' for 21 days storage at 8°C. The effectiveness of these treatments in reducing strawberry fruit decay was also examined.

6.2. MATERIALS AND METHODS

The treatments consisted of immersing the fruits for 5 minutes at room temperature in: tap water (control, C); citric acid 2% (CA); acid electrolyzed water

(AEW); 0.2% benzoic acid (BA); 0.2% sorbic acid (SA). After treatment, the fruits were allowed to dry and then packed in plastic containers (500 ml capacity), each containing about 250 g, covered with a lid and stored at 8°C and 85% relative humidity for 21 days.

6.3. RESULTS AND DISCUSSIONS

Weight loss was significantly lower in treated fruits than in control fruits. Bigger weight loss was recorded between 14 and 21 days of storage for all fruits. At the end of storage, the highest loss was found in control fruits (1.65%) and the lowest loss in those treated with sorbic acid (SA) (0.46%), followed by fruits treated with citric acid (CA) (0.86%), with acid electrolyzed water (AEW) (0.90%) and benzoic acid (BA) (0.94%) (Table 6.1).

Table 6.1. Effect of different sanitation treatments on weight loss (%) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	$0,04 \pm 0,01^{a}$	$0,53 \pm 0,03^{a}$	$0,93 \pm 0,05^{a}$	$1,65 \pm 0,08^{a}$
AEW	$0,05 \pm 0,01^{a}$	$0,33 \pm 0,03^{b}$	$0,71 \pm 0,04^{b}$	$0,90 \pm 0,06^{b}$
CA	$0,04 \pm 0,01^{a}$	$0,27 \pm 0,03^{c}$	$0,63 \pm 0,03^{c}$	$0,86 \pm 0,04^{b}$
BA	$0,00 \pm 0,01^{b}$	$0,20 \pm 0,02^{d}$	$0,49 \pm 0,02^{d}$	$0,94 \pm 0,03^{b}$
SA	$0,00 \pm 0,01^{b}$	$0,13 \pm 0,02^{e}$	$0,30 \pm 0,02^{e}$	$0,46 \pm 0,03^{b}$

Table 6.2. Effect of different sanitation treatments on firmness (kg/cm2) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	$1,76 \pm 0,13$	$1,42 \pm 0,10^{b}$	$1,27 \pm 0,08^{b}$	$1,14 \pm 0,11^{bc}$
AEW	$1,80 \pm 0,12$	$1,77 \pm 0,13^{a}$	$1,45 \pm 0,11^{ab}$	$1,12 \pm 0,12^{bc}$
CA	$1,82 \pm 0,12$	$1,58 \pm 0,12^{ab}$	$1,27 \pm 0,15^{b}$	$1,06 \pm 0,12^{c}$
BA	$1,72 \pm 0,11$	$1,63 \pm 0,15^{ab}$	$1,58 \pm 0,09^{a}$	$1,30 \pm 0,13^{ab}$
SA	$1,82 \pm 0,14$	$1,67 \pm 0,11^{a}$	$1,57 \pm 0,11^{a}$	$1,52 \pm 0,15^{a}$

The largest decreases in firmness throughout the entire storage period were recorded in fruits treated with acid electrolyzed water (AEW) and 2% citric acid (CA). However, fruits treated with 0.2% benzoic acid (BA) or 0.2% sorbic acid (SA) maintained their firmness better than control fruits after 21 days of storage (Table 6.2).

Fruit acidity increased during the first 7 days after treatment and decreased thereafter in all samples. Titratable acidity showed the least decrease in

strawberries treated with sorbic acid (SA) compared to the control, while soaking in 2% citric acid led to a more significant decrease (Table 6.3).

Table 6.3. Effect of different sanitation treatments on titratable acidity (g citric acid / 100 g fw) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	0,58 ± 0,04	0,61 ± 0,03^{b}	0,51 ± 0,03^{ab}	0,44 ± 0,03^{ab}
AEW	0,58 ± 0,03	0,61 ± 0,03^{b}	0,48 ± 0,04^{b}	0,45 ± 0,02^{ab}
CA	0,61 ± 0,04	0,63 ± 0,03^{ab}	0,48 ± 0,03^{b}	0,41 ± 0,02^{b}
BA	0,61 ± 0,04	0,64 ± 0,02^{ab}	0,48 ± 0,02^{b}	0,44 ± 0,03^{ab}
SA	0,61 ± 0,03	0,67 ± 0,02^{a}	0,54 ± 0,02^{a}	0,48 ± 0,02^{a}

The evolution of the total soluble solids content of strawberry fruits during storage is presented in Table 6.4. TSS decreased slowly during the first 14 days in all treatments, followed by a sharp decrease during the last 7 days of fruit storage.

Table 6.4. Effect of different sanitation treatments on soluble dry matter (TSS %) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	9,92 ± 0,24^{c}	9,80 ± 0,26^{b}	9,44 ± 0,18^{b}	7,92 ± 0,16^{c}
AEW	10,54 ± 0,32^{ab}	9,64 ± 0,14^{b}	9,12 ± 0,24^{bc}	8,14 ± 0,18^{bc}
CA	10,12 ± 0,28^{bc}	9,52 ± 0,22^{b}	8,82 ± 0,16^{c}	7,54 ± 0,20^{d}
BA	10,74 ± 0,20^{a}	10,46 ± 0,26^{a}	10,06 ± 0,20^{a}	8,36 ± 0,18^{ab}
SA	10,62 ± 0,14^{a}	10,38 ± 0,18^{a}	9,98 ± 0,26^{a}	8,62 ± 0,16^{a}

The highest TSS content was recorded in fruits soaked in sorbic acid (SA), followed by strawberries treated with benzoic acid (BA).

After 21 days of storage, the highest content of total phenolic compounds was found in fruit treated with BA and AEW, followed by fruit treated with SA (Table 6.5).

Table 6.5. Effect of different sanitation treatments on total phenolic content (mg GAE/100 g fw) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	73,27 ± 2,24^{b}	79,98 ± 1,66^{b}	78,73 ± 1,22^{b}	67,52 ± 1,22^{b}
AEW	80,34 ± 3,02^{a}	85,83 ± 2,88^{a}	75,62 ± 1,86^{b}	73,34 ± 1,86^{a}
CA	74,07 ± 2,68^{b}	79,01 ± 2,34^{b}	70,15 ± 1,30^{c}	62,72 ± 1,30^{c}
BA	80,54 ± 2,86^{a}	85,16 ± 3,56^{a}	90,19 ± 1,78^{a}	73,69 ± 1,78^{a}
SA	77,34 ± 1,89^{ab}	81,47 ± 2,55^{ab}	88,07 ± 1,06^{a}	68,23 ± 1,06^{b}

The average total anthocyanin content of strawberry fruits before sanitation treatments was 53.08 mg CGE / 100 g fw. (Table 6.6).

The results showed that using refrigerated storage, the anthocyanin content was better retained when the strawberries were previously immersed in 0.2% benzoic acid, 2% citric acid or 0.2% sorbic acid.

Table 6.6. Effect of different sanitation treatments on total anthocyanin content (mg CGE / 100 g fw) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	53,08 ± 1,26	45,64 ± 1,66^{c}	44,19 ± 1,25^{b}	28,44 ± 0,84^{c}
AEW	53,03 ± 1,46	47,25 ± 1,82^{bc}	48,49 ± 1,30^{a}	30,07 ± 1,26^{c}
CA	52,49 ± 1,34	49,43 ± 1,34^{ab}	47,16 ± 0,97^{a}	43,38 ± 1,38^{a}
BA	52,49 ± 0,88	50,91 ± 1,68^{a}	47,33 ± 1,28^{a}	43,52 ± 0,98^{a}
SA	50,93 ± 1,84	49,90 ± 1,52^{ab}	48,35 ± 1,86^{a}	39,87 ± 1,06^{b}

The antioxidant activity of fresh strawberries before sanitation treatments was 4.8 mmol Trolox / 100 g fw and no significant differences were found between samples immediately after treatments (Table 6.7).

Table 6.7. The effect of different sanitizing treatments on the DPPH free radical scavenging activity (mmol Trolox / 100 g fw) of strawberries during storage at 8 °C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	4,80 ± 0,28	4,80 ± 0,19	4,67 ± 0,18	4,11 ± 0,21^{b}
AEW	4,90 ± 0,15	5,03 ± 0,23	4,62 ± 0,22	4,21 ± 0,22^{ab}
CA	5,00 ± 0,28	4,96 ± 0,26	4,58 ± 0,30	4,39 ± 0,23^{ab}
BA	4,93 ± 0,22	4,98 ± 0,18	4,73 ± 0,24	4,58 ± 0,11^{a}
SA	4,83 ± 0,24	5,02 ± 0,22	4,60 ± 0,24	4,52 ± 0,25^{a}

After 14 days of storage at 8°C, the DPPH antioxidant activity decreased steadily. The highest values were found in samples treated with 0.2% benzoic acid (5.58 mmol Trolox / 100 g fw) and 0.2% sorbic acid (4.52 mmol Trolox / 100 g fw).

Acid electrolyzed water significantly delayed the decay of strawberries during cold storage compared to control samples (Table 6.8). CA treatment was more effective than acid electrolysed water in slowing the decay of fresh strawberries during storage.

Table 6.8. Effect of different sanitation treatments on strawberry decay (%) during storage at 8°C for 21 days

	Storage time (days)			
Treatment	1	7	14	21
C	0.00 ± 0.00	6.70 ± 0.64^{a}	37.77 ± 2.18^{a}	84.11 ± 3.35^{a}
AEW	0.00 ± 0.00	3.80 ± 0.31^{b}	28.56 ± 1.57^{b}	66.88 ± 3.26^{b}
CA	0.00 ± 0.00	2.62 ± 0.20^{c}	23.22 ± 1.23^{c}	54.26 ± 2.84^{c}
BA	0.00 ± 0.00	1.21 ± 0.08^{d}	16.73 ± 0.44^{d}	48.11 ± 2.58^{d}
SA	0.00 ± 0.00	0.00 ± 0.00^{e}	10.68 ± 0.64^{e}	41.42 ± 3.18^{e}

BA and SA treatments were the most effective in reducing strawberry decay. Sorbic and benzoic acids are preservative food additives capable of inhibiting the growth of yeasts, molds and bacteria.

6.4. PARTIAL CONCLUSIONS

Fresh strawberry wash treatments with 2% citric acid, 0.2% benzoic acid, 0.2% sorbic acid, and acid electrolyzed water delayed the physiological collapse of fruit during storage by slowing water loss. Immersion of strawberries in aqueous solutions of 0.2% sorbic acid or 0.2% benzoic acid delayed the loss of firmness in fresh strawberries. In addition, sanitization treatments maintained anthocyanins and

phenolic content at a higher level, with benzoic acid and sorbic acid treatments being the most effective. As a result, fruits immersed in benzoic or sorbic acid maintained a higher antioxidant activity during storage than the control samples. Sanitizing treatments consisting of immersion in 0.2% benzoic acid or 0.2% sorbic acid solutions can extend the life of strawberry fruit by about 7 days under cold storage conditions.

CHAPTER 7

EFFECT OF DIP WASH TREATMENTS WITH ORGANIC ACIDS AND ACIDIC ELECTROLYZED WATER COMBINED WITH ULTRAVIOLET IRRADIATION ON QUALITY OF STRAWBERRY FRUIT DURING STORAGE

7.1. STUDY OPPORTUNITY

The present study was carried out to investigate the effects of postharvest chemical treatments followed by UV-C irradiation on the quality characteristics of strawberry fruits (weight loss, firmness, titratable acidity, total dry matter), the content of bioactive compounds (phenolic compounds, anthocyanins) and the antioxidant activity of strawberries of the cultivar "Malvina" during 21 days of storage at 8 °C. The effectiveness of these treatments in reducing strawberry fruit decay was also examined.

7.2. MATERIALS AND METHODS

The fruits were randomly divided into six groups (80 fruits per group) corresponding to the following treatments: (C) - fruits immersed in tap water; (UV) - fruit soaked in tap water and irradiated with UV-C; (CA + UV) - fruits immersed in 2% citric acid solution and UV-C irradiated; (AEW + UV) - fruits immersed in acid electrolyzed water and irradiated with UV-C; (BA + UV) - fruits immersed in 0.2% benzoic acid solution and UV-C irradiated; (SA + UV) - fruits immersed in 0.2% sorbic acid solution and UV-C irradiated. The immersion time in the treatment solutions was approximately 5 min at ambient temperature (20 °C).

Weight loss, firmness, total soluble solids, titratable acidity, total phenolic content, total anthocyanin content, DPPH antioxidant activity and fruit decay were evaluated at 0, 7, 14 and 21 days of storage. Each determination was performed in duplicate.

7.3. RESULTS AND DISCUSSIONS

The influence of treatments on fruit weight loss is shown in Figure 7.1. Weight loss of treated and untreated fruit increased during storage.

Weight loss of all UV-treated fruits was significantly lower than that of control fruits. After 14 days of storage, the weight loss of the control fruit was about 32% higher compared to the samples treated with UV-C only.

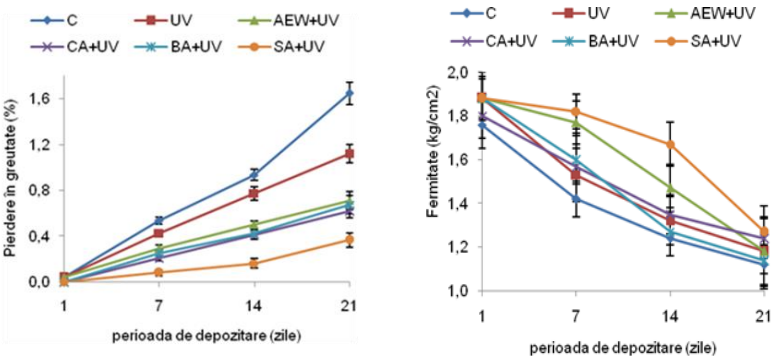


Figure 7.1. Effect of immersion and UV-C irradiation treatments on weight loss (a) and firmness (b) of strawberries during storage at 8 °C for 21 days. (Control C), immersed in tap water; (C + UV), immersed in tap water and irradiated with UV-C; (AEW + UV), immersed in acid electrolyzed water and irradiated with UV-C; (CA + UV), immersed in 2% citric acid and irradiated with UV-C; (BA + UV), immersed in 0.2% benzoic acid and irradiated with UV-C; (SA + UV), immersed in 0.2% sorbic acid and irradiated with UV-C. Vertical bars represent standard deviation (n = 3).

Strawberry firmness decreased during the storage period at 8 °C in both control and treated fruits. However, UV treatment had a beneficial effect on fruit firmness, as UV-treated fruit remained significantly firmer than control samples throughout the storage period (Figure 7.1).

After 14 days of storage, samples treated with 0.2% sorbic acid followed by UV-C irradiation (SA + UV) maintained significantly higher firmness than the other treated and control samples. Softening was also significantly delayed in AEW and UV-C treated fruit after 7 days of storage.

Fruit degradation occurred rapidly in control strawberries stored at 8 °C, with 37.77% of control fruits showing signs of infection after 14 days of storage (Figure 7.2). UV treatment alone delayed the onset of decay in fruit during cold storage.

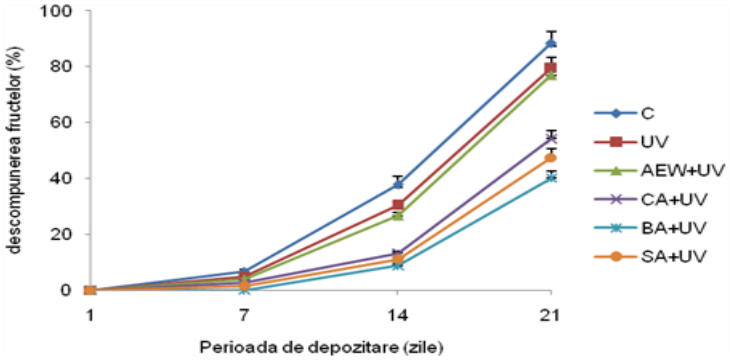


Figure 7.2. Effect of surface treatments and UV-C irradiation on strawberry decay during storage at 8 °C for 21 days. (Control C), immersed in tap water; (C + UV), immersed in tap water and irradiated with UV-C; (AEW + UV), immersed in acid electrolyzed water and irradiated with UV-C; (CA + UV), immersed in 2% citric acid and irradiated with UV-C; (BA + UV), immersed in 0.2% benzoic acid and irradiated with UV-C; (SA + UV), immersed in 0.2% sorbic acid and irradiated with UV-C. Vertical bars represent standard deviation (n = 3)

At the end of storage, the highest decay rate was determined in control fruits (83.33%) and the lowest decay rate was determined in fruits treated with BA + UV (40.11%), followed by SA + UV (47.44%) and CA + UV (54.26%).

The change in TSS content of strawberries as a function of storage time is shown in Figure 7.3. The content of soluble substances decreased slowly at the beginning of the storage period in all samples. In the last 14 days there was a noticeable drop in fruit TSS probably caused by fruit senescence.

At the end of 21 days of storage, the highest TSS content was recorded in the BA + UV and SA + UV treatments (8.8%), followed by the CA + UV treatment (8.5%), while the lower TSS content was recorded in the control samples (7.9%) and the AEW + UV treatment (7.8%).

Titratable acidity increased slightly during the first 7 days of storage, but decreased steadily after this period in all samples (Figure 7.3).

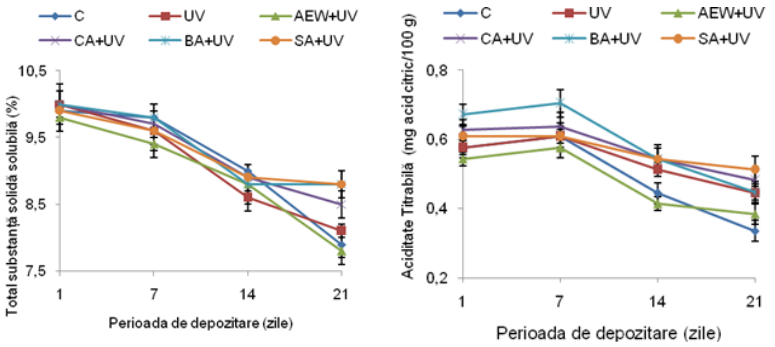
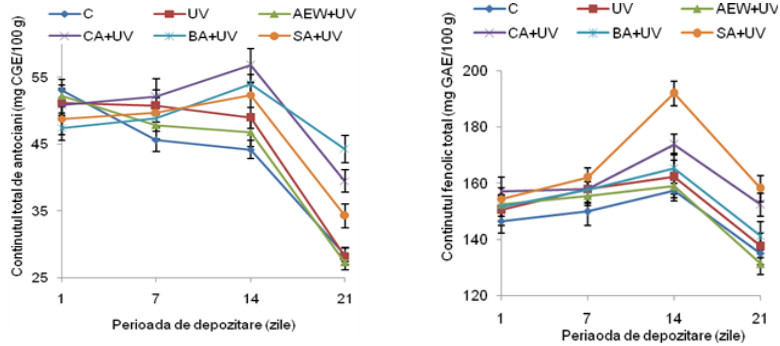


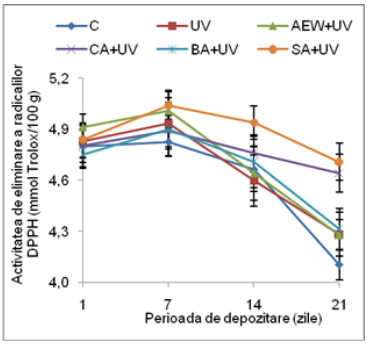
Figure 7.3. Effect of surface treatments and UV-C irradiation on the content of soluble substances (a) and titratable acidity (b) in strawberries during storage at 8 °C for 21 days. (Control C), immersed in tap water; (C + UV), immersed in tap water and irradiated with UV-C; (AEW + UV), immersed in acid electrolyzed water and irradiated with UV-C; (CA + UV), immersed in 2% citric acid and irradiated with UV-C; (BA + UV), immersed in 0.2% benzoic acid and irradiated with UV-C; (SA + UV), immersed in 0.2% sorbic acid and irradiated with UV-C. Vertical bars represent standard deviation (n = 3)

The total anthocyanin content in the control strawberries was 53.08 mg CGE / 100 g. The anthocyanin content gradually increased during storage up to day 14 in the UV-treated fruits immersed in organic acids, while there was a slight decrease in control fruits and in fruits treated with AEW + UV (Figure 7.4).

Furthermore, the anthocyanin content sharply decreased in all samples until the 21st day of storage, when the fruits would be overripe and senescent.



(a) (b)



(c)

Figure 7.4. Effect of surface treatments and UV-C irradiation on total anthocyanin content (a), total phenolic content (b) and DPPH radical scavenging activity (c) in strawberries during storage at 8 °C for 21 days. (Control C), immersed in tap water; (C + UV), immersed in tap water and irradiated with UV-C; (AEW + UV), immersed in acid electrolyzed water and irradiated with UV-C; (CA + UV), immersed in 2% citric acid and irradiated with UV-C; (BA + UV), immersed in 0.2% benzoic acid and irradiated with UV-C; (SA + UV), immersed in 0.2% sorbic acid and irradiated with UV-C. Vertical bars represent standard deviation (n = 3).

The total phenolic content of strawberry fruits increased in all UV-treated and control samples during the 14-day storage period, after which they decreased sharply during the rest of the storage period (Figure 7.4). However, growth was relatively lower in control fruits compared to UV-treated fruits.

7.4. PARTIAL CONCLUSIONS

The results showed that UV irradiation of fresh strawberries significantly reduced water loss, maintained firmness and delayed the onset of fruit decay symptoms during cold storage. In addition, UV treatment alone promoted the accumulation of phenolic compounds and increased the antioxidant activity of strawberries.

The use of immersions in acid solutions and acid electrolyzed water before UV treatment significantly reduced the postharvest degradation of strawberries (benzoic acid 0.2% > sorbic acid 0.2% > citric acid 2%) and was more effective in maintaining the content of health-promoting compounds (polyphenols, anthocyanins) and antioxidant capacity of fruits in relation to UV treatment applied alone. The results suggest that postharvest treatments of strawberries with organic acids followed by UV irradiation may be a useful way to maintain strawberry fruit quality and extend their shelf life.

CHAPTER 8

QUALITY OF FRESH-CUT APPLES AS AFFECTED BY DIP WASH TREATMENTS WITH ORGANIC ACIDS AND ACIDIC ELECTROLYZED WATER

8.1. STUDY OPPORTUNITY

The objective of this study was to investigate the effects of immersion in organic acid solutions and in acid electrolyzed water on the quality characteristics and surface microbiota of fresh-cut apples of the cultivars 'Florina' and 'Ionathan', packed in plastic containers under normal atmospheric conditions during storage for 14 days at 8 °C.

8.2. MATERIALS AND METHODS

Treatments were made by immersing the apple cuboids for 5 minutes in the test solutions. Tested solutions included 2% citric acid (CA, pH = 1.67), acid electrolyzed water (AEW, pH = 3.54), 0.2% benzoic acid (BA, pH = 2.62), 0.0% sorbic acid .2% (SA, pH = 2.78) and ascorbic acid 0.5% (AE, pH = 3.50). Control samples (C) were immersed in distilled water. Color, firmness, titratable acidity, total phenolic content, DPPH antioxidant activity and surface microbiota were measured at 0, 7 and 14 days of storage.

8.3. RESULTS AND DISCUSSIONS

Color, as the browning on the cut surface, has been shown to be a critical quality parameter that determines the shelf life and purchase decision of fresh cut fruit.

The bigest decrease in L* parameter levels during the storage period was observed for samples treated with benzoic acid (BA) of both cultivars. The a* values increased during the 2-week storage period in all samples. The b* parameter values of the apple samples increased during storage. b* values were significantly higher in BA and SA samples.

Figure 8.1 shows the firmness of fresh cut apples stored for 14 days at 8 °C.

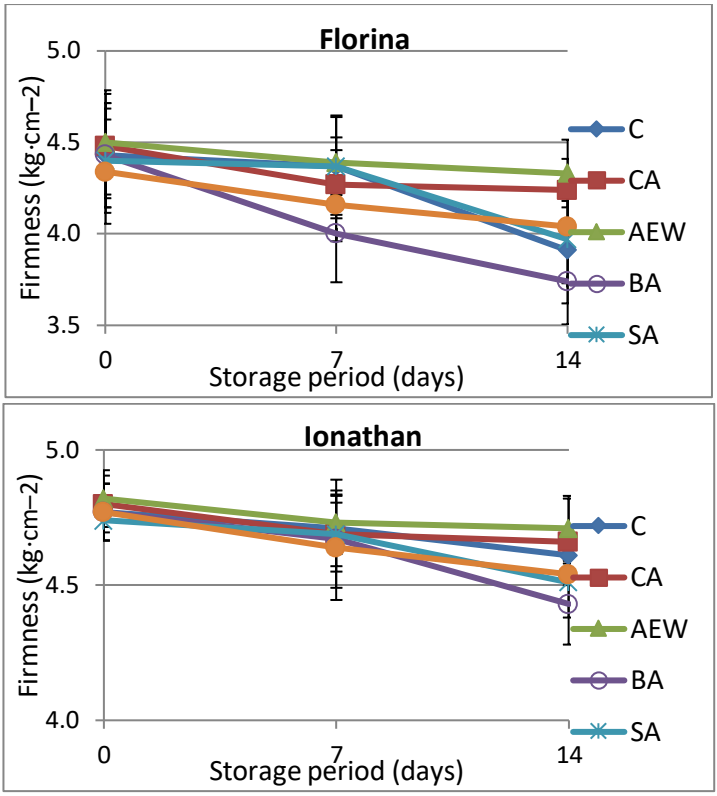


Figure 8.1. The effect of chemical treatments on the firmness of fresh-cut apples ("Florina" and "Ionathan" varieties) during 14 days of storage. Freshly cut apple cuboids were immersed for 5 min in water (control C), 2% citric acid (CA), acid electrolyzed water (AEW), 0.2% benzoic acid (BA), 0.2% sorbic acid (SA) and 0.5% ascorbic acid (AA) and then store at 8 oC. Data represent the mean of three replicates ± SD

Among the treatments, samples treated with acid electrolyzed water (AEW) reached the highest total phenolic content after two weeks of storage, probably due to the antioxidant activity of AEW that prevented high phenolic degradation (Figure 8.2).

Figure 8.3 presents the results regarding the DPPH free radical scavenging activity of apple cuboids during cold storage. The DPPH antioxidant activity values on the day of processing were 2.67 and 1.53 mmol Trolox/100 g fw for 'Florina' and 'Ionathan' cultivars, respectively.

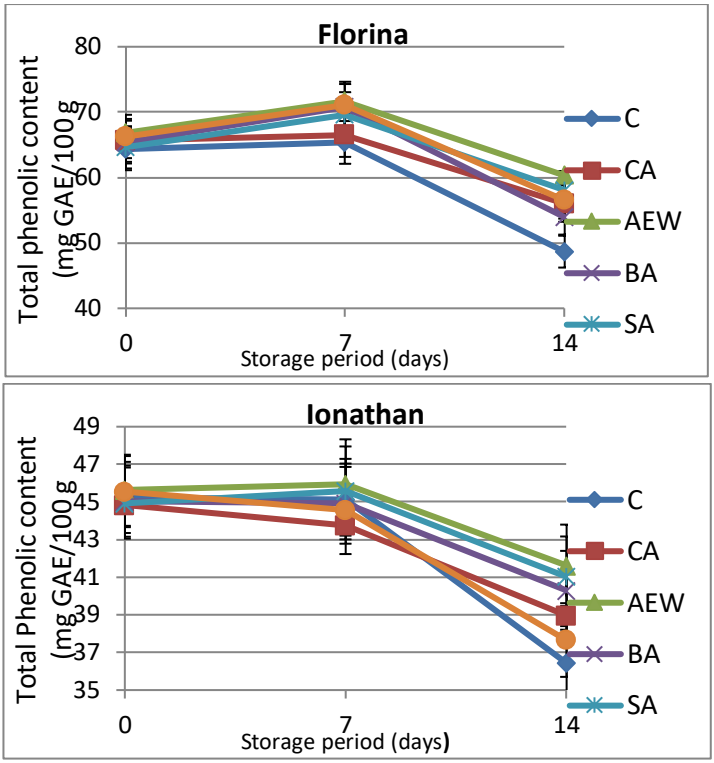


Figure 8.2. The effect of chemical treatments on the total phenolic content of fresh-cut apples ("Florina" and "Ionathan" cultivars) during 14 days of storage. Freshly cut apple cuboids were immersed for 5 min in water (control C), 2% citric acid (CA), acid electrolyzed water (AEW), 0.2% benzoic acid (BA), 0.2% sorbic acid (SA) and 0.5% ascorbic acid (AA) and then store at 8 ℃. Data represent the mean of three replicates ± SD

At the end of the 14-day storage period, the samples treated with acid electrolyzed water and those with 2% citric acid showed higher values of antioxidant activity, while the samples treated with sorbic acid 0.2%, benzoic acid 0.2% and ascorbic acid 0.5% showed lower antioxidant activity values than control samples.

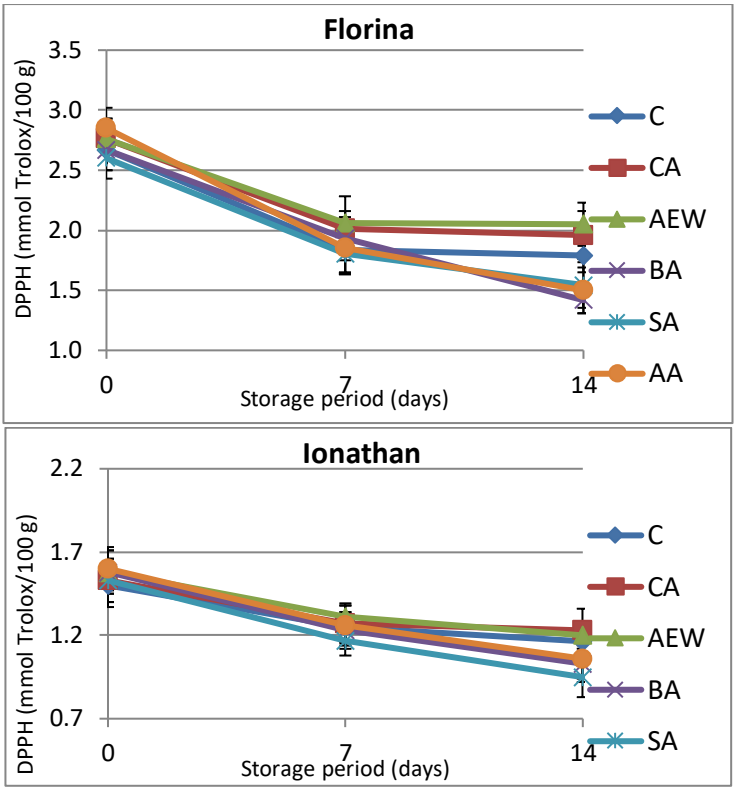


Figure 8.3. The effect of chemical treatments on the DPPH radical scavenging activity of freshly cut apples ("Florina" and "Ionathan" cultivars) during 14 days of storage. Freshly cut apple cuboids were immersed for 5 min in tap water (control C), 2% citric acid (CA), acid electrolyzed water (AEW), 0.2% benzoic acid (BA), 0.0% sorbic acid .2% (SA) and 0.5% ascorbic acid (AA) and then store at 8 °C. Data represent the mean of three replicates ± SD

Microbiological analysis of the surface of fresh-cut control and treated apples showed significant differences between treatments. Citric acid completely inhibited bacterial growth throughout the storage period compared to control samples.

Immersion treatment of fresh-cut apples with acid electrolyzed water resulted in a considerable reduction in the number of microorganisms (5 CFU/cm2) compared to control samples.

Benzoic acid successfully suppressed the growth of bacteria and yeasts on fresh-cut apples throughout the storage period.

Treatment with 0.2% sorbic acid determined an effective inactivation of microorganisms on freshly cut apples, materialized in a significantly lower microbial load than that of control samples throughout the storage period.

Immersion in 0.5% ascorbic acid also resulted in a considerable reduction in microbial load compared to control samples. However, after treatment, bacteria of the genus Bacillus (1 CFU/cm2) and yeasts (16 CFU/cm2) were found on the surface of the fruit.

8.4. PARTIAL CONCLUSIONS

According to the results obtained in this study, immersion in acid electrolyzed water or 2% citric acid solution improved the keeping ability of fresh-cut apples by inhibiting browning and microbial growth and by reducing the loss of firmness, total phenolic content and antioxidant activity during storage. Acidic electrolyzed water was more effective than citric and ascorbic acids in controlling enzymatic browning of fresh-cut apples. Treatment with 0.5% ascorbic acid inhibited bacteria but promoted yeast growth during storage. Immersion in 0.2% benzoic acid or 0.2% sorbic acid solution ensured effective inactivation of microorganisms on fresh-cut apples throughout the storage period. However, these treatments resulted in more intense browning, yellowing, and loss of firmness and antioxidant activity during storage.

CHAPTER 9

PECTIN-BASED EDIBLE COATING COMBINED WITH CHEMICAL DIPS CONTAINING ANTIMICROBIALS AND ANTIBROWNING AGENTS TO MAINTAIN QUALITY OF FRESH-CUT PEARS

9.1. STUDY OPPORTUNITY

The aim of this study was to maintain the quality of fresh cut pears during storage at 8 °C by using an edible pectin coating combined with chemical treatments containing 0.2% potassium sorbate (PS) or 0.2% benzoate of sodium (SB) as antimicrobials and 1% N-acetyl cysteine (N-AC) or 1% ascorbic acid (AA) + 1% citric acid (CA) as anti-browning agents. Weight loss, color parameters, browning index, firmness, titratable acidity, soluble solids content, total phenolic compounds content, antioxidant activity and sensory attributes of fresh cut pears were monitored during 15 days of storage at 8 °C.

9.2. MATERIALS AND METHODS

The pectin powder was dissolved in distilled water at 2% (w/v) at a temperature of 70 °C under stirring until it became clear. After cooling to room temperature, 0.1% glycerol was added as a plasticizer. An aqueous crosslinking solution based on 1% calcium chloride was prepared. Preservatives and

antibrowning agents were incorporated into the aqueous crosslinking solution. Treatment recipes and respective codes are presented in Table 9.1.

Tabel 9.1. Treatment recipes and their codes

Treatment	Components
T0	Distiled water (control)
T1	2% PE + 1% $CaCl_2$
T2	2% PE + 1% $CaCl_2$ + 0.2% PS
T3	2% PE + 1% $CaCl_2$ + 0.2% PS + 1% N-AC
T4	2% PE + 1% $CaCl_2$ + 0.2% PS + 1% CA + 1% AA
T5	2% PE + 1% $CaCl_2$ + 0.2% SB
T6	2% PE + 1% $CaCl_2$ + 0.2% SB + 1% N-AC
T7	2% PE + 1% $CaCl_2$ + 0.2% SB + 1% CA + 1% AA

Weight loss, firmness, color, total soluble matter content, titratable acidity, total phenolic compound content, and DPPH antioxidant activity were evaluated at 0, 3, 6, 9,12 and15 days during storage. Each determination was performed in a minimum of three replicates.

9.3. RESULTS AND DISCUSSIONS

Figure 9.1 shows the evolution of the percentage weight loss during 15 days of storage for both control and coated samples.

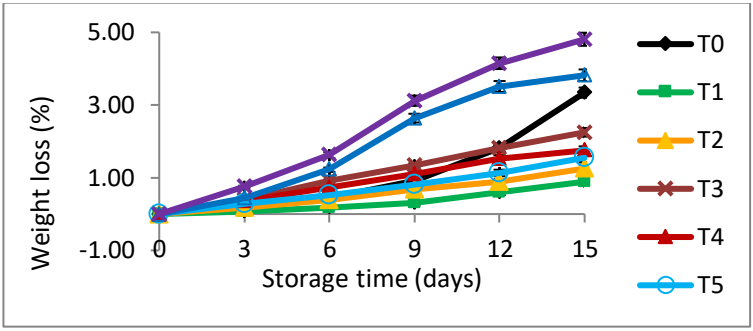


Figure 9.1. Weight loss of fresh-cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

The best control of weight loss during storage was obtained for samples coated only with pectin.

In the present work, the BI of fresh-cut pear cuboids in control (T0) and coated only with pectin (T1) showed a slight increase up to 12 days and then showed a rapid increase up to the fifteenth day of storage (Figure 9.2.).

Pear samples soaked in pectin coating solution and crosslinking solution containing antimicrobials and N-acetyl-cysteine (samples T3 and T6) showed similar behaviors throughout storage and maintained the lowest and fairly stable BI values during the 15 days of storage, indicating the positive effect of these combinations to control enzymatic browning.

Images of the appearance of fresh cut pears after 12 days of storage are shown in Figure 9.2.

Figure 9.2. Appearance of freshly cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

Figure 9.3. show that the firmness of untreated pear cuboids decreased significantly after 15 days of storage, demonstrating substantial softening.

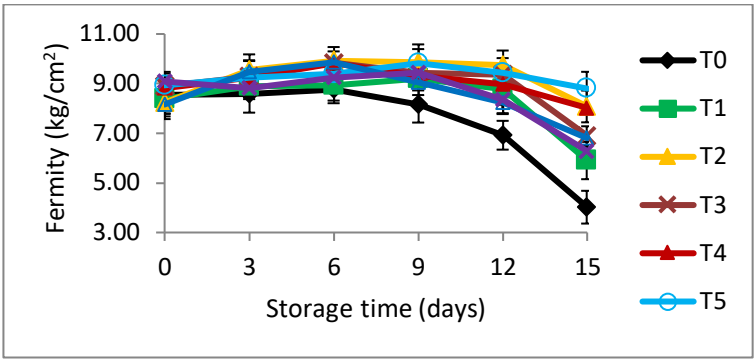


Figure 9.3. Firmness of fresh-cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

Changes in TA and TSS during storage of fresh-cut pear cuboids are shown in Figure 9.4 and Figure 9.5.

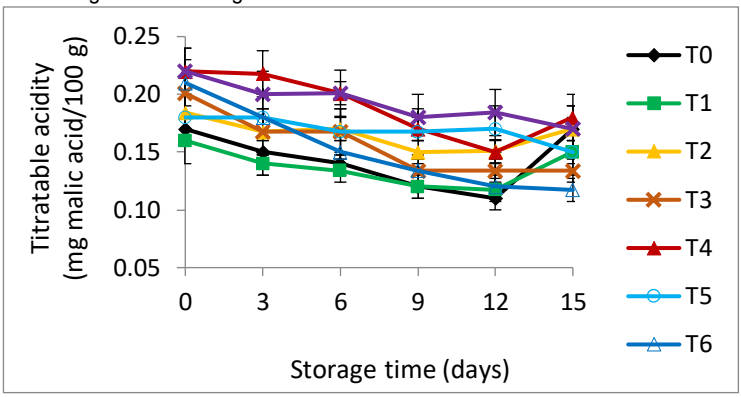


Figure 9.4. Titratable acidity of fresh-cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA

Samples coated with pectin (T1) and those coated with pectin and immersed in 0.2% preservative solution (T2 and T5) showed the least decrease in titratable acidity in 12 days of storage.

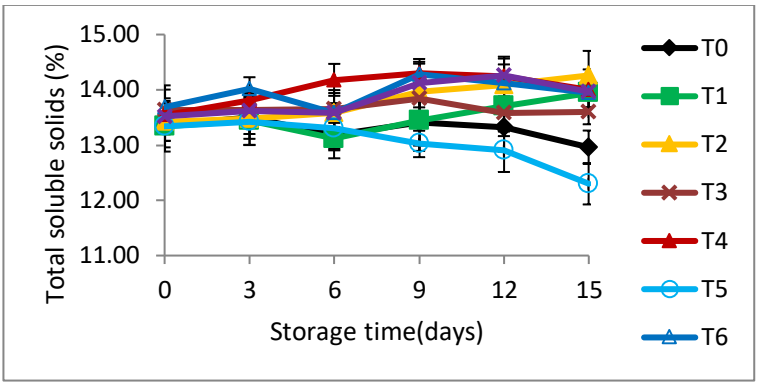


Figure 9.5. Total soluble content of fresh-cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

Control (T0) and pectin-coated samples immersed in 0.2% SB (T5) showed the lowest values (12.96% and 12.3%, respectively). TSS increased slightly during the first three days in most samples, then tended to decrease up to 6 days, but increased with longer storage. The control samples showed a decrease in the total content of soluble substances during the last three days of storage.

The total content of phenolic compounds increased initially, but remained relatively stable or slightly decreased after 3 days of storage, after which it increased again in all samples up to 12 days of storage (Figure 9.6.).

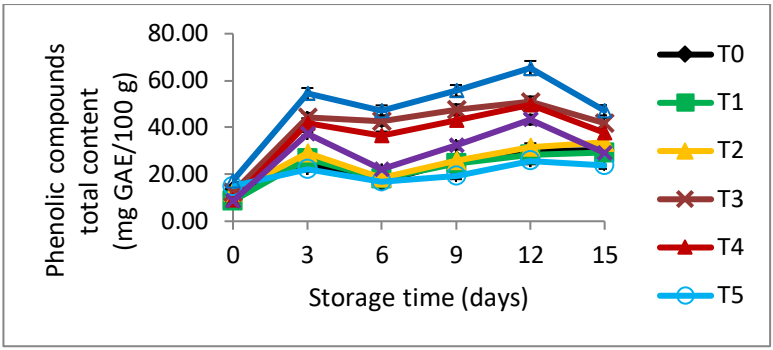


Figure 9.6. Total phenolic content of fresh cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 - 0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

Figure 9.7. shows the DPPH scavenging activity of fresh-cut pears as influenced by pectin coating and chemical treatment. The DPPH antioxidant activity of the samples with treatments containing N-acetyl-cysteine (T3 and T6) was significantly higher than that of the other samples immediately after the coating treatment (Figure 9.7).

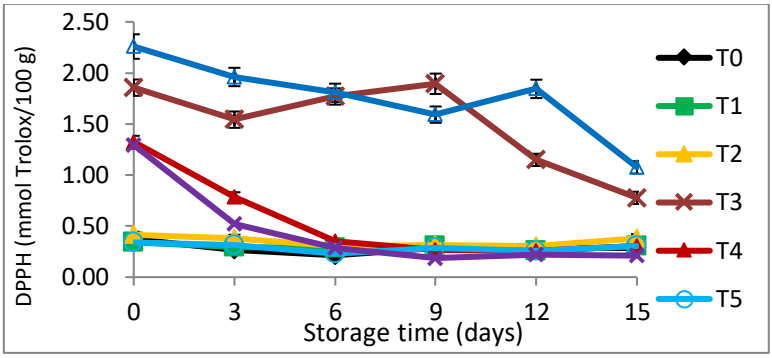


Figure 9.7. Free radical scavenging activity of fresh cut pear cuboids immersed in different coating solutions and stored for 15 days at 8 ± 1 °C. T0 - Witness; T1 - 0.2% PE + 1% CaCl2; T2 - 0.2% PE + 1% CaCl2 + 0.2% PS; T3 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% N-AC; T4 - 0.2% PE + 1% CaCl2 + 0.2% PS + 1% CA + 1% AA; T5 -

0.2% PE + 1% CaCl2 + 0.2% SB; T6 - 0.2% PE + 1% CaCl2 + 0.2% SB + 1% N-AC; T7- 0.2% PE + 1% CaCl2 + 0.2% SB + 1% CA + 1% AA.

Combining pectin coating with an immersion treatment in a solution containing ascorbic acid (T4 and T7) resulted in a substantial initial increase in DPPH antioxidant activity.

9.4. PARTIAL CONCLUSIONS

Pectin coating followed by immersion in solutions containing 1% CaCl2 was effective in controlling weight loss and firmness of fresh-cut pears compared to uncoated samples. The incorporation of 1% N-AC or 1% AA + 1% CA as anti-browning agents in the formulation of chemical treatments after pectin coating helped to protect the content of phenolic compounds and improve the antioxidant activity of fresh-cut pears during storage.

Pectin coating combined with dipping in solution containing 0.2% SB or 0.2% PS and 1% N-AC were the most effective treatments in preserving color and reducing browning index in fresh-cut pears for 12 days of storage at 8 °C. These treatments allowed fresh-cut pears to achieve prolonged storage periods with sensory scores above the threshold of sensory acceptability (3.0) for all attributes evaluated. The results of this study demonstrate that pectin-based edible coatings followed by chemical treatment with the incorporation of 0.2% SB or 0.2% PS as antimicrobials and 1% N-AC as anti-browning agent have the potential to extend the shelf life of freshly cut pears.

CHAPTER 10

EFFECT OF SOME POLYSACCHARIDE-BASED EDIBLE COATINGS ON FRESH WHITE BUTTON MUSHROOMS (Agaricus bisporus) QUALITY DURING COLD STORAGE

10.1. STUDY OPPORTUNITY

The aim of this study was to investigate the effects of edible coatings based on pectin, chitosan, sodium alginate and carboxymethyl cellulose, individually and/or in combination with N-acetyl cysteine as an anti-browning agent, on the quality of white mushrooms during 14 days of refrigerated storage (4 ± 1◦C), measured by weight loss, color change, browning index, degree of cap opening, soluble solids content, total phenolic content and DPPH antioxidant activity. The effects of coatings on MDA content, as an indicator of lipid peroxidation, were also evaluated.

10.2. MATERIALS AND METHODS

Coatings were used with pectin (PE), based on sodium alginate (SA), with chitosan (CH) (2%, w/v), with carboxymethyl cellulose (CMC) (1% w/v). Glycerol 0.5% was added to all coatings as a plasticizer (w/v) after cooling them to room temperature (~20 °C). An aqueous crosslinking solution of 1% calcium chloride was

prepared. Antibrowning agent (N-AC, 1% w/v) was incorporated into the coating solutions. The treatments presented in Table 10.1 were carried out.

Table 10.1. Treatment formulations and codes

Treatments	Components
C	Distiled water (control)
TP0	2% PE + 1% $CaCl_2$
TP1	2% PE + 1% $CaCl_2$ + 1% N-AC
TC0	2% CH + 1% $CaCl_2$
TC1	2% CH + 1% $CaCl_2$ + 1% N-AC
TA0	2% SA + 1% $CaCl_2$
TA1	2% SA + 1% $CaCl_2$ + 1% N-AC
TM0	2% CMC + 1% $CaCl_2$
TM1	2% CMC + 1% $CaCl_2$ + 1% N-AC

Weight loss, color, browning index, percentage of open caps, soluble solids content, total phenolic content, DPPH antioxidant activity and MDA content were evaluated on day 1, 7 and 14 during storage. The experiment was repeated three times and each determination was run in triplicate within each experiment.

10.3. RESULTS AND DISCUSSIONS

Table 10.2 illustrates the loss of moisture content in mushrooms over time, depending on the treatment applied.

At the end of the storage period, the highest level of weight loss was observed in the control samples (34.13%) and the lowest level was observed in the samples coated with sodium alginate (22.37%).

Table 10.2. Effects of treatments on weight loss (%) of button mushrooms during storage for 14 days at 4 ± 1 °C. Data are presented as means ± SD

Treatments	Storage time (days)		
	1	7	14
C	3.89 ± 0.21^{fA}	19.94 ± 0.11^{gB}	34.13 ± 0.18^{fC}
TP0	2.76 ± 0.13^{dA}	13.60 ± 0.08^{dB}	32.71 ± 0.95^{eC}
TP1	2.43 ± 0.09^{bcA}	12.92 ± 0.38^{cB}	29.73 ± 0.98^{dC}
TC0	3.27 ± 0.19^{eA}	14.85 ± 0.66^{fB}	29.61 ± 1.26^{dC}
TC1	2.28 ± 0.14^{bA}	16.40 ± 0.67^{eB}	31.15 ± 1.48^{deC}
TA0	1.97 ± 0.06^{aA}	10.82 ± 0.39^{aB}	22.37 ± 1.06^{aC}
TA1	2.54 ± 0.12^{cdA}	11.74 ± 0.46^{bB}	25.04 ± 1.32^{bC}
TM0	2.47 ± 0.08^{bcA}	14.24 ± 0.57^{deB}	27.89 ± 1.21^{cC}
TM1	2.27 ± 0.10^{bA}	14.09 ± 0.45^{deB}	28.73 ± 0.96^{cC}

Different lowercase letters indicate significant differences between treatments ($p < 0.05$) for the same storage period, while different uppercase letters indicate significant

differences between sampling times for the same treatment ($p < 0.05$). C – distilled water (control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC.

The browning index (BI) gradually increased during storage in both control and edible coating samples. At the end of the 14-day storage period, the lowest BI values were found in the samples coated with sodium alginate (22.05) and those coated with pectin (22.44).

The percentage of cap opening increased in all samples during the storage period; the highest level of cap opening was found in uncoated samples (62.67% after 14 days of storage) (Table 10.3).

Table 10.3. Effect of treatments on percentage of cap opening (%) of button mushrooms during storage for 14 days at 4 ± 1 °C. Data are presented as means ± SD

Treatments	Storage time (days)	
	7	14
C	29.41 ± 1.22^{h}	62.67 ± 2.88^{h}
TP0	16.67 ± 0.69^{de}	37.50 ± 1.45^{f}
TP1	17.65 ± 0.83^{ef}	46.67 ± 1.89^{g}
TC0	11.50 ± 0.56^{b}	22.22 ± 0.87^{c}
TC1	15.38 ± 0.87^{d}	27.27 ± 1.09^{d}
TA0	9.52 ± 0.36^{a}	15.79 ± 0.66^{a}
TA1	13.68 ± 0.58^{c}	18.75 ± 0.76^{b}
TM0	18.87 ± 0.88^{fg}	31.25 ± 1.25^{e}
TM1	19.18 ± 0.82^{g}	35.00 ± 1.18^{f}

Different lowercase letters indicate significant differences between treatments ($p < 0.05$) for the same storage period, while different uppercase letters indicate significant differences between sampling times for the same treatment ($p < 0.05$). C – distilled water (control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC.

TSS showed an upward trend during the storage period (Table 10.4) in all samples. Coated samples showed significantly lower TSS levels ($p < 0.05$) compared to controls, both after 7 and 14 days of storage. The lowest level of TSS change was observed in the samples coated with sodium alginate, followed by the samples coated with pectin and chitosan.

Table 10.4. Effect of treatments on total soluble substance content (%) of button mushrooms during storage for 14 days at 4 ± 1 °C. Data are presented as means ± SD

Treatments	Storage time (days)		
	1	7	14
C	4.68 ± 0.18^{aA}	9.88 ± 0.44^{dB}	14.68 ± 0.56^{fC}
TP0	5.04 ± 0.29^{bA}	7.70 ± 0.37^{bB}	10.24 ± 0.59^{bC}
TP1	5.22 ± 0.27^{bA}	8.28 ± 0.41^{cB}	10.96 ± 0.36^{bcC}
TC0	5.14 ± 0.23^{bA}	7.72 ± 0.83^{bB}	12.12 ± 0.48^{dC}
TC1	5.04 ± 0.24^{bA}	7.66 ± 0.42^{bB}	11.46 ± 0.42^{cdC}
TA0	5.28 ± 0.22^{bA}	6.44 ± 0.35^{aB}	8.46 ± 0.36^{aC}
TA1	5.08 ± 0.31^{bA}	6.66 ± 0.22^{aB}	7.74 ± 0.13^{aC}
TM0	5.12 ± 0.16^{bA}	7.44 ± 0.22^{bB}	11.98 ± 1.24^{dC}
TM1	5.20 ± 0.20^{bA}	7.74 ± 0.23^{bcB}	13.20 ± 0.45^{eC}

Different lowercase letters indicate significant differences between treatments ($p < 0.05$) for the same storage period, while different uppercase letters indicate significant differences between sampling times for the same treatment ($p < 0.05$). C – distilled water (control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC.

The total content of phenolic compounds in coated button mushrooms and in the control during 14 days of storage at 4 ± 1 ◦C is shown in Table 10.5. The initial total content of phenolic compounds in mushrooms was 45.28 mg GAE/100 g. The results show an increasing trend in the accumulation of phenolic compounds in mushrooms in all samples. The highest total content of phenolic compounds was identified in the samples coated with pectin, which was significantly ($p < 0.05$) higher than in the other coated samples.

Table 10.5. Effects of treatments on the total content of phenolic compounds (mg GAE/100 g) in button mushrooms during storage for 14 days at 4 ± 1 °C. Data are presented as means ± SD

Treatments	Storage time (days)		
	1	7	14
C	46.67 ± 1.65^{aA}	54.00 ± 1.48^{aB}	65.33 ± 2.89^{aC}
TP0	46.85 ± 2.03^{aA}	67.67 ± 2.33^{dB}	83.33 ± 3.86^{eC}
TP1	47.00 ± 1.58^{aA}	82.33 ± 3.66^{eB}	99.33 ± 4.26^{fC}
TC0	45.88 ± 1.55^{aA}	57.23 ± 1.62^{bB}	77.33 ± 3.67^{cdC}
TC1	47.67 ± 2.08^{aA}	58.33 ± 2.44^{bB}	80.33 ± 3.46^{deC}
TA0	46.85 ± 1.28^{aA}	58.33 ± 1.88^{bB}	71.67 ± 2.56^{bC}
TA1	47.25 ± 1.72^{aA}	59.09 ± 2.76^{bB}	72.22 ± 2.96^{bcC}
TM0	47.06 ± 1.02^{aA}	63.42 ± 2.34^{cB}	72.67 ± 2.85^{bcC}
TM1	47.67 ± 0.89^{aA}	63.33 ± 1.78^{cB}	72.88 ± 2.56^{bcC}

Different lowercase letters indicate significant differences between treatments ($p < 0.05$) for the same storage period, while different uppercase letters indicate significant differences between sampling times for the same treatment ($p < 0.05$). C – distilled water

(control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC.

Mushrooms treated with edible coatings showed significantly ($p < 0.05$) higher antioxidant activity compared to uncoated samples at the end of the storage period (Table 10.6).

On the 14th day of storage, pectin-coated mushrooms incorporating 1% N-AC showed the highest antioxidant activity (1.59 mmol Trolox/100 g).

Table 10.6. Effects of treatments on DPPH antioxidant activity (mmol Trolox/100 g) of button mushrooms during storage for 14 days at 4 ± 1 °C. Data are presented as means ± SD.

Treatments	Storage time (days)		
	1	7	14
C	0.65 ± 0.02^{aA}	0.85 ± 0.03^{aB}	0.95 ± 0.03^{aC}
TP0	0.92 ± 0.03^{eA}	1.14 ± 0.04^{dB}	1.38 ± 0.06^{fC}
TP1	0.84 ± 0.04^{dA}	1.16 ± 0.05^{dB}	1.59 ± 0.06^{gC}
TC0	0.73 ± 0.03^{cA}	1.00 ± 0.04^{bB}	1.25 ± 0.06^{eC}
TC1	0.92 ± 0.04^{eA}	1.09 ± 0.06^{cdB}	1.23 ± 0.06^{deC}
TA0	0.67 ± 0.03^{abA}	1.00 ± 0.04^{bB}	1.14 ± 0.04^{bcC}
TA1	0.71 ± 0.03^{bcA}	1.04 ± 0.04^{bcB}	1.18 ± 0.04^{cdeC}
TM0	0.79 ± 0.03^{dA}	1.09 ± 0.04^{cdB}	1.16 ± 0.05^{bcdB}
TM1	0.83 ± 0.03^{dA}	1.06 ± 0.03^{bcB}	1.08 ± 0.04^{bB}

Different lowercase letters indicate significant differences between treatments ($p < 0.05$) for the same storage period, while different uppercase letters indicate significant differences between sampling times for the same treatment ($p < 0.05$). C – distilled water (control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC.

MDA increased gradually in all samples during the 14 days of storage. However, the control samples showed large increases in MDA content, while the treatments effectively delayed the generation of MDA during storage, as shown in Figure 10.1.

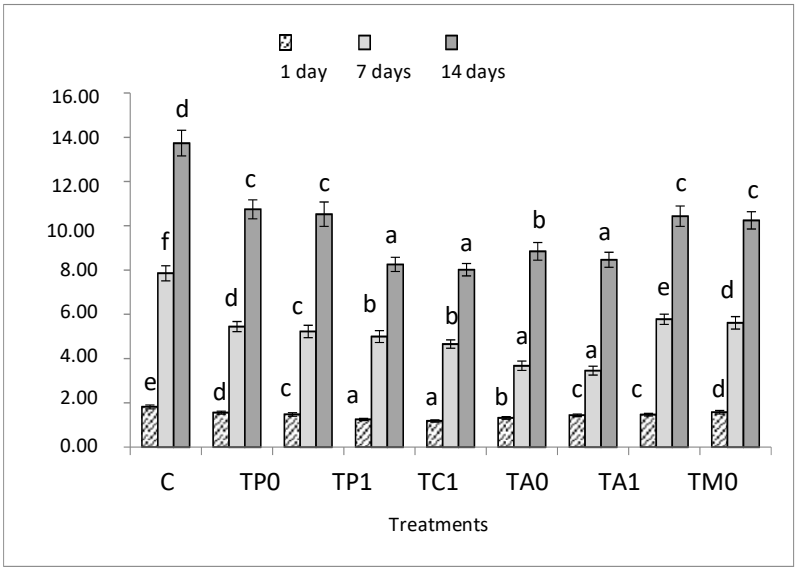


Figure 10.1. Effect of coating treatments on MDA (malondialdehyde) content (µmol Trolox/kg) of button mushrooms during storage for 14 days at 4 ± 1 °C. Different lowercase letters indicate significant differences between treatments for the same storage period ($p < 0.05$). C – distilled water (control); TP0 – 2% PE + 1% CaCl2; TP1 – 2% PE + 1% CaCl2 + 1% N-AC; TC0 – 2% CH + 1% CaCl2; TC1 – 2% CH + 1% CaCl2 + 1% N-AC; TA0 – 2% SA + 1% CaCl2; TA1 – 2% SA + 1% CaCl2 + 1% N-AC; TM0 – 2% CMC + 1% CaCl2; TM1 – 2% CMC + 1% CaCl2 + 1% N-AC

mushrooms compared to the control. The most effective in controlling weight loss was sodium alginate, followed by carboxymethylcellulose, chitosan and pectin. Coatings based on sodium alginate and pectin were most effective in slowing browning of mushrooms during storage. The total content of phenolic compounds and antioxidant activity increased in mushrooms during storage, and the coated samples showed significantly higher values compared to the control. The highest total phenolic content was found in pectin-coated samples, followed by chitosan-coated samples. The MDA content gradually increased in all samples during the 14 days of storage, but the increase was delayed in the coated samples relative to the control. Chitosan coating was the most effective in slowing down the increase in MDA content, but caused a severe reduction in L* values and an increase in browning index of button mushrooms throughout storage. Addition of N-acetylcysteine to edible coatings caused a significant increase in cap opening and browning index of all coated samples, and did not cause significant changes in the evolution of MDA content compared to samples without anti-browning agent. The results demonstrate the feasibility of using sodium alginate and pectin coatings to extend the shelf life of button mushroom

CHAPTER 11

FINAL CONCLUSIONS

→ The use of organic acids and acid electrolysed water offers interesting possibilities for extending the shelf life and quality of minimally processed and freshly cut fruits;

→ Immersion in organic acids of fresh fruit serves to complement or replace traditional preservation methods. The use of this preservation method has shown promising results in reducing microbial development and microbial metabolic rate, delaying the ripening process and extending the shelf life of fresh fruit. Immersion in organic acids helps to maintain the desired quality characteristics of fresh fruit;

→ The development of new techniques to improve the marketable properties of fresh fruit immersed in antimicrobial substances is an important concern for future research;

→ Research carried out on blueberries showed that immersion in acid solutions caused a significant increase in moisture loss, the weight loss of control samples being significantly lower than in the case of chemically treated samples (sorbic acid > benzoic acid > citric acid > water) . Conversely, dipping peaches in citric, benzoic, and sorbic acid reduced fruit weight loss during 28 days of cold storage;

→ Citric (2%), sorbic (0.2%) or benzoic (0.2%) acids can slow down the enzyme activity, thus controlling the action of polyphenoloxidase on the content of polyphenols in the presence of oxygen. Thus, the total phenolic content of fruits (blueberries and peaches) and antioxidant activity increased continuously during storage, the highest phenolic content being found in fruits immersed in 0.2% sorbic acid. The 0.2% benzoic acid treatment was found to be the most effective in maintaining the physico-chemical characteristics of peaches under refrigerated storage conditions;

→ The use of preservative organic acids, in combination with the action of low temperature, slowed down the development of the microbial flora on the fruit surface (blueberries and peaches) as a result of inhibiting the metabolic activity of microorganisms due to the low pH;

→ Research on strawberries showed that washing with 2% citric acid, 0.2% benzoic acid, 0.2% sorbic acid and acid electrolysed water delayed physiological collapse of fruit during storage, slowing water loss and loss of firmness. In addition, the sanitizing treatments maintained at a higher level the phenolic, anthocyanin content and antioxidant activity, the most effective being the treatments with benzoic acid and sorbic acid;

→ UV irradiation of fresh strawberries significantly reduced water loss, maintained firmness, and delayed the onset of fruit decay symptoms during cold

storage. In addition, UV treatment alone promoted the accumulation of phenolic compounds and increased the antioxidant activity of strawberries;

→ The use of immersions in acid solutions and acid electrolyzed water before UV treatment significantly reduced the postharvest degradation of strawberries (benzoic acid 0.2% > sorbic acid 0.2% > citric acid 2%) and was more effective in maintaining the content of phenolic compounds and the antioxidant capacity of fruits in relation to the UV treatment applied singularly;

→ Postharvest treatments of strawberries with organic acids followed by UV irradiation can be a useful way to maintain strawberry fruit quality and extend their postharvest life;

→ Freshly cut fruits and vegetables are convenient, ready-to-eat products that offer consumers a multitude of benefits. However, the development of new technologies to maintain quality and extend their shelf life is a major challenge for the food industry and a topic for future research;

→ The use of edible coatings allows the incorporation of additives such as antimicrobials and anti-tanning agents, while increasing their effectiveness, thus also contributing to better consumer acceptance;

→ Immersion in acidic electrolyzed water or 2% citric acid solution improved the keeping ability of fresh-cut apples by inhibiting browning and microbial growth and by reducing the loss of firmness, total phenolic content and antioxidant activity during storage. Acidic electrolysed water was more effective than citric and ascorbic acids in controlling enzymatic browning of fresh-cut apples;

→ Edible pectin-based coatings made with the incorporation of 0.2% sodium benzoate or 0.2% potassium sorbate as antimicrobials and 1% N-acetyl cysteine as an anti-browning agent have shown potential in extending the shelf life of fresh-cut pears. They were effective in controlling weight loss and firmness of fresh-cut pears, protected the content of phenolic compounds and improved the antioxidant activity of fresh-cut pears during storage;

→ Sodium alginate and pectin coating were most effective in slowing the browning process of mushrooms during storage and delayed weight loss and cap opening in mushrooms. Although chitosan coating was the most effective in retarding lipid oxidation, it caused an increase in browning index of button mushrooms throughout storage. Although a very effective anti-browning agent in other applications, N-acetylcysteine added to edible coatings applied to mushrooms caused a significant increase in cap opening and browning index of all coated samples;

→ The use of edible coatings can be considered a safe and effective treatment, resulting in good preservation of most quality parameters, without significantly affecting the nutritional value of fresh and freshly cut fruits and vegetables. The use of edible coatings can help improve product safety and extend shelf life. In addition, coatings can be used to incorporate active/functional ingredients (antimicrobials, anti-tan agents, antioxidants, enzymes) to help extend the life of coated products;

→ It can be concluded that there are many technologies for reducing/eliminating microorganisms present on fresh and freshly cut fruits and vegetables. The correct use of these techniques will allow an increase in the safety of minimally processed products. However, none of the sanitation methods can control all the parameters that maintain the quality and shelf life of these products. Therefore, the development of additional studies using combined methods is required to expand and enhance the safety of this type of products.

CHAPTER 12

CONTRIBUTIONS AND PROSPECTS FOR FURTHER RESEARCH

Minimal processing is a growing processing method that provides consumer convenience, "freshness", quality, nutrition and safety. Because it involves removing or reducing natural barriers to spoilage, minimal processing presents scientists with an enormous challenge in trying to extend the shelf life of minimally processed fresh products. However, consumer demand for minimally processed products, changes in consumer perception of freshness and quality of fresh products, and the convenience of such products warrant further research and development in this area. For this, a deeper understanding of the physiology and biochemistry of plant products used for minimal processing is essential, and more research is needed on post-harvest treatments and shelf-life extension methods applied to different fruits and vegetables and even to different varieties.

The fresh-cut produce industry is expected to continue to expand rapidly in the future and is still in urgent need of improved technologies to extend the shelf life of produce. Extending the shelf life of fresh and freshly cut products, without compromising sensory and nutritional qualities, can sometimes be achieved by the correct combination of several appropriate techniques.

Considering these objectives, during the research developed in the framework of this doctoral thesis, studies were carried out on the effectiveness of a) surface treatments with aqueous solutions of organic acids (citric, benzoic, sorbic, ascorbic) and acid electrolyzed water as antimicrobial agents and anti-browning, sometimes combined with UV-C irradiation, and b) edible coatings incorporating organic acids and anti-browning agents, to improve the quality of fresh and freshly cut fruits and vegetables and to extend their shelf life.

The originality of the research carried out, in accordance with the scientific objectives of the doctoral thesis, is realized through a series of novel elements, which increase the scientific value of the studies carried out. Based on the original experimental results obtained in the thesis, the following can be highlighted as scientific contributions:

→ Investigation of the effects of post-harvest treatments with organic acids (citric, sorbic and benzoic) on the physicochemical, biochemical and microbiological changes of fresh blueberries and peaches during refrigerated storage;

→ Study of the effects of washing treatments with organic acids and acid electrolyzed water on quality characteristics, bioactive compounds content and antioxidant activity of strawberries during refrigerated storage;

→ Study of the effects of post-harvest chemical treatments combined with UV-C irradiation on strawberry fruit quality characteristics, bioactive compounds content and antioxidant activity during refrigerated storage;

→ Investigation of the effects of immersion in solutions of organic acids (citric, benzoic, sorbic, ascorbic) and in acid electrolyzed water on the quality characteristics of freshly cut apples packed in plastic containers under normal atmospheric conditions during refrigerated storage;

→ Development of edible pectin-based coatings combined with chemical treatments containing potassium sorbate or sodium benzoate as antimicrobials and N-acetyl cysteine or ascorbic acid + citric acid as anti-browning agents to maintain the quality of fresh-cut pears during refrigerated storage;

→ Development of edible coatings based on pectin, chitosan, sodium alginate and carboxymethyl cellulose, single or active, incorporating N-acetyl cysteine as an anti-browning agent, for maintaining the quality of white mushrooms during refrigerated storage.

The outcome of this study constitute a scientific database that can be the starting point for continuing research on the use of post-harvest chemical treatments, single or combined with UV irradiation, as well as active edible coatings to extend the shelf life and capacity marketing of fresh and freshly cut fruits and vegetables.

The results obtained indicated that some of the studied treatments play an effective role in controlling weight loss, degradation percentage, color evolution and have a favorable effect on other compositional changes (titratable acidity, total content of soluble substances, polyphenols, anthocyanins and antioxidant activity) of fresh and freshly cut fruits and vegetables stored under refrigerated conditions, thus proving that they have the potential to extend their shelf life while maintaining their nutritional quality.

Nevertheless, further studies are needed on the development of microorganisms as well as the physiological mechanisms that contribute to the preservation of quality in relation to these combined treatments. More research is also needed to exploit the practical protective advantages of these new technologies for a variety of fruits and vegetables by understanding their physiology and minimizing unwanted side effects.

Carrying out advanced research on the coating of fruits with different coating materials or different combinations of edible films incorporating combinations of active/functional ingredients (additives, antimicrobial agents), determining the thickness and barrier properties of the films/coatings, the food safety of the products coated, could be alternative research areas for improving the coating effect of fresh and freshly cut fruits and vegetables. Also, future research should aim to determine the additive, antagonistic or synergistic effects of treatments with antimicrobial agents, anti-browning agents, irradiation and edible coatings when they are used in combination.

CHAPTER 13

DISSEMINATION OF THE RESEARCH RESULTS CARRIED OUT ON THE THEME OF THE DOCTORAL THESIS

Articles/studies published in ISI listed journals

1. **Plesoianu, A.M.**, Nour, V. 2022. Effect of Some Polysaccharide-Based Edible Coatings on Fresh White Button Mushroom (Agaricus bisporus) Quality during Cold Storage. Agriculture, 12, 1491. https://www.mdpi.com/2077-0472/12/9/1491 (IF = 3.408), JCR - Q1 (*Agronomy*)

2. **Plesoianu, A. M.**, Nour V. 2022. Pectin-Based Edible Coating Combined with Chemical Dips Containing Antimicrobials and Antibrowning Agents to Maintain Quality of Fresh-Cut Pears. Horticulturae, 8, 449. https://doi.org/10.3390/horticulturae8050449 (IF = 2,923) JCR - Q1 (*Horticulture*)

3. Nour, V., **Plesoianu, A. M.**, Ionica M.E. 2021. Effect of dip wash treatments with organic acids and acidic electrolyzed water combined with ultraviolet irradiation on quality of strawberry fruit during storage. Bragantia, 80, e1921, https://doi.org/10.1590/1678-4499.20200440 (IF=1,179) (JCR - Q2 (*Agricultural and Biological Sciences*)

4. **Plesoianu, A. M.**, Nour, V., Tutulescu, F., Ionica M.E. 2021. Quality of fresh-cut apples as affected by dip wash treatments with organic acids and acidic electrolyzed water. Food Science and Technology, https://doi.org/10.1590/fst.62620 (IF=1,718)

5. **Plesoianu, A. M.**, Tutulescu, F., Nour, V. 2020. Postharvest antimicrobial treatments with organic acids to improve the shelf life of fresh blueberries. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 48(1), 90-101. https://doi.org/10.15835/nbha48111828

Articles/studies published in ISI emerging journals

1. Ionică M., **Pleșoianu A.M.**, Nour V. 2022. Effect of Some Sanitizing Treatments on Strawberry Fruit Quality during Cold Storage. Bulletin of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology, 79(1), 51-60, https://journals.usamvcluj.ro/index.php/fst/article/view/14411

Articles/studies published in journals indexed in BDI international databases

1. **Plesoianu A.M.**, Nour V., Tutulescu F. 2019. Effect of benzoic, sorbic and citric acid treatments on physicochemical and quality characteristics of peach fruits during cold storage. Analele Universităţii din Craiova, seria Biologie, Horticultură, Tehnologia Prelucrării Produselor Agricole, Ingineria Mediului, vol. XXIV (LX), 179-185.
https://horticultura.ucv.ro/horticultura/sites/default/files/horticultura/Reviste/Analele/2019/anale_2019_fh.pdf

2. **Plesoianu A.M.**, Tutulescu F., Nour V. 2019. The effect of certain preservative substances on the microorganisms found on the fruit surface. Analele

Universităţii din Craiova, seria Biologie, Horticultură, Tehnologia Prelucrării Produselor Agricole, Ingineria Mediului, vol. XXIV (LX), 173-178. https://horticultura.ucv.ro/horticultura/sites/default/files/horticultura/Reviste/Analele/2019/anale_2019_fh.pdf

Papers presented at international scientific sessions

1. **Plesoianu A.M.**, Tutulescu F., Nour V. 2020. Quality of fresh-cut apples as affected by dipping in organic acids and acidic electrolyzed water. Scientific Conference of Doctoral Schools. SCDS-UDJG 2020, The 8th Edition, Galaţi, 18th-19th of June 2020.

2. **Plesoianu A.M.**, Ionica M., Nour V. 2021. Effect of dip wash treatments with organic acids and acidic electrolyzed water combined with ultraviolet irradiation on the quality of strawberry fruit during storage. Scientific Conference of Doctoral Schools. SCDS-UDJG 2021, The 9th Edition, Galaţi, 10th-11th of June 2021.

3. **Plesoianu A.M.**, Nour V. 2022. Pectin edible coating combined with chemical dips containing antimicrobials and antibrowning agents to maintain quality and antioxidant properties of fresh-cut pears. Scientific Conference of Doctoral Schools. SCDS-UDJG 2022, The 10th Edition, Galaţi, 9th-10th of June 2022.

4. **Plesoianu A.M.** Pectin edible coating combined with chemical dips containing antimicrobials and antibrowning agents to maintain quality and antioxidant properties of fresh-cut pears. 88 International scientific conference of young scientist and students "Youth scientific achievements to the 21st century nutrition problem solution“, April 15-16, 2022, National University of Food Technologies, Ukraine, Kiev

5. **Plesoianu A.M.**, Tutulescu F., Nour V. 2020. Postharvest antimicrobial treatments with organic acids to improve the shelf life of fresh blueberries. EuroMicropH 1st Open Meeting, COST Action CA18113: Understanding and Exploitation the Impacts of Low pH on Micro-organisms, 12th-14th February, 2020, Lisbon, Portugal

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