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Artículo original

Application of ozone in post-harvest conservation of orange *(Citrus sinensis)* in La Troncal, Ecuador

Aplicación de ozono en la conservación poscosecha de naranja *(Citrus sinensis)* en La Troncal, Ecuador

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Abstract

Objective: To evaluate the effect of ozone concentration and exposure time on oranges (*Citrus sinensis*) through experimental methods aimed at reducing the incidence of phytopathogenic fungi and extending their shelf life during storage. **Methodology:** A total of 384 oranges were collected and stored in a warehouse, forming 32 experimental units. A completely randomized design was used, assessing eight treatments: six corresponding to combinations of two factors, along with two control treatments. Factor A consisted of three liquid-ozone doses (1, 2, and 3 ppm), while Factor B involved the contact time with the fruit (10 and 20 minutes). Among the controls, one was a conventional treatment with sodium hypochlorite and the other an absolute control. The evaluated variables included pH, °Brix, incidence, and severity. Data were statistically analyzed using analysis of variance (ANOVA) and Tukey's test ($p < 0.05$). **Results:** The untreated control showed the highest values for pH, incidence, and severity. Ozone doses consistently reduced these variables, particularly 1 ppm applied for 10 minutes, while the remaining treatments presented slight and consistent differences. Severity, as defined in the study, showed variations ranging from 11.3% to 17.7% in the factorial treatments, 23.2% in the absolute control, and 10.9% in the conventional treatment with sodium hypochlorite. **Conclusions:** Ozone application decreases pH, incidence, and severity compared to the untreated control. Differences among doses were small, but 1 ppm for 10 minutes produced the most pronounced effects, even outperforming the conventional sodium hypochlorite treatment. Overall, ozone improved all evaluated conditions relative to the controls.

Keywords: conservation; orange; ozone; post-harvest.

Resumen

Objetivo: Evaluar el efecto de la concentración y tiempo de exposición del ozono en la Naranja (*Citrus sinensis*), a través de métodos experimentales, para la reducción de la incidencia de hongos fitopatógenos y prolongar su vida útil durante el almacenamiento. **Metodología**: Se recolectaron 384 naranjas, y almacenadas en una bodega; creando 32 unidades experimentales. Se empleó un diseño completamente aleatorizado, evaluando ocho tratamientos, seis de los cuales fueron combinaciones de dos factores, junto con dos tratamientos de control. El factor A consistió en tres dosis de ozono líquido (1, 2 y 3 ppm), mientras que el factor B involucró los tiempos de contacto con la fruta (10 y 20 minutos). Entre los controles, uno fue un tratamiento convencional con hipoclorito de sodio y el otro fue un control absoluto. Las variables evaluadas incluyeron pH, grados Brix, incidencia y severidad. Los datos se analizaron estadísticamente mediante análisis de varianza (ANOVA) y la prueba de Tukey ($p < 0{,}05$). **Resultados**: Los testigos sin ozono muestran los valores más altos en pH, incidencia y severidad. Las dosis de ozono reducen consistentemente estas variables, especialmente 1 ppm, sometida a un tiempo de 10 minutos; mientras que los demás tratamientos presentan diferencias leves y coherentes entre La severidad, como indicador definido en la postura del trabajo mostró ciertas diferencias que oscilaron entre el 11,3 % y el 17,7 % en los tratamientos factoriales, el 23,2 % en el control absoluto y el 10,9 % en el tratamiento convencional con hipoclorito de sodio. **Conclusiones**: La aplicación de ozono disminuye pH, incidencia y severidad respecto al testigo sin ozono. Las diferencias entre dosis son pequeñas, pero 1 ppm, durante 10 minutos, muestra efectos más marcados; inclusive con respecto al tratamiento convencional (Aplicación de Hipoclorito de Sodio). En conjunto, el ozono mejora las condiciones evaluadas frente a los controles.

Palabras clave: conservación; naranja; ozono; poscosecha.

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Introduction

The agri-food sector is one of the fundamental pillars of the Ecuadorian economy, contributing 15% to the Gross Domestic Product (GDP) and employing one in every three people in the country. Its significance lies not only in agricultural, livestock, and fishery production but also in its capacity to generate employment and improve living conditions in rural areas (Food and Agriculture Organization, 2021).

Citrus fruits are among the leading fruit crops worldwide, cultivated in over 140 countries across the globe. Oranges, lemons, mandarins, and grapefruits are among the most commonly grown citrus varieties, primarily marketed and consumed as fresh fruit, juice, or concentrate (Food and Agriculture Organization of the United Nation, 2020).

In Ecuador, fruit production accounts for 4.5% of the total cultivated hectares, which reached 2.6 million hectares in 2021. The main concentration of fruit cultivation is in the Sierra region, with a 54% share; the rest of the Ecuadorian coast accounts for 41%, and the eastern region for 5% of the total (Treid, 2022).

The country's diverse altitudes result in wide climatic variations across different regions. Consequently, Ecuador cultivates a variety of fruits, ranging from tropical to temperate. It is the world's leading exporter of bananas; other fruits cultivated for export include melons, pineapples, strawberries, and mangoes. Pears, peaches, apples, grapes, and plums are grown in the highland areas. Citrus fruits, avocados, mangoes, and a wide range of tropical fruits are produced along the coast (Ecuador.com, 2025).

Sweet orange (*Citrus sinensis*) is a fruit of great importance due to its high nutritional value, which benefits community health and is suitable for subtropical climates. It exhibits physical characteristics such as color, size, flavor, and shape (Plúa, 2016). Postharvest losses of oranges are caused by fungal diseases, which reduce shelf life and negatively impact the fruit's commercial value (Guédez et al, 2014). *Citrus sinensis* is affected by various postharvest fungal diseases, including Penicillium digitatum, Penicillium italicum, Alternaria alternata, Phytophthora, Fusarium, and Trichoderma. These fungi are among the most common in Citrus sinensis, with their incidence and severity depending on environmental conditions such as temperature (Campos, 2015).

The use of chemical products postharvest to control fungal rot affects consumers due to the residue levels of these products. Environmentally friendly control methods include biological control (microorganisms - antagonists) and chemical products like thiabendazole, which are more efficient in reducing severity from 0.5% to 1.75% (Rubio, 2015).

Since 1982, the U.S. Food and Drug Administration (FDA) has recognized ozone as a generally safe substance, promoting its use in direct contact with food. Several factors—economic, cultural, and social—have facilitated its adoption within the food industry (Bataller et al., 2015).

Cosemar (2017), explainsexplain, ozone acts as an antiseptic by inhibiting microbiological agents present postharvest. It has a biocidal effect that prevents the multiplication of microorganisms responsible for decay, and it is also considered effective in reducing microbial load and extending the shelf life of the fruit while preserving its organoleptic characteristics.

The presence of diseases during orange storage reduces shelf life, which affects the available consumable quantity of the harvest during accumulation and consumption periods for producers. However, it is important to consider the production zone, climatic conditions, and the proliferation of molds and yeasts, as these are the main causes of fruit decay postharvest (Vásquez, 2025).

In orange postharvest, certain cases involve the proliferation of pathogenic microorganisms that diminish food quality, thereby reducing the profitability of agricultural production. This situation leads to a critical period of economic losses affecting large, medium, and small citrus farmers (Decco, 2018).

Agriculture, in conjunction with ecology, is framed as a process that leverages the biological functions of the ecosystem to optimize the processes within it. This approach aims to promote fertilization, pest and disease management, with minimal intervention from external inputs, which often tend to disrupt agroecosystems. Such disruptions can impact not only environmental stability but also the profitability of agricultural production (Vargas et al., 2019).

The present study aims to evaluate the use of ozone (liquid state) at different doses and contact times on oranges. Two control treatments are included: one without ozone and another with sodium hypochlorite application. The goal was to reduce the effect of phytopathogens on the fruit under storage conditions, hypothesizing that one of these treatments could be viable for decreasing the incidence and severity of fungi and yeasts in storage.

Methodology

The experiment was conducted in the province of Cañar, La Troncal canton, which is georeferenced at latitude 2°25'28.8"S and longitude 79°20'29.6"E.

This research was of an experimental nature, in which liquid ozone was applied during the post-harvest stage, specifically in the storage of oranges, to evaluate different concentrations according to the treatments, thereby fulfilling the established objectives. The goal was to achieve profitability for the producers of La Troncal canton and subsequently for orange marketers from other cantons who transport the fruit to La Troncal. It is important to note that this study has an exploratory characteristic due to limited foundational information, and some aspects of the proposed methodology may not be fully established.

Research Design

An experimental design based on a Completely Randomized Block Design (CRBD) was employed, demonstrating the development of a new product supported by the investigative source of the work.

Treatments

According to the study plan, two factors were evaluated: Factor A, represented by ozone, and Factor B, represented by immersion time. Within Factor A, three concentrations were tested, while in Factor B, two immersion times were evaluated. The factorial combinations assessed are listed in Table 1. Along with the conventional control sample and a normal control, a total of eight treatments were generated.

Materials and Equipmenth

To achieve the research objectives, the following materials and equipment were used:

- Refractometer, used for measuring the Brix degrees of each evaluated fruit.
- Microscope, employed for observing different infectious agents present in the experiment (diseases).
- Valencia orange variety, considered one of the most common varieties, characterized by its sweet flavor, small to medium size, thin and smooth skin, and high juice content.
- Slides and cover slips, used for placing samples and subsequent microscopic observation.
- Insertion needle, used for the measurable extraction of samples.
- Bunsen burner, used for sterilizing materials.
- Petri dishes, used for placing samples, facilitating the development of infectious agents, observation, and identification.
- Methylene blue, a dye applied to improve the visualization of fungi in the samples.
- Trays, used for receiving the fruits.
- Distilled water, used for treating materials and samples

Methods and techniques

The basic material for the analysis (orange) was obtained from the Caluma canton, known as one of the points with the highest citrus production in Ecuador. For analysis, a population of 160,000 oranges was considered, from which a sample of 384 oranges was obtained, with a 5% margin of error and a 95% confidence level, as shown in the sample size calculator provided by (Asesoría Económica & Marketing, 2025).

Experimental Unit

The collected material was transported to La Troncal canton and subsequently stored in a concrete warehouse measuring 6 m x 5 m. The environment within this space presents typical conditions for the months of February and March, as detailed below:

- Temperature: 20°C to 29°C
- Relative Humidity: 75% to 85%

- Heliofanía (Sunshine Hours): 35 to 50 hours
- Cloud Cover: 6 to 8 octas
- Precipitation: 10 to 60 mm/day
- Wind Speed: 5 to 20 km/h (Instituto Nacional de Meteorología e Hidrología – INAMHI, 2020)

Subsequently, 32 experimental units were placed and stored with their respective treatments on the day the experiment commenced. Each experimental unit was housed in plastic boxes of blue and black colors, measuring 60 cm x 40 cm x 25 cm, commonly used for handling and transporting products in the domestic market. Each drawer contained twelve oranges with similar characteristics, based on the standards outlined in NTC 4086:

- Caliber B (Diameter: 84 mm – 92 mm)
- Color (Color 1: The green color is lighter, with yellowish hues)
- Average weight: 318 g. (Instituto Colombiano de Normas Técnicas y Certificación Norma Técnica Colombiana – ICONTEC, 1997).

Sequential Evaluations

Evaluations were conducted every seven days, randomly sampling two oranges each time. The process was repeated across four assessments, completing the experiment after twenty-eight days.

Variables Studiet

The variables evaluated included molds incidence (%), severity (%), Brix degrees, and pH. These variables determined the shelf life of the oranges following the application of three ozone doses at two different concentration times. Four evaluations were performed at seven-day intervals until day twenty-eight, with the last fruits remaining in good physiological condition.

The presence of different disease types was also verified, focusing on molds such as *Penicillium digitatum and Penicillium italicum* across various treatments. These assessments were carried out in the laboratory of the Universidad Agraria del Ecuador, with samples examined and verified by the research team.

Mold Insidence %

The percentage of fruits infected by the fungi (*Penicillium digitatum and Penicillium italicum*) was measured every six days. The total number of infected fruits per experimental unit was recorded, and the incidence percentage was calculated using the following formula:

$$I = \frac{FS}{FT} \times 100$$

Where:

I= Incidence (%),

FS= Number of diseased fruits,

FT= Total number of fruits examined per experimental unit.

Mold Severity (%)

Two oranges within the incidence sample were randomly selected. In cases where no fruits showed symptoms, two oranges were randomly chosen from the total per experimental unit. Two vertical cuts were made through the peduncle, dividing the fruit into four parts. The pericarp (peel) was removed, and each part was weighed to obtain the total weight in grams. The infected sections were then excised and weighed to determine severity using the following formula:

$$S = \left(\frac{CI(1) + CI(2)}{CT(1+2)}\right) \times 100$$

Where:

(S) = severity (%),

(CI (1)) = Infected peel weight of fruit 1 (g),

(CI (2)) = Infected peel weight of fruit 2 (g),

(CT (1)) = Total peel weight of fruit 1 (g),

(CT (2)) = Total peel weight of fruit 2 (g).

Brix Degrees

Juice was extracted from two samples per experimental unit and mixed to obtain 0.10 ml from each sample. A refractometer was used to measure the Brix degrees, with 32 measurements taken per evaluation, resulting in a total of 128 samples across all assessments.

pH

Juice from the two oranges was combined and placed into 16 x 100 mm test tubes. The pH was measured using a pH meter at the Universidad Agraria del Ecuador, with recorded values ranging from 3.5 to 4.9.

Statistical Analysis

Data obtained from this experiment were subjected to analysis of variance (ANOVA) to detect significant differences among treatments. The ANOVA model to be used considered the 3 x 2 + 2 factorial arrangement, under the consideration of a completely randomized design.

Tukey's test was used for the comparison of means; all these analyses were carried out with a 5% probability of type 1 error using the free version of the Infostat software.

Results

Evaluation of pH in fruits

Table 1 presents the comparative results of pH for the established treatments, considering factors such as ozone application and contact time. Six treatments were performed, including an absolute control and a conventional control, with an analysis of the interaction between factors AB (controls vs. factorial), control 1 vs. control 2.

Table 1

Analysis of Variance (ANOVA) for the pH

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	p-value
Total	127	11.440	0.090		
Factor A (Ozone)	2	0.510	0.255	13.9	0.000
FactorB (Contact Time)	1	0.004	0.004	0.2	0.649
AB Interaction	2	0.120	0.060	3.3	0.041
Controls vs. Factorial	1	0.150	0.150	8.2	0.005
Control 1 vs. Control 2	1	0.106	0.106	5.8	0.018
Dates	3	8.410	2.803	153.3	0.000
Experimental Error	117	2.140	0.018		

This table shows the ANOVA analysis indicating that factors A (ozone), the controls versus factorial, control 1 versus control 2, and the AB interaction significantly affect the application, with statistically significant differences reported. Conversely, factor B (contact time) did not show significant differences, indicating it does not affecthas no effect on the pH variable.

Table 2

Effect of ozone dose and immersion time on juice acidity

N	Ozone Dose (Factor A)	Contact Time (Factor B)	Mean pH
1	a1: 1 ppm	b1: 10 min	3.55 c
2	a1: 1 ppm	b2: 20 min	3.66 bc
3	a2: 2 ppm	b1: 10 min	3.80 ab
4	a2: 2 ppm	b2: 20 min	3.73 ab
5	a3: 3 ppm	b1: 10 min	3.75 ab
6	a3: 3 ppm	b2: 20 min	3.75 ab
7	Control (no ozone)	3.84 a	
8	Conventional control	3.73 ab	CV: 3.63 %

Tukey test, 5% probability of type 1 error

In Table 2, ozone application at different doses and contact times did not produce significant differences compared to the control treatments, as all mean values fall within a narrow range (3.55 to 3.84) and share common letters (a, ab, bc, c), indicating statistical similarity. The control (no ozone) showed the highest mean pH (3.84), while the treatment with 1 ppm ozone for 10 minutes had the lowest (3.55). The coefficient of variation (CV) was low (3.63%), reflecting good experimental precision.

Furthermore, Figure 1 illustrates the pH behavior over time. AllIt is evident that all treatments experienced an increase in pH during the experiment, starting below 3.5 and reaching values between 3.8 and 4.3 by the end.

Figure

Projection scheme and pH behavior over the study period

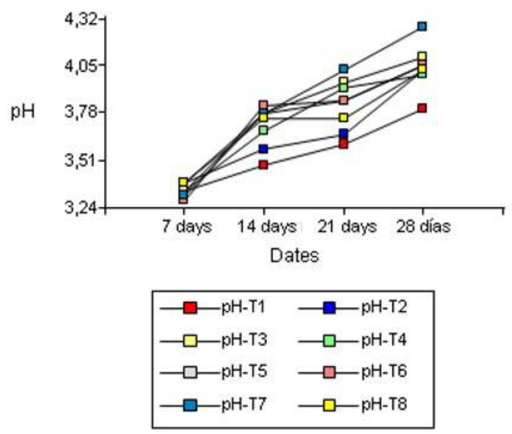


Table 3

Analysis of Variance (ANOVA) for the Brix Degrees

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	p-value
Total	127	194.34	1.530		
Factor A (Ozone)	2	0.63	0.315	1.5	0.226
Factor B (Contact Time)	1	1.68	1.680	8.0	0.005
AB Interaction	2	2.22	1.110	5.3	0.006
Controls vs. Factorial	1	0.63	0.630	3.0	0.085
Control 1 vs. Control 2	1	2.71	2.710	13.0	0.000
Dates	3	161.99	53.997	258.1	0.000
Experimental Error	117	24.48	0.209		

This table indicates that factor A (ozone) and the controls versus factorial do not show significant differences among the ozone-based treatments. It was verified that factor B (contact time), as well as the comparison between control 1 and control 2, exhibitsexhibit significant differences, and that there is a significant interaction between factors A and B.

Table 4

Effect of ozone dose and immersion time on Brix Degree

N	Ozone Dose (Factor A)	Contact Time (Factor B)	Mean
1	a1: 1 ppm	b1: 10 min	7.44 c
2	a1: 1 ppm	b2: 20 min	8.13 ab
3	a2: 2 ppm	b1: 10 min	7.96 ab
4	a2: 2 ppm	b2: 20 min	7.99 ab
5	a3: 3 ppm	b1: 10 min	7.90 abc
6	a3: 3 ppm	b2: 20 min	7.97 ab
7	Control (no ozone)	8.35 a	
8	Conventional control	7.77 bc	CV: 5.76%

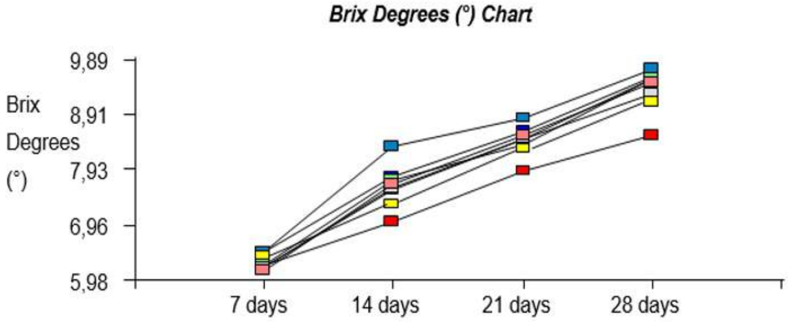
Tukey test, 5% probability of type 1 error

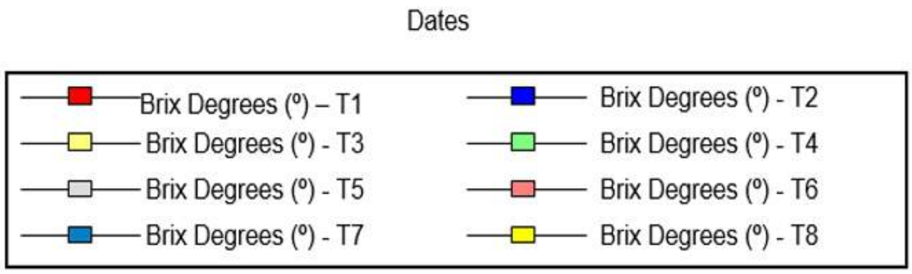
In Table 4, it is shown that treatment T1 exhibits the lowest Brix degrees, indicating differences compared to treatments T2, T3, T4, and T6, which contain the same maturity level. Treatment T5 shows varying maturity levels among its treatments, while T8 is at an average maturity level, and T7 is represented as the highest index.

Furthermore, Figure 2 illustrates the behavior of Brix degrees over time. AllIt is evident that all treatments showed an increase in Brix values during the experimental period, starting below 6.3 at the beginning and reaching values between 8.9 and 9.8 at the end.

Figure 2

Projection scheme and pH behavior over the study period





Assessment of mold incidence

Table 5 presents the comparative effects of Incidence. Eight treatments were established, consisting of six with ozone at different contact times, one absolute control, and one conventional control. An interaction between factors AB (controls vs. factorial, control 1 vs. control 2) was identified.

Table 5

Analysis of Variance (ANOVA) for the mold Incidence

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	p-value
Total	127	70,585.87	555.794		
Factor A (Ozone)	2	571.74	285.870	1.2	0.307
Factor B (Contact Time)	1	678.41	678.410	2.8	0.095
AB Interaction	2	449.06	224.530	0.9	0.395
Controls vs. Factorial	1	0.45	0.450	0.0	0.966
Control 1 vs. Control 2	1	1,109.21	1,109.21	4.6	0.034
Dates	3	39,733.	13,244.4	55.3	0.000
Experimental Error	117	28,043.8	239.691		

The ANOVA table demonstrates that factors A (ozone), B (contact time), the AB interaction, and the controls versus factorial do not have significant effects on the application, indicating no statistically significant differences. However, the comparison between control 1 and control 2 revealed significant differences, reflecting the effect of application within the incidence variable.

Table 6

Effect of ozone dose and immersion time on Incidence Measurements (%)

N	Ozone Dose (Factor A)	Contact Time (Factor B)	Mean Incidence (%)
1	a1: 1 ppm	b1: 10 min	11.66 a
2	a1: 1 ppm	b2: 20 min	23.07 a
3	a2: 2 ppm	b1: 10 min	22.39 a
4	a2: 2 ppm	b2: 20 min	24.21 a
5	a3: 3 ppm	b1: 10 min	19.58 a
6	a3: 3 ppm	b2: 20 min	22.29 a
7	Control (no ozone)		26.56 a
8	Conventional control	CV: 75.28%	14.78 a

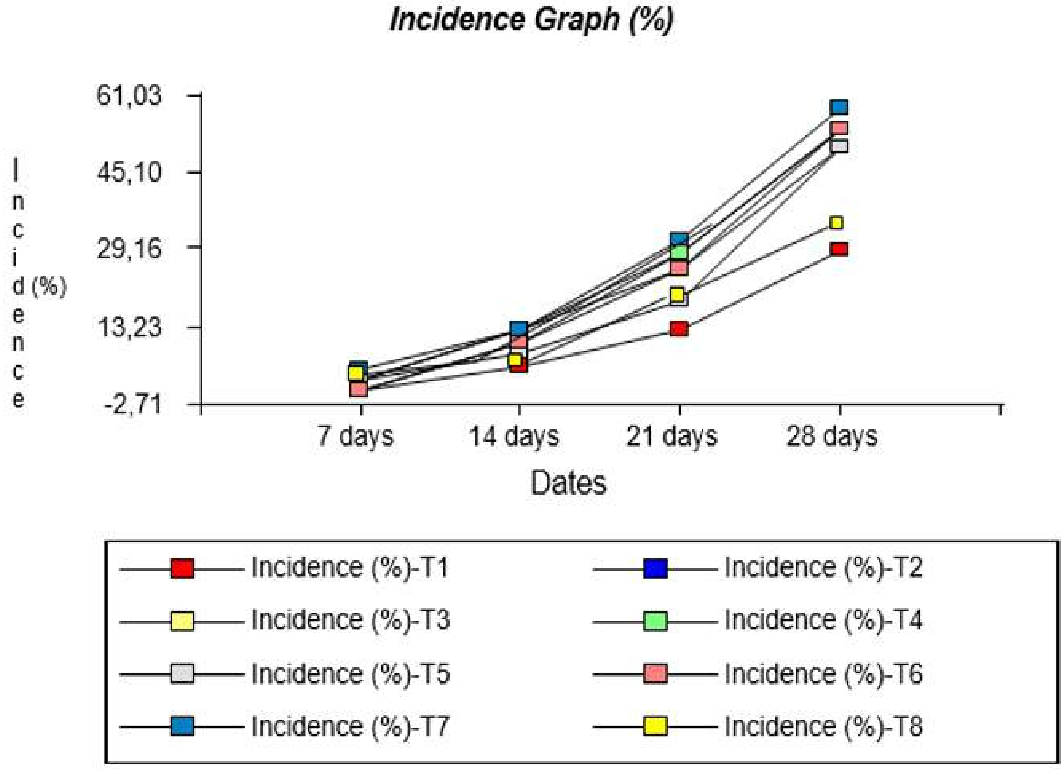
Tukey test, 5% probability of type 1 error

In most cases, treatments with ozone at different doses and contact times did not differ statistically from the control treatments, as they share common letters in the mean comparison. The ozone-free control exhibited the highest average incidence (26.56%), while the lowest dose (1 ppm for 10 min) showed the lowest incidence (11.66%). The high coefficient of variation (CV = 75.28%) indicates considerable variability in the data.

Furthermore, Figure 3 illustrates the incidence behavior over time. AllIt is evident that all treatments showed an increasing trend in incidence during the days of the experiment, starting below 3.0 at the beginning and reaching values between 29.6 and 58.9 at the end.

Figure 3

Projection scheme and behavior of the Incidence variable, over the study period



Severity Assessment

Table 7 presents a comparative analysis of severity effects, including eight treatments: six with varying ozone concentrations and two different contact times, one absolute control, and one conventional control. The interaction AB (ozone × contact time), controls versus factorial treatments, and comparisons between Control 1 and Control 2 were assessed.

Table 7

Analysis of variance (ANOVA) for the severity variable

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	P
Total	127	35,971.02	283.236		
Factor A (Ozone)	2	13.07	6.535	0.1	0.936
Factor B (Contact Time)	1	90.09	90.090	0.9	0.342
Interaction AB	2	256.23	128.115	1.3	0.278
Controls vs. Factorial	1	110.51	110.510	1.1	0.293
Control 1 vs. Control 2	1	1200.50	1200.500	12.1	0.001
Dates	3	22,718.44	7572.813	76.5	0.000
Experimental Error	117	11,582.18	98.993		

The results of Table 7 above sshowhow show that the comparison between Control 1 and Control 2 had a statistically significant effect on the treatment. In contrast, Factor A (ozone), Factor B (contact time), the AB interaction, and the contrast between controls and factorial treatments did not present significant differences.

Table 8

Effect of ozone dose and immersion time on Severity Measurements (%)

N	Ozone Dose (Factor A)	Contact Time (Factor B)	Mean Severity (%)
1	a1: 1 ppm	b1: 10 min	11.26 b
2	a1: 1 ppm	b2: 20 min	17.74 ab
3	a2: 2 ppm	b1: 10 min	14.59 ab
4	a2: 2 ppm	b2: 20 min	14.98 ab
5	a3: 3 ppm	b1: 10 min	15.92 ab
6	a3: 3 ppm	b2: 20 min	14.86 ab
7	Control (no ozone)		23.16 a
8	Conventional Control	CV: 64.49%	10.91 b

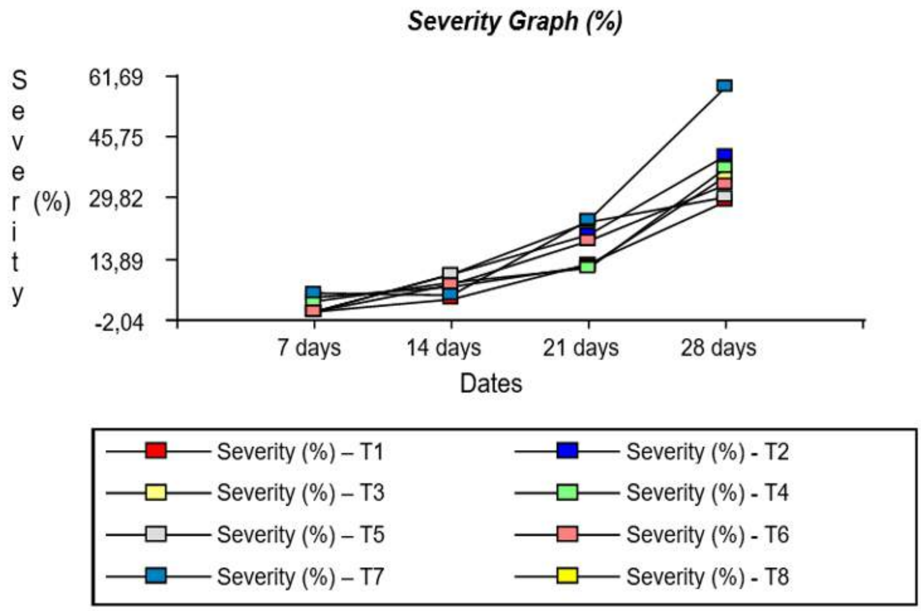
Tukey test, 5% probability of type 1 error

According to Tukey's test results shown in Table 8, Treatments 1 and 8 exhibited the lowest severity levels, indicating lower particle dispersion and thus lower severity. Treatments 2 through 6 showed intermediate severity levels, while Treatment 7 (the absolute control) was the most affected, showing significantly higher severity compared to the other treatments.

Figure 4 illustrates the progression of severity over time. All treatments showed an upward trend in severity during the course of the trial, with initial values below 2.5, increasing to final values ranging between 25.8 and 60.0.

Figure 4

Projection scheme and behavior of the Severity variable, over the study time



Discus

This study was conducted for research purposes, considering the relevance of ozone as a non-toxic agent for humans with biological action potential. Ozone acts as a germicide, targeting phytopathogenic agents. The experiment evaluated low ozone concentrations and immersion times to identify effects on various parameters.

Ozone treatments applied to postharvest orange management showed slight or statistically insignificant differences in °Brix and pH values, as reflected in the results. Similar findings were reported, Jaramillo., (2017), who investigated the impact of gaseous ozone on pH, °Brix, titratable acidity, and the optical and rheological properties of freshly squeezed peach juice. The juice was exposed to ozone (0.06–2.48 $g \cdot L^{-1}$) in a bubbling column at 20 ± 1 °C. Only minor or non-significant changes in pH, °Brix, and titratable acidity were observed during ozonation. These findings were also corroborated, Tiwari., (2009), who demonstrated that when orange juice was treated with ozone at concentrations ranging from 0.6% to 100% (w/w), with flow rates between 0 and 25 $L \cdot min^{-1}$ for 0 to 10 minutes, no significant changes were observed in pH, °Brix, acidity, turbidity, or browning index.

These results suggest limited or negligible influence of ozone on the physicochemical properties of fruit, particularly °Brix and pH, as also supported, Paulikiene., (2021), who concluded that ozone treatment did not significantly affect pH, titratable acidity, or °Brix from a statistical standpoint.

This study also demonstrates a nominal reduction in fungal presence in response to ozone application, particularly at 1 ppm for 10 minutes. This is consistent with the findings of Lemic., (2024), who investigated the effectiveness of ozone as an alternative strategy to control blue mold in mandarins. Various gaseous ozone treatments were tested—single, double, and triple applications—with exposure durations ranging from 10 to 60 minutes and concentrations from 3.3 to 20 ppm. The results showed that ozone treatments significantly reduced mold growth.

The present study highlights a lower incidence and severity in the treatment involving 1 ppm ozone with a 10-minute exposure time, in comparison with the other treatments. This suggests that ozone effectively targets the pathogens studied, controlling and reducing spore dissemination (Di Renzo., 2005). Also noted that ozone can reduce the pathogenic spore load in storage rooms and inhibit superficial mold growth on packaging, walls, and floors, thereby lowering the inoculum available for reinfection of stored products. In his study, exposure to gaseous ozone significantly reduced aging and weight loss in oranges compared to those stored in non-ozonated environments. This was based on experiments evaluating the effect of ozone exposure on the postharvest development of green and blue molds (*Penicillium digitatum and Penicillium italicum)* in artificially inoculated citrus fruit (10^4 $CFU \cdot mL^{-1}$)**.**

Conclusions

The pH values (3.55-3.84) and °Brix (7.44-8.35) did not show significant differences between the ozone treatments. The lowest incidence (11.66%) and severity of the disease were obtained with Treatment 1 (1 ppm ozone, 10 min), while the control without ozone (T7) showed the highest values. Ozone treatments demonstrated moderate effectiveness, although lower than conventional sodium hypochlorite. The predominant microorganisms identified were Penicillium digitatum and Aspergillus spp.

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