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ENHANCING GROWTH, YIELD, AND QUALITY OF OKRA BY FOLIAR APPLICATION OF SALICYLIC ACID AND CHITOSAN UNDER SALT STRESS

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ABSTRACT

Two pot experiments were conducted on a private farm in Abu Hummus region, Beheira governorate, during two successive summer seasons: 2023 and 2024. The study aimed to investigate the effects of either salicylic acid or chitosan in mitigating the adverse effects of salinity on vegetative growth, yield, and chemical composition of okra (Lady's fingers variety) under different salinity levels. Each experiment included 20 treatment combinations, resulting from four salinity levels (tap water, 1000, 2000, and 3000 ppm) and five foliar spray treatments: salicylic acid (50 and 100 ppm), chitosan (50 and 100 ppm), and distilled water as a control. The experiments were carried out as a randomized complete block design (RCBD) in a split-plot system with three replicates. Whereas the salinity levels arranged in the main plots and (salicylic acid and chitosan) treatments were randomly located in the sub-plots. The obtained results, generally, indicated that increasing salinity levels caused significant reductions in plant height, fresh and dry weight, number of branches and leaves, and leaf area. The lowest mean value was recorded at 3000 ppm, while the highest one was observed under tap water irrigation. Similarly, the number of fruits, fruit weight, and total yield per plant decreased as salinity increased. The contents of

nitrogen, carbohydrates, phosphorus, potassium, crude protein, and mucilage in leaves and fruits declined, whereas sodium and chloride concentrations increased. Foliar application of chitosan or salicylic acid improved all measured traits, except sodium and chloride concentrations. The most effective treatment was chitosan at 100 ppm, followed by salicylic acid at 50 ppm.

Keywords: Salinity, Okra, Salicylic Acid, Chitosan

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) is a crop of considerable economic importance, predominantly cultivated across tropical and subtropical climates. Despite its significance, its development and yield are substantially hindered by salinity, which represents a major abiotic stressor. Globally, okra production has reached around 11.5 million tonnes, with India accounting for approximately 62% of the total output. In Egypt, the cultivated area of okra in 2023 was estimated at 8,853 hectares, achieving an average yield of 12,164.9 kg/ha (**FAO, 2024**). Salt stress restricts water uptake, disrupts ionic equilibrium, and interferes with essential metabolic processes, thereby hampering plant performance (**Munns and Tester, 2008**).

In okra, salinity stress results in the excessive accumulation of sodium (Na^+) and chloride (Cl^-) ions, which damage cellular membranes, impair enzyme activity (**Parida and Das, 2005**), and reduce chlorophyll content and photosynthetic efficiency (**Sairam *et al.,* 2002**). Additionally, osmotic stress adversely affects root and leaf growth (**Ashraf and Harris, 2004; Brengi *et al.,* 2024**). NaCl concentrations exceeding 100 mM have been associated with declines in germination rates, biomass production, and reproductive success (**Akinci and Akinci, 2010; Kumar *et al.,* 2017**). These changes reduce pod number, size, and weight, and negatively impact nutritional quality, including levels of vitamin C and essential minerals (**Javid *et al.,* 2012**).

Yield loss under salinity stress is primarily driven by ionic toxicity and osmotic imbalance, which impair flowering and pod set (**Haq** ***et al.,*** **2023**). Sensitive okra varieties exposed to 70 mM NaCl may experience yield reductions of 50% (**Haq** ***et al.,*** **2023**). Pod weight reduction is attributed to limited photosynthesis, which hinders carbohydrate synthesis and cell enlargement (**Habib** ***et al.,*** **2016**). Moreover, salinity reduces chlorophyll, proteins, and antioxidants such as ascorbic acid and phenolic compounds (**Naqve** ***et al.,*** **2021**), while elevating sodium levels and diminishing the availability of potassium and calcium, ultimately degrading fruit quality and market appeal (**Naqve** ***et al.,*** **2021; Haq** ***et al.,*** **2023**).

To counteract the negative impacts of salinity, salicylic acid (SA), a naturally occurring phenolic phytohormone, has been studied for its potential to improve stress tolerance. It contributes to plant defense by modulating antioxidant enzymes, stabilizing membranes, and sustaining physiological functions under saline conditions (**Hayat** ***et al.,*** **2010**). In okra, external application of SA has shown positive effects on maintaining chlorophyll content, relative water content, and seedling growth under salt stress (**El-Kinany** ***et al.,*** **2019; Kumar** ***et al.,*** **2020**). SA also plays a role in sustaining ionic balance by reducing Na^+ uptake and enhancing K^+ absorption, thus alleviating ion toxicity (**Arfan** ***et al.,*** **2007**). When delivered through foliar spraying or seed priming, SA presents an efficient and environmentally sustainable strategy to enhance salt stress tolerance in okra.

Chitosan, a biopolymer derived from chitin, has likewise emerged as a promising biostimulant for mitigating the effects of salinity. When applied exogenously, it elicits a spectrum of physiological and biochemical adjustments that enhance plant resilience to salt-induced stress (**El-Tanahy** ***et al.,*** **2012; Kumaraswamy** ***et al.,*** **2018; Asgari-Targhi** ***et al.,*** **2018**). One of the major consequences of salinity is the accumulation of Na^+ ions, which disrupts nutrient balance and uptake. Chitosan application has been reported to reduce Na^+ accumulation while enhancing the uptake of essential ions such as K^+ and Ca^{2+}, thereby supporting key metabolic activities and maintaining ionic equilibrium (**Asgari-Targhi *et al.*, 2018**).

Therefore, this study aimed to evaluate the effectiveness of salicylic acid and chitosan as eco-friendly bio-stimulants in mitigating the harmful effects of salt stress on okra plants. It also sought to assess their potential influence on the plant's growth performance and chemical composition when irrigated with water of varying salinity levels.

MATERIALS AND METHODS

Pot trials were carried out over the two successive summer seasons (2023 and 2024) in Abu Hummus region of El-Baharia Governorate, Egypt. The experimental substrate was characterized as clay-textured soil. Before sowing in each season, surface soil samples were collected for the analysis of physical and chemical properties according to (**Ryan *et al.*, 2001**) (Table 1).

Table 1. Some physical and chemical analyses of the experimental site during both seasons of 2023 and 2024.

Soil properties			2023 Season	2024 Season
Physical properties	Sand (%)		23.59	23.75
	Silt (%)		9.11	10.00
	Clay (%)		67.30	66.25
	Textural class		Clay	Clay
Chemical properties	pH (1:2)		8.03	8.01
	Ca CO_3 (%)		9.14	10.03
	EC (1:2, water extract) dS/m		1.14	1.09
	O.M (%)		1.43	1.39
	Soluble cations (meq/l)	Ca^{2+}	9.72	9.54
		Mg^{2+}	2.88	2.91
		K^{+}	1.91	1.75
	Soluble anions (meq/l)	HCO_3^{-}	10.2	9.81
		SO_4^{2-}	2.34	2.41
	Available nutrients (mg/kg)	Nitrogen (N)	393	412
		Phosphorus (P)	14.43	14.60
		Potassium (K)	246	239

The physical and chemical properties of the soil subjected to field testing were analyzed in the laboratory of the Organic Agriculture Department, part of the Rural Development Project within the Beheira Directorate of Agriculture, under the Egyptian Ministry of Agriculture.

The study was conducted using the "Lady's Fingers" okra variety and involved two growth regulators: salicylic acid (SA) and chitosan (Chito) applied at concentrations of 50 and 100 ppm. Three seeds were sown in each 5-gallon plastic bag (25 cm diameter × 30 cm height), with ten bags representing one experimental unit. Sowing took place on March 20 in both growing seasons, and after three weeks, seedlings were thinned to retain the most vigorous plant. Conventional agronomic practices were followed. A split-plot system within a randomized complete block design (RCBD) was used. The main plots were assigned to four salinity levels (tap water, 1000, 2000, and 3000 ppm), while the subplots included foliar treatments with SA, Chito, and a control (distilled water) at two concentrations. This setup resulted in 20 treatment combinations; each replicated three times. Foliar applications were carried out on 28, 43, 58, and 73 days after sowing.

Vegetative Growth Parameters

At 90 days after sowing, measurements were taken for plant height, number of branches, and number of leaves per plant. Leaf area was estimated using a gravimetric method, following the procedure outlined by **Kaushik *et al.* (2021)**.

Yield and its components

The assessed parameters included the number of days from sowing to first flowering, fruit length and diameter, number of fruits per plant, and total yield per plant.

Chemical composition

The following chemical properties were analyzed: leaf and fruit nitrogen content were determined following the method of **Chapman and Pratt (1978)**, phosphorus and potassium concentrations were measured according to **Jackson (1973),** sodium and chloride levels were estimated as described by **Asch *et al.* (2022)**. Crude protein content was calculated by multiplying the nitrogen percentage by 6.25, in accordance with **AOAC (1990)**. Carbohydrate content in the fruits was assessed using the procedure outlined by **Yemm and Willis (1954)** and **Jain and Jain (2009)**, while the mucilage content was quantified based on the method of **Rao and Sulladurath (1977)**.

Statistical Analysis

The collected data were subjected to the statistical analysis of variance (ANOVA) following the procedure outlined by **Gomez and Gomez (1984)**. Treatment means were compared using the revised least significant difference (RLSD) test at a 0.05 probability level to assess significant variations among treatments.

RESULTS AND DISCUSSION

Vegetative Growth Characteristics

The data presented in Table 2 demonstrate that escalating salinity levels led to a significant and progressive decline in all evaluated vegetative growth parameters of okra across both growing seasons. The highest values for plant height, fresh weight, and dry weight were consistently recorded under non-saline conditions, whereas the most severe reductions were observed at 3000 ppm. Specifically, plant height was reduced by 42.86% and 43.52%, fresh weight by 36.72% and 38.84% and dry weight by 43.91% and 37.95% during the first and second seasons, respectively.

These findings were consistent with prior research indicating that salinity exerts a concentration-dependent inhibitory effect on plant biomass. **Augie *et al.* (2022)** and **Buah and Okeseni (2022)** reported significant reductions in shoot and root biomass of okra with increasing NaCl concentrations, with the most notable decline occurring at 10 g NaCl. Similarly, **Sarabi *et al.* (2024)** recorded a progressive decrease in dry mass with NaCl levels up to 200 mM, beyond which plant survival was not sustained. In agreement, **Naseem *et al.* (2023)** found that exposure to 50 mM NaCl markedly impaired osmotic potential and water-use efficiency, thereby hindering cell expansion and biomass accumulation.

The observed growth suppression is primarily attributed to the osmotic and ionic components of salinity stress. High salt concentrations restrict water uptake, reduce turgor pressure, and limit cell elongation (**Munns and Tester, 2008**). Concurrently, excessive accumulation of Na^+ and Cl^- disturbs ion homeostasis, nutrient availability, and enzymatic activities, particularly in root tissues (**Parida and Das, 2005**). Furthermore, salinity interferes with phytohormonal balance, notably affecting auxin and cytokinin signaling pathways that are essential for vegetative growth (**Zhu, 2001**). Conversely, foliar applications of chitosan and salicylic acid markedly improved vegetative growth under saline conditions. Both treatments significantly enhanced plant height, fresh weight, and dry weight in comparison to untreated controls in both seasons. The 100 ppm chitosan treatment produced the most substantial improvements, increasing plant height by 22.02% and 20.14%, fresh weight by 7.41% and 3.75%, and dry weight by 21.68% and 11.61% during the first and second seasons, respectively.

The positive effects of these biostimulants are attributed to their ability to enhance stress tolerance mechanisms. Chitosan improves nutrient uptake, promotes water retention, maintains cellular homeostasis, and activates genes and enzymes involved in stress responses (**Kumaraswamy *et al.*, 2021**). Salicylic acid contributes to the regulation of ion distribution, minimization of sodium toxicity, and enhancement of antioxidant defense systems, thereby maintaining chloroplast stability and photosynthetic efficiency (**Hayat *et al.*, 2010**).

Table 2. Effect of salinity levels, protective treatments, and their interactions on plant height, plant fresh and dry weight of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
Plant height (cm) 2023 Season					
Control	96.57c	79.57e	72.43fg	48.30j	74.22D
SA at 50	105.63ab	79.97e	79.72e	53.80ij	79.78C
SA at 100	96.70c	92.37cd	77.17ef	57.63hi	80.97C
Chito at 50	102.63b	90.97d	82.73e	62.83h	84.79B
Chito at 100	109.93a	92.93cd	89.78d	69.63g	90.57A
Mean	102.29A	87.16B	80.37C	58.44D	
Plant height (cm) 2024 Season					
Control	97.63cd	80.63fg	73.67ij	49.70i	75.41D
SA at 50	104.10b	84.10f	79.58fgh	55.07k	80.71B
SA at 100	95.07cde	80.40fg	74.75hij	54.43ki	76.16CD
Chito at 50	99.10bc	82.10fg	77.48ghi	55.87k	78.64BC
Chito at 100	109.53a	92.53de	89.95e	70.37j	90.60A
Mean	101.09A	83.95B	79.09C	57.09D	
Plant fresh weight (g) 2023 Season					
Control	449.17b	350.75d	312.20f	218.25i	332.59C
SA at 50	455.43b	360.84d	314.39f	232.19hi	340.71B
SA at 100	430.43c	365.69d	303.35f	230.51hi	332.50C
Chito at 50	453.10b	359.60d	317.32ef	243.96h	343.49B
Chito at 100	472.57a	364.67d	331.23e	260.45g	357.23A
Mean	452.14A	360.31B	315.70C	237.07D	
Plant fresh weight (g) 2024 Season					
Control	460.50a	360.31bc	323.88e	230.69g	343.85B
SA at 50	468.90a	375.68b	328.24e	246.49fg	354.83A
SA at 100	457.60a	349.43cd	318.22e	236.36g	340.40B
Chito at 50	464.10a	347.23cd	315.61e	230.64g	339.40B
Chito at 100	472.27a	362.56bc	331.67de	260.50f	356.75A
Mean	464.67A	359.04B	323.52C	240.94D	
Plant dry weight (g) 2023 Season					
Control	75.22a	60.57cde	54.84fgh	43.48jk	48.10D
SA at 50	70.01ab	56.53efg	50.26hi	42.70jk	54.88B
SA at 100	59.07def	51.23ghi	43.49jk	38.62k	51.59C
Chito at 50	63.37cd	51.39ghi	46.29ij	42.41jk	50.87C
Chito at 100	64.74bc	51.09ghi	47.38ij	43.14jk	58.53A
Mean	66.48A	54.16B	48.45C	42.07D	
Plant dry weight (g) 2024 Season					
Control	68.74bc	52.46ef	45.29gh	40.46ij	51.74C
SA at 50	73.10a	60.23d	52.42ef	45.24gh	54.50B
SA at 100	66.81c	52.36ef	46.58gh	40.20j	51.49C
Chito at 50	68.58c	50.96f	46.77gh	43.56hi	52.47C
Chito at 100	72.01ab	54.46e	47.40g	44.13gh	57.75A
Mean	69.85A	54.09B	47.69C	42.72D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 probability.

Collectively, these actions mitigate the negative impacts of salt-induced osmotic and oxidative stress, resulting in improved vegetative performance under saline environments. The most effective treatment combination was the foliar application of 100 ppm chitosan under non-saline conditions, which yielded the highest values for all assessed growth attributes.

Number of branches, leaves, and leaf area

Table 3 demonstrates that salinity stress significantly inhibited vegetative growth in okra, primarily through osmotic and ionic mechanisms that hinder water uptake, cell expansion, and metabolic activity. Increasing salinity levels led to notable reductions in the number of branches, leaves, and total leaf area. At 3000 ppm, branch numbers declined by 47.57% and 48.14%, leaf numbers by 48.49% and 50.35%, and leaf area by 53.62% and 54.27% during the first and second seasons, respectively. These reductions are largely attributed to osmotic stress, which limits water availability and induces physiological drought, thereby restricting cell division and elongation (**Munns and Tester, 2008**). Moreover, the accumulation of toxic ions such as Na^+ and Cl^- disrupts nutrient uptake, photosynthesis, and hormone regulation, all critical for vegetative development (**Parida and Das, 2005**). The observed decrease in leaf area may also result from inhibited leaf expansion or premature senescence, which are adaptive strategies to minimize transpiration (**Zhu, 2001**).

Foliar application of chitosan and salicylic acid effectively mitigated the harmful effects of salinity and significantly improved all vegetative traits compared to untreated plants. The most notable improvement was achieved with 100 ppm chitosan, which increased branch numbers by 39.86% and 21.40%, leaf numbers by 55.75 and 45.92%, and leaf area by 51.76 and 44.09% in the first and second seasons, respectively. These positive effects are attributed to the physiological functions of chitosan and salicylic acid under stress conditions.

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Table 3. Effect of salinity levels, protective treatments, and their interactions on the number of branches, number of leaves, and leaf area of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentration (ppm)				
	Tap water	1000	2000	3000	Mean
Number of branches 2023 Season					
Control	3.78de	3.10ghi	2.78ij	1.78	2.86D
SA at 50	4.22c	3.56ef	3.56ef	2.33k	3.42C
SA at 100	4.67b	4.22c	3.33fgh	2.67jk	3.72B
Chito at 50	4.44bc	3.67ef	3.44efg	2.67jk	3.56BC
Chito at 100	5.11a	4.11cd	3.78de	3.00hij	4.00A
Mean	4.44A	3.73B	3.38C	2.49D	
Number of branches 2024 Season					
Control	4.21abc	3.55def	3.22fg	2.11i	3.27C
SA at 50	4.33abc	4.00bcd	4.00bcd	2.56hi	3.72B
SA at 100	4.44ab	4.11abc	3.33fg	2.67h	3.64B
Chito at 50	4.44ab	3.56def	3.44efg	3.00gh	3.61B
Chito at 100	4.56a	4.11abc	3.89cde	3.33fg	3.97A
Mean	4.40A	3.87B	3.58C	2.73D	
Number of leaves 2023 Season					
Control	21.67f	18.33gh	14.67ij	9.33k	16.00D
SA at 50	26.33c	22.67ef	19.67g	14.33ij	20.75C
SA at 100	26.67c	23.33de	19.67g	13.33j	20.75C
Chito at 50	28.33b	24.67d	21.33f	15.33i	22.42B
Chito at 100	31.67a	27.33bc	23.67de	17.00h	24.92A
Mean	26.93A	23.27B	19.80C	13.87D	
Number of leaves 2024 Season					
Control	23.00efg	19.33i	16.33j	11.00m	17.42E
SA at 50	27.67c	24.00ef	21.00h	14.67k	21.83C
SA at 100	26.33cd	22.67fg	19.33i	13.00i	20.33D
Chito at 50	30.67b	26.00d	22.33gh	15.00jk	23.50B
Chito at 100	33.33a	27.67c	24.33e	16.33j	25.42A
Mean	28.20A	23.93B	20.67C	14.00D	
Leaves area per plant (cm^2) 2023 Season					
Control	1564.89cdef	1293.17fg	1067.34gh	589.14i	1128.63C
SA at 50	1720.81bcde	1444.53ef	1284.86fg	848.75hi	1324.74B
SA at 100	1808.65bc	1545.40cdef	1333.82fg	814.98hi	1375.71B
Chito at 50	1748.78bcd	1485.87def	1317.00fg	854.91hi	1351.64B
Chito at 100	2219.57a	1879.30b	1657.79bcde	1095.02gh	1712.92A
Mean	1812.54A	1529.65B	1332.16C	840.56D	
Leaves area per plant (cm^2) 2024 Season					
Control	1761.99bcde	1436.31efg	1252.65gh	771.78j	1305.68D
SA at 50	1722.40bcde	1446.12efg	1306.50fg	833.15ij	1327.04CD
SA at 100	1983.04bc	1656.91cdef	1453.44efg	899.98hij	1498.34BC
Chito at 50	2032.73b	1676.45bcde	1480.70defg	918.21hij	1527.02B
Chito at 100	2508.14a	2033.08b	1831.40bcd	1152.85ghi	1881.37A
Mean	2001.66A	1649.78B	1464.94C	915.19D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Chitosan enhances nutrient uptake, improves water-use efficiency, strengthens cell walls, and activates genes related to growth and stress resistance (**Kumaraswamy *et al.,* 2021**). Salicylic acid, functioning similarly to plant hormones, helps regulate stress-response pathways, maintains chlorophyll levels, and reduces ion toxicity (**Hayat *et al.,* 2010**). Both substances also enhance antioxidant activity and photosynthetic performance, contributing to sustained vegetative development under saline conditions. The optimal treatment for vegetative growth characters was the combination of non-saline irrigation and foliar application of 100 ppm chitosan, which yielded the highest growth performance. However, no significant difference in leaf area was observed between 100 ppm chitosan and 50 ppm salicylic acid.

Leaf chlorophyll and protein content

Table 4 shows that increasing salinity levels significantly reduced both chlorophyll and protein content in okra leaves, with the most severe declines observed at 3000 ppm. Compared to non-saline conditions, total chlorophyll content dropped by 13.37% and 11.89%, while protein content fell by 15.54% and 15.24% during the first and second growing seasons, respectively. These decreases are largely due to accelerated chlorophyll breakdown, inhibited pigment biosynthesis, and increased production of reactive oxygen species (ROS), which damage chloroplast structures and impair photosynthetic efficiency (**Ashraf and Harris, 2013**). Similarly, the reduction in protein levels can be attributed to impaired nitrogen metabolism, protein oxidation, and decreased enzymatic activity caused by ionic and osmotic stress (**Parida and Das, 2005**). As a result, salinity disrupts essential physiological functions, ultimately reducing plant growth and productivity.

Table 4. Effect of salinity levels, protective treatments, and their interactions on leaves, total chlorophyll, and protein contents of okra during the 2023 and 2024 seasons.

Treatments (ppm)	Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
Total chlorophyll (SPAD Unit) 2023 Season					
Control	44.67 b	43.67 bc	42.00 de	37.00 h	41.83 C
SA at 50	44.67 b	44.00 bc	42.67 cd	40.00 fg	42.83 B
SA at 100	43.67 bc	42.67 cd	41.00 ef	39.33 g	41.67 C
Chito at 50	46.67 a	44.00 bc	41.00 ef	39.67 fg	42.83 B
Chito at 100	47.33 a	45.00 b	42.67 cd	40.67 efg	43.92 A
Mean	45.40 A	43.87 B	41.87 C	39.33 D	
Total chlorophyll (SPAD Unit) 2024 Season					
Control	45.00 bc	43.33 def	41.33 gh	37.67 i	41.83 D
SA at 50	45.00 bc	43.67 de	42.33 fg	40.33 h	42.83 BC
SA at 100	45.00 bc	43.33 def	41.33 gh	40.33 h	42.50 C
Chito at 50	45.67 ab	44.33 cd	42.33 fg	41.33 gh	43.42 AB
Chito at 100	46.33 a	45.00 bc	42.67 ef	40.33 h	43.58 A
Mean	45.40 A	43.93 B	42.00 C	40.00 D	
Protein in leaves (%) 2023 Season					
Control	20.19 cd	19.25gh	18.06 j	16.25 l	18.44 D
SA at 50	20.75 ab	19.69 ef	19.25gh	18.06 j	19.44 AB
SA at 100	20.50 bc	19.63efg	19.19 h	17.94 j	19.31 BC
Chito at 50	20.75 ab	19.69ef	18.63 i	17.56 k	19.13 C
Chito at 100	20.88a	19.81 de	19.38 fgh	18.25ij	19.63 A
Mean	20.63 A	19.63B	18.88 C	17.63D	
Protein in leaves (%) 2024 Season					
Control	20.38bc	19.69d	17.63g	16.44h	18.56C
SA at 50	20.63ab	20.50bc	18.94e	17.75g	19.44A
SA at 100	20.25bc	20.44bc	18.38f	17.56g	19.19B
Chito at 50	20.44bc	20.13c	18.44f	17.44g	19.13B
Chito at 100	20.88a	20.63ab	19.13e	17.75g	19.63A
Mean	20.50A	20.31B	18.50C	17.38D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Foliar applications of bio-stimulants such as chitosan and salicylic acid effectively mitigated these negative effects of salinity through improving chlorophyll and protein contents under saline conditions. The most notable enhancement occurred with 100 ppm chitosan, which increased chlorophyll content by 5.0% and 4.18% and protein content by 6.44% and 5.72%, respectively, across the two seasons. The observed enhancements may be attributed to the ability of both substances to alleviate oxidative damage, support the integrity of chloroplast membranes, and stimulate the production of pigments and photosynthetic activity (**Farouk and Amany, 2012; Hayat *et al.,* 2010**).

Moreover, their involvement in up-regulating stress-related genes and enhancing antioxidant enzyme activities contributes to the preservation of chlorophyll content under saline stress (**Kumaraswamy *et al.,* 2021**). The rise in protein levels could also be associated with improved nitrogen utilization and increased metabolic resilience under adverse conditions (**Ali *et al.,* 2007**). While both treatments demonstrated beneficial effects, the statistical outcomes revealed no significant distinction between them, implying that they offer similar biochemical protection under salinity. The best interactive treatment was the tap water irrigation with 100 ppm chitosan, yielding the highest contents of chlorophyll and protein.

Nitrogen, phosphorus, potassium, sodium, and chloride content

As shown in Tables 5 and 6, higher salinity levels led to a marked reduction in the concentrations of essential macronutrients nitrogen, phosphorus, and potassium in okra leaves. The most substantial declines were observed at the highest salinity level (3000 ppm), with nitrogen decreasing by 15.54% and 15.24%, phosphorus by 27.45% and 34.61%, and potassium by 30.76% and 24.00% during the first and second growing seasons, respectively. These reductions are likely the result of physiological disturbances induced by salinity, such as osmotic imbalance and ion toxicity, which impair root membrane function and hinder nutrient absorption and internal transport (**Munns and Tester, 2008**). Moreover, due to their similar transport mechanisms, sodium competes with potassium at membrane channels, often leading to reduced K^+ uptake (**Zhu, 2003**). In contrast, the levels of Na^+ and chloride in okra foliage significantly increased under saline conditions by 180.00% and 168.93% for Na^+, and by 55.53% and 59.28% for Cl^- relative to the control. Such excessive accumulation can result in ionic toxicity, adversely affecting cell structure and photosynthetic efficiency (**Parida and Das, 2005**).

Foliar applications of the biostimulants, such as chitosan and salicylic acid, effectively alleviated these negative effects. Treated plants under saline conditions showed significant improvements in leaf N, P, and K content. Nitrogen levels increased by 6.44% and 5.72%, phosphorus by 11.90% and 9.30%, and potassium by 11.70% and 14.12% during the first and second seasons, respectively, compared to untreated, salt-stressed plants. These benefits are likely linked to chitosan's ability to enhance membrane stability and activate metabolic pathways related to nutrient uptake and stress resistance (**Kumaraswamy *et al.,* 2021**). Salicylic acid, acting as a regulatory signal, also supports nutrient retention by reducing oxidative stress and maintaining ion transport efficiency (**Hayat *et al.,* 2010**). Simultaneously, the accumulation of toxic ions was significantly reduced by these treatments. Sodium content decreased by 20.37% and 19.18%, while chloride content was reduced by 15.45% and 14.95% across the two seasons. These reductions may be attributed to the bio stimulants' capacity to promote selective ion uptake and decrease the permeability of root plasma membranes to sodium (**Ali *et al.,* 2007; Farouk and Amany, 2012**). The most effective treatment combination was tap water irrigation with foliar spraying of 100 ppm chitosan, which resulted in the most favorable chemical composition.

Table 5. Effect of salinity levels, protective treatments, and their interactions on leaves' nitrogen, phosphorus, and potassium contents in okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentration (ppm)				
	Tap water	1000	2000	3000	Mean
Leaf's N content (%) 2023 Season					
Control	3.23cd	3.08gh	2.89j	2.60l	2.95 D
SA at 50	3.32ab	3.15ef	3.08gh	2.89j	3.11 AB
SA at 100	3.28bc	3.14efg	3.07h	2.87j	3.09 BC
Chito at 50	3.32ab	3.15ef	2.98i	2.81k	3.06 C
Chito at 100	3.34a	3.17de	3.10fgh	2.92ij	3.14 A
Mean	3.30A	3.14B	3.02C	2.82D	
Leaf's N content (%) 2024 Season					
Control	3.26bc	3.15d	2.82g	2.63h	2.97C
SA at 50	3.30ab	3.28bc	3.03e	2.84g	3.11A
SA at 100	3.24bc	3.27bc	2.94f	2.81g	3.07B
Chito at 50	3.27bc	3.22c	2.95f	2.79g	3.06B
Chito at 100	3.34a	3.30ab	3.06e	2.84g	3.14A
Mean	3.28A	3.25B	2.96C	2.78D	
Leaf's P content (%) 2023 Season					
Control	0.48cde	0.45fg12	0.42h	0.34j	0.42D
SA at 50	0.52ab	0.49cde	0.45fgh13	0.38i	0.46AB
SA at 100	0.50bc	0.47def	0.44gh	0.38i	0.45BC
Chito at 50	0.49cd	0.47def	0.45fg11	0.36ij	0.45C
Chito at 100	0.54a	0.49cde	0.46efg	0.38i	0.47A
Mean	0.51A	0.47B	0.44C	0.37D	
Leaf's P content (%) 2024 Season					
Control	0.51bc	0.47efg	0.41i	0.33k	0.43D
SA at 50	0.53b	0.49cde	0.45gh	0.34jk	0.45B
SA at 100	0.49cde	0.49cde	0.43hi	0.34jk	0.44CD
Chito at 50	0.50cd	0.48def	0.45gh	0.34jk	0.44BC
Chito at 100	0.58a	0.50cd	0.46fg	0.36j	0.47A
Mean	0.52A	0.49B	0.44C	0.34D	
Leaf's K content (%) 2023 Season					
Control	3.24ab	3.07c	2.47f	1.82i	2.65C
SA at 50	3.23ab	3.15bc	2.74e	2.42fg	2.89B
SA at 100	3.25ab	3.20ab	2.80de	2.29h	2.89B
Chito at 50	3.26ab	3.18abc	2.83de	2.32gh	2.90AB
Chito at 100	3.29a	3.21ab	2.88d	2.45f	2.96A
Mean	3.26A	3.16B	2.74C	2.26D	
Leaf's K content (%) 2024 Season					
Control	3.19ab	2.87de	2.55g	1.89h	2.62C
SA at 50	3.24a	3.11bc	2.88de	2.57fg	2.95Ab
SA at 100	3.26a	3.07c	2.84e	2.61fg	2.94B
Chito at 50	3.26a	3.10bc	2.85de	2.61fg	2.96AB
Chito at 100	3.28a	3.11bc	2.94d	2.65f	2.99A
Mean	3.25A	3.05B	2.81C	2.47D	

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*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Table 6. Effect of salinity levels, protective treatments, and their interactions on leaves' sodium, and chloride contents of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
			Na^+ content (mg/g) 2023 Season		
Control	1.13 j	1.77 g	2.40 d	3.13 a	2.11A
SA at 50	0.97 k	1.50 hi	2.20 e	2.67bc	1.83 BC
SA at 100	1.00 jk	1.50 hi	2.43 d	2.63 c	1.89 B
Chito at 50	0.90 k	1.50 hi	1.93 f	2.80 b	1.78 C
Chito at 100	1.00 jk	1.37 i	1.60 h	2.77bc	1.68 D
Mean	1.00 D	1.53 C	2.11 B	2.80 A	
			Na^+ content (mg/g) 2024 Season		
Control	1.23 i	1.70 f	2.33 c	3.20 a	2.12A
SA at 50	0.90 k	1.40 gh	2.20 cd	2.70 b	1.80 B
SA at 100	1.00 jk	1.53 g	2.10 de	2.60 b	1.81 B
Chito at 50	0.95 jk	1.40 gh	2.00 e	2.70 b	1.76 BC
Chito at 100	1.07 j	1.33 hi	1.73 f	2.67 b	1.70 C
Mean	1.03 D	1.47 C	2.07 B	2.77 A	
			Cl^- content (mg/g) 2023 Season		
Control	6.63 cde	6.67cde	7.92 bc	9.58 q	7.70 A
SA at 50	5.42 ef	5.83 def	6.67 cde	8.33 ab	6.56 B
SA at 100	5.00 f	5.42 ef	6.67cde	7.50 bc	6.15 B
Chito at 50	4.58 f	5.42 ef	7.08 bcd	7.92 bc	6.25 B
Chito at 100	5.00 f	5.83 def	7.08 bcd	8.13 b	6.51 B
Mean	5.33 C	5.83 C	7.08 B	8.29 A	
			Cl^- content (mg/g) 2024 Season		
Control	6.07 fgh	6.67 def	7.86 bc	9.10 a	7.42 A
SA at 50	4.81 ij	5.21 hi	6.67 def	7.58 bcd	6.07 B
SA at 100	5.08 hi	5.48 ghi	7.00 cdef	7.13 cde	6.17 B
Chito at 50	4.02 j	5.15 hi	7.40 bcde	7.86 bc	6.11 B
Chito at 100	5.08 hi	5.54 ghi	6.40 efg	8.22 ab	6.31 B
Mean	5.01 C	5.61 C	7.07 B	7.98 A	

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Yield and its components

As shown in Table 7, escalating salinity levels had a consistently adverse impact on the growth and productivity of okra. This reduction is primarily attributed to osmotic and ionic disturbances, which interfere with essential physiological and biochemical mechanisms related to fruit development. Elevated salinity limited water absorption, led to nutrient imbalances, and increased the accumulation of reactive oxygen species (ROS), ultimately reducing fruit size, fruit set, and total yield (**Munns and Tester, 2008; Parida and Das, 2005**). At the salinity level of 3000 ppm, significant declines were recorded: average fruit weight dropped by 60.37% and 60.39%, the number of fruits per plant fell by 73.35% and 72.79%, and overall fruit yield decreased by 89.82% and 89.15% in the first and second seasons, respectively. These observations are consistent with earlier findings indicating that severe salinity interferes with hormonal regulation, restricts nutrient accessibility, and impedes cell division and expansion in fruit tissues, often leading to premature fruit abortion (**Ashraf and Harris, 2004; Tavakkoli *et al.,* 2011**). The severity and consistency of these declines underscore the necessity for efficient salinity mitigation strategies in okra cultivation, particularly in regions where saline soils or irrigation sources are prevalent (**Munns, 2002; Parida and Das, 2005**).

Foliar spraying of biostimulants such as chitosan and salicylic acid helped alleviate the detrimental effects of salinity and significantly improved okra yield components. Chitosan, a natural biopolymer extracted from chitin, contributes to plant resilience by enhancing nutrient uptake, stimulating antioxidant responses, and boosting tolerance to environmental stressors (**Khan *et al.,* 2017; Elrys *et al.,* 2019**). Similarly, salicylic acid, a plant signaling molecule with hormone-like functions, plays a key role in triggering physiological and biochemical processes that sustain growth and yield under saline stress (**Khan *et al.,* 2015; Brengi, 2019**).

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Table 7. Effect of salinity levels, protective treatments, and their interactions on number of pods, pod weight, and weight of pods per plant of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
Pod weight 2023 Season					
Control	4.79 f	4.07 g	3.00 i	1.92 k	3.44 D
SA at 50	5.69 c	5.12 e	3.73 h	2.33 j	4.22 C
SA at 100	6.16 b	5.36 de	3.86 gh	2.36 j	4.43 B
Chito at 50	6.46 a	5.49 cd	4.00 g	2.51 j	4.62 A
Chito at 100	6.29 ab	5.66 c	4.09 g	2.52 j	4.64 A
Mean	5.88 A	5.14 B	3.74 C	2.33 D	
Pod weight 2024 Season					
Control	5.05 e	4.30 f	3.15 h	1.99 j	3.62 C
SA at 50	5.92 b	5.33 cde	3.87 g	2.40 I	4.38 B
SA at 100	5.93 b	5.16 de	3.77 g	2.37 i	4.31B
Chito at 50	6.37 a	5.41 cd	3.94 g	2.46 i	4.54 A
Chito at 100	6.13 ab	5.52 c	3.99 g	2.45 i	4.52 A
Mean	5.88 A	5.14 B	3.74 C	2.33 D	
Number of pods/plant 2023 Season					
Control	25.67 d	20.67 f	15.00 i	5.67 l	16.75 D
SA at 50	28.00 c	22.67 e	19.00 gh	9.33 j	19.75 C
SA at 100	30.00 b	24.00 e	17.67 h	7.67 k	19.83 C
Chito at 50	32.00 a	26.00 d	18.33 h	6.67 kl	20.75 B
Chito at 100	32.00 a	26.00 d	20.00 fg	10.00 j	22.00 A
Mean	29.53 A	23.87 B	18.00 C	7.87 D	
Number of pods/plant 2024 Season					
Control	24.33 b	19.33 c	13.33 d	6.33 f	15.83 B
SA at 50	30.33 a	24.33 b	19.33 c	10.00 e	21.00 A
SA at 100	30.33 a	24.33 b	17.33 c	7.67ef	19.92 A
Chito at 50	30.67 a	24.67 b	18.67 c	6.33 f	20.08 A
Chito at 100	31.33 a	25.00 b	19.00 c	9.67 e	21.25 A
Mean	29.40 A	23.53 B	17.53 C	8.00 D	
Weight of pods /plant 2023 Season					
Control	123.38 ef	84.33 g	45.06 j	10.82 l	65.90 D
SA at 50	159.48 c	116.16 f	70.78 hi	21.71 kl	92.03 C
SA at 100	184.70 b	128.56 e	68.22 i	18.06 kl	99.88 B
Chito at 50	206.72 a	142.74 d	73.39 ghi	16.75 kl	109.90 A
Chito at 100	201.17 a	147.07 d	81.93 gh	25.20 k	113.84 A
Mean	175.09 A	123.77 B	67.87 C	18.51 D	
Weight of pods per plant 2024 Season					
Control	124.52 b	84.15 c	42.21 d	12.62 e	65.87 C
SA at 50	179.49 a	129.54 b	74.81 c	24.00 de	101.96 AB
SA at 100	179.86 a	125.54 b	65.36 c	18.20 e	97.24 B
Chito at 50	195.31a	133.50 b	73.47 c	15.57 e	104.46 AB
Chito at 100	192.21a	138.00 b	75.87 c	23.72 de	107.45 A
Mean	174.28 A	122.15 B	66.34 C	18.82 D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Among all treatments, foliar application of chitosan at 100 ppm resulted in the greatest improvements, increasing average fruit weight by 34.88% and 24.86%, fruit number per plant by 31.34% and 34.24%, and total yield by 72.74% and 63.12% in the first and second seasons, respectively. These enhancements can be attributed to improved photosynthetic efficiency, better osmotic adjustment, and reinforced antioxidant defense systems, all of which promote healthier fruit development under salinity pressure (**Farouk, 2011; Rady *et al.*, 2018**). The findings support the potential of using chitosan and salicylic acid as effective and sustainable foliar treatments to enhance okra productivity in salt-affected areas. The most favorable outcome was observed under the combination of non-saline irrigation (tap water) and foliar application of 100 ppm chitosan, whereas the poorest performance across all yield parameters occurred under the highest salinity level (3000 ppm) without any biostimulants application.

Fruit's nutrient composition

Table 8 illustrates that increasing salinity stress significantly impairs the nutrient composition of okra fruits by disrupting uptake and transport mechanisms. Increased salinity leads to osmotic stress and disturbances in ion balance, which negatively impact the availability and movement of key macronutrients like nitrogen, phosphorus, and potassium to the fruits during development (**Munns and Tester, 2008; Parida and Das, 2005**). Salinity-stressed plants commonly exhibit marked reductions in fruit nutrient content, adversely affecting both fruit quality and overall plant health. Specifically, under 3000 ppm salinity, nitrogen content in fruits declined by 27.90% and 27.40%, phosphorus by 33.84% and 33.85%, and potassium by 18.50% and 19.25% during the first and second seasons, respectively. Saline environments significantly disrupt nutrient uptake and movement within plants due to the high concentrations of sodium (Na^{+}) and chloride (Cl^{-}) ions, which interfere with the absorption of essential elements like nitrogen, phosphorus, and potassium (**Ashraf and Harris, 2004; Tavakkoli *et***

***al.,* 2011**). Such imbalances often lead to deficiencies that compromise fundamental physiological activities, including protein formation, energy production, and osmotic adjustment, ultimately intensifying the adverse impacts of salinity on plant development and productivity (**Khan *et al.,* 2010**).

Foliar application of chitosan and salicylic acid significantly mitigated these adverse effects by enhancing the nutrient content of okra fruits under saline conditions. The application of 100 ppm chitosan was particularly effective, increasing nitrogen content by 8.45% and 7.23%, phosphorus by 9.80% and 14.00%, and potassium by 6.11% and 6.84% in the first and second growing seasons, respectively. Such enhancements can be attributed to the ability of chitosan to promote nutrient absorption and utilization, improve cellular membrane permeability, and trigger key enzymes associated with nutrient metabolism (**Khan *et al.,* 2017; Rady *et al.,* 2018**).

Furthermore, the combination of tap water irrigation and foliar application of 100 ppm chitosan produced the highest nutrient concentrations in fruits. The observed synergistic impact may stem from a combination of enhanced water availability, which promotes nutrient mobility, and the role of chitosan in boosting nutrient uptake and mitigating the adverse effects of salinity on nutrient balance (**Ashraf and Foolad, 2007; Farouk, 2011**).

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Table 8. Effect of salinity levels, protective treatments, and their interactions on nitrogen, phosphorus, and potassium in pods of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
N% in pod 2023 Season					
Control	2.50b	2.36cd	1.93hi	1.72k	2.13C
SA at 50	2.52b	2.39c	2.24fg	1.98h	2.29A
SA at 100	2.55b	2.37cd	2.20g	1.88ij	2.25B
Chito at 50	2.66a	2.32de	2.19g	1.84j	2.25B
Chito at 100	2.69a	2.40c	2.29ef	1.87ij	2.31A
Mean	2.58A	2.37B	2.17C	1.86D	
N% in pod 2024 Season					
Control	2.53c	2.39d	2.07g	1.83i	2.21C
SA at 50	2.56bc	2.50c	2.24ef	2.07g	2.34A
SA at 100	2.62ab	2.49c	2.20f	1.82i	2.28B
Chito at 50	2.69a	2.57bc	2.18f	1.86hi	2.33A
Chito at 100	2.67a	2.57bc	2.30d	1.94h	2.37A
Mean	2.62A	2.51B	2.20C	1.90D	
P % in pods 2023 Season					
Control	0.64ab	0.54bcde	0.47defg	0.39g	0.51B
SA at 50	0.65a	0.61abc	0.52cdef	0.43fg	0.55AB
SA at 100	0.65a	0.57abcd	0.54bcde	0.45efg	0.56AB
Chito at 50	0.65aC	0.58abc	0.57abcd	0.43fg	0.56AB
Chito at 100	0.64ab	0.61abc	0.55abcd	0.44efg	0.56A
Mean	0.65A	0.58B	0.53C	0.43D	
P% in pods 2024 Season					
Control	0.64a	0.53c	0.45d	0.38e	0.50C
SA at 50	0.66a	0.58b	0.57b	0.43d	0.56AB
SA at 100	0.63a	0.60b	0.54c	0.45d	0.56AB
Chito at 50	0.65a	0.58b	0.53c	0.43d	0.55B
Chito at 100	0.65a	0.63a	0.53c	0.45d	0.57A
Mean	0.65A	0.59B	0.53C	0.43D	
K% in pods 2023 Season					
Control	2.62a	2.42cd	2.22fg	1.89h	2.29B
SA at 5	2.63a	2.52b	2.28ef	2.24fg	2.42A
SA at 100	2.70a	2.50bc	2.29ef	2.16g	2.41A
Chito at 50	2.62a	2.46bc	2.29ef	2.21fg	2.39A
Chito at 100	2.63a	2.50bc	2.35de	2.26f	2.43A
Mean	2.64A	2.48B	2.29C	2.15D	
K% in pods 2024 Season					
Control	2.64c	2.46e	2.28gh	1.94j	2.33D
SA at 50	2.69bc	2.54d	2.35f	2.25h	2.46BC
SA at 100	2.70b	2.51de	2.32fg	2.18i	2.43C
Chito at 50	2.70b	2.53d	2.35f	2.25h	2.46B
Chito at 100	2.77a	2.57d	2.37f	2.26gh	2.49A
Mean	2.70A	2.52B	2.33C	2.18D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Biochemical composition of okra fruits

Table 9 shows that salinity stress significantly alters the biochemical composition of okra fruits by disturbing water balance and mineral nutrient uptake within plant tissues. High salinity conditions typically reduce fruit moisture content due to osmotic stress, which impairs water absorption and retention. This results in lowered turgor pressure and reduced fruit succulence (**Munns and Tester, 2008; Ashraf and Foolad, 2007**). Likewise, ash content as an indicator of total mineral accumulation decreases under saline conditions, as excessive sodium (Na^+) and chloride (Cl^-) ions interfere with the uptake and accumulation of essential minerals (**Parida and Das, 2005**).

In contrast, fiber content in okra fruits increases substantially under high salinity, potentially as a structural adaptation to enhance cell wall rigidity and support tissue resilience against osmotic and ionic stress (**Ashraf and Harris, 2004**). At a salinity level of 3000 ppm, fruit moisture content decreased by approximately 2.05% and 2.08%, ash content declined by 9.85% and 7.80%, while fiber content increased markedly by 49.67% and 50.40% during the first and second seasons, respectively. These compositional changes reflect the plant's adaptive stress response, whereby reductions in hydration and mineral content are counterbalanced by enhancements in structural constituents to preserve fruit integrity under saline conditions (**Khan *et al.,* 2017**). Interestingly, the highest fiber levels were observed in untreated plants, suggesting that foliar biostimulants may influence cell wall dynamics (**Khan *et al.,* 2017**). Application of 100 ppm chitosan significantly reduced fiber content by 5.58% and 5.07% in the first and second seasons, respectively, compared to the control. This reduction may be due to improved cell expansion and altered cell wall metabolism, contributing to softer, more palatable fruit (**Elrys *et al.,* 2019**).

Table 9. Effect of salinity levels, protective treatments, and their interactions on moisture, fiber, and ash content in pods of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean
Moisture (g/100 g fresh weight) 2023 Season					
Control	82.43cd	82.43cd	81.73fg	81.03h	81.91D
SA at 50	83.50b	82.82c	82.40cde	81.93ef	82.66B
SA at 100	82.73c	82.73c	82.20def	81.30gh	82.24C
Chito at 50	83.83ab	82.87c	82.40cde	81.90f	82.75AB
Chito at 100	84.30a	82.83c	82.47cd	82.10def	82.93A
Mean	83.36A	82.74B	82.24C	81.65D	
Moisture (g/100 g fresh weight) 2024 Season					
Control	82.50d	82.43d	82.07e	81.07g	82.02B
SA at 50	83.57a	83.01c	82.13e	81.77f	82.62A
SA at 100	83.33ab	83.43ab	82.60d	81.53f	82.73A
Chito at 50	83.40ab	83.23bc	82.57d	81.70f	82.73A
Chito at 100	83.43ab	83.53a	82.53d	81.57f	82.77A
Mean	83.25A	83.13A	82.38B	81.53C	
Fiber content (g/100 g fresh weight) 2023 Season					
Control	1.51mn	1.73k	2.17d	2.36a	1.94B
SA at 50	1.54m	1.82i	2.10e	2.28bc	1.93B
SA at 100	1.59l	1.87h	2.13de	2.30b	1.97A
Chito at 50	1.52mn	1.78ij	2.05f	2.29b	1.91C
Chito at 100	1.49n	1.76jk	1.97g	2.24c	1.86D
Mean	1.53D	1.79C	2.08B	2.29 A	
Fiber content (g/100 g fresh weight) 2024 Season					
Control	1.52i	1.75g	2.13c	2.34a	1.94B
SA at 50	1.51i	1.80fg	2.08cd	2.28ab	1.92B
SA at 100	1.59h	1.86f	2.12cd	2.31ab	1.97A
Chito at 50	1.54hi	1.81fg	2.05dd	2.29ab	1.92B
Chito at 100	1.49i	1.76g	1.98e	2.26b	1.87C
Mean	1.53D	1.80C	2.07B	2.30A	
Ash content (g/100 g fresh weight) 2023 Season					
Control	1.20cd	1.24cd	1.27cd	1.29cd	1.25BC
SA at 50	1.18d	1.21cd	1.24cd	1.28cd	1.23C
SA at 100	1.40bc	1.20cd	1.25cd	1.28cd	1.28ABC
Chito at 50	1.60ab	1.22cd	1.25cd	1.28cd	1.34AB
Chito at 100	1.73a	1.19cd	1.23cd	1.27cd	1.36A
Mean	1.42A	1.21D	1.25C	1.28B	
Ash content (g/100 g fresh weight) 2024 Season					
Control	1.30a	1.23e	1.19fgh	1.18h	1.21D
SA at 50	1.30a	1.24de	1.20fgh	1.18h	1.22CD
SA at 100	1.28ab	1.25cde	1.20fgh	1.20fgh	1.23BC
Chito at 50	1.28ab	1.25cde	1.21f	1.18gh	1.24AB
Chito at 100	1.26bcd	1.27bc	1.23e	1.19fgh	1.25A
Mean	1.28A	1.25B	1.20C	1.18D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

Meanwhile, both moisture and ash contents increased with biostimulant treatments. Foliar application of 100 ppm chitosan yielded the highest improvements, raising moisture content by 1.23% and 0.90% and ash content by 8.80% and 3.30% across the two seasons. These enhancements are likely related to chitosan's ability to improve membrane permeability and facilitate better water and nutrient transport (**Farouk, 2011; Rady *et al.,* 2018**).

The most effective treatment combination was tap water irrigation in conjunction with a 100 ppm chitosan foliar spray, which resulted in the highest recorded mean values for moisture, ash, protein, mucilage, and carbohydrate contents. This indicates a synergistic interaction between optimal water availability and biostimulant application in improving fruit quality parameters (**Khan *et al.,* 2017**). In contrast, the combination of 3000 ppm salinity and 100 ppm salicylic acid produced the highest fiber content, possibly reflecting a stress-induced reinforcement of cell wall structures as part of the plant's adaptive defense mechanisms (**Ashraf and Foolad, 2007**).

Fruit's protein, mucilage, and carbohydrate content

Table 10 demonstrates that increasing salinity imposes considerable physiological stress on okra plants, resulting in significant reductions protein, mucilage, and carbohydrate contents in the fruits. In the present study, protein content declined by approximately 27.90% and 27.40%, mucilage by 51.85% and 52.04%, and carbohydrates by 16.00% and 16.25% during the first and second growing seasons, respectively. These substantial decreases underscore the adverse impact of high salinity on the nutritional quality and biochemical integrity of okra fruits (**Ashraf and Foolad, 2007; Tavakkoli *et al.,* 2011**). The osmotic and ionic stresses induced by elevated salinity disrupt metabolic pathways associated with nutrient assimilation and the biosynthesis of essential macromolecules (**Munns and Tester, 2008; Parida and Das, 2005**). Proteins, which serve critical roles in enzymatic functions and structural integrity, are particularly vulnerable to salinity-induced oxidative stress, leading to diminished synthesis and accumulation (**Ashraf and Harris, 2004**). Mucilage, a polysaccharide important for water retention and seed coat protection, exhibits even more marked decreases under salinity stress, as metabolic resources are redirected from its biosynthesis towards mechanisms of stress alleviation (**Farooq *et al.,* 2015**). Carbohydrate content similarly declines, attributable to impaired photosynthetic activity and reduced translocation of photo assimilates to the fruit tissues (**Khan *et al.,* 2015**).

Foliar applications of chitosan and salicylic acid significantly improved the biochemical composition of okra fruits, notably increasing protein, mucilage, and carbohydrate contents. Foliar application of chitosan at 100 ppm produced the most pronounced improvements, elevating protein content by 8.45% and 7.23%, mucilage by 7.53% and 8.60%, and carbohydrate content by 1.18% and 2.25% during the first and second seasons, respectively. These enhancements are likely due to chitosan’s ability to stimulate biosynthetic pathways, enhance photosynthetic efficiency, and improve water relations within fruit tissues, thereby facilitating greater accumulation of these vital nutritional compounds (**Elrys *et al.,* 2019; Rady *et al.,* 2018**). These agents function as elicitors, enhancing plant metabolism and stress tolerance by modulating antioxidant enzyme activities and promoting nutrient uptake and assimilation (**Khan *et al.,* 2017; Farouk, 2011**).

The combination of tap water irrigation and foliar application of 100 ppm chitosan produced the highest mean values for fruit protein, mucilage, and carbohydrate contents across both seasons, indicating a synergistic effect between optimal irrigation and bio stimulant treatment in improving okra fruit quality.

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Table 10. Effect of salinity levels, protective treatments, and their interactions on protein, mucilage, and carbohydrate contents in pods of okra plants during the 2023 and 2024 seasons.

Treatments (ppm)	Salinity Concentrations (ppm)				
	Tap water	1000	2000	3000	Mean B
Protein (%) 2023 Season					
Control	15.60b	14.75cd	12.06hi	10.75k	13.29C
SA at 50	15.77b	14.96c	14.02fg	12.38h	14.28A
SA at 100	15.92b	14.81cd	13.73g	11.77ij	14.06B
Chito at 50	16.60a	14.48de	13.69g	11.50j	14.07B
Chito at 100	16.81a	15.02c	14.29ef	11.69ij	14.45A
Mean	16.14A	14.80B	13.56C	11.62D	
Protein (%) 2024 Season					
Control	15.83c	14.96d	12.92g	11.42i	13.78C
SA at 50	16.02bc	15.65c	13.98ef	12.92g	14.64A
SA at 100	16.40ab	15.56c	13.77f	11.35i	14.27B
Chito at 50	16.81a	16.08bc	13.65f	11.63hi	14.54A
Chito at 100	16.67a	16.06bc	14.35e	12.13h	14.80A
Mean	16.35A	15.66B	13.73C	11.89D	
Mucilage % 2023 Season					
Control	5.41a	4.26c	3.46de	2.27h	3.85B
SA at 50	5.43a	4.42bc	3.09ef	2.80fg	3.94B
SA at 100	5.40a	4.54bc	3.52d	2.47gh	3.98AB
Chito at 50	5.39a	4.72b	3.73d	2.68g	4.13A
Chito at 100	5.38a	4.65b	3.75d	2.76fg	4.14A
Mean	5.40A	4.52B	3.51C	2.60D	
Mucilage % 2024 Season					
Control	5.28a	4.42b	3.24de	2.30i	3.81C
SA at 50	5.39a	4.47b	3.10ef	2.84fg	3.95BC
SA at 100	5.36a	4.49b	3.51cd	2.46hi	3.96ABC
Chito at 50	5.42a	4.79b	3.71c	2.65ghi	4.14A
Chito at 100	5.54a	4.59b	3.67c	2.71c	4.13AB
Mean	5.40A	4.55B	3.45C	2.59D	
Carbohydrate content (g/100 g fresh weight) 2023 Season					
Control	10.19c	9.30gh	9.02j	8.73k	9.31C
SA at 50	10.38b	9.41ef	9.12i	8.67k	9.40B
SA at 100	10.37b	9.47de	9.10ij	8.65k	9.40B
Chito at 50	10.24c	9.37fg	9.10ij	8.68k	9.35C
Chito at 100	10.50a	9.53d	9.23h	8.65k	9.48 A
Mean A	10.34A	9.42B	9.11C	8.68D	
Carbohydrate content (g/100 g fresh weight) 2024 Season					
Control	10.22c	9.33f	9.10g	8.73hi	9.35C
SA at 50	10.37b	9.39ef	9.12g	8.64i	9.38BC
SA at 100	10.42b	9.45de	9.09g	8.67hi	9.41B
Chito at 50	10.24c	9.38ef	9.12g	8.73hi	9.37BC
Chito at 100	10.65a	9.53d	9.29f	8.75h	9.56A
Mean	10.38A	9.42B	9.15C	8.70D	

*Values having the same alphabetical letter (s) in common are not significantly different, using the revised L.S.D. test at 0.05 level of probability.

CONCLUSION

Overall, the findings show that, in the climatic circumstances of the Beheira Governorate and comparable areas, foliar application of 100 ppm chitosan considerably improved the vegetative development, yield, and fruit quality characteristics of okra under salinity stress. This was followed by the foliar application of 50 ppm salicylic acid.

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الملخص العربي

تعزيز النمو والإنتاجية وجودة البامية من خلال الرش الورقي بحمض الساليسيليك والشيتوسان تحت تأثير الإجهاد الملحي

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أجريت تجربتان في أصص في مزرعة خاصة بمركز أبو حمص بمحافظة البحيرة خلال موسمي الزراعة الصيفي لعامى 2023 و2024. هدفت الدراسة إلى تقييم التأثيرات الفردية لحامض الساليسيليك (SA) والشيتوزان(Chito) ، كلٌ منهما عند تراكيز 50 و100 ملجم/لتر، تحت مستويات ملوحة مختلفة (مياه الصنبور، 1000، 2000، و3000 جزء في المليون) على أداء نمو نبات البامية (نوع "اصابع الست"). تم التركيز على الصفات المظهرية والفسيولوجية، والمحصول، والمكونات الكيمائية. أدى ارتفاع مستوى الملوحة إلى انخفاضات ملحوظة في ارتفاع النبات، والوزن الطازج والجاف، وعدد الفروع والأوراق، والمساحة الورقية. وسجلت أدنى القيم عند 3000 جزء في المليون، في حين سجلت أعلى القيم تحت الري بمياه الصنبور. وبالمثل، انخفض عدد الثمار ووزن الثمرة والإنتاج الكلي للنبات مع زيادة تركيزات الملوحة. كما انخفضت محتويات الاوراق والثمار من النيتروجين والفوسفور والبوتاسيوم، والبروتين الخام، وكذلك الكربوهيدرات، والمادة المخاطية في الثمار، بينما زادت تركيزات الصوديوم والكلوريد في الاوراق. ولقد أدت المعاملة بالرش الورقي بالشيتوزان أو حمض الساليسيليك إلى تحسن جميع الصفات المقاسة، باستثناء مستويات الصوديوم والكلوريد في الأوراق ومحتوى الألياف في الثمار، والتي انخفضت عكست انخفاضا ملحوظا. وكانت أكثر المعاملات فعالية هي الرش الورقي بالشيتوزان عند 100 ملجم/لتر، تلاها حمض الساليسيليك عند 50 ملجم/لتر تحت ظروف الدراسة.

الكلمات الدلالة: الملوحة، البامية، حمض الساليسيليك، الشيتوسان