Effect of washing duration using ozone and ultraviolet light treatments on the quality of *Capsicum frutescens* L. during cold storage

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Abstract. The washing horticultural commodity with ozone (O_3) and ultraviolet (UV) light presents an innovative technology to extend postharvest shelf life. This study aimed to analyze the effect of washing duration with ozone and UV light on the quality of *Capsicum frutescens L.* during storage. A randomized complete block design (RCBD) with two factors was employed. The first factor was the washing treatment (ozone, UV light, and plain water) and the second factor was the washing duration (5, 10, and 15 minutes). The experiment was set up as a 3x3 factorial with three replications. The observed parameters included weight loss, color, texture, moisture content, and total microbial test, measured at 28 days of storage. The results indicated that the washing treatment had a significant effect ($p<0.05$) in weight loss and color in almost all day storage (exclude day 0), texture (day 14), moisture content in all days storage, and total microbial count (days 0, 14 and 21). Furthermore, washing duration and interaction of both factors had a significant effect only on moisture content (days 28). Among all treatments, ozone application for 15 minutes was identified as the most effective method in maintaining the physicochemical and microbiological quality of *Capsicum frutescens L.*

1 Introduction

Chili peppers are a climacteric fruit vegetable commodity that is perishable and susceptible to quality degradation, resulting in a relatively short shelf life and high economic value. At room temperature, chili peppers can last for 7 days, after which they experience quality degradation [1]. Chili peppers are generally sold fresh, requiring mastery of post-harvest

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handling technologies that can increase their shelf life until they reach consumers. One emerging post-harvest technology for handling fresh food is UV light [1] and ozonation [2].

Ozone (O3) is an unstable gas, easily decomposed into oxygen, and is a strong oxidizer. Standardized treatment parameters for ozone in perishable horticultural commodities are effective concentrations ranging from 0.3 to 0.9 mg/L [3] with optimal treatment temperatures around 10°C to 20°C [4]. For effective exposure times, range from 5 to 15 minutes, with an optimized duration of approximately 11.7 minutes [5]. A study [6] showed that sonolytic ozonation (O_3/US) significantly reduced pesticide residues in various vegetables, including chillies, by up to 99.3% for certain chemicals. Similarly, ozone treatment combined with cold storage decreased weight loss in cucumbers and tomatoes [4].

UV treatment is non-chemical and does not leave residues, making it safe for use on food products [7]. Effective doses vary depending on the commodity. For example, doses for mangoes range from 4.0 to 11.7 kJ/m² [8], while for champignons, effective doses range from 219.5 to 800.0 J/m² [9]. The study demonstrated that slices of "Chokanan" mango and "Josephine" pineapple subjected to UV-C light treatment and stored under refrigeration at 10 °C experienced notably less tissue breakdown and maintained freshness longer than mango samples that did not receive UV-C exposure [10]. Additionally, applying UV-C irradiation for a duration of about 5 to 10 minutes effectively minimized surface injury in strawberries and grapes [11]. UV treatment significantly reduced weight loss in potatoes by retaining water in the cells and delaying sprouting [12]. Ozone and UV light treatment resulted in a 97.18% and 96.36% respectively reduction of E. coli O157:7 on bird's eye chili within 10 minutes and kept in polyethylene bags under 4°C for 12 days [13]. Research on *Capsicum frutescens L.* treated with ozone technology and UV light dissolved in water during cold storage for 28 days and three washing times has never been conducted. This is crucial for achieving the best treatment especially for *Capsicum frutescens L* in between three washing and time treatment during cold storage to get optimal condition.

2 Materials and Methods

The samples used in this research is cayenne pepper (*Capsicum frutescens L.*) with standardized size and colors from farmers in Lembang, West Java (total 18 kg with each treatment 200 gr). The materials used in this research are water, distilled water, polypropylene box, and fruit foam net. The chemicals used include Plate Count Agar (PCA) media, Buffered Peptone Water (BPW), and 70% alcohol. The treatment design in this study consists of two factors, namely washing treatment using ozone and UV light, denoted by (A) which consists of 3 levels (a1 = ozone; a2 = UV light; a3 = water), and the length of washing time, denoted by (Y) which consists of 3 levels (y1 = 5 minutes; y2 = 10 minutes; y3 = 15 minutes). Each parameter was monitored five times: on day 0 (H0), day 7 (H7), day 14 (H14), day 21 (H21), and day 28 (H28).

The research tools used are ozone (0.93 ppm at 30ºC and pH 6.5), UV light (circulation of water flowing is 280 ml/second and the wavelength is 253.58 nm) washing machines, analytical balance with the brand FV Gram FV-220C type, standard model spinner type E with a capacity of up to 10 kg and dimensions 70 x 30 x 80 cm, Memmert oven with a temperature capacity of up to 300°C, Konica Minolta chromameter Konica brand Stable Micro Systems series, TAXT Plus Connect with a force capacity of 50 kg, measuring 650 mm x 280 mm with a sample testing area of 247 mm x 228 mm, desiccator has a diameter of 200 mm, autoclave with the brand Hirayama HVA series type HVA-85 type, laminar flow meter with the brand Esco stainless steel side wall, fixed sash, ose needle, and Memmert water bath WNB 14. All tools have calibration before use. This study consisted of five testing parameters: color intensity [14], water content [15], weight loss [16], total microbial count using the Total Plate Count (TPC) [17], and texture [18]. The experimental design used in

this study was the Randomized Block Design (RBD) method. This study had a 3x3 factorial, with each factor repeated three times.

3 Results and Discussion

3.1 Physical Response

3.1.1 Weight Loss Test

Table 1 show based on the results of the analysis of variance (ANOVA), it was found that the washing treatment (A) had a significant effect (sig≤0.05) on the quality of the weight loss of cayenne pepper on days 7, 14, 21, and 28. Cayenne pepper continues to undergo a respiration process that involves the use of carbohydrate reserves and the release of carbon dioxide (CO2), water, and heat. Both processes cause cayenne pepper to experience water loss, the growth of microbes or pathogenic microorganisms, resulting in a decrease in total weight in cayenne pepper [19]. Ozone and UV light treatments tend to experience less than 70% weight loss than others. It happened because ozone and UV light can be used as disinfectants to kill pathogenic microorganisms such as viruses, bacteria, and fungi, thereby slowing the rate of decay [20]. This result align with [21] that ozone-treated chili showed higher moisture content and less weight loss compared to untreated samples.

Table 1. Duncan's Advanced Test Results for Washing Treatment (A) Chili Weight loss Cayenne Pepper during storage

Washing Treatment	Weight Loss (gr)			
	H7	H14	H21	H28
Ozone	3.67a	7.08a	11.15a	14.92a
UV light	3.40a	7.22a	10.58a	13.84a
Without ozone and UV light	4.68b	9.33b	13.61b	17.16b

Remarks:
Lowercase letters indicate a noticeable difference in the same column in each parameter.
H7 = days 7; H14 = days 14; H21 = days 21; H28 = days 28

3.1.2 Color Intensity Test (L, a* and b* Value)*

Based on the results of the analysis of variance (ANOVA), it was found that the washing treatment (A) had a significant effect (sig≤0.05) on the L* and b* value of cayenne pepper on days 7, 14, and 21 and on the a* value of cayenne pepper on days 14 and 28, so there was need for further Duncan tests with results in Table 2.

In all of the color components, ozone has a higher value than other treatments. Example for H7 in L*, ozone has 47.91 instead of UV light (44.02) and without treatment (45.51). Ozone can eliminate damaging compounds such as free radicals or oxidation products that have formed on the surface of cayenne peppers. Ozone treatment at the right dose can stimulate the chili's natural protective mechanisms, including an increase in antioxidant compounds such as ascorbic acid. This helps maintain the intensity of the chili's natural color pigments, so that the color remains bright. Ozone-treated chili paste showed better lightness and shininess during storage [11].

On the other hand, UV light gets less value in all color components. UV light can increase the formation of Reactive Oxygen Species (ROS) compounds in cayenne pepper tissue that can damage natural pigments such as carotenoids and chlorophyll, accelerate color fading, and cause a decrease in chromatic value during storage [22]. Enzymatic reactions that

occur during storage, such as the polyphenol oxidase and lipoxygenase enzymes naturally present in cayenne pepper, which can trigger pigment degradation and the formation of brown compounds during storage [23].

Table 2. Duncan's Advanced Test Results for Washing Treatment (A) Chili L*, a*, b* value of Cayenne Pepper during storage

Washing Treatment	L*			a*		b*		
	H7	H14	H21	H14	H28	H7	H14	H21
Ozone	47.91b	46.70b	47.45b	44.75b	45.12b	35.46b	35.10b	35.96b
UV light	44.02a	44.67a	43.35a	43.34a	45.13a	31.19a	31.28a	29.68a
Without ozone and UV light	45.51a	46.10ab	46.25b	43.86a	45.14a	33.11ab	34.34b	34.55b

Remarks:
Lowercase letters indicate a noticeable difference in the same column in each parameter.
H7 = days 7; H14 = days 14; H21 = days 21; H28 = days 28

3.1.3 Texture Test

Based on the results of the analysis of variance (ANOVA), it was found on the 14th day, the washing treatment (A) had a significant effect (sig≤0.05) on the texture quality of cayenne pepper (Table 3). This aligns with [24] that ozone treatment has been shown to help retain the firmness of fruits and vegetables by inactivating softening enzymes. In other research [25], UV light treatment is effective in microbial reduction without significantly affecting the physical, chemical, nutritional, and sensory properties of foods, including texture [3] .

Table 3. Duncan's Advanced Test Results for Washing Treatment (A) Chili Texture on Day 14

Washing Treatment (A)	Texture	Different level 5%
a1 (Ozone)	13143.645	b
a2 (UV light)	2188.456	a
a3 (without ozone and UV light)	2867	a

Remarks:
Lowercase letters indicate a noticeable difference in the same column in each parameter.
H7 = days 7; H14 = days 14; H21 = days 21; H28 = days 28

On the 14th day, each treatment experienced an increase in texture compared to the 7th day (from 559.30 to 13143.645 for ozone; from 630.867 to 2188.456 for UV light; from 657.30 to 2867 for water), indicating that each treatment reached the climax of the ripening process (data not shown). This ripening process is triggered by the degradation of pectin in the cell walls of cayenne peppers, reducing moisture on the surface and within the tissue, which can result in a harder texture. On days 21 and 28, each treatment experienced a decline in yield because the cayenne peppers had passed their peak and were undergoing a downward curve or decay process. This decline was triggered by damage to the cayenne pepper cell wall structure, leading to decreased tissue strength due to oxidative or photochemical reactions. Furthermore, this decline could occur due to increased permeability caused by changes in pectin (which binds cells within the tissue), resulting in the cayenne pepper tissue becoming softer and losing its firmness.

3.2 Chemical Response/ Water Rate Analysis

In general, water content during storage on various treatments decreases (Figure 1). The continued oxidation of organic compounds in chili peppers during storage makes cayenne peppers more susceptible to decreased water content during storage. Ozone has lower water content (< 80%) than other treatments (< 82%). UV light exposure can trigger photochemical reactions in organic compounds on the chili's surface, such as proteins, lipids, or wax compounds. These reactions can produce hygroscopic compounds (easily absorbing water), such as hydroxyl (OH-) or carbonyl (C=O) groups, which make the chili's surface more capable of absorbing air moisture during storage [26]. Based on FAO/WHO regulations stipulated in Codex Standard 307-2011 for cayenne pepper, the range water content requirement for fresh cayenne peppers is 60–85%. The results showed that the water content of cayenne peppers at each storage treatment on days 0, 7, 14, 21, and 28 (65 – 82%) met the requirements.

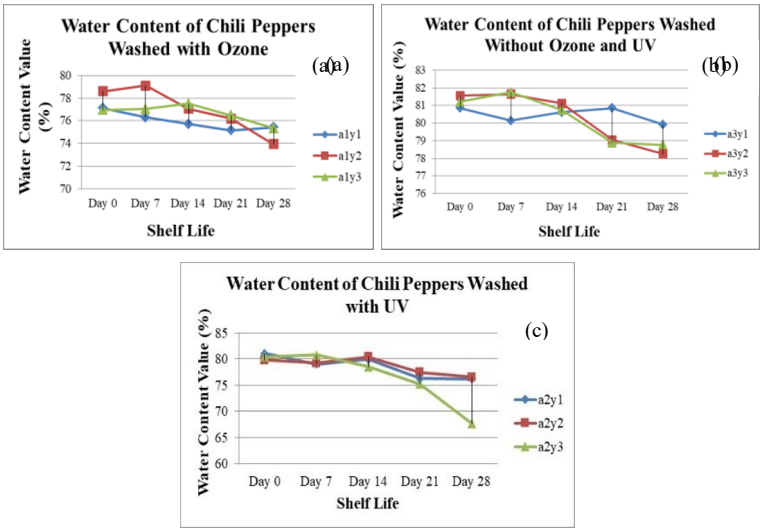

Fig. 1. Water Content of Cayenne Pepper Washing (a) Ozone; (b) UV light; (c) without ozone and UV light

3.3 Microbiological Response/ Total Microbial Test

Based on FAO/WHO regulations listed in Codex Standard 307-2011, the maximum tolerance requirement for Total Microbes in cayenne pepper for sale in fresh condition is 8 x 10^{12} CFU/g or if converted in log is 12.90. Figure 2 shows that each treatment on days 0, 7, 14, 21, and 28 of storage meets the standards between 4log until 8log. Total microbial tests on days 7 and 14 showed a decrease in the total number of microbes in the ozone washing treatment. Meanwhile, the UV light washing treatment experienced an increase in the total number of microbes, but the rate of increase was lower than the washing treatment without ozone and UV light. Ozone decomposes into oxygen (O2) shortly after application, so there is no residual effect that can prevent the growth of microorganisms during storage [4]. UV light (200-280 nm) is most commonly used for its effectiveness in microbial inactivation [7]. All treatments experienced an increase in the total number of microbes on days 21 and 28. This indicates that ozone effectiveness in killing pathogenic microorganisms only lasts until day 14.

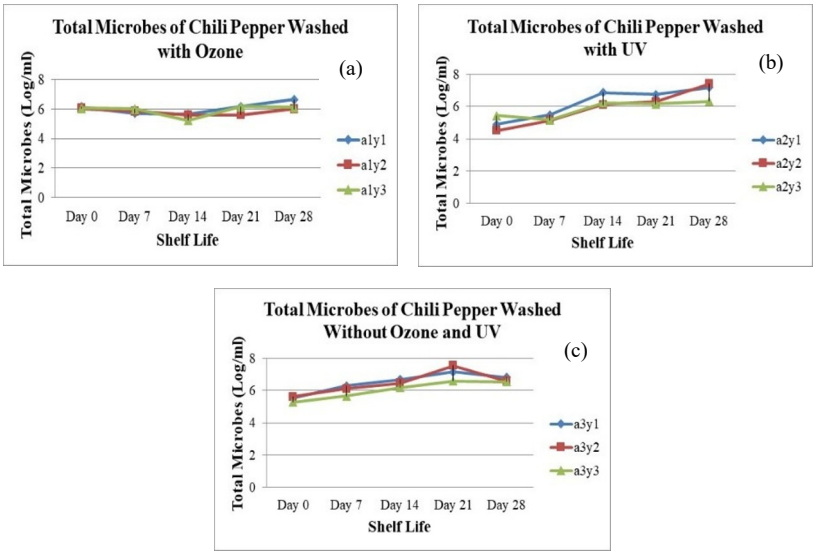

Fig. 2. Total Microbial of Chili Peppers Washing with (a) Ozone; (b) UV light; (c) without ozone and UV light

4 Conclusion

The washing time, ozone and UV light treatment with the storage process at cold temperatures affect the quality of cayenne pepper during storage. This can have practical implications especially for farmers, supermarkets and supply chains. Washing treatment with ozone, UV light, and without ozone and UV light affected the response of weight loss of cayenne pepper on days 7, 14, 21, and 28, color intensity on days 7, 14, 21, and 28, texture on day 14, water content on days 0, 7, 14, 21, and 28, and total microbes on days 0, 14, and 21. Washing times of 5 minutes, 10 minutes, and 15 minutes affected the response of water content of cayenne pepper on the 28th day. The interaction between washing treatment and washing time had an acceptable effect on the response of water content of cayenne pepper on day 28. Based on the research results with parameters of weight loss testing, color intensity testing, texture testing, water content analysis, and total microbial testing, the best treatment was washing treatment using ozone. But this research meets limitations because storage is only 28 days and only for one commodity. For future research, tandem technology between ozone and UV light or other technology like cold plasma, HWT, are very promising to get better results.

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