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The Role of Ozone and Chitosan as Eco-Friendly Treatments in Enhancing Growth, Yield, and Storage Quality of Processing Potato (*Solanum tuberosum* L.) cv. Lady Rosetta

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Abstract: The experimental results showed that chitosan and ozone had a very significant effect on the growth characteristics, yield and quality of tubers. Also, the two had a synergistic effect. Ozone treatment enhanced vegetative growth by increasing plant height, stem count and chlorophyll content in crops. This highlights the stimulation of defensive processes, photosynthetic activity and transport of nutrients towards the productive organ of plant. According to previous studies, Ozone enhances the total and marketable yield, minimizes unmarketable yield, reduces weight loss during storage, maintains tuber firmness, and enhances dry matter, starch content, and specific gravity before and after storage. It suggests the ability of O2 to slowly respire and degrade to keep the processing quality traits of the tuber stable. On the other hand, all parameters improved ever steadily with chitosan's increasing concentration. It increased nutrients intake, stimulated cellular division and elongation, enhanced sugar and chlorophyll formation as well as film formation on tuber surface. According to the research, 'chemical treatment' helps in creating a coating that decreases storage losses and moisture loss from the fruit. The coating maintains tissue firmness and stabilization of pH and total soluble solids (TSS) during storage. The relationship that exists between ozone and chitosan treatments recorded a strong synergistic effect to achieve maximum plant height, maximum number of stems, maximum total and marketable yield and minimum unmarketable yield. Moreover, after storage, this combined treatment exhibited the least weight loss together with maximum tuber firmness, dry matter, starch content, and specific gravity. Together, the physiological stimulation from ozone and the structural and nutritional protection from chitosan are likely to bring about effective, sustainable and ecological improvement of the tuber growth, productivity and storage quality. According to this conclusion, we suggest the application of 300 ppm ozone + 2500 ppm chitosan as the effective option in potato plant growth and yield improvement and tuber quality enhancement along storage which helps in enhancing economic value of the crop and reducing postharvest losses.

Key words: Potato، ozone treatment، chitosan، postharvest storage; sustainable agriculture، synergistic integration of biostimulants.

1. Introduction

Potato (*Solanum tuberosum* L.) is considered as one of the most important food crops whose quality deteriorates in storage. Along with the decline of this vegetation the weight loss, increase in respiration, microbial disease and change in the soil's physical and chemical properties. In light of the growing popularity of green and sustainable means for enhancing post-harvest yield and quality, non-conventional biological treatments like ozone and chitosan are being increasingly considered as it has the ability to enhance plant growth and shelf life of tubers (**Mbuyisa and Ngcobo, 2025).**

Using ozone as a technology will be useful to improve potato tuber quality. Ozone has powerful oxidative capacity and is capable of destroying the microbial population. It could minimize disease and rotting which otherwise reduces the shelf life of tubers. Recent studies suggest that ozone can bring about physiological and even chemical alterations in the potato which depend on its activity as an antioxidant and as a regulator of certain metabolic pathways. The quality attributes of tubers during and after storage clearly show this. According to **Soumya *et al*. (2025).** the method involving the ozone treatment of tubers is a novel process. Inducing controlled oxidative stress does improve tuber strength, reduce disease and promote growth is what it does in the process. According to **Palou *et al*. (2007, 2022),** using gaseous ozone during storage is very effective in controlling rot, especially Fusarium dry rot. The results showed that at the right concentration, ozone treatment can effectively and rapidly control the growth of fungal species, diminish the subsequent deterioration of quality, and have no adverse effect on the physical properties of tubers. As per obtain information, ozone treatment will be practical and eco-friendly to ensure the safety and quality of potato storage. Ozone has harmful effects on potato plants **(Biswas *et al*., 2014).** Ozone alters the structural and physiological composition of the structure and functions of plants. When the concentration of ozone is high, it injures the leaf tissue, reduces the activity of the stomata and alters the composition of the vascular tissue. The transport of carbohydrates to tubers is not only inhibited but is reduced in its efficiency. Genetic responses to ozone were found to differ amongst various potato cultivar, according to studies. Some varieties show higher tolerance towards oxidative stress than others. According to **Feng *et al*. (2023),** exposure of potato to high concentrations of ozone causes considerable decrease in the growth and productivity, including tuber number and total yield. The concentration and exposure time of ozone impacted its effects so that there was a difference between the harmful effects of chronic environmental exposure to ozone and deliberate treatments with short-term harmful phytotoxicity. The results obtained can effectively be used to interpret cultivar responses to ozone and improving strategies for sustainable use of ozone to improve the quality and productivity of potato. Furthermore, **Skrobacz *et al*. (2024)** discovered that ozone might change the chemical composition of potato tubers. Reactive oxygen species (ROS) scavenging mechanisms studied in plants include increased activity of antioxidant systems and accumulation of phenolic compounds. Quality characteristics associated with tuber storability and potato processing quality such as sugars and starch were also modified. Based on the findings of this experiment, ozone can be utilized as a postharvest treatment to improve the chemical and qualitative characteristics of potato tubers.

Chitosan is a biopolymer that has many abilities in agriculture, it is being evaluated for its ability to regulate plant growth and biostimulation. The substance can be sprayed on the plants. By improving the plant's own defense mechanisms, enhancing antioxidant enzymes' activity and supporting photosynthesis and nutrient uptake, chitosan has various benefits. The polysaccharide that results from the deacetylation of chitin is called chitosan. Research indicates that spraying leaves with chitosan at varying concentrations modifies vegetative growth, efficiency of the photosynthetic process as well as storage of carbohydrates, which in turn alters tuber quality and yield **(Szczepanik *et al*., 2024).** In the study of **González-López *et al*. (2017)** potato plants whose vegetative phase was sprayed with the agent called chitosan had a higher height, fresh weight, number of tubers, and yield compared to the control. The hypothesis put forth is based on the information that the action mechanism of chitosan is due to its simulative effect on the reproduction of cells, its activation of growth related enzymes, and its enhancement of the efficiency of utilization of nutrients. Plants can grow and produce tremendously in this. The foliar chitosan treatments (1000–5000 ppm) used in this study were effective. Therefore, the use of chitosan treatment is an environmental-friendly approach to enhancing the physiological capability and yield potential of potatoes. A field experiment was conducted by **Falcón-Rodríguez *et al*. (2017)** where different concentrations of chitosan of different molecular weights were sprayed at different developmental stages of potatoes. The findings showed that various types of chitosan strongly influence the yield parameters. The treatment group produced a greater total yield of tubers and had a wider size distribution relative to the control. It was observed that application of lower rates (200 and 325 mg ha^{-1}) showed greater impact on performance parameters. Which means that the biological capacity of chitosan is affected by its chemical and physical properties. Consequently, chitosan can be used as a growth booster in increasing production. In a postharvest study, **Aider (2010)** used 0.5%, 1.0%, and 2.0% chitosan in the storage of potatoes for quality storage and reduction of physiological problem. The results indicated that chitosan treatment resulted in a reduction of tuber sprouting and greening and increased their storage life. One of the applications of chitosan is as a post-harvest tuber treatment for vegetables tubers. In this way, it helps improve the overall quality of vegetables to a larger extent. These effects occur due to promoting the resistance of tubers to low temperature and Hypoxia. It is altered by the action of oxidases and curbing the generation of free radicals. Thus, chitosan promotes the resistance of tubers. The application took place after harvest and these mechanisms have the effect of increasing shelf life and reducing quality loss without affecting the growth and yield. The findings of this study indicate chitosan may be used as a biologically based treatment to maintain the physiological and physical properties of potato during storage. **Khan *et al*. (2020)** found that the application of chitosan, at concentrations of 1000 and 2000 ppm, to freshly harvested potatoes could improve their storage stability as well as prevent the deterioration of the quality of the product during storage. Using chitosan was effective for the reduced weight loss of tubers as well as an increased rate of germination and a lowered quality of the tubers due to greening or other damages. Improved sensory properties increased the quality of the tuber increased the shelf life and value of the product increased tuber fermeté. According to the authors, this occurred due to the ability of chitosan to form a semi-permeable membrane that lowered water and metabolic activities loss as well as the physiological processes related to storage that cause spoilage. According to **Ribeiro *et al*. (2021),** the application of 500 to 2000 ppm chitosan on the potatoes after harvesting alters the chemical composition during storage. With a prolonged process, phenolic compound content and the antioxidant enzymes activity increased substantially which reflects an improvement in the oxidative stability of tubers during the storage. A chitosan treatment enhances the antioxidant capacity and carrot tuber carbohydrate composition which are increased nutritional properties and environmental stress tolerance characteristics associated with heat and drought – that is good. This study demonstrates the quality and safety of processing chitosan application in potato tubers. According to a study by **(Zhu *et al*. 2023).** application of chitosan on potato plants before harvest, improves the quality of the tuber. This speedy addition creates physical and chemical barriers to slow water flow and help reduce disease incidence. The defensive enzymes activity was increased and the accumulation of chemical compounds with a Phenolic or Lignin composition in the stored tubers was promoted due to Chitosan treatment. Besides, chitosan enhances the uptake of nutrients like nitrogen and water which boost the overall growth, yield and quality tubers can display after harvest. Chitosan is an effective treatment technology for improving quality and performance of potato after harvest based on the results above. The stimulatory effects of chitosan on plant potatoes were also acknowledged by the recent investigation by **Szczepanik *et al*. (2024).** The application and conditions of the field determine its effectiveness (14 words) The use of chitosan spraying enhances the vegetative growth of plants by mechanisms which promote the leaf content of chlorophyll and stop the infestation of microorganisms and insects. Chitosan has the ability to boost the effectiveness of the plant defense mechanisms. It does so by increasing antioxidant enzymes, storing phenolic compounds, which will enhance the overall growth and health of the plant. Furthermore, applying chitosan positively supports the healing of post-harvest tubers. This effect reduces the weight loss of the tubers and improves the quality of the tubers, their storage, and the processing capabilities. It means the amount and frequency of chitosan should be suited to the developmental stage of plants with environmental setup.

A recent study done by **Al-Malikshah and Abdulrasool (2025)** indicated that foliar spray of potato plant with nano-chitosan charged with macronutrients (NPK) as well as plant extracts (nettle and green tea), might enhance vegetative growth and productivity of potato. A significant increase in plant height, number of leaves, branching and leaf area as well as yield per plant and tuber dry matter percent were observed compared to control treatments. Tuber number weight and physical and chemical quality attributes improved due to improved physiological activities induced by nano-chitosan supplemented with nutrients and the antioxidant defensive systems were stimulated by nano-chitosan. Laboratory studies demonstrated that the application of chitosan and its derivatives enhanced growth of potato plants cultivar 'Lady Rosetta'. In laboratory tests using a suitable artificial culture medium, the stem length, number of leaves, chlorophyll contents, and branching of the shoots were higher compared to the control treatments. This reveals the effect of chitosan and its nature as a growth-promoting agent **(Lady Rosetta Potato Farming, 2025).**

The present investigation is undertaken to evaluate the individual and combined impact of ozone and chitosan treatments on vegetative growth, yield attributes, and physiological and chemical characteristics of potato tubers during storage (cv. Lady Rosetta) with special emphasis on their effect on antioxidant defence systems. This study aims at presenting a more sustainable and environmentally friendly strategy to achieve better productivity, storage quality and to minimize postharvest loss.

2. Materials and Methods

2.1. Experimental Site, Land Preparation, Crop Management, and Harvesting

The study was carried out in 2025 in the experimental field located at the recreation area of Agricultural and Forestry College. Before the cultivation, the field was plowed repeatedly in the vertical direction by reversible plough followed by harrowing. The experiment land was then separated with many sheets. There were 1.50 m long and 1.50 m wide stripes in each plot that covered 2.25 square meter. Using this planting method, the plot received the planting of 10 plants of potato with a spacing in between the ridge and the plant of 75 CM and 30 CM spacing. The certified seed potato A grade (*Solanum tuberosum* L.) and its variety 'Lady Rosetta' were procured from a local dealer. The cold storage lost the seed potatoes for two weeks before planting. In a temperature-supported ventilation area around 15-17C, the germination process begins. Scheduled planting date was February 3, 2025. All agricultural measures were performed uniformly on all experimental plots: fertilization, weeding, hilling, and prevention and treatment of pest, disease, and weed attacks. After fertilization, **Al-Obaidi (2005)** advised using 400 kg/ha urea (46% nitrogen), 600 kg/ha superphosphate (45% phosphorus), and 400 kg/ha potassium sulphate (48% potassium).

2.2. Experiment two parts were there.

1. Diverse concentrations of ozone were used (0 and 300 ppm).
2. The foliage was sprayed with chitosan at five concentrations (0, 1000, 1500, 2000, and 2500 ppm) for the analysis.

Potato tubers were subjected to floatation in a container of known capacity. Thereafter, ozone gas was introduced in the reaction chamber from an ozone generator for defined periods of time such that the ozone ambient concentration at room temperature 20-25 °C reached 300 ppm. This procedure happened only a single time. The three different applications of chitosan were made in the early morning as foliar sprays.

Random Block Design with three replications was adopted for the experiment. The effects of each treatment on growth, yield, and post-harvest characteristics were recorded Between June 1, 2025, (±150 days after planting), the tubers were harvested using a hoe without injury.

Following the harvesting, the tubers were kept for four months at 7 ± 1oC and at 90-95% RH. The quality traits were assessed for a period of storage. The differences were tested for significance with help of the statistical software **SAS (2017).** Duncan's test was used to determine the difference of each treatment and its significance **(Al-Rawi & Khalafallah, 2000).**

2.3. Studied traits

Plant height (cm plant^{-1})

The heights of the plants from the soil level to the tip of the tallest fully expanded leaf were measured with the help of measuring tape. Five plants for each experimental unit were measured and then their mean value was calculated.

Number of aerial stems per plant (stems plant^{-1})

From the five plants an average stem number were counted and recorded from each.

Total leaf chlorophyll content (SPAD units)

We utilized a chlorophyll meter (SPAD-502, Japan) to evaluate leaf chlorophyll content. The mean was calculated after taking five readings of each plant.

Number of tubers per plant (tubers plant^{-1})

The calculation of the average number of tubers produced per plant was done by dividing the total number of tubers of all the plants.

Number of marketable tubers (tubers plant^{-1})

This property got derived by dividing the number of marketable tubers, through the exaction of overt diseased, deformed tubers and that tubers which are less than 25 g.

Number of unmarketable tubers (tubers plant^{-1})

The division of the number of marketable tubers by the total number of tubers.

Total yield per plant (g plant^{-1})

The yield of each plant was calculated as the experimental unit yield per number of plants in that experimental unit.

Marketable yield per plant (g plant^{-1})

The marketable yield per plant was computed by dividing the marketable yield by the number of plants included in the experimental unit (all harvested tubers were considered after discarding small tubers (<25 g), damaged and deformed tubers).

Unmarketable yield per plant (g plant^{-1})

Marketable yield per plant was computed by dividing the marketable yield by the number of plants in the experimental unit.

Weight loss percentage (%)

Weight loss was calculated according to the following equation:
Weight loss (%)=Initial tuber weight before storage−Final tuber weight after storage/Initial tuber weight before storage×100

Total soluble solids (TSS, %) before and after storage

The TSS of the tuber juice was measured using a hand refractometer following **AOAC (2000).**

Tuber firmness before and after storage (lb in^{-2})

A plunge tester was used to measure the firmness of tubers after harvest storage. On each tuber, five measurements were taken with their average taken.

pH value

A pH meter was employed to detect tuber juice pH.

Dry matter percentage of tubers before and after storage (%)

The tubers were washed, air-dried and sliced after harvesting. After weighing the samples, they were placed in the oven. If you take the ratio of dry weight and fresh weight and multiply it by 100 you get dry matter percentage.

Starch percentage of tubers before and after storage (%)

Starch content was estimated according to the **AOAC (1970)** method using the following equation:

$$\text{Starch (\%)} = 17.55 + 0.89 \times (\text{Dry matter (\%)} - 24.18)$$

Specific gravity of tubers before and after storage

Specific gravity was calculated based on dry matter percentage, as described by **Hassan (1999)**, using the following equation:

$$\text{Specific gravity gm/cm}^3 = 1.0988 + 24.182 - \text{Dry matter} / 211.04$$

3. Results and Discussion

Based on Table (1) Application of ozonized water or ozone gas alone was significantly higher plant height, number of stems and chlorophyll content.

Plants that were exposed to 300 ppm ozone showed a mean plant height which increased from 59.91 cm to 66.20 cm. Similarly, the number of stems increased from 3.77 to 4.44. Moreover, the chlorophyll content increased from 29.42 to 35.30 SPAD unit. This advancement may be accounted for by the power of ozone to enhance the activity of some antioxidant enzymes as well as efficiency of photophosphorylation **(Agathokleous, 2024).** Availability of energy will be diverted towards making vegetative-growth. Chitosan showed a gradual increase with increasing concentration wherein maximum plant height was observed at 2500 ppm. Chitosan has the ability to improve nutrient uptake, activate signaling for cell division and elongation, stimulate chlorophyll synthesis, and improve absorption capacity **(Chandrasekaran, 2024). Steglińska *et al*. (2024)** likewise had similar finding who reported that physiological growth gradual improvement due to chitosan foliar application on potato plants followed by increase in plant height and chlorophyll content. Chitosan enhances the essential metabolic processes within plants. The interaction of chitosan with ozone exhibited the maximum values in all respects. The combination of 300 ppm ozone and 2500 ppm chitosan produced the highest plant with the most stems and the greatest chlorophyll content. It shows that the two treatments can have a combined beneficial effect. Furthermore, the application of chitosan enhances the defense stimulation caused by the application of ozone. Chitosan likewise enhances the absorption of chlorophyll and other nutrients and hormones in plants. This type of cooperation enhances the efficiency of photosynthetic growth as well as vegetative growth.

According to the data in Table 2, the application of ozone gas caused the total tuber number to increase from 12.40 to 13.20 tubers per plant. In addition, the number of marketable tubers increased from 9.06 to 10.53 tubers per plant with the decrease in unmarketable tubers from 3.33 to 2.66 tubers per plant. As a result, beneficial impacts would occur on tuber growth due to the increase in the net rates of photosynthesis. The total tuber numbers and marketable tuber numbers gradually increased with foliar application of chitosan at 2500 ppm. The measurement of maximum total tuber number was 16.00 tubers per plant whereas that of maximum marketable tuber number was 14.25 tubers per plant. The lowest unmarketable tuber number was 1.75 tubers per plant. According to **Rojas-Pirela (2024),** these impacts are associated with better uptake of nutrients, increases in the translocation of nutrients within the tubers, and enhanced physiological processes for tuber differentiation and development. The highest total number of tubers per plant was recorded in chitosan at a concentration of 2500 ppm and ozone at a concentration of 300 ppm with a value of 16.50 tubers per plant, followed by the highest marketable number with a value of 15.00 tubers per plant, and the lowest unmarketable one with a value of 1.50 tubers per plant. Ozone stimulates the defense mechanism while chitosan enhances nutrition and hormones which together aid the formation of more productive and better-quality tubers/tuberose **(Chandrasekaran, 2024, Entoplast, 2025).**

Table (1). Effect of ozone gas and chitosan treatments and their interaction on selected vegetative growth traits of potato cv. Lady Rosetta, including plant height (cm plant^{-1}), number of aerial stems (stems plant^{-1}), and chlorophyll content (SPAD)

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Plant height (cm plant^{-1})	Number of aerial stems (stems plant^{-1})	Chlorophyll content (SPAD)
0	0	52.30 j	2.98 i	23.50 i
	1000	57.50 h	3.43 g	26.83 g
	1500	61.33 g	3.96 f	29.33 f
	2000	63.16 e	4.13 e	33.16 de
	2500	65.26 d	4.33 d	34.30 d
300	0	55.36 i	3.26 h	24.83 h
	1000	62.83 f	3.96 f	32.33 e
	1500	68.73 c	4.66 c	36.66 c
	2000	70.26 b	4.93 b	39.33 b
	2500	73.80 a	5.36 a	43.33 a
Mean effect of ozone gas (ppm)	0	59.91 b	3.77 b	29.42 b
	300	66.20 a	4.44 a	35.30 a
Mean chitosan effect (ppm)	0	53.83 e	3.12 e	24.16 e
	1000	60.16 d	3.70 d	29.58 d
	1500	65.03 c	4.31 c	33.00 c
	2000	66.71 b	4.53 b	36.25 b
	2500	69.53 a	4.85 a	38.81 a

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table (2). Effect of ozone gas and chitosan treatments and their interaction on total tuber number, marketable tuber number, and unmarketable tuber number (tubers plant^{-1}) of potato cv. Lady Rosetta

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Number of tubers (tuber plant^{-1})	Number of marketable tubers (tuber plant^{-1})	Number of unmarketable tubers (tuber plant^{-1})
0	0	10.50 f	5.66 g	4.83 a
	1000	11.33 e	7.50 f	3.83 b
	1500	12.00 de	8.66 ef	3.33 bc
	2000	12.66 d	10.00 d	2.66 cde
	2500	15.50 b	13.50 b	2.00 ef
300	0	11.50 e	8.00 f	3.50 bc
	1000	11.66 e	8.50 ef	3.16 bc
	1500	12.66 d	9.66 de	3.00 bcd
	2000	13.66 c	11.50 c	2.16 def
	2500	16.50 a	15.00 a	1.50 f
Mean effect of ozone gas (ppm)	0	12.40 b	9.06 b	3.33 a
	300	13.20 a	10.53 a	2.66 b
Mean chitosan effect (ppm)	0	11.00 d	6.83 e	4.16 a
	1000	11.50 d	8.00 d	3.50 b
	1500	12.33 c	9.16 c	3.16 b
	2000	13.16 b	10.75 b	2.41 c
	2500	16.00 a	14.25 a	1.75 d

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Based on the data presented in Table (3), it can be observed that the application of ozone gas significantly increased both total yield and marketable yield per plant. The total yield per plant rose from 729.53 g to 819.20 g. Along with this the marketable yield also increased from 671.00 g to 779.80 g per plant with the drop in the unmarketable yield from 58.53 g to 39.40 g per plant. The rise in yield may be due to the stimulation of photosynthesis through ozone and enhancement of efficiency of assimilate translocation to tubers resulting in increased production and lower unmarketable tubers **(Feng *et al*., 2023 and Scimone, 2024)**. According to Vandermeiren et al. **report (2005),** subjecting seed tubers to appropriate dose of ozone, that is, 300 ppm is beneficial in respect to physiology, growth and quality of potato; it would not have any adverse effect on potato yield.

Use of chitosan could increase all yield components progressively. The biggest average yield from a single plant (924.66 g), the bigger marketable yield (892.83 g) and the lower unmarketable yield (31.83 g), achieved at 2500 ppm. The effect occurs because of chitosan function that enhances nutrient uptake and supports tuber formation by making carbohydrates available in storage organ to mitigate yield loss **(Sun *et al.*, 2023).** Chitosan does this by stimulating the immune system in plants by activating defence pathways e.g. phenolic pathway and peroxidase pathway which helps lower incidence of fungal diseases and bacterial diseases. In tomatoes, the foliar application of chitosan has increased the production of cytokinin that increases the number of trusses per plant, number of fruits per truss, number of flowers per truss and average fruit weight **(Abdalla *et al*., 2015).**

The treatment of ozone and chitosan gave total yield per plant 1025.33 g, marketable yield 1004.00 g, and unmarketable yield 21.33 g, which was the lowest. Ozone improves qualitative and quantitative tuber traits of five varieties of Colombian native potatoes **(Theodora *et al*., 2021).** It demonstrates synergy as ozone enhances physiological defenses **(Hanjra, 2024)** and chitosan has an effect on nutrition and growth which improves tuber quality and boosts yield environmentally friendly way **(Reyes-Pérez *et al*., 2025; Entoplast, 2025).**

Table (3). Effect of ozone gas and chitosan treatments and their interaction on total yield per plant, marketable yield, and unmarketable yield (g plant^{-1}) of potato cv. Lady Rosetta

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Total yield per plant (g plant^{-1})	Marketable yield (g plant^{-1})	Unmarketable yield (g plant^{-1})
0	0	572.33 h	493.33 j	79.00 a
	1000	710.00 f	643.33 h	66.66 b
	1500	758.66 e	703.33 f	55.33 bcd
	2000	782.66 d	733.33 e	49.33 cde
	2500	824.00 c	781.66 a	42.33 de
300	0	640.00 g	580.00 i	60.00 bc
	1000	710.66 f	661.66 g	49.00 cde
	1500	786.66 d	748.33 d	38.33 ef
	2000	933.33 b	905.00 b	28.33 fg
	2500	1025.33 a	1004.00 a	21.33 g
Mean effect of ozone gas (ppm)	0	729.53 b	671.00 b	58.53 a
	300	819.20 a	779.80 a	39.40 b
Mean chitosan effect (ppm)	0	606.16 e	536.66 e	69.50 a
	1000	710.33 d	652.50 d	57.83 b
	1500	772.66 c	725.83 c	46.83 c
	2000	858.00 b	819.16 b	38.83 cd
	2500	924.66 a	892.83 a	31.83 d

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

According to table (4), it improves the quality attributes of potato tubers during storage using ozone gas (300 ppm) only.

Exposure to ozone decreased significantly % weight loss compared to control treatment, which increased total soluble solids (TSS) content before storage, which decreased thereafter after storage operation. The ability of the ozone to curtail the respiratory and water loss rate and impair some enzymes associated with degradation during storage, thereby limiting their physiological weight loss and preserving quality components **(Glowacz *et al*., 2020; Scimone *et al*., 2024)**. As the concentration of chitosan increased, weight loss decreased gradually, with the least weight loss observed in the case of 2500 ppm concentration. Also, TSS showed a substantial increase before the storage and then the TSS stabilised after the storage. The thick coating on tubers which limits moisture loss and gas exchange is possibly due to chitosan. As a result, respiration and sugar degradation slow down maintaining osmotic equilibrium of the tissue inside. The effect may improve quality stability during storage **(El-Ghaouth *et al*., 2019; Rojas-Pirela *et al*., 2024)**. The results of all traits analyzed reflect a better interaction of ozone-chitosan. The 300 ppm ozone + 2500 ppm chitosan treatment exhibited the least weight loss percentage as well as the highest TSS before storage and the lowest reduction in TSS during storage. The combined disinfectant and respiration-regulating effect of ozone and the physical barrier property of chitosan may slow the decomposition of internal tuber components and extend storage quality. The use of this strategy is an effective and sustainable approach to optimising potato storage and minimising postharvest losses **(Khalil *et al*., 2023).**

Table (4). Effect of Ozone Gas, Chitosan, and Their Interaction on Weight Loss (%) and Total Soluble Solids (TSS%) Before and After Storage of Potato Tubers cv. Lady Rosetta

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Weight loss (%)	TSS% before storage	TSS% after storage
0	0	11.14 a	2.73 g	5.86 a
	1000	9.40 c	3.20 ef	5.50 ab
	1500	8.74 d	3.40 de	5.53 ab
	2000	8.16 e	3.76 c	5.56 ab
	2500	7.98 e	4.10 b	5.60 ab
300	0	10.09 b	3.03 f	5.63 ab
	1000	8.18 e	3.26 e	5.43 b
	1500	8.12 e	3.50 d	5.40 b
	2000	7.86 e	3.86 c	5.33 b
	2500	6.95 f	4.43 a	5.33 b
Mean effect of ozone gas (ppm)	0	9.08 a	3.44 b	5.61 a
	300	8.24 b	3.62 a	5.42 b
Mean chitosan effect (ppm)	0	10.61 a	2.88 e	5.75 a
	1000	8.79 b	3.23 d	5.46 ab
	1500	8.43 c	3.45 c	5.46 ab
	2000	8.01 d	3.81 b	5.45 b
	2500	7.46 e	4.26 a	5.46 ab

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table 5 shows that ozone gas application of 300 ppm significantly maintained the firmness of the tuber either before or after storage the treatment control. The storage of "potato tuber" juice was apparently due to the continuing metabolism of tubers. It is the activities like respiration and degradation of carbohydrate that may lead to the accumulation of organic acids in the cell juice. The way it is stored may damage the buffering capacity of the tissues due to breakdown of certain phosphate compounds.

Also, the emergence of microorganism activation occurs under these storage conditions, resulting in increased acidity and decreasing pH values, increase in storage time **(Nguyen and Nguyen, 2024)**.

Tuber juice pH values increase before and after storage because of the role of ozone that reduces the activity of the enzyme responsible for the degradation of pectin as well as hemicellulose, which are important components of the cell wall and reduces the intensity of respiration as well as cell degradation during storage. Consequently, it minimizes the softening of the tissue while maintaining the structural integrity of the tuber tissue **(Scimone, 2024)**. **Glowacz and Rees (2016)** also reach this conclusion.

Chitosan exhibited a clear gradual effect on tuber firmness and tuber pH with the increasing rate. The treatment containing 2500 ppm showed the highest firmness both pre-storage and post-storage, as well as higher pH values. Chitosan has the ability to increase the deposition of structural compounds in the cell wall, such as cellulose and pectin. It produces a thick coat that impedes moisture loss and reduces the action of cell wall degrading enzymes. Consequently, it can help to maintain firmness of tissue and stabilize the acid–base balance of the tuber during storage **(El-Ghaouth *et al*., 2019 and Rojas-Pirela *et al*., 2024)**.

The interactions between ozone and chitosan generated maximum firmness levels and stability of pH levels before and after storage. Especially in the context of the interaction treatment involving 300 ppm ozone and 2500 ppm chitosan. The synergy relates the regulatory effect of ozone to reduce metabolism and cellular decay with the cell wall structural protection of chitosan. Chitosan can also reduce physiological loss. Through the use of this technology, tubers of better integrity and superior storage quality are produced. So, this integration as a sustainable practice to enhance quality as well as reducing quality deterioration of Potato tubers during long storage has been confirmed **(Khalil *et al.*, 2023)**.

Table (5). Effect of Ozone Gas, Chitosan, and Their Interaction on Tuber Firmness (lb in^{-2}) Before and After Storage, and Tuber Juice pH Before and After Storage of Potato Plants cv. Lady Rosetta

Ozone gas (ppm)	Chitosan (ppm)	Studied traits			
		Tuber firmness before storage (lb in^{-2})	Tuber firmness after storage (lb in^{-2})	Tuber juice pH before storage	Tuber juice pH after storage
0	0	15.26 e	12.60 h	5.86 g	5.30 f
	1000	15.56 cde	13.36 fg	6.06 f	5.63 e
	1500	15.90 cde	14.00 ef	6.18 e	5.79 d
	2000	16.30 bc	14.80 cd	6.26 cd	5.88 bc
	2500	16.83 b	15.63 b	6.34 ab	5.96 ab
300	0	15.50 de	13.00 gh	6.30 bc	5.77 d
	1000	15.83 cde	13.63 efg	6.15 e	5.78 d
	1500	16.13 bcd	14.23 de	6.20 de	5.82 d
	2000	16.70 b	15.16 bc	6.28 bc	5.94 b
	2500	17.83 a	16.80 a	6.36 a	6.03 a
Mean effect of ozone gas (ppm)	0	b 15.97	14.08 b	6.14 b	5.71 b
	300	16.40 a	14.56 a	6.26 a	5.87 a
Mean chitosan effect (ppm)	0	15.38 d	12.80 e	6.08 d	5.54 e
	1000	15.70 cd	13.50 d	6.11 d	5.71 d
	1500	16.01 bc	14.11 c	6.19 c	5.80 c
	2000	16.50 b	14.98 b	6.27 b	5.91 b
	2500	17.33 a	16.21 a	6.35 a	6.00 a

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

Table (6) show that 300 ppm Ozone gas treatment increased the dry matter, starch and specific gravity of tubers before storage. The dry matter ranged from 19.46 to 20.65%, gain in starch from 13.35 to 14.41%, and specific gravity from 1.0767 to 1.0823 g/cm³. Ozone contributes to improving photosynthetic efficiency and nutrient balance, which helps in the transfer of photosynthates from leaves to tubers and their accumulation in the form of starches and carbohydrates. As a result, the direct impact of this is in the rise of dry matter and specific gravity which are the most prominent indicators of the processing quality of potato **(Agathokleous, 2024 and Gu *et al*., 2025)**.

In the case of chitosan, all concentrations tested (2500 ppm) led to an increasing trend with the highest value for dry matter (22.23%), starch content (15.81%), and specific gravity (1.0898 g/cm3). The explanation for this is that application of chitosan could enhance the uptake efficiency of nutrients (notably nitrogen and potassium) and regulate enzyme activity related to starch storage in the tuber while improving efficiency in carbon-use, resulting in greater accumulation of solid compounds and specific gravity **(Chandrasekaran, 2024 and Rojas-Pirela *et al*., 2024).**

The maximum absolute values of all the traits were found in the ozone and chitosan interaction. The combined application of 300 ppm ozone and 2500 ppm chitosan resulted in the greatest value for olive dry matter (23.26%), starch content (16.73%) and specific gravity (1.0947 g/cm³). It shows synergy in effect from ozone assisted enhancement of photosynthetic efficiency and improved partitioning of nutrient towards tubers and chitosan which helps in enhancement of metabolic process and stabilizing of photosynthates in storage tissue. The tuber is high-quality and can be used for both fresh and processed food, according to **Khalil *et al*. (2023)** and **Entoplast (2025).**

Table (6). Effect of ozone gas, chitosan, and their interaction on dry matter content (%), starch content (%), and specific gravity (g cm⁻³) of Lady Rosetta potato tubers before storage

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Dry matter (%) before storage	Starch (%) before storage	Density (g cm⁻³) before storage
0	0	17.60 g	11.69 g	1.0678 g
	1000	19.00 ef	12.93 ef	1.0745 ef
	1500	19.36 de	13.26 de	1.0762 de
	2000	20.16 cd	13.97 cd	1.0800 cd
	2500	21.20 b	14.89 b	1.0849 b
300	0	18.23 fg	12.25 fg	1.0708 fg
	1000	19.66 cde	13.53 cde	1.0776 cde
	1500	20.36 c	14.15 c	1.0809 c
	2000	21.73 b	15.37 b	1.0874 b
	2500	23.26 a	16.73 a	1.0947 a
Mean effect of ozone gas (ppm)	0	19.46 b	13.35 b	1.0767 b
	300	20.65 a	14.41 a	1.0823 a
Mean chitosan effect (ppm)	0	17.91 d	11.97 d	1.0693 d
	1000	19.33 c	13.23 c	1.0760 c
	1500	19.86 c	13.71 c	1.0786 c
	2000	20.95 b	14.67 b	1.0837 b
	2500	22.23 a	15.81 a	1.0898 a

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

According to tabel (7), ozone gas treatment at 300 ppm contributed in maintaining dry matter from 16.56 to 18.20 per cent, increase in starch from 10.77 to 12.22 per cent and increase in specific gravity from 1.0627 to 1.0704 gm/cm3 over control treatment. This happens because ozone helps to decrease the respiration rate and the level of stored carbohydrates during storage and inhibits the process of microorganisms and enzymes that break down starch into simple sugars. Consequently, this can lead to a reduction in solid loss, which helps the quality of the tubers in storage **(Glowacz & Rees, 2016 and Gu *et al*., 2025)**. Similar work by **Palou *et al.* (2007)** also had comparable results, which suggest, the ozone exposure may keep chemical properties and enhance quality traits of stored potatoes. On the other hand, spraying with 2500 ppm chitosan is showing significantly less loss in dry matter (20.45 %), starch (14.23 %) and specific gravity (1.0811 g/cm³). Chitosan can form a coating that is semi-permeable which decreases moisture loss and gaseous exchange. As a result, the deceleration takes place in respiration, starch metabolic degradation and rot pathogen's production. By decelerating these processes, general higher solid contents are preserved within the tuber during prolonged storage **(El-Ghaouth *et al*., 2019 and Khalil *et al*., 2023).**

After storage, according to the author's analysis, most of the traits were better preserved in the interaction of ozone and chitosan. The combination of 300 ppm ozone and 2500 ppm chitosan produced the highest dry matter (21.73%), highest starch (15.37%), and the highest specific gravity (1.0871 g/cm³). There exists a clear synergic effect of ozone, which acts as a regulator to reduce the metabolic consumption of carbohydrates, and chitosan which acts as a protector to reduce loss of respiration water. Therefore, the enhanced processing quality stability of the tubers post-storage verified the effectiveness of the combination as a cost-effective sustainable approach to maintaining the quality of potato tubers in storage **(Glowacz *et al*., 2020; Rojas-Pirela, 2024).**

Table (7). Effect of Ozone Gas and Chitosan Treatments and Their Interaction on Dry Matter Content (%), Starch Content (%), and Specific Gravity (g cm⁻³) after Storage of Potato Tubers (Lady Rosetta Variety)

Ozone gas (ppm)	Chitosan (ppm)	Studied traits		
		Dry matter (%) after storage	Starch (%) after storage	Density (g cm⁻³) after storage
0	0	13.60 g	8.13 g	1.0486 g
	1000	15.90 e	10.18 e	1.0595 e
	1500	16.63 d	10.83 d	1.0630 d
	2000	17.53 c	11.63 c	1.0672 c
	2500	19.16 b	13.08 b	1.0750 b
300	0	15.20 f	9.55 f	1.0562 f
	1000	16.73 d	10.92 d	1.0635 d
	1500	17.83 c	11.90 c	1.0687 c
	2000	19.50 b	13.38 b	1.0766 b
	2500	21.73 a	15.37 a	1.0871 a
Mean effect of ozone gas (ppm)	0	16.56 b	10.77 b	1.0627 b
	300	18.20 a	12.22 a	1.0704 a
Mean chitosan effect (ppm)	0	14.40 e	8.84 e	1.0524 e
	1000	16.31 d	10.55 d	1.0615 d
	1500	17.23 c	11.36 c	1.0658 c
	2000	18.51 b	12.50 b	1.0719 b
	2500	20.45 a	14.23 a	1.0811 a

*Means followed by the same letter are not significantly different according to Duncan's multiple range test at $p \leq 0.05$.

4. Conclusion

Ozone gas and chitosan significantly improved potato growth, yield and tuber quality after harvest, a study finds. Ozone enrichment increased the plant height, stem number and chlorophyll content of plants which significantly improved the vegetative growth of the plants. Weight loss lessened hence single-plant yield and marketable yield also benefitted from this treatment. The approach likely worked by stimulating photosynthesis and activating defense mechanisms and protecting cells. Chitosan has been recognized to enhance nutrient absorption, raise the dry matter and starch content, and improve tuber firmness; however, the performance of this biopolymer is not always consistent. Furthermore, the treatment also stabilized pH and TSS. Due to metabolic processes, the effect of it is attributed to cell wall modulation. Maximum values for all the studied traits were observed in case of combined treatment. It suggests that chitosan has protective properties in terms of structure and nutrition in ozone stimulation. To summarize, the mixed application is an effective and eco-friendly management tool to enhance the efficacy and storage quality of potato production with distinct and clear cut environmental and agronomic benefits for commercial cultivation.

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دور الأوزون والكيتوسان كمعاملات صديقة للبيئة في تعزيز النمو والحاصل والصفات الخزنية للبطاطا الصناعية (*Solanum tuberosum* L.) صنف Lady Rosetta

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الخلاصة

أظهرت نتائج التجربة أن كل من غاز الأوزون والكيتوسان لهما تأثيرات معنوية ومستقلة على صفات نمو وإنتاجية وجودة درنات البطاطا، مع وجود تأثير تآزري واضح عند استخدامهما معًا. فقد أدى الأوزون إلى تعزيز النمو الخضري وزيادة ارتفاع النبات وعدد السيقان ومحتوى الكلوروفيل، مما يعكس تحفيزًا للعمليات الدفاعية والتمثيل الضوئي وتحسين توزيع العناصر الغذائية نحو الأجزاء الإنتاجية للنبات. كما ساهم في تحسين حاصل النبات والتسويقي وتقليل الحاصل غير التسويقي، وتقليل فقدان الوزن أثناء التخزين، والحفاظ على صلابة الدرنات ورفع المادة الجافة والنشا والكثافة النوعية قبل الخزن والمحافظة عليهم بعد الخزن، مما يدل على دوره في إبطاء عملية التنفس والتحلل الأيضي والحفاظ على استقرار الصفات التصنيعية للدرنات. أما الكيتوسان فقد أظهر تحسينًا تدريجيًا ومتسقًا لجميع الصفات مع زيادة التركيز، حيث عزز امتصاص العناصر الغذائية، وحفز الانقسام والاستطالة الخلوية، وزاد تراكم الكربوهيدرات والكلوروفيل، وساهم في تكوين طبقة واقية على سطح الدرنات، مما قلل فقد الرطوبة والفاقد أثناء التخزين وحافظ على متانة الأنسجة واستقرار pH وTSS. وقد أظهرت معاملة التداخل بين الأوزون والكيتوسان تأثيرًا تآزريًا واضحا حيث حققت أعلى ارتفاع للنبات وأعلى عدد سيقان وحاصل الكلي والتسويقي وأدنى حاصل غير التسويقي، بالإضافة إلى أقل فقدان وزن وأعلى صلابة ومادة جافة ونشا وكثافة نوعية بعد الخزن. ويعكس هذا التكامل على القدرة على تحسين النمو والإنتاجية والجودة التخزينية للدرنات بطريقة مستدامة وصديقة للبيئة، من خلال دمج التحفيز الفسيولوجي للأوزون مع الحماية البنيوية والتغذوية للكيتوسان. وبناءً على النتائج يُوصى باستخدام المعاملة التآزرية 300 ppm أوزون + ٢٥٠٠ ppm كيتوسان كاستراتيجية فعالة لتعزيز نمو وإنتاجية البطاطا وتحسين جودتها أثناء التخزين، مما يساهم في رفع القيمة الاقتصادية للمحصول وتقليل الفاقد بعد الحصاد.

الكلمات المفتاحية: البطاطا، معالجة الأوزون، الكيتوسان، التخزين بعد الحصاد، الزراعة المستدامة، التكامل التآزري للمحفزات الحيوية