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# Ozonation Technique Effect on Horticultural Products Quality: A Review

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**ABSTRACT**

Fruit and vegetables are horticultural products wealthy in water-soluble vitamins and other essential nutrients for human requirements. These products have, however, been shown to contribute to the transmission of various diseases caused by microbial contamination. Ozone is a strong, effective, and safe oxidizing and disinfectant in the handling of horticultural products. The use of ozone can eliminate the contamination of pesticides, bacteria, and heavy metals that stick to the surface of fruit and vegetables to be safe for human consumption. It can also maintain the products' shelf life and quality as the nutritional content is secured and not easily damaged. Due to evaporation, ozone compounds will automatically disappear. If exposed to the sun, ozone will also decompose back into oxygen molecules so that residues are not lost. This brief review discusses the effects of ozone on quality, the ability to reduce microbes, antioxidant activity, pesticides, and the sensory assessment of horticultural products.

**Key words:** Antioxidant, horticultural, microbiology, nutrient, ozone, preservation

## 1. INTRODUCTION

Consumption of horticultural products, vegetables, and fruits has become a trend in the community due to the health benefits that it has after consuming those fresh products. Vegetables and fruits are high in antioxidants, especially phenolic compounds, carotene, and ascorbic acid [1], [2]. Fresh vegetables and fruits are easily damaged due to microbiological and physicochemical factors [3], [4]. These factors can lead to loss of product quality, including nutritional value, reducing health benefits [5], [6]. About 50% of fresh horticultural products in developing countries are not consumed because of postharvest losses [7].

Along with postharvest metabolism of vegetables and fruits, physiological changes cause increased respiration and transpiration rates so that the lost moisture is high [8]. The quality of these fresh products decreased. Significant efforts were made to reduce the level of pre-to postharvest damage to these commodities. Various postharvest treatments, such as chemical treatment [9], low-temperature storage [10], irradiation [11], controlled atmosphere [12], modified atmospheric packaging [13] and coating techniques [14], were done to reduce these losses. Huge steps are, therefore, needed to maintain nutrient content and eliminate pathogenic contaminants in these commodities.

In horticultural products, postharvest handling technology is increasingly developing towards improving storage quality, product safety free from harmful chemical residues, and cost efficiency [15]. The use of ozone can be one of the alternatives for overcoming quality declines. It's because of the ozone's high oxidation potential so that it can be used as a strong disinfectant. Ozone disinfection potential is about 150% stronger than chlorine, a commercial disinfectant. Ozone may change bacterial cell membranes' permeability to be more susceptible than chlorine [16]. Due to its high specificity, it is shown to be the better antimicrobial agent than chlorine dioxide, capable of reducing competitive microflora did lead to *L. monocytogens* growth [17].

Ozone ($O_3$) is a triatomic molecule composed of three oxygen atoms in unstable bonds. A single oxygen atom, which is weakly bound, quickly breaks and reacts with most organic and inorganic molecules of contact [18]. Ozonation (often known as ozonization) is a method of chemical water treatment based on ozone infusion into the water. This technique involves producing highly reactive oxygen species that can attack different organic compounds and microorganisms [19]. Different ozonation related studies have been reported as a pretreatment on fresh commodities before storage. Such as berries [20], raspberries [21], apples [22], [23], papayas [24], black mulberries [25], tomatoes [26], fresh parsley leaves [27], carrots [28], cucumber [29], green leaf lettuce [30]. Microbial activity in ozone makes it an appropriate candidate to control postharvest pathogenic horticulture diseases, and the treated product does not contain any residues [31].

Ozone may be used in the form of gas or ozone may be used in a water solution [32]. It has been proven to reduce microbes in fresh produce. Several factors may affect ozone efficiencies, such as microbial population, exposure time, ozone concentration, type of product, relative humidity, and ingredients used to package the outcome [33]. Ozone is effective in preserving food so that it can enhance the commodities shelf-life. European regulators have decided to use ozone 'Generally Recognized as Safe (GRAS) in the food industry on various aspects [34]. Several studies had been done to investigate the influence of ozone on the quality of horticultural commodities. However, not widely discussed the relationship between these quality parameters. This review will, therefore, discuss ozone, which includes the mechanism and efficacy of ozone and its application in fresh vegetables and fruits. Also, it reviewed the effects of the product's ozone treatment, antioxidant activity, ability to reduce microbes, and organoleptic properties.

## 2. OZONE MECHANISM

Fresh vegetables and fruits are ozonated by spraying and washing to reduce the number of microbes that come into contact with the material surface [35]. Ozone can kill microbes that stick to the product's surface by attacking the cell wall, leading to cell permeability changes. Cells lose cytoplasm and cannot reactivate. Its permeability change causes bacterial cell lysis [36].

Specifically, by attempting to attack glycoproteins and glycolipids in cell membranes, causing cell broken out, ozone destroys bacteria [16], [36]. Moreover, some enzymes' sulfhydryl group disrupts cellular enzymatic activity and functionality [37]. Ozone also attacks purine bases and nucleic acids that damage DNA [38]. Ozone 's antimicrobial capacity includes not only bacteria, but molds, viruses, and protozoa [36]. Ozone can also oxidize metal ions like Fe (II), Mn (II), or As (III), which produce insoluble solid oxides. Thus, filtering or sedimentation can easily separate it from water [39].

## 3. OZONE TREATMENT EFFECTIVENESS

Ozone is an unstable product from the use of powerful energy such as radiation, electricity, or oxygen molecules [40]. Using ozone as a disinfectant in horticultural products proved its efficacy [41]. Ozone is applied directly as gas or its use in aqueous solution. It significantly reduces fresh product microbes [40]–[43]. After exposure to ozone, various types of microbes such as *E. coli, S. typhimurium, L. monocytogenes,* and *Y. enterocolitica* showed significant decreases [36], [44], [45]. Research Fontes et al. [46] stated that low-dose ozone nebulation inhibits the growth of strains of potentially pathogenic bacteria such as *E. coli, S. aureus, E. faecalis, K. pneumoniae,* and *P. aeruginosa*. Ozone exposure for 4 hours with two ppm concentrations was reported in vitro studies [47], which showed a disinfectant influence on *E. coli, S. aureus, S. liquefaciens,* and *L. innocua*. Pereira et al. [48] reported that an $O_3$: $O_2$ gas mixture of 0.4%: 99.6% for one hour could inhibit the growth of *E. coli, S. aureus*, and *P. aeruginosa* on constant pressure and flow and controlled temperature. Broadwater et al. [49] specify the minimum dose of water-dissolved ozone necessary to eliminate the growth of three bacteria species when applied for 5 minutes. Results showed that 0.12 mg/ L of ozone was deadly to *B. cereus*; and 0.19 mg/ L for *B. megaterium* and *E. coli*.

Factors affecting ozone efficiency consist of microbial population, exposure time, ozone concentration, type of product, relative humidity, and material used to package the outcome [33], [50]. The ozone oxidation potential is 2.07 volts, nearly doubling chlorine oxidation potential [36]. Ozone is quite bactericidal, even at deficient concentrations of 0.01 ppm [36], [51]. The half-life of ozone in distilled water is around 20 to 30 minutes at 20 ° C before being converted back into oxygen molecules [36], [52]. Ozone gas is also more stable, with a half-life of about 12 hours of atmospheric air. Temperature, pH, and ozone oxidation influence the rate of ozone decomposition and half-life [36].

Ozone-containing water can wash vegetables and fruits until sterile, without removing color, aroma, or damage to essential compounds in vegetables and fruits. Thus, obtained vegetables and fruits that are safe for consumption and still have nutritional value can maintain freshness and extend their shelf-life [51], [53], [54]. Preserving vegetables and fruits with ozone does not damage nutritional content, as evaporation will lose the ozone content itself [34]. Ozone, if exposed to sunlight, will break down into oxygen molecules too [40].

## 4. THE OZONE EFFECT ON HORTICULTURAL PRODUCTS

### 4.1 Ozone Effect on Horticultural Products Quality

Ozone techniques were widely applied to improving the quality of vegetables and fruits from postharvest. Ali et al. [24] fumigate papaya fruit ozone from 1.5 to 5.0 ppm; 96 hours before storage. Results showed that 2.5 ppm ozone concentration could maintain papaya quality at 25 °C with 70% relative humidity during 14 days of storage. Li et al. [55] study also obtained the same concentration to maintain Chinese winter jujube quality. At the same time, Glowacz and Rees [56] use an optimal ozone level of 0,9 µmol/ mol to extend the chili shelf life. Table 1 shows, in general, various studies relating to the impact of ozone on vegetable and fruit quality during storage.

**Table 1:** Ozone Effect on Horticultural Products Quality

| Commodity | Ozone Treatment | Efficacy | Ref. |
|---|---|---|---|
| Papaya | 1.5 to 5.0 ppm concentration of ozone. Papaya is used as a control without ozone treatment. The | Papaya fruit treated to 2,5 ppm ozone had a higher level of total soluble solids, β-carotene content, | [24] |

| Commodity | Ozone Treatment | Efficacy | Ref. |
|---|---|---|---|
| | exposure time of ozone 96 hours before storage. Store conditions, temperature 25±3 °C; RH 70±5%; storage time 14 days | lycopene content, antioxidant activity, and a minimized weight loss compared to the control on day ten. | |
| | Ozone exposure in the water of 1.5 to 3.0 mg/ L for 5 minutes on Chinese winter jujube | Ozone treatment at a concentration of 2.5 mg/ L can maintain firmness, titrable acidity, ascorbic acid, total soluble solid, inhibit discoloration, and maturity compared to non-ozonation | [55] |
| Chili peppers | Ozone exposure at a concentration of 0.45; 0.9 and 2.0 µmol/ mol for changes in the quality of red and green chili peppers at a storage temperature of 10 °C | Ozone exposure at 0.9 µmol/ mol can reduce red chili disease, reduce weight loss in green chili, increase firmness during storage, and extend chili shelf life | [33] |
| Citrus | Continuous and intermittent exposure to ozone in 6 citrus varieties; ozone gas concentration 1.6 to 60 mg/ kg; at 5 °C for 28 days and the next shelf life at 20 °C for 15 days | Ozone may inhibit *P. digitatum* and *P. italicum* growth. *P. italicum*'s lag phase in citrus under ozone is three times higher than in air; exposure to ozone in citrus fruits can reduce spoilage during cold storage. Besides ozone, the development of red in citrus can also be delayed | [57] |
| Carrots | Fresh carrots: water ozonation 0.5 w/ v; 200 mg $O_3$/ h for 10 min. Stored at 6 °C and 85% RH for up to 30 days, under controlled atmosphere $CO_2$: $O_2$: $N_2$ 5%: 2%: 93%, respectively | Fresh carrots washed with ozone water and stored under controlled atmospheric conditions, significantly lower lignification, PPO and POD activity and maintain discoloration. The combination of ozonation and controlled atmosphere limits microbe growth during storage to maintain the quality of carrot freshness | [58] |
| Kiwifruit | Ozone used in constant flow at 300 ppb in 9 $m^3$ cold place well-kept at 2 and 4 °C with 85% RH for 60 days | Ozone treatment may induce maturation. High dissolved solids in ozone-containing fruits at 2 °C and 4 °C storage prove it. Low-temperature storage can delay microbial growth to maintain fruit quality better | [59] |

### 4.2 Ozone Effect on Microorganisms Activity

Ozone treatment reduces *L. innocua* in red peppers, total mesophilic in strawberries, and total coliform in watercress [60]. Ozone with a minimum concentration of 5 ppm for 1 hour may reduce dates for Coliform and S. aureus, while longer exposure times may eliminate total mesophilic bacteria and fungi [61]. Glowacz and Rees, [56] red peppers treated with 0.9 µmol/ mol ozone, can prevent spoilage during seven days of storage. According to Chauhan et al. [58], ozone in fresh-cut carrots can minimize microbial decontamination 1–2 log cycles. Combining ozonation processes and controlled atmospheric storage can control microbial lignification and carrot sticks decay. Various ozone studies to reduce microbial growth Showed in Table 2.

**Table 2:** Ozone Effect on Microorganisms Activity

| Commodity | Ozone Treatment | Efficacy | Ref. |
|---|---|---|---|
| Date | Ozone was used in gas with concentrations 1, 3, and 5 ppm for 15, 30, 45, and | Reduced total of mesophilic microorganisms , coliforms, and yeast/mold | [61] |

| Commodity | Ozone Treatment | Efficacy | Ref. |
|---|---|---|---|
| | 60 min. | count | |
| Red bell, Strawberries, and Watercress | The ozone was exposed by the bubble method at 15 °C to three different times (1, 2, and 3 min.) | Reduced *L. innocua* in red bell peppers, total mesophilic in strawberries, and total coliforms in watercress | [60] |
| Carrots | Fresh carrots: water ozonation 0.5 w/ v; 200 mg $O_3$/ h for 10 min. Stored at 6 °C and 85% RH for up to 30 days, under controlled atmosphere $CO_2$: $O_2$: $N_2$ 5%: 2%: 93%, respectively | Controlling in the microbial spoilage of carrot sticks (minimized plate count 1–2 log cycle) | [58] |
| Papaya | Ozone 9.2 µL/ L for 10, 20, and 30 min. | Decreased total of coliforms and mesophilic bacteria | [62] |

### 4.3 Ozone Effect on Antioxidant Activity

Glowacz and Rees [56] show that ozone treatment is appropriate for red peppers to prevent microbiological damage, but can maintain total phenolic content and antioxidant activity. Likewise, in green chili, which showed no significant differences in antioxidant activity until the end of storage 14 days after receiving 2.0 µmol/ mol ozone treatment. Tomatoes exposed to ozone at a concentration of 1.0 µmol/ mol for six days showed no changes in antioxidant activity in the tissue [63]. Ali et al. [24] study in papaya treated with 2.5 ppm ozone treatment showed that DPPH radical scavenging activity increased 6.3% on day ten compared to controls. In comparison, ozone exposure is 1.5-3.5 ppm, ferric reduction activity increases 0.03%-21.9% after ten days of storage. Increased antioxidant activity correlates positively with total phenolic content [64]–[66], but not with fruit ascorbic acid content [24]. Monaco et al. [67] report that ozonation water can maintain higher antioxidant activity, quality, and manga shelf-life. Various studies have investigated the association of ozone on antioxidant properties in horticultural commodities are shown in Table 3.

**Table 3:** Ozone Effect on Antioxidant Activity

| Commodity | Ozone Treatment | Efficacy | Ref. |
|---|---|---|---|
| Kiwifruit | Ozone 0.3 µL/ L and later could ripen at a higher temperature (20 °C) | Ozone treatment can stimulate antioxidant activity, which plays a role in scavenging DPPH-free radicals and reducing ferric ions. Also, it can increase ascorbic acid and total phenolic in kiwifruit after one-day storage | [68] |
| Tomato | Gaseous ozone 0.9 and 2.5 mg/L for 30 and 120 min, stored for 15 days at 12±1 °C | Increased antioxidant activity (DPPH radical scavenging activity), decreased weight loss during storage, and improved quality characteristics to extend tomato storage durability | [69] |
| Lettuce, spinach, and parsley | Water ozonated 12 mg/ L and chlorinated for 20 min. | Produces a 1.0-1.5 log reduction in the number of *E. coli* and *L. innocua* microorganisms, but a loss in antioxidant activity, essential bioactive compounds, total phenolic content, and ascorbic acid occurs | [70] |
| Pepper | Gaseous ozone 2 mg/ L for 1 and 3 hours. With controlled storage conditions | The highest level of flavonoid was obtained in ozone-treated peppers for 3 hours; 10 days of storage. The most top total phenolic content was achieved while ozonating for 1 hour and storing for 20 days. High total phenolic content indicates high anti-radical activity | [71] |

### 4.4 Ozone Effect on Pesticide Content

Ozone treatments are more significant and useful than washing the fruits and vegetables with water and antiseptic solution to eliminate tomato pesticides. The most effective treatment for the removal of all pesticides was tomatoes placed in water bubbled with 3 mg/ L of ozone, reducing 70 to 90 % of the compounds. It was due to the response between ozone and pesticide compounds [26].

Ozone water on tomato was processed into *R. solanacearum* in other previous studies. The results showed that the surviving *R. solanacearum* count was 2.49, 1.99, 1.71, 0.86, and 0.00 log after 1 min with ozone dose 0.0, 0.2, 0.4, 0.6, and 0.8 mg/ L respectively. Log reduction was elevated when the concentration of ozone water increased. It was lower than the control value. So, it can be suggested that the best way to prevent pathogen (*R. solanacearum*) was to treat ozone water in tomatoes at 0.8 mg/ L—moreover, the number of bacteria, declining with the rising concentration of ozone water [72].

### 4.5 Ozone Effect on Sensory Evaluation

After a 12 day storage period, sensory assessment of ozone-treated papaya exposed to 2,5 ppm indicated an improvement in sensory characteristics such as sweetness and texture [24]. Nevertheless, after eight days of ozone treatment 25 to 30 ppm, black spots appeared on bananas [73]. Moreover, the sensory evaluation was not affected by the ozone-treated, as samples stored for four weeks did not notice abnormal changes in flavor [57]. Nadas et al. [74] reported 1.5 mg/ kg ozone treatment in strawberries, after two days of 20 $^{o}$C storage, can eliminate the distorted odor.

The storage period must be controlled because the processing of ozonation caused physiological damage due to the oxidizing activities [35]. Ozone treatment at the appropriate concentration can, therefore, be used to sterilize and preserve the product in such a way that quality and shelf life can be improved [75], [76].

## 5 CONCLUSION

Using ozone with the right concentration and exposure time has proved effective in improving the quality of horticultural products in terms of physicochemical, microbiological, nutritional, and organoleptic properties. Ozone's primary function as an oxidizer and disinfectant is powerful, effective, and safe. Applying ozone technology in the handling of agricultural products can remove contamination of pesticides, bacteria, and heavy metals that adhere to the surface of vegetables and fruits, making it safe for human health consumption. Ozone-containing water is capable of washing vegetables and fruits until it is sterile, without removing color, aroma, or damage to essential compounds in vegetables and fruits. Thus, it will obtain vegetables and fruits that are safe for consumption, and that still contain nutritional value, can maintain freshness, and can extend the shelf life.

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