The Future of Horticulture

FSA

Article

Towards Sustainable Potato Production: Synergistic Effects of Salicylic Acid and Chitosan on Growth, Yield, and Tuber Quality in the Hermes Cultivar

Angham T. M. Al-Chalabi

Department of Horticulture and Landscape Design, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq.

***Corresponding author:** angham.talal@uomosul.edu.iq

https://doi.org/10.37229/fsa.fjh.2026.05.17

Future Science Association

Available online free at
www.futurejournals.org

Print ISSN: 2692-5826

Online ISSN: 2692-5834

Received: 20 March 2026
Accepted: 3 May 2026
Published: 17 May 2026

Publisher's Note: FA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: The study findings demonstrated that foliar application of salicylic acid and chitosan resulted in tremendous changes in vegetative growth characteristics, yield characteristics, and chemical characteristics of potato plants (*Solanum Tuberum L.*) cv. Hermes. These gains were realized either in cases of administration of each treatment separately or in combination of both. Salicylic acid, particularly at a concentration of 100 mg L^{-1}, enhanced growth indices, increased productivity, and improved the nutritional composition of tubers in terms of mineral elements, nitrogen, and protein content. This effect is attributed to its role in stimulating physiological processes, enhancing photosynthetic efficiency, and improving the translocation of photosynthates toward storage organs. In contrast, chitosan exhibited a concentration-dependent stimulatory effect, leading to marked improvements in vegetative growth and yield, as well as enhancing tuber quality through improved nutrient uptake, activation of metabolic activity, and increased accumulation of carbohydrates, including dry matter, starch content, and specific gravity of tubers. It also contributed to the overall enhancement of plant physiological efficiency. The combined treatments of salicylic acid and chitosan showed a clear synergistic effect compared with individual applications. The treatment (100 mg L^{-1} salicylic acid + 1.5 g L^{-1} chitosan) recorded the highest values for most studied traits, including vegetative growth parameters, yield components, and tuber number, as well as quality traits such as dry matter, starch content, and specific gravity, in addition to improving nutritional content in terms of NPK and protein. This dominance is credited to a synergistic relationship between the two compounds in which salicylic acid can control physiological functions and increase the translocation of nutrients into the body as well as chitosan can increase metabolism, better nutrient absorption and accumulation of organic compounds. In general, the work proves the fact that Salicylic acid/chitosan combination is a beneficial and green agronomic approach to enhancing potato growth and quality of tubers in the field.

Key words: Salicylic acid, chitosan, sustainable agriculture, synergistic integration of biostimulants.

1. Introduction

Potato (*Solanum tuberosum* L.) is a food crop that is of great significance in the world. Following the current trend of switching to sustainable and environmentally friendly farming methods in order to increase productivity and improve the quality of produce, there has been more focus on the application of non-conventional biostimulant agents like salicylic acid and chitosan, because they can potentially lead to greater efficiency of plants and increase their yield capacity and quality of tubers **(Mbuyisa and Ngcobo, 2025).**

Potato (*Solanum tuberosum* L.) is a very important food crop in the world. With the current tendency of switching to sustainable and environmentally friendly farming practices to achieve higher productivity and better the quality of the produce, there has been an upsurge on the use of non-conventional biostimulant agents, such as salicylic acid and chitosan, since they have the potential to result in greater efficiency of the plants and increase their yield capacity and quality of produce. This compound is then subjected to a series of enzyme reactions which culminate into the ultimate production of salicylic acid. Alternatively, synthesis of SA can also be done through the shikimate pathway by the production of isochorismate, especially during times of stress. Salicylic acid builds up in the potato plants to both biotic and abiotic stimuli, and is a key signaling molecule in the defense responses, systemic acquired resistance (SAR), and pathogenesis-related protein expression. In this respect, the regulation of SA biosynthesis is regarded as one of the primary mechanisms that help potato plants to adjust to a variety of environmental factors and stresses **(Coquoz *et al*., 1998).** One of the studies showed that the potato plants react to foliar application of the biotic and abiotic elicitors by dynamically regulating the concentrations of salicylic acid (SA) and jasmonic acid (JA) among the most crucial signaling molecules involved in the regulation of plant defense reactions. Such elicitors trigger signaling pathways that are linked to systemic acquired resistance (SAR) and stress responses leading to enhanced accumulation of SA and JA in plant tissues. This buildup increases defense-associated gene expression, promotes antioxidant enzymes and minimizes oxidative harm due to adverse environmental conditions or pathogen infection. Additionally, the interaction between SA and JA pathways is regulated by a high degree of physiological complexity in plants since this interaction can be either synergistic or antagonistic depending on the nature of elicitor and the stress conditions. In this regard, foliar treatment using both biotic and abiotic elicitors is deemed as an effective solution to reprogramming the hormonal balance of potato plant and to increasing their adaptability to unfavourable environmental conditions **(González-Gallegos *et al*., 2015). Acevedo *et al.* (2023)** found that the use of salicylic acid (SA) as a folliar treatment is a promising method to increase potato resistance to drought stress. SA is a growth regulator and physiological activator, which triggers the antioxidant defense mechanism, enhancing catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD) activity, which leads to a decrease in oxidative stress caused by water stress. SA Foliar application, also enhances the chlorophyll content, sustains photosynthetic efficiency and water balance of the plants. Therefore, it affects positively vegetative growth and yield characteristics by enhancing the number of tubers, enhancing the weight of tubers and increasing marketable quality. Consequently, SA application is a promising approach in sustainable agricultural production systems to counteract the impacts of water stress in potato. **Khilji *et al.* (2024)** found that salicylic acid applied to foliage has a significant positive impact on morphological features and anatomical characteristics of potato plants even in conditions of stress caused by wastewater irrigation. SA is a significant physiological regulator, which promotes an extensive spectrum of biological functions, such as stimulation of vegetative growth by promoting plant height, leaf count, and stem growth. It has also positive effects on the leaf anatomical structure wherein it enhances the palisade tissue thickness and better organization of the parenchyma cells that conduct the photosynthetic efficacy, and thus enhances overall physiological performance. Besides this, SA also alleviates the negative impacts of the pollutants and salinity linked with wastewater through the activation of the antioxidant system and decreasing the intracellular oxidative stress. **Acevedo *et al*. (2025)** demonstrated that pre-harvest foliar application of salicylic acid improves the biochemical and physiological quality of potato tubers under water stress conditions. Water deficit increases oxidative stress and deteriorates tuber quality due to the accumulation of reactive oxygen species (ROS), whereas SA application helps mitigate these effects by enhancing antioxidant defense mechanisms. This is done by the increased activity of antioxidant enzymes, such as catalase (CAT), superoxide dismutase (SOD) and peroxidase (POD), which minimize the damage to cells and preserve the state of their membranes. The findings also reported that moderate concentrations of SA especially at 1 mM are most suitable in enhancing postharvest tuber quality, which supports its role as a potential valuable tool in the management toolkit in sustainable management practices to mitigate the effects of water stress in potato. Chitosan is a natural polysaccharide biopolymer, which has acquired a growing significance in the contemporary agricultural practice especially its application as a foliar spray since it possesses growth-promoting and physiological control characteristics. It falls into the category of biostimulant/elicitor that can stimulate plant defense and cause multiple biological responses. Chitosan also increases the enzyme activity of antioxidant enzymes including catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD), thus decreasing oxidative stress and enhancing the overall plant physiological functioning. It also increases the efficiency of photosynthesis and nutrient uptake, which has a positive impact on metabolic functions and overall growth of the plants.

A number of studies have revealed that foliar application of chitosan at various concentrations enhances vegetative growth, photosynthetic efficiency and carbohydrate accumulation which eventually result in high productivity and quality of tubers **(Al-Mokadem *et al*., 2022).** According to **Gonzalez-Lopez et al. (2017),** foliar application of chitosan on the vegetative growth stage of potato plants led to remarkable growths in plant height, biomass, number of tubers, and total yield as compared to the control group. These were due to the capacity of the chitosan to induce cell division, promote growth-related enzymes and increase the efficiency of nutrient uptake, which positively affected the growth and productivity. It was also shown that the range of 1000-5000 ppm was found to be effective in promoting physiological responses and growth performance in plants.

In an experimental field study of potato, **Falcón-Rodríguez *et al.* (2017)** indicated that the use of chitosan of various molecular weights and low doses at various stages of growth considerably enhanced yield-related characteristics. The total yield and optimized tuber size distribution were highly increased in treated plants in relation to the control. The findings revealed that the most effective applications (200 and 325 mg ha -1) were the most effective in improving some of the components of the yield suggesting that the physicochemical characteristics of chitosan including its molecular weight and rate of application is important in the establishment of its bioactivity and plant reaction.

Ribeiro *et al.* (2021) proved that chitosan solution (500-2000 ppm) treatment of potato tubers augmented the phenolic compounds content and antioxidant action. It also enhanced carbohydrate balance in the tubers thus positively influencing their nutritional value and quality. Under conditions associated with enhancement of the quality of tubers under mechanical stress, **Zhu *et al.* (2023)** found that foliar application of chitosan during pre-harvest mitigated deposition of suberin and lignin at the wound sites, creating an effective protective layer that minimized water loss. This reaction was linked to higher defense-related enzyme activities and phenolic compounds buildup and better nutrient and water using efficiency, ultimately resulting in growth, yield performance, and postharvest tuber quality.

More recently, **Zhang *et al.* (2024)** showed that potato plants nano-loaded with the macronutrient (NPK) and plant extracts showed significant enhancement of vegetative growth and productivity. The plant height, the number of leaves and branches, the area of the leaves, the total yield weight and the content of dry matter were significantly greater when compared with the conventional treatment.

This was credited to the increased nutrient uptake efficiency and better internal translocation of nutrients, the activation of plant defense mechanisms and the triggering of physiological processes related to growth and yield.

In conclusion, chitosan is a promising biostimulant in sustainable agricultural practices because of its two-fold ability to stimulate plant growth and improve productivity. In addition, its combination with other physiological elicitors like salicylic acid can be effective in offering a synergistic strategy towards enhancing the physiological and productive performance of potato plants. In this regard, the study will be conducted to compare the individual and synergistic effects of salicylic acid and chitosan on vegetative growth, yield, and physiological and biochemical tuber characteristics and their effect on antioxidant defense system. This is done in the context of coming up with a sustainable and environmentally friendly agricultural policy that will enhance potato productivity and quality and minimize the postharvest losses.

2. Materials and Methods

2.1. Experimental site, land preparation, cultural practices, and harvesting

This experiment was carried out in the research area of the College of Agriculture and Forestry in the growing season of 20242025. Preparation of the soil was done by repeated cross ploughing using a moldboard plough to enhance soil structure and to provide the proper condition to plant. It was then followed by a process of leveling and smoothing the soil surface with the help of a harrow to give uniformity in the fields. The experimental field was broken down into experimental units each comprising of two ridges whereby each ridge had a length and width of 150 cm and the area of an experimental unit was 2.25 m^2. It was decided to use a distance between rows of 0.75 m, and between plants of 30 cm, which gave 10 plants in each experimental unit.

Potato cultivar tube seed tubers were taken (Hermes). Two weeks before planting, tubers were taken out of cold storage and stored in a shaded and well-ventilated environment at 1520C to get them physiologically ready, to initiate sprouting. To reduce non-experimental variation and achieve accurate data, all cultural practices were uniformly used in all experimental units. Such practices involved fertilization, weed management, ridging, and routine preventive and curative disease and insect management programs. Fertilizers were applied at rates of 400 kg ha^{-1} urea (46% N), 600 kg ha^{-1} triple superphosphate (45% P_2O_5), and 400 kg ha^{-1} potassium sulfate (48% K_2O), based on Al-Obaidi (2005).

2.2. Experimental treatments

The study included two factors:

- Factor A: Salicylic acid (SA) at concentrations of 0 and 100 mg L^{-1}
- Factor B: Chitosan at four concentrations (0, 0.5, 1, and 1.5 g L^{-1})

Foliar applications were carried out in the early morning in three equal sprays during the growing season.

Experimental design and statistical analysis

To minimize experimental error and enhance accuracy, the experiment was set up in a Randomized Complete Block Design (RCBD) with three replicates. Each experimental unit was measured in terms of data on vegetative growth, yield and postharvest traits.

Care was taken to avoid mechanical damage to the tubers and after 150 days post planting, tubers were harvested by digging to hand using a digging hoe. The SAS software (2017) was used to conduct statistical analysis. Duncan Multiple Range Test was applied at the desired level of significance to compare means of different treatments **(Al-Rawi and Khalaf Allah, 2000).**

2.3. Studied traits

1. Plant height (cm plant $^{-1}$): The distance of the soil surface to the tallest growing leaf was measured with a measuring tape; the average was obtained.
2. Aerial stems (stem plant $^{-1}$): Measured on five plants and averaged.
3. Leaf chlorophyll content (SPAD value): Measured in a SPAD-502 chlorophyll meter (Japan). Fully expanded leaves of 5 plants were read and the average was computed.
4. Number of tubers (tuber plant $^{-1}$): It is determined by dividing the total number of tubers in each unit of the experiment by the number of plants.

5. Marketable tuber number: The number of marketable tubers is calculated by discounting the diseased, deformed, or tubers that weigh less than 25 g, and then dividing the number by the total number of tubers.
6. Non-marketable tuber number: Division of the number of unmarketable tubers per plant to the total number of tubers.
7. Total yield per plant (g plant $^{-1}$): Calculated by dividing total yield per experimental unit by the number of plants.
8. Marketable yield per plant (g plant $^{-1}$): Computed by omitting the tubers that have weights below 25 g or the damaged tubers.
9. Non-marketable yield per plant (g plant $^{-1}$): Computed using unmarketable tuber yield per plant.
10. Yield per experimental unit (kg): The total fresh weight of the harvested tubers in the plot. Total yield (t ha^{-1}): Calculated by converting plot yield to hectare basis (kg per 2.25 m² converted to 10,000 m²).
11. Total soluble solids (TSS%): Determined using a hand refractometer according to **A.O.A.C. (2000)**.
12. Dry matter percentage: Calculated as dry weight divided by fresh weight × 100 after oven-drying to constant weight.
13. Starch percentage: Estimated using **AOAC (1970)** equation: Starch % = 17.55 + 0.89 (Dry matter % – 24.18)
14. Specific gravity of tubers (before and after storage): Determined based on dry matter content according to Hassan (1999) using the equation:
15. Specific gravity = 1.0988 + (24.182 – Dry matter %)/211.04

3. Results and Discussion

The findings in Table (1) showed that foliar application of salicylic acid and chitosan, and or their combination had a significant effect on enhancing the vegetative growth characteristics of potato plants. The results showed that foliar spraying salicylic acid at a concentration of 100 mg L -1 had significant positive effects on all the traits studied. This is attributable to its functions as a plant growth regulator that increases physiological functions, enzymatic activity, photosynthetic efficiency, and morphological and physiological characteristics of potato plants, and eventually resulting in a significant growth (vegetative) increase. This establishes its importance in improving the performance of plants **(Khilji *et al*., 2024).** In the case of chitosan application, the effect was gradually positive and depended on the concentration, which led to positive changes in plant height, stem number, and chlorophyll level. This is due to its role as a biostimulant which stimulates metabolism, improves the efficiency of nutrient uptake and the efficiency of photosynthesis. As a result, chitosan enhances the growth of potatoes, their ability to exchange gases, and chlorophyll levels, as well as resistance to biotic factors and environmental stresses **(Steglińska *et al*., 2024).** Regarding the reaction between salicylic acid and chitosan, it was shown that the combination of the two compounds (100 mg L $^{-1}$ and 1.5 g L $^{-1}$) gave the highest values in all the characteristics under investigation, which proved a clear synergistic action between the two compounds. This is attributable to the fact that salicylic acid is a growth regulator and defense elicitor and chitosan is a biostimulant that improves immune response and nutrient uptake leading to better vegetative growth. **Steglińska *et al.* (2024)** established that combined uses of these compounds result in better growth, improved physiological properties, and greater antioxidant activity than the single uses of these compounds.

Table (1). Effect of foliar application of salicylic acid and chitosan and their interaction on some vegetative growth traits, including plant height (cm plant⁻¹), number of aerial stems (stem plant⁻¹), and chlorophyll content (SPAD) in potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits		
		Plant height (cm plant⁻¹)	Number of aerial stems (stem plant⁻¹)	Chlorophyll content (SPAD)
0	0	**57.7000 g**	**2.98333 g**	**22.333 f**
	0.5	**60.8667 f**	**3.26667 f**	**23.933 ef**
	1	**61.6000 ef**	**3.43333 e**	**25.333 e**
	1.5	**62.7333 e**	**3.95000 d**	**28.667 d**
100	0	**66.0667 d**	**3.98333 d**	**31.067 c**
	0.5	**69.1333 c**	**4.13333 c**	**32.167 bc**
	1	**71.4000 b**	**4.33333 b**	**33.633 b**
	1.5	**74.6667 a**	**4.46667 a**	**37.167 a**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**60.7250 b**	**3.40833 b**	**25.0667 b**
	100	**70.3167 a**	**4.22917 a**	**33.5083 a**
Mean effect of chitosan (g L⁻¹)	0	**61.8833 d**	**3.48333 d**	**26.7000 c**
	0.5	**65.0000 c**	**3.70000 c**	**28.0500 bc**
	1	**66.5000 b**	**3.88333 b**	**29.4833 b**
	1.5	**68.7000 a**	**4.20833 a**	**32.9167 a**

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The findings in Table (2) demonstrated that foliar application of salicylic acid and chitosan has a large effect and their combination has a large effect on the total yield per plant, marketable as well as non-marketable yield of potato (*Solanum tuberosum L.*) cv. Hermes. The use of salicylic acid at a rate of 100 mg L -1 as foliar application led to significant increase in total yield per plant and marketable yield and a decrease in non-marketable yield. This is because it has been known to improve physiological processes in the plant, photosynthetic efficiency and translocation of photosynthates to tubers hence productivity. These results align with the findings of **Khilji *et al.* (2024),** who have found that salicylic acid improves the productivity of potatoes through better growth performances and efficiency in the utilization of resources.

Conversely, chitosan showed an increasingly positive impact with the increase of the concentration (0 to 1.5 g L $^{-1}$) and the optimum performance of the chitosan was recorded with the highest concentration on all yield characteristics. This reaction is credited to its role as a biostimulant which improves nutrient uptake, metabolic activities and carbohydrate storage in plant economically significant organs. Chitosan, therefore, enhances potato yield by raising physiological growth, biomass growth and photosynthetic efficiency **(Steglińska *et al*., 2024).** In terms of salicylic acid and chitosan interaction, the combined approach (100 mg L $^{-1}$ + 1.5 g L $^{-1}$) gave the most positive results, achieving the maximum total yield of the plant and the maximum marketable one, as well as a significant decrease in the non-marketable yield. This implies that there is enhanced efficiency in channelling assimilates to form tubers and minimising non-economic losses. This synergistic effect can be explained by the role of salicylic acid in regulating plant growth and improving internal nutrient transport, while chitosan enhances physiological activity and photosynthetic efficiency, leading to a marked improvement in overall productivity. Recent studies on the interaction between growth regulators and biostimulants have confirmed that the combined application of these compounds enhances productivity and improves carbohydrate partitioning within the plant **(Poznanski *et al*., 2024).**

Table (2). Effect of foliar application of salicylic acid and chitosan and their interaction on total yield per plant, marketable yield, and non-marketable yield (g plant⁻¹) of potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits		
		Total yield per plant (g plant⁻¹)	Marketable yield (g plant⁻¹)	Non-marketable yield (g plant⁻¹)
0	0	**502.667 g**	**395.333 h**	**107.333 a**
	0.5	**518.667 f**	**410.000 g**	**108.667 a**
	1	**560.667 e**	**461.333 f**	**99.333 ab**
	1.5	**582.667 d**	**491.333 e**	**91.333 bc**
100	0	**590.000 d**	**505.333 d**	**84.667 cd**
	0.5	**626.000 c**	**539.333 c**	**86.667 cd**
	1	**734.667 b**	**656.000 b**	**78.667 de**
	1.5	**841.333 a**	**773.333 a**	**68.000 e**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**541.167 b**	**439.500 b**	**101.667 a**
	100	**698.000 a**	**618.500 a**	**79.500 b**
Mean effect of chitosan (g L⁻¹)	0	**546.333 d**	**450.333 d**	**96.000 ab**
	0.5	**572.333 c**	**474.667 c**	**97.667 a**
	1	**647.667 b**	**558.667 b**	**89.000 b**
	1.5	**712.000 a**	**632.333 a**	**79.667 c**

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The results presented in Table (3) showed that foliar application of salicylic acid at a concentration of 100 mg L⁻¹ significantly increased the total number of tubers and marketable tubers compared with the control treatment, while markedly reducing the number of non-marketable tubers. This advancement can be explained by the fact that it regulates physiological processes, increases the translocation of photosynthates to storage organs, and the efficiency of the tuberization process. The results are in agreement with **Khilji *et al.* (2024)**, who found that salicylic acid increases yield characteristics by increasing the growth and the metabolic activity of the plant. When it comes to the use of chitosan, the best results were obtained with the highest concentration (1.5 g L⁻¹) in terms of total and marketable tubers, and the lowest non-marketable tubers. This reaction is explained by its role as a biostimulant, which increases cell division in the tuber initiation areas, enhances the efficiency of nutrient uptake and optimizes hormonal balance in the plant, which ultimately leads to an enhancement in marketable tuber development. These findings coincide with those of **Steglińska *et al.* (2024)**. As for the interaction between salicylic acid and chitosan, the combined treatment (100 mg L⁻¹ + 1.5 g L⁻¹) produced the most pronounced effects, recording the highest total tuber number and marketable tuber number (11.6333 and 10.7333 tubers plant⁻¹, respectively), along with the lowest number of non-marketable tubers (0.9000 tuber plant⁻¹). This indicates a high efficiency in directing photosynthates toward the formation of marketable tubers and reducing non-economic yield losses.

The synergistic effect can be attributed to the fact that salicylic acid helps in improving internal transport and growth control and chitosan boosts metabolic activity and carbohydrate formations, thus improving efficiency of assimilate partitioning and the number of marketable tubers. The results are in agreement with **Poznanski *et al.* (2024).**

Table (3). Effect of foliar application of salicylic acid and chitosan and their interaction on total number of tubers, marketable tubers, and non-marketable tubers (g plant⁻¹) of potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits		
		Total number of tubers (tuber plant⁻¹)	Marketable tuber number (tuber plant⁻¹)	Non-marketable tuber number (tuber plant⁻¹)
0	0	**6.0000 g**	**3.3333 h**	**2.6667 a**
	0.5	**6.3400 g**	**4.0667 g**	**2.2733 b**
	1	**7.1667 f**	**5.1333 f**	**2.0333 b**
	1.5	**7.5333 e**	**6.0667 e**	**1.4667 c**
100	0	**8.0667 d**	**6.6000 d**	**1.4667 c**
	0.5	**8.8667 c**	**7.6667 c**	**1.2000 dc**
	1	**10.5000 b**	**9.4667 b**	**1.0333 d**
	1.5	**11.6333 a**	**10.7333 a**	**0.9000 d**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**6.76000 b**	**4.6500 b**	**2.11000 a**
	100	**9.76667 a**	**8.6167 a**	**1.15000 b**
Mean effect of chitosan (g L⁻¹)	0	**7.0333 d**	**4.9667 d**	**2.0667 a**
	0.5	**7.6033 c**	**5.8667 c**	**1.7367 b**
	1	**8.8333 b**	**7.3000 b**	**1.5333 b**
	1.5	**9.5833 a**	**8.4000 a**	**1.1833 c**

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The results presented in Table (4) showed that foliar application of salicylic acid at a concentration of 100 mg L⁻¹ significantly increased yield per experimental unit and total yield, in addition to enhancing total soluble solids (TSS%) compared with the control treatment. This improvement can be attributed to its role in enhancing photosynthetic efficiency and increasing the translocation of photosynthates toward tubers, which results in greater dry matter accumulation and improved tuber quality. Such results align with **Khilji *et al.* (2024)** who have found that salicylic acid positively affects productivity and physiological characteristics in potato. Conversely, chitosan showed a gradually increasing positive response to increasing concentration such that the highest concentration (1.5 g L^{-1}) gave the highest values in yield per experimental unit, total yield and TSS%. This has been blamed on its capacity as a biostimulant to stimulate nutrient uptake, improve metabolic activities and carbohydrate storage in tubers leading to improvement of yield and quality. These findings correlate with **Steglińska *et al.* (2024)** who emphasized the use of chitosan in enhancing potato growth and physiological properties. When it comes to the interplay between salicylic acid and chitosan, the most successful treatment (100mg L^{-1} + 1.5g L^{-1}) had the highest yield per unit of the experiment (8.41333kg), the highest total yield (37.3552 t ha^{-1}), and the highest TSS (4.56667%). This implies that both compounds have a high synergistic effect on enhancing the productivity and quality. This advantage can be attributed to the fact that salicylic acid increases physiological transportation and assimilate partitioning whereas chitosan enhances metabolic activity and carbohydrate accumulation resulting in concomitant improvements in yield and quality. Such results align with **Poznanski *et al.* (2024),** who indicated that the two compounds interplay to increase the efficiency of production and accumulation of dry matter in tubers.

Table (4). Effect of foliar application of salicylic acid and chitosan and their interaction on plot yield (kg), total yield (t ha⁻¹), and total soluble solids percentage (TSS%) of potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits		
		Yield per experimental unit (kg)	Total yield (t ha⁻¹)	**TSS**
0	0	**5.02667 g**	**22.3184 g**	**2.90000 f**
	0.5	**5.18667 f**	**23.0288 f**	**3.33333 e**
	1	**5.60667 e**	**24.8936 e**	**3.46667 de**
	1.5	**5.82667 d**	**25.8704 d**	**3.56667 d**
100	0	**5.90000 d**	**26.1960 d**	**3.83333 c**
	0.5	**6.26000 c**	**27.7944 c**	**4.03333 c**
	1	**7.34667 b**	**32.6192 b**	**4.26667 b**
	1.5	**8.41333 a**	**37.3552 a**	**4.56667 a**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**5.41167 b**	**24.0278 b**	**3.31667 b**
	100	**6.98000 a**	**30.9912 a**	**4.17500 a**
Mean effect of chitosan (g L⁻¹)	0	**5.46333 d**	**24.2572 d**	**3.36667 d**
	0.5	**5.72333 c**	**25.4116 c**	**3.68333 c**
	1	**6.47667 b**	**28.7564 b**	**3.86667 b**
	1.5	**7.12000 a**	**31.6128 a**	**4.06667 a**

Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

Findings in Table (5) indicated that foliar application of salicylic acid and chitosan and the combination of the two had significant impacts on quality characteristics depicted by dry matter percentage, starch content, and specific gravity. Salicylic acid applied as a foliar at a concentration of 100 mg L -1 has a significant positive effect on all the traits studied in applicability as compared to the control treatment. This was improved by the fact that it helps in improving photosynthetic effectiveness and increasing photosynthates accumulation in tubers resulting in greater dry matter and starch level and specific gravity. This is similar to **Khilji *et al.* (2024).** Conversely, chitosan showed an upward trend in response to increasing concentration with the highest concentration (1.5 g L^{-1}) showing the highest values of dry matter, starch content and specific gravity. This is explained by the fact that it acts as a biostimulant which boosts the extent of nutrient absorption, metabolic activities and stored carbohydrates in tubers hence enhancing the quality of tubers. The findings are consistent with **Steglińska *et al.* (2024).** Concerning the combination of salicylic acid and chitosan, the combination (100mg L^{-1} + 1.5 g L^{-1}) performed the best, with the highest dry matter percentage (20.33%), starch content (14.12%) and specific gravity (1.0808 g cm -3). This implies that there is an evident synergistic effect between the two compounds in enhancing the quality of tubers traits. This effect may be attributed to the effects of salicylic acid to increase physiological transport and guide photosynthates to the storage organs, whereas chitosan enhances carbohydrate storage and metabolic activity, resulting in a combined effect to improve the quality of tubers. These results are in line with **Zhang *et al.* (2024).**

Table (6) results indicated a strong impact of foliar salicylic acid and chitosan application, and the interaction of these two, on nitrogen, protein, phosphorus and potassium contents. Salicylic acid (100 mg L^{-1}) foliar application showed significant increase in all the characteristics studied than under the control treatment. This has been possible due to its ability to improve the efficiency of nutrient uptake, increase protein biosynthesis, and translocation of nutrients in the plant, which in turn enhances the nutritional status of the plant. These results are in line with those of **Hayat and Damalas (2023)**, who found that salicylic acid improves nutrient absorption and elevates protein levels in potato. Conversely, chitosan showed an increasingly positive response to the work, with the maximum concentration (1.5 g L^{-1}) registering the highest values on all the traits of the study. The levels of nitrogen, protein, phosphorus and potassium became significant. This reaction is explained by the fact that chitosan is considered a biostimulant which enhances nutrient absorption, increases permeability of membranes and activates enzymes related to metabolism, resulting in the improved accumulation of mineral nutrients and the high protein. These results agree with **El Hadrami *et al.* (2024)** who obtained that chitosan improves nutrient absorption and metabolic activity in potato. In terms of the effect between salicylic acid and chitosan the individual treatment (100 mg L^{-1} + 1.5 g L^{-1}) had the highest values of each of the traits under study, including nitrogen (1.046%), protein (6.5375%), phosphorus (0.4644%), and potassium (0.9453%). This shows that there is high synergistic effect of the two compounds. This enhancement could be attributed to the presence of salicylic acid in controlling nutrient uptake and transport in the plant and chitosan improves metabolism, protein synthesis and efficiency of nutrient use. These data are in line with **Zhang *et al.* (2024)**, who discovered that the interplay of these compounds positively affects nutrient distribution and metabolic efficiency.

Table (5). Effect of foliar application of salicylic acid and chitosan and their interaction on dry matter (%), starch content (%), and specific gravity (g cm⁻³) of potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits		
		Dry matter (%)	Starch (%)	Specific gravity (g cm⁻³)
0	0	**16.3000 f**	**10.5368 f**	**1.061708 f**
	0.5	**16.6667 ef**	**10.8631 ef**	**1.063445 ef**
	1	**17.0667 def**	**11.2191 def**	**1.06534 def**
	1.5	**17.4667 de**	**11.5751 de**	**1.067236 ed**
100	0	**17.7333 cd**	**11.8125 cd**	**1.068499 cd**
	0.5	**18.4000 bc**	**12.4058 bc**	**1.071658 bc**
	1	**18.8000 b**	**12.7618 b**	**1.073554 b**
	1.5	**20.3333 a**	**14.1265 b**	**1.080819 a**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**16.8750 b**	**11.0486 b**	**1.0644321 b**
	100	**18.8167 a**	**12.7766 a**	**1.0736326 a**
Mean effect of chitosan (g L⁻¹)	0	**17.0167 c**	**11.1746 c**	**1.065103 c**
	0.5	**17.5333 bc**	**11.6345 bc**	**1.067552 bc**
	1	**17.9333 b**	**11.9905 b**	**1.069447 b**
	1.5	**18.9000 a**	**12.8508 a**	**1.074027 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). Effect of foliar application of salicylic acid and chitosan and their interaction on nitrogen, protein, phosphorus, and potassium contents (%) in potato (*Solanum tuberosum* L.) cv. Hermes

Salicylic acid spray (mg L⁻¹)	Chitosan (g L⁻¹)	Studied traits			
		% N	Protein (%)	**%** P	% K
0	0	**1.027667 f**	**6.422917 f**	**0.288767 h**	**0.76500 e**
	0.5	**1.030667 e**	**6.441667 e**	**0.320933 g**	**0.81600 d**
	1	**1.033667 d**	**6.460417 d**	**0.356267 f**	**0.82700 cd**
	1.5	**1.034667 d**	**6.466667 d**	**0.376667 e**	**0.83933 cd**
100	0	**1.036000 cd**	**6.475000 cd**	**0.403533 d**	**0.85900 bc**
	0.5	**1.037333 c**	**6.483333 c**	**0.417767 c**	**0.86600 bc**
	1	**1.042667 b**	**6.516667 b**	**0.439467 b**	**0.89400 b**
	1.5	**1.046000 a**	**6.537500 a**	**0.464433 a**	**0.94533 a**
Mean effect of salicylic acid (mg L⁻¹)	**0**	**1.0316667 b**	**6.447917 b**	**0.335658 b**	**0.811833 b**
	100	**1.0405000 a**	**6.503125 a**	**0.431300 a**	**0.891083 a**
Mean effect of chitosan (g L⁻¹)	0	**1.0318333 d**	**6.448958 d**	**0.346150 d**	**0.81200 c**
	0.5	**1.0340000 c**	**6.462500 c**	**0.369350 c**	**0.84100 b**
	1	**1.0381667 b**	**6.488542 b**	**0.397867 b**	**0.86050 b**
	1.5	**1.0403333 a**	**6.502083 a**	**0.420550 a**	**0.89233 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

The findings showed that salicylic acid and chitosan had a positive and significant impact on enhancing the vegetative growth, yield, and quality characteristics of potato (*Solanum tuberosum L.*) cv. Hermes. Salicylic acid, especially at the concentration level of 100 mg L -1, had a positive effect on all parameters studied, but chitosan responded positively as the concentration increased. The association between the two treatments showed a definite great superiority over single applications where the combined treatment (100 mg L^{-1} salicylic acid + 1.5 g L^{-1} chitosan) registered the best values in most of the characteristics under study. This advantage can be explained by the physiological synergy of the two compounds, salicylic acid controls essential metabolic processes and promotes photosynthetic performance, whereas chitosan increases mineral nutrient uptake, metabolic activity, and assimilates accumulation in plant tissues. In this regard, this paper suggests the application of such a combination as an efficient and sustainable agronomic approach to enhance the productivity and quality of potatoes in the field.

References

A.O.A.C. (1970). Official Methods of Analysis11th ed. Washington. D. C. Association of official analytical chemist1015 P482-487.

A.O.A.C. International. (2000). Official methods of analysis of AOAC International (17th ed.). Gaithersburg, MD, USA: AOAC International.

Acevedo, A. F. G., Avilez, A. M. A., de Almeida Silva, J. C. and Vieites, R. L. (2025). Effects of water deficit stress and salicylic acid preharvest treatments on postharvest biochemical parameters of potato. Food and Humanity, 4, 100463.

Acevedo, A. F. G., da Silva Gomes, J. W., Avilez, A. A., Sarria, S. D., Broetto, F., Vieites, R. L. and de Souza Guimarães, M. L. C. (2023). Foliar salicylic acid application to mitigate the effect of water deficiency on potato (*Solanum tuberosum* L.). Plant Stress, 7, 100135.

Al-Malikshah, Z. R. J. and Abdulrasool, I. J. (2025). Increasing Yield and Its Quality of Potato by Spraying with Nanochitosan Loaded with NPK, Nettle and Green Tea Extracts. Iraqi Journal of Agricultural Sciences, 56(3), 1060–1072.

Al-Mokadem, A. Z., Alnaggar, A. E. A. M., Mancy, A. G., Sofy, A. R., Sofy, M. R., Mohamed, A. K. S. and Agha, M. S. (2022). Foliar application of chitosan and phosphorus alleviate the potato virus Y-induced resistance by modulation of the reactive oxygen species, antioxidant defense system activity and gene expression in potato. Agronomy, 12(12), 3064.

Al-Obaidi, A. S. K. H. (2005). Physiological studies on improving growth, yield, seed production, and reducing water stress damage in potato *(Solanum tuberosum L.)* [Doctoral dissertation, College of Agriculture and Forestry, University of Mosul, Ministry of Higher Education and Scientific Research, Iraq].

Coquoz, J. L., Buchala, A. and Métraux, J. P. (1998). The biosynthesis of salicylic acid in potato plants. Plant physiology, 117(3), 1095-1101.

El Hadrami, A., Adam, L. R., El Hadrami, I. and Daayf, F. (2010). Chitosan in plant protection. Marine drugs, 8(4), 968-987.

Falcón Rodríguez, A. B., Costales, D., Gónzalez Peña, D., Morales, D., Mederos, Y., Jerez, E. and Cabrera, J. C. (2017). Chitosans of different molecular weight enhance potato (*Solanum tuberosum* L.) yield in a field trial. Spanish Journal of Agricultural Research, 15(1), e0902. https://doi.org/10.5424/sjar/2017151 9288

González-Gallegos, E., Laredo-Alcalá, E., Ascacio-Valdés, J., de Rodríguez, D. J. and Hernández-Castillo, F. D. (2015). Changes in the production of salicylic and jasmonic acid in potato plants (*Solanum tuberosum*) as response to foliar application of biotic and abiotic inductors. American Journal of Plant Sciences, 6(11), 1785.

González-López, J., Pacheco-Vázquez, F. and Hernández-Ruiz, J. (2017). Chitosan as an elicitor of growth and yield in potato plants. Scientia Horticulturae, 219, 179–187. https://doi.org/10.1016/j.scienta.2017.02.018

Hassan, A. A. (1999). Potato. Arab House for Publishing and Distribution, Cairo, Egypt.

Hassan, H. and Suleiman, S. (2022). Effect of humic and salicylic acid on potato vegetative area, yield and quality at two different irrigation levels. Al-Qadisiyah Journal of Pure Science, 27(1), 1-12.).

Hayat, S., Siddiqui, H. and Damalas, C. A. (Eds.). (2021). Salicylic acid-a versatile plant growth regulator. Heidelberg: Springer International Publishing. https://doi.org/10.3390/horticulturae9060663

Kaya, C., Olgun, M., Dursun, A., Pehluvan, M., Dizikisa, T. and Kumlay, A. M. (2000, October). Comparison of seasonal change of specific gravity, dry matter accumulation and starch content of four potatoe (*Solanum tuberosum* L.) varieties. In II Balkan Symposium on Vegetables and Potatoes 579 (pp. 255-258

Khilji, S. A., Rafique, A., Sajid, Z. A., Rauf, M., Shah, A. A., Shaffique, S. and Gatasheh, M. K. (2024). Foliar application of salicylic acid improved morpho-anatomical features of potato by irrigating with wastewater. BMC Plant Biology, 24(1), 754.

Mbuyisa, S., Bertling, I. and Ngcobo, B. L. (2025). Preserving nutritional quality attributes of potatoes (Solanum tuberosum L.) through pre- plus post-harvest application of various plant extracts. Potato Research. Springer. https://doi.org/10.1007/s11540-025-09562-3

Poznanski, P., Shalmani, A., Bryla, M. and Orczyk, W. (2024). Salicylic Acid Mediates Chitosan-Induced Immune Responses and Growth Enhancement in Barley. International Journal of Molecular Sciences, 25(24), 13244.

Ribeiro, A. R., Santos, J. A. and Rodrigues, P. (2021). Chitosan-induced changes in antioxidant metabolism and phenolic content in potato tubers. Food Chemistry, 347, 129017. https://doi.org/10.1016/j.foodchem.2020.129017

SAS (2017). Statistical Analysis System. SAS Institute. Inc. Cary Nc.

Steglińska, A., Nowak, A., Janas, R., Grzesik, M., Śmigielski, K., Kręgiel, D. and Gutarowska, B. (2024). Chitosan as an antimicrobial, anti-insect, and growth-promoting agent for potato (Solanum tuberosum L.) plants. Molecules, 29(14), 3313.

Zhang, J., Lin, Q., Mao, L., Min, T., Guan, W., Qi, X. and Wang, H. (2024). Salicylic acid treatment inhibits cold-induced sweetening by regulating the transcription factors StAP2/ERF and StNAC2 in potato. Food Quality and Safety, 8, fyae036.

Zhu, Y., Zhang, W., Zhao, Y., Chen, F., Zhu, F., Yang, J., Ge, X., Gong, W., Cui, R. and Sheng, W. (2023). Foliar Application of Chitosan Accelerates Wound Periderm Formation with an Intensified Deposition of Suberin Polyphenolic and Lignin in the Wounds of Potato Tubers. Horticulturae, 9(6), 663.

نحو إنتاج مستدام للبطاطا: التأثيرات التآزرية لحمض الساليسيليك والكيتوسان على النمو والحاصل وجودة الدرنات في الصنف هرمز

أنغام طلال محمود الجلبي

قسم البستنة وهندسة الحدائق، كلية الزراعة والغابات، جامعة الموصل، الموصل، العراق.

الخلاصة

اظهرت نتائج الدراسة إلى أن الرش الورقي لكلٍ من حامض الساليسيليك والكيتوسان أدى إلى تحسينات معنوية واضحة في صفات النمو الخضري والإنتاجي والخصائص الكيميائية لنبات البطاطا صنف Hermes، سواء عند استخدام كل منهما بشكل منفرد أو عند تداخلهما معاً، وأسهم حامض الساليسيليك خاصة عند تركيز 100 ملغم/لتر$^{-1}$ في تعزيز مؤشرات النمو وزيادة الإنتاجية وتحسين المحتوى الغذائي للدرنات من العناصر المعدنية والنيتروجين والبروتين، ويُعزى ذلك إلى دوره في تنشيط العمليات الفسيولوجية، ورفع كفاءة التمثيل الضوئي، وتحسين توجيه نواتج البناء الضوئي نحو الأعضاء التخزينية. في حين أظهر الكيتوسان تأثيراً محفزاً يعتمد على التركيز، حيث أدى إلى تحسين واضح في النمو الخضري وزيادة الحاصل وتحسين جودة الدرنات من خلال تعزيز امتصاص العناصر الغذائية، وتنشيط النشاط الأيضي، وزيادة تراكم الكربوهيدرات، بما في ذلك المادة الجافة والنشا والكثافة النوعية للدرنات، فضلاً عن تحسين الكفاءة الفسيولوجية العامة للنبات. وقد أظهرت معاملات التداخل بين حامض الساليسيليك والكيتوسان تفوقاً واضحاً مقارنة بالمعاملات الفردية، إذ سجلت المعاملة (100 ملغم/لتر$^{-1}$ + 1.5 غم/لتر$^{-1}$) أفضل القيم في معظم الصفات المدروسة، بما في ذلك النمو الخضري، ومكونات الحاصل، وعدد الدرنات، إضافة إلى صفات الجودة مثل المادة الجافة والنشا والكثافة النوعية، فضلاً عن تحسين المحتوى الغذائي من NPK والبروتين. ويُعزى هذا التفوق إلى وجود تأثير تآزري واضح بين المركبين، حيث يعمل حامض الساليسيليك على تنظيم العمليات الفسيولوجية وتعزيز كفاءة النقل الداخلي للعناصر، في حين يسهم الكيتوسان في تحفيز النشاط الأيضي وزيادة كفاءة الامتصاص وتراكم المركبات العضوية. تؤكد هذه الدراسة أن التكامل بين حامض الساليسيليك والكيتوسان يمثل استراتيجية زراعية فعالة ومستدامة لتحسين إنتاجية وجودة البطاطا تحت الظروف الحقلية.

الكلمات المفتاحية: الساليساليك، الكيتوسان، الزراعة المستدامة، التكامل التآزري للمحفزات الحيوية