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Research Article

# Foliar application of exogenous gibberellin or cytokinin mitigates salinity stress on faba bean (*Vicia faba* L.)

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## Abstract

Soil salinity significantly impairs plant development by reducing the availability of water and essential nutrients. This study explores the potential of gibberellin (GA) and cytokinin (CK) in mitigating detrimental effects of salinity stress on faba bean. Seeds were sown in saline soil, and plants were subjected to foliar applications of GA and CK at concentrations of 25 and 50 mg $L^{-1}$. Results revealed that both hormones significantly enhanced key growth attributes, including plant height, total leaf area, and dry biomass. Moreover, chlorophyll (chl. a, b, total chl.) content increased alongside elevated levels of proline, total phenols, crude protein, membrane stability, and macronutrient (NPK) concentrations. Gibberellin and CK treatments also promoted branching and flowering, while reducing the percentage of flower shedding. In terms of yield-related traits, significant improvements were observed in seed yield per hectare, weight of 100-seed, seed number/pod, seed weight per pod, and overall reduction in flower drop. The most significant enhancements in the evaluated traits were recorded with the application of GA and CK at a concentration of 50 mg $L^{-1}$ during both seasons. These findings highlight the effectiveness of GA and CK in strengthening salt tolerance mechanisms and boosting the productivity of faba bean under saline conditions.

***Keywords:*** antioxidant enzymes; chlorophyll; flower shedding; membrane stability; proline; total phenols

## Introduction

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The faba bean *Vicia faba* L. (family Fabaceae) also known as broad bean, is a significant legume crop. It has ability to grow in wide range of climatic environments (Abdel Latef *et al.*, 2018). As reported by FAOSTAT (2019), this crop is cultivated on approximately 2.6 million hectares worldwide, yielding around 5.4 million tons annually. Renowned for its nutritional value, the faba bean contains 27-40% protein, 50-60% carbohydrates, along with essential minerals and vitamins. Moreover, its nitrogen-fixing ability contributes to agricultural sustainability by improving soil fertility and enhancing overall crop yields (Kumar *et al.*, 2015).

Soil and water salinization poses a major environmental challenge that jeopardizes global agricultural productivity, affecting approximately 20% of irrigated lands (Park *et al.*, 2016). This problem is further intensified by a range of factors, including environmental degradation, the use of inefficient irrigation techniques, and the impacts of climate change (Ziska *et al.,* 2012). Rising sea levels caused by global warming, the increasing utilizes of saline water for irrigation, and widespread soil erosion are all contributing to the rapid escalation of soil salinization on a global scale. With the global population expected to increase by approximately 2 billion within the next 30 years, tackling this issue becomes critically important (Nachshon, 2018).

Salinization primarily results from accumulation of sodium ($Na^+$) and chloride ($Cl^-$) ions, leading to hyperionic salt stress that harms cellular structures and promotes the formation of sodic soils (Foronda, 2022). Elevated $Na^+$ concentrations hinder water uptake and nutrient absorption, triggering osmotic and ionic stress that led to oxidative stress and other physiological problems (Zhu, 2025). These stresses disrupt critical plant functions, including seed germination, growth, flowering, and fruiting. Salt stress also disrupts photosynthesis, limits the availability of essential resources, and hinders both cell division and expansion (El-Beltagi *et al.,* 2022). In response, researchers are actively developing efficient and affordable strategies to alleviate effect of salt-induced stress on agriculture, aiming to ensure food security for the increasing global population (El-Beltagi *et al.,* 2023).

Plant growth regulators act as signaling molecules that help plants sustain growth and developmental adaptability, positioning them as crucial components in plant responses to both biotic and abiotic stresses. They play vital role in mitigating salt stress by initiating various physiological and developmental changes (Pál *et al,* 2018; Ramadan *et al*, 2022). Specifically, plant growth regulators improve physiological availability of water and essential nutrients, helping plants mitigate the toxic impacts of salt buildup. In addition, plant growth regulators play significant role in modulating activity of antioxidant enzymes, which enhances plant's ability to tolerate stressful environmental conditions (Faghih *et al.,* 2019).

Gibberellins (GAs) play crucial role in strengthening plant tolerance to salt stress. Shahzad *et al,* (2021) found that applying $GA_3$ to maize enhanced growth, increased chlorophyll, soluble protein, and raised $K^+$ ion concentrations, while also alleviating oxidative stress and reducing $Na^+$ buildup under saline conditions. Likewise, Bauenova *et al*, (2024) observed that exogenous $GA_3$ treatment significantly mitigated salt stress by reducing oxidative damage and promoting growth and biomass accumulation in rice. Furthermore, gibberellins (GAs) modulate expression of stress-responsive genes, thereby enhancing plant's ability to adapt more effectively to high-salinity environments (Guo *et al.,* 2024).

Cytokinins (CKs) play crucial role in helping plants manage salt stress by modulating expression of stress-responsive genes, which in turn strengthens their tolerance mechanisms. They activate antioxidant systems, reducing oxidative damage caused by salinity, and protect the photosynthetic apparatus to maintain energy production under stress (Ghassemi-Golezani *et al.,* 2022). Additionally, CKs interact with other phytohormones like ethylene and abscisic acid, integrating various stress response pathways to improve resilience. They also promote the absorption and translocation of nutrients, ensuring that essential minerals remain accessible to plants even under saline conditions (Latef *et al,* 2021).

This study sought to explore positive effects of gibberellins (GAs) and cytokinins (CKs) in alleviating salt stress and improving salt tolerance in faba bean plants. The research specifically examined their role in promoting osmoprotectant accumulation, enhancing antioxidant enzyme activity, protecting the photosynthetic apparatus, and improving growth-related characteristics and yield outcomes.

## Materials and Methods

*Plant material, experimental design, and crop management practices*

Field experiments were conducted at farm in the South El Huasinia plain, El-Sharkeya Governorate, Egypt, located at 31°00′29″ N and 32°08′20″ E, throughout winter seasons of 2021/2022 and 2022/2023. The study aimed to evaluate impact of various concentrations of gibberellins and cytokinins applied as foliar sprays at 25 and 50 mg $L^{-1}$ on the morphological, physiological, and yield traits, in addition to chemical composition of faba bean plants. Seeds of faba bean cultivar Nubaria 1 were sourced from the Legume Research Department at the Field Crop Research Institute, Agricultural Research Center, Egypt.

Faba bean seeds were sown on November 9th and 7th during the two growing seasons, following inoculation with a Rhizobium strain and immediate irrigation to establish the experimental plants. Rhizobium strain was obtained from Microbiology Department, Agricultural Research Center, Egypt. The cultivation process followed randomized complete block design, with three replicates for each treatment. Each replicate consisted of single plot measuring 3.5 × 4 m, arranged with five ridges spaced 70 cm apart. Seeds were planted along one side of the ridge at a rate of two seeds per hill, with hills spaced 20 cm apart.

The sources of N, phosphorus, and potassium were ammonium sulphate (20.5% N), calcium superphosphate (15.5% $P_2O_5$), and potassium sulphate (48% $K_2O$), respectively. All standard agricultural practices, including land preparation, irrigation, fertilization, and other field procedures, were conducted as recommended for optimal faba bean production in the area.

The gibberellin and CK concentrations were applied twice as foliar sprays using an atomizer sprayer. These solutions, dissolved in distilled water, were sprayed onto the plants, with the first application occurring four weeks after sowing and second two weeks later. Spray volume per plot was approximately 1.25 liters for the first application and 1.5 liters for the second, ensuring thorough wetting of the plants with some excess dripping. A control treatment was also included in the experiment.

The physical and chemical properties of soil (0-30 cm depth) at experimental site were determined as per the method outlined by Jackson (Jackson, 1967) Table (1).

**Table 1.** Some chemical properties of the studied experimental site

| Seasons | EC | PH (1.2.5) | Texture | Cations (ml equivalent/L) | | | | Anions (ml equivalent/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Ca^{++}$ | $Mg^{+}$ | $Na^{+}$ | $K^{+}$ | $CO_3^-$ | $HCO_3^-$ | $Cl^-$ | $SO_4^-$ |
| 2019/2020 | 7.97 | 8.37 | Clay | 9.98 | 11.94 | 63.24 | 2.39 | - | 1.8 | 65.7 | 20.05 |
| 2020/2021 | 8.02 | 8.54 | Clay | 10.32 | 12.16 | 64.47 | 2.51 | - | 1.93 | 65.41 | 22.12 |

*Sampling, measurements, and determination*

A randomly selected sample of five plants from each plot of the tested treatments was selected for investigation. Data collection was performed on individual plants at 90 days post sowing for morphological traits and at harvest time (150 days after sowing) for yield characteristics. At 90 days after sowing, the following parameters were measured: dry weight of plant, total leaf area and flower shedding (%). To measure plant dry weight (g), fresh plant samples were dried in electric oven at 70 °C until they reached constant weight. The leaf area per plant ($cm^2$) was determined using a leaf area meter, Model LI-3100.

*Chlorophyll and carotenoids pigments*

At 90 days after sowing, leaflets from the third leaf from stem tip were sampled. Five leaf discs were taken and immersed in 5 mL of N, N-dimethylformamide (DMF) for pigment extraction. The extraction was performed overnight at room temperature under dark conditions. Chlorophyll pigments (a, b and total chlorophyll) were quantified in micrograms/cm$^2$ following method described by Moran (1982).

*Antioxidant enzymes*

To evaluate antioxidant enzyme activities, lipid peroxidation, tocopherol, and protein content, fresh faba bean leaf tissues were extracted using cold sodium phosphate or Tris-HCl buffers containing stabilizing agents, followed by centrifugation at 4 °C to preserve enzyme integrity. The supernatants were used for biochemical assays. Catalase (CAT) activity was measured by monitoring the decomposition of $H_2O_2$ at 240 nm following Aebi's method (Aebi, 1984). Peroxidase (POD) activity was assessed according to Polle *et al*, (1994), while superoxide dismutase (SOD) activity was determined using the photochemical inhibition of NBT reduction, as described by Giannopolitis and Ries (1977). Protein concentration and tocopherol content were quantified from the same extracts, ensuring consistency across assays.

*Endogenous proline content*

At 90 days after sowing, fresh leaf samples were used to quantify proline content, expressed in µmol/gram of fresh weight (µmol $g^{-1}$ FW). The measurement was performed utilizing spectrophotometer (Shimadzu UV 1601) at absorbance of 520 nm, following procedure described by Bates *et al,* (1973).

*Membrane stability, and total phenol content*

At 90 days after sowing, fresh leaves were used to assess membrane stability following method described by Lutts *et al,* (1996). The total phenolic compounds were quantified following procedure outlined by Bessada *et al,* (2016).

*Mineral element nutrients*

Dried faba bean leaves were subjected to wet digestion using a mixture of sulfuric and perchloric acids to evaluate concentrations of N, P and K in seed straw. Nitrogen content was determined utilizing Kjeldahl (Model:054120-01, Japan) method, phosphorus was measured spectrophotometrically, and potassium levels were assessed using a flame photometer (FP910 Brochure, Russian). All analyses were performed according to Walinga *et al*, (2013).

*Plant height and yield parameters*

At harvest (150 days after sowing), various yield-related traits were evaluated. This included plant height, number of branches and pods/plant, 100-seed weight (g), seed yield (ton/ha). Additionally, crude protein content in dried pea seeds was estimated according to A.O.A.C. (2005) protocols.

Crude protein = Total nitrogen × 6.25

*Statistical analysis*

Statistical analysis was performed utilizing analysis of variance (ANOVA) suitable for randomized complete block design (RCBD), after conducting a preliminary test for homogeneity of error variances as described (Gomez and Gomez, 1984). When significant differences were found at $p \leq 0.05$, mean comparisons were carried out utilizing Duncan's Multiple Range Test (DMRT).

## Results

*Soil salinity*

As presented in Table 1, the chemical analysis of soil samples from study site indicated elevated salinity levels and increased electrical conductivity across both growing seasons. In response to these challenging conditions, the application of growth-promoting regulators i.e. gibberellin (GA) and cytokinin (CK) offers a viable strategy for mitigating adverse effects of salinity.

*Total leaf area, plant height, and plant dry weight*

Figure 1 demonstrates that foliar application of GA and CK at 25 and 50 mg $L^{-1}$ significantly increased total leaf area, plant height, and dry weight of faba bean grown under saline soil conditions, compared to untreated controls, during both seasons. The most pronounced increases in plant height and leaf area were observed with GA and CK at 50 mg $L^{-1}$ across both seasons.

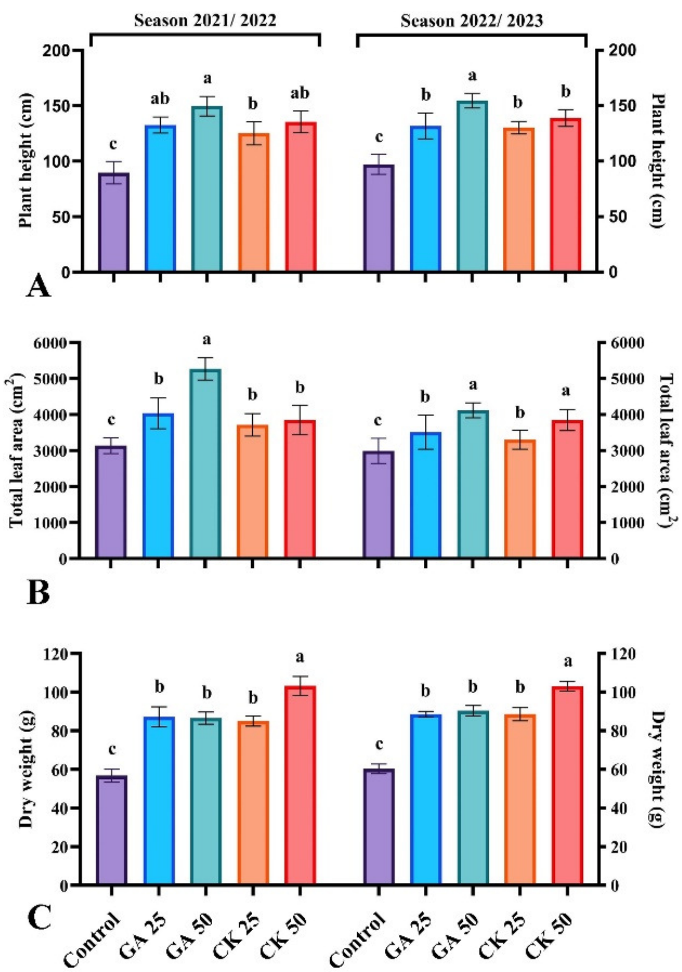


**Figure 1.** Effect of gibberellins (GA) and cytokinin (CK) at concentrations of 25 and 50 mg $L^{-1}$ on the plant height (A), total leaf area ($cm^2$) per plant (B) and plant dry weight (g/plant) of broad beans cultivated under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labeled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Chlorophyll content*

Figure 2 illustrates that spraying of cytokinin (CK) significantly improved chlorophyll (chl.) content including chl. a, b, and total chl. across both growing seasons. The most substantial enhancement in chlorophyll levels was observed at 50 mg $L^{-1}$ of CK. In addition to CK, application of GA at both 25 and 50 mg $L^{-1}$ significantly increased chl. b levels during both seasons. Gibberellins have been shown to enhance the accumulation of photosynthetic pigments, particularly chl. a and b.

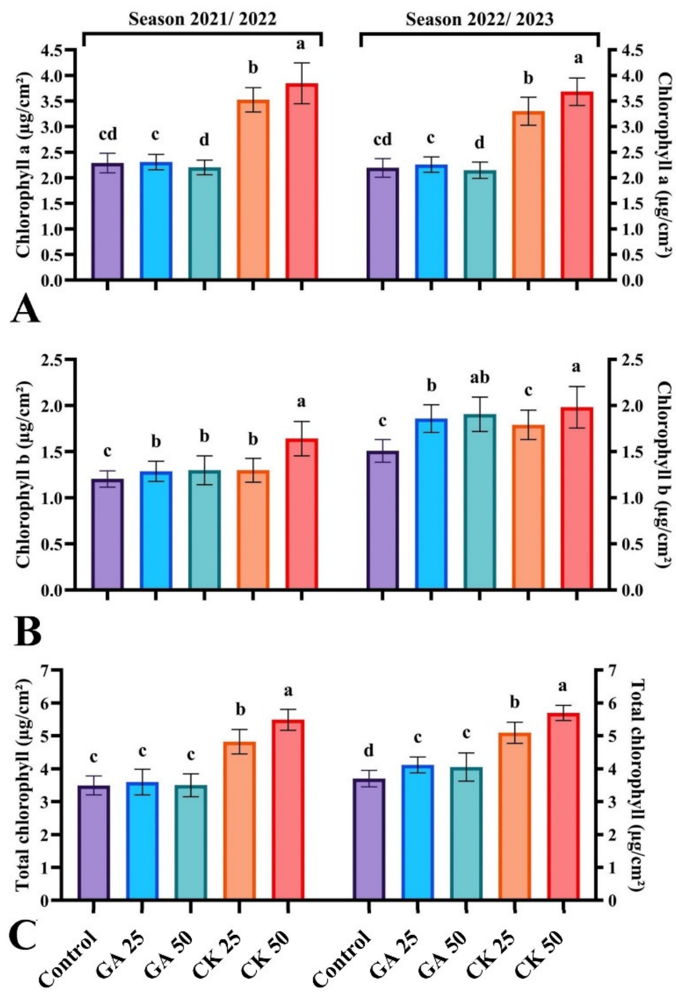


**Figure 2.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on chlorophyll (chl.) content (µg/$cm^2$) including chl. *a* (A), chl. *b* (B) and total chl. (C) of broad beans cultivated under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labeled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Antioxidant enzymes activity*

As shown in Figure 3, applying GA and CK as foliar sprays at 25 and 50 mg $L^{-1}$ significantly increased activity of major antioxidant enzymes (CAT, POD, SOD) in faba bean plants. The increase in enzyme activity corresponded positively with higher concentrations of GA and CK, with CK proving more effective than GA in amplifying the antioxidant defense system across both seasons.

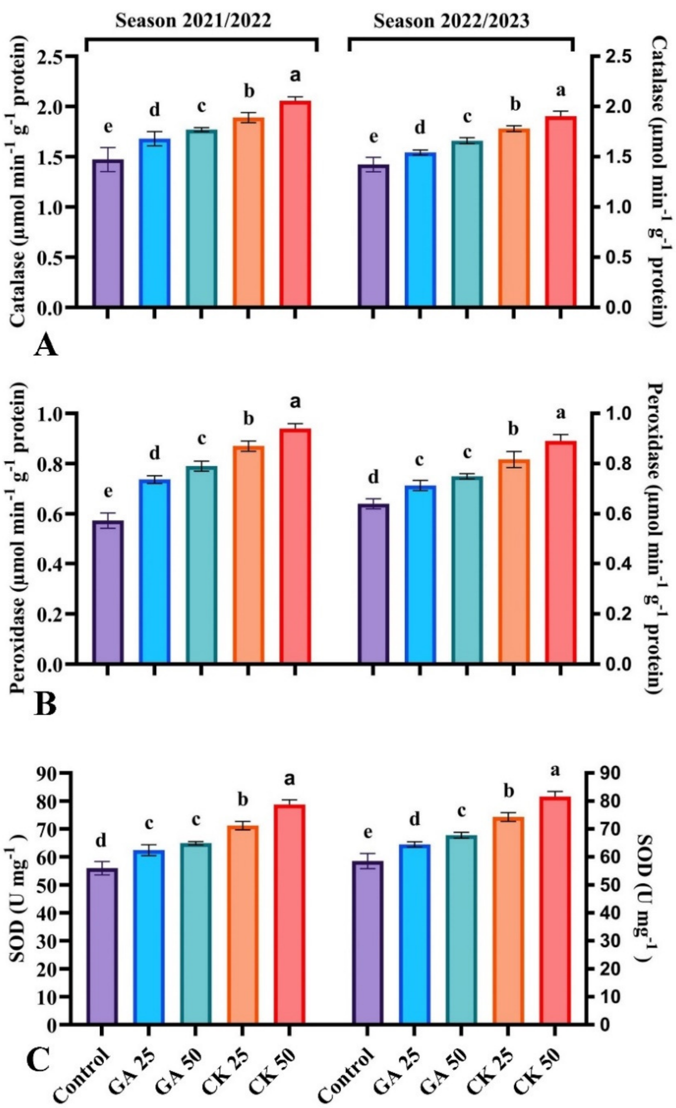


**Figure 3.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on antioxidant enzymes activity including catalase A: catalase (μmol $min^{-1}$ $g^{-1}$ protein), B: peroxidase (μmol $min^{-1}$ $g^{-1}$ protein), C: superoxide dismutase, SOD (U $mg^{-1}$) of broad beans cultivated under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Proline content, membrane stability and total phenols content*

Figure 4 shows that foliar application of GA and CK at 25 and 50 mg $L^{-1}$ caused significant increase in proline levels and membrane stability. However, GA treatments alone actually caused a notable reduction in proline content during both growing seasons. Among all treatments, cytokinin sprays produced the highest levels of proline, membrane stability, and total phenolic content. Specifically, the 100 mg $L^{-1}$ concentration of CK yielded better results compared to the lower concentration.

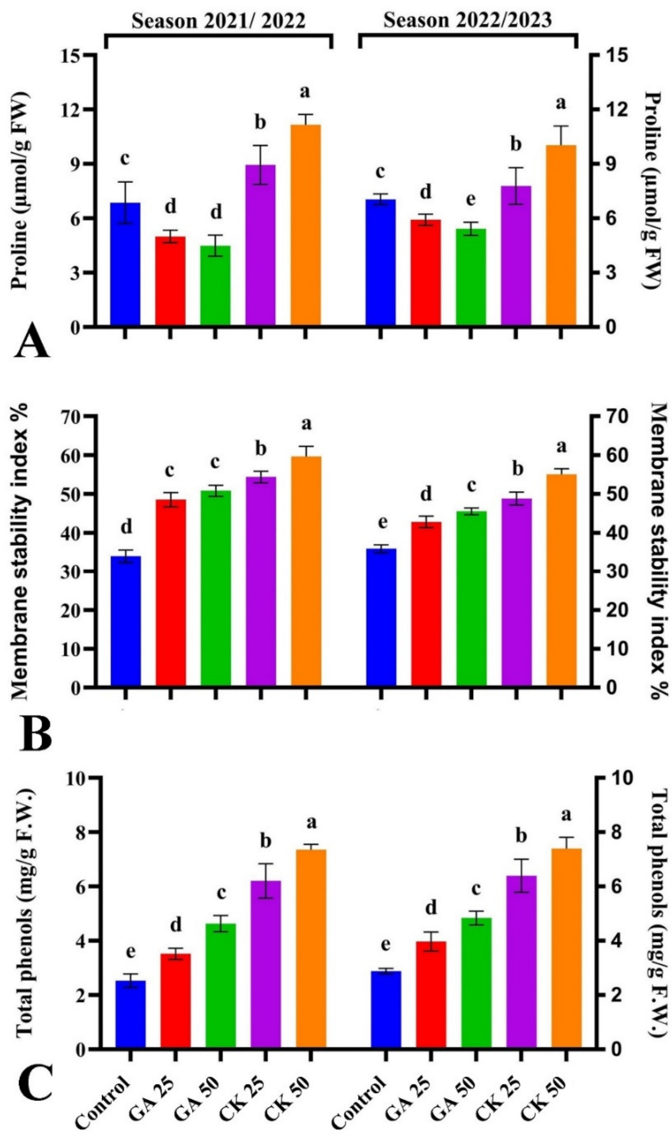


**Figure 4.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on proline content (µmol/g fresh weight) (A), membrane stability index percentage (B) and total phenols content (mg/g fresh weight) of broad beans grown under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Nitrogen, phosphorus and potassium percentage*

Figure 5 demonstrates that application of GA and CK, when applied individually, significantly increased the N, P, K content in faba bean leaves during both growing seasons. Among the treatments, CK consistently showed a more pronounced effect than GA. The highest concentrations of N, P, K were found in response to CK at 50 mg $L^{-1}$.

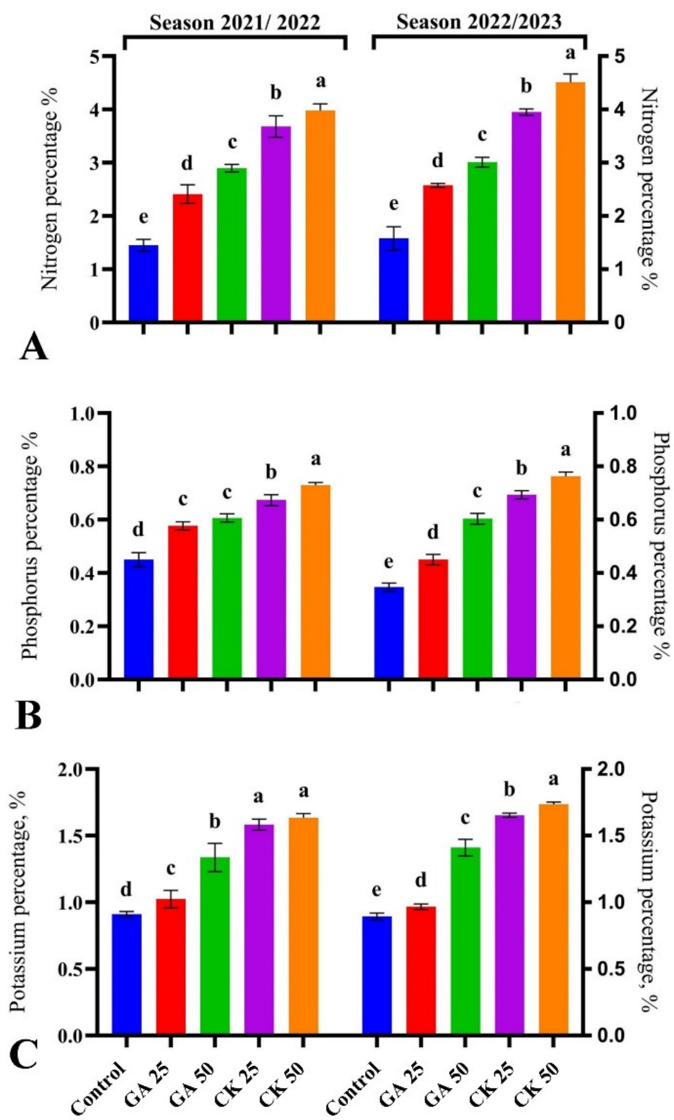


**Figure 5.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on percentage of nitrogen (A), phosphorus (B) and potassium of broad beans leaves grown under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Crude protein percentage*

Figure 6 shows that the application of GA and CK significantly enhanced crude protein content (%) in faba bean seeds across both growing seasons.

Among the treatments, CK exhibited a more pronounced effect than GA. Notably, the highest crude protein percentage was recorded with the application of CK at 50 mg $L^{-1}$ during both seasons.

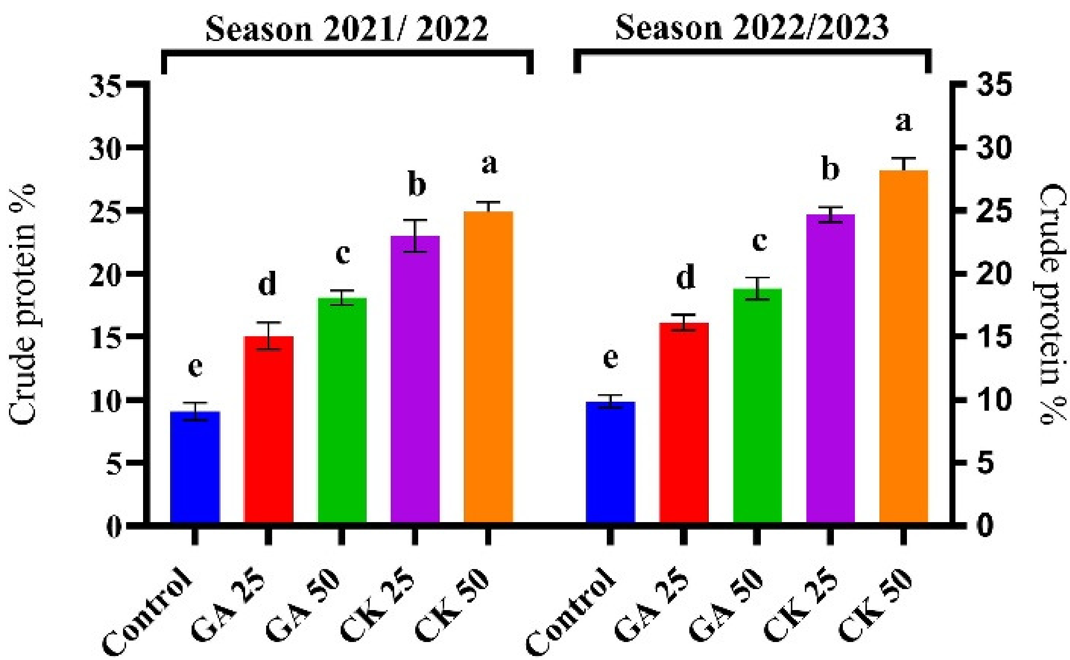


**Figure 6.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on percentage of crude protein of broad beans seeds grown under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons.

Data are expressed as mean ± standard deviation.

Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Branches and flowers numbers and flower shedding percentage*

Data presented in Figure 7 demonstrate that foliar application of GA and CK, individually applied at 25 and 50 mg $L^{-1}$, significantly enhanced number of branches and flowers/plant while reducing the percentage of flower shedding compared to the control.

The improvements in these traits were positively correlated with increasing concentrations of GA and CK, with higher concentrations leading to greater increases in branch and flower numbers, as well as a more pronounced reduction in flower shedding across both seasons.

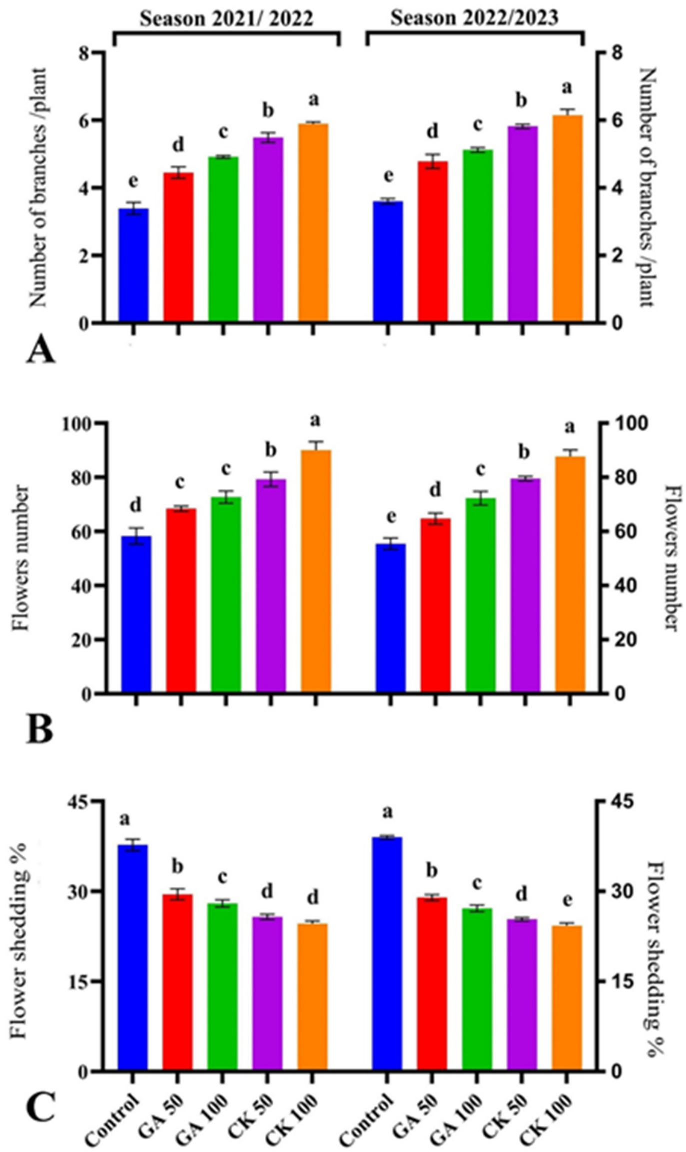


**Figure 7.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg L$^{-1}$ on number of branches (A), flowers (B) and flower sledding percentage of broad beans seeds grown under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons. Data are expressed as mean ± standard deviation. Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

*Number of seeds/plant 100 seed weight and seed yield/ha*

Regarding faba bean yield traits, foliar application of gibberellins (GA) and cytokinins (CK) significantly enhanced the seed number/plant, weight of 100-seed (g), and total seed yield per hectare under salt stress conditions, compared to control across both growing seasons. A consistent increase in these yield traits was observed with rising concentrations of GA and CK, with CK treatments demonstrating greater efficacy in improving yield traits (Figure 8).

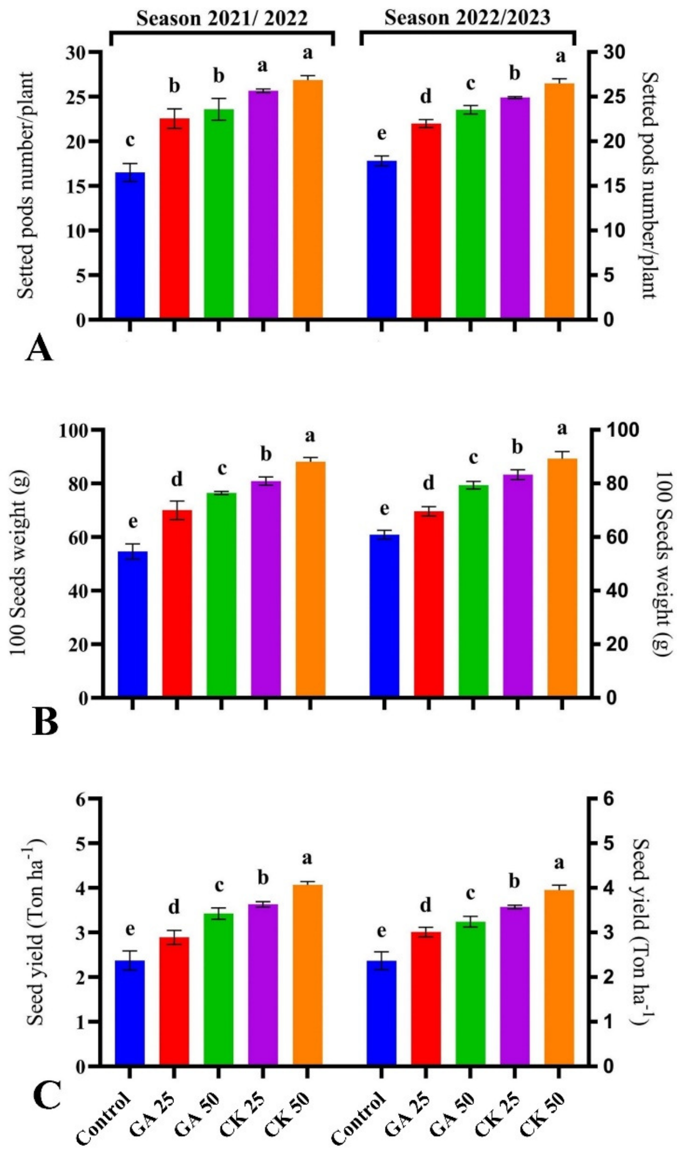


**Figure 8.** Effect of gibberellins (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on number of seeds/plant (A), 100 seed weight (gm) (B) and seed yield (ton/ha) of broad beans seeds grown under soil salinity conditions during the 2021/2022 and 2022/2023 growing seasons. Data are expressed as mean ± standard deviation. Columns labelled with different letters represent significant differences between treatments at a statistical significance level of $P < 0.05$

## Discussion

This study demonstrated that spraying faba bean plants with gibberellin (GA) and cytokinin (CK) helped mitigate the harmful impact of salt stress. These benefits are consistent with earlier findings showing that GA and CK stimulate cell elongation and division, thereby offsetting the inhibitory effects of salinity on plant growth (Abdel Naby *et al*, 2016). Additionally, the increase in leaf area observed with these treatments supports improved photosynthetic performance (Islam *et al*, 2021).

Improved nutrient uptake and photosynthesis, driven by GA and CK applications, likely account for the observed increase in dry matter accumulation (Mwami, 2017) a key factor in maintaining plant growth under saline stress. These growth enhancements were strongly linked to increased chlorophyll content. Cytokinins play a crucial role in delaying leaf senescence and preserving chlorophyll levels, thus promoting continuous photosynthesis in saline environments (Islam *et al,* 2022). It regulates genes involved in chlorophyll biosynthesis and essential photosynthetic proteins, thereby ensuring higher chlorophyll concentrations under stress (Park *et al,* 2016).

Moreover, CK helps protect the photosynthetic apparatus by preserving chloroplast ultrastructure and enhancing the efficiency of photosystem II. It also bolsters plant's antioxidant defense mechanisms, reducing oxidative stress damage to chlorophyll and other cellular components (Ghassemi-Golezani and Samea-Andabjadid, 2022). Cytokinin interacts with hormones like ABA and ethylene to finely regulate stress responses and maintain chlorophyll stability.

Similarly, GA has been shown to enhance total chlorophyll levels under salt stress conditions, thereby enhancing photosynthetic capacity (Sardoei and Shahdadneghad, 2014). This is supported by findings from Alam *et al,* (2022), which demonstrated that GA and CK upregulate antioxidant enzyme activities contributing to ROS (reactive oxygen species) detoxification. Gibberellin stimulates expression of genes responsible for these enzymes, while CK modulates ROS-related signalling pathways to strengthen the plant's antioxidant response (Shahzad *et al*, 2021).

These increases in antioxidant activity were closely associated with earlier observed physiological improvements, including plant growth and chlorophyll content. Gibberellin protects chloroplasts from oxidative stress, maintaining energy metabolism under salinity, while CK ensures chlorophyll retention and supports energy production, crucial for sustaining plant vitality under stress (Rodrigues de Queiroz *et al,* 2023). The enhanced antioxidant defense system appears to be a key mechanism underlying the observed improvements in plant performance.

Proline is essential for stress tolerance as it helps stabilize proteins and cellular membranes. Cytokinin (CK) enhances proline accumulation, thereby increasing plant resilience to salt stress. Phenolic compounds, another important defense mechanism, also contribute to stress mitigation. Under high salinity, cellular membranes can become damaged, leading to ion leakage and loss of cell contents. However, foliar applications of gibberellin (GA) and CK can reinforce membrane integrity, minimizing such damage in faba bean. These treatments have been shown to elevate total phenol content, which helps reduce oxidative stress under saline conditions (Pantoja-Benavides *et al,* 2021).

The findings align with earlier studies that reported improved nutrient uptake under saline conditions due to GA and CK applications (Hafez *et al,* 2021). These hormones promote root development and facilitate uptake of essential nutrients, supporting better vegetative growth, increased yields, and enhanced yield components (Lyzenga *et al,* 2023). Furthermore, GA and CK activate enzymes involved in nutrient metabolism and transport, improving the internal distribution and utilization of nutrients. They also induce protective proteins and antioxidants, helping plants counteract oxidative stress (Klippenstein *et al,* 2022).

Gibberellin and CK also improve water absorption and retention—key traits under saline conditions where water availability is limited. This enhances turgor pressure and nutrient transport, which are crucial for maintaining physiological balance. Increases in N, P, and K levels were found to correlate with elevated proline content and improved membrane stability. Gibberellin and CK are particularly effective in promoting nitrogen uptake and assimilation—critical for protein synthesis. Improved nitrogen metabolism results in higher amino acid levels, leading to greater protein accumulation in seeds. These hormones also regulate key enzymes and genetic pathways involved in protein biosynthesis, including the upregulation of ribosomal RNA (Sun *et al,* 2024).

By fostering robust root development and maintaining ion homeostasis, GA and CK further support the uptake of essential nutrients, particularly nitrogen (Ghassemi-Golezani and Samea-Andabjadid, 2022).

Additionally, these hormones help maintain hormonal balance, which is vital for optimal growth and stress adaptation. GA enhances cell division and elongation, promoting vegetative growth, branching, and flowering (Bouazzi *et al.*, 2024). CK aids in nutrient redistribution, ensuring that developing branches and flowers receive adequate support, thereby reducing premature flower drop. Gibberellin and CK are both effective in minimizing flower shedding; GA achieves this by delaying aging processes and sustaining floral structures, while CK supports it by promoting nutrient allocation to reproductive tissues (Kumar *et al.*, 2022).

These reproductive improvements are closely associated with better vegetative growth and physiological traits. Increases in seed number per plant result from enhanced flower retention, while the rise in 100-seed weight is likely due to improved nutrient allocation and overall plant vigor (Latef *et al.,* 2021). Gibberellin and CK thus play central roles in countering salinity stress by supporting essential physiological processes, which in turn promote higher productivity (Afzal *et a.l*, 2022). Overall, the observed improvements in faba bean yield under salt stress are clearly linked to beneficial effects of GA and CK on growth, physiology, and reproductive success.

The graphical abstract (Figure 9) illustrates the beneficial effects of foliar application of gibberellin (GA) and cytokinin (CK) at 25 and 50 mg $L^{-1}$ on faba bean plants grown under soil salinity stress. These treatments effectively alleviated the salinity stress adverse impacts by enhancing various morphological, physiological, and yield-related traits. Improvements were observed in growth traits (plant height, leaf area, dry biomass, and number of branches), alongside notable reduction in flower shedding percentage. Additionally, GA and CK treatments increased chl. pigment content (chl. a, b, and total), antioxidant enzyme activities (CAT, POD, SOD), total phenol levels, and proline accumulation. Yield-related enhancements included increases in pod number/plant, weight of 100-seed, and total seed yield per hectare across both growing seasons.

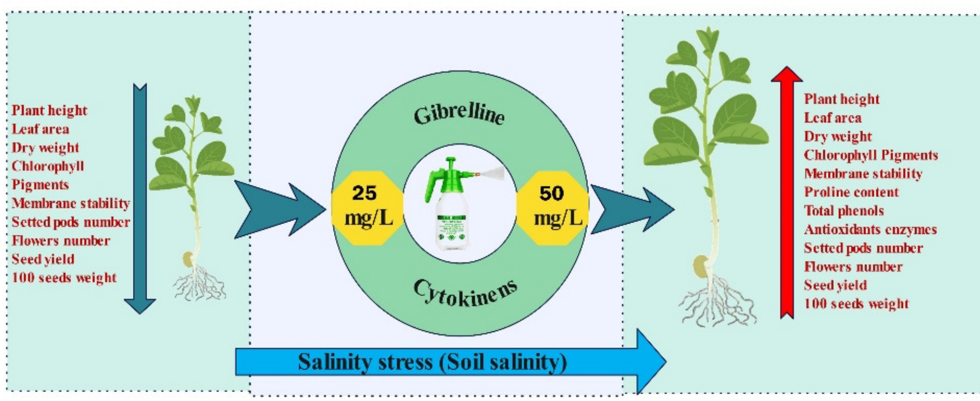

**Figure 9.** The beneficial effects of applying impact of gibberellin (GA) and cytokinin (CK)

The treatments at concentrations of 25 and 50 mg $L^{-1}$ on *Vicia faba* (faba bean) plants subjected to soil salinity stress significantly enhanced key growth traits, including plant height, leaf area, dry biomass, and number of branches per plant. Physiological improvements included increased chlorophyll pigment content (chl. *a*, *b*, and total chl.), elevated activities of antioxidant enzymes (CAT, POD, and SOD), as well as higher phenol and proline levels in leaves. Moreover, these treatments reduced the percentage of flower shedding and promoted yield-related traits, such as number of pods per plant, 100-seed weight, and total seed yield per hectare.

## Conclusions

In conclusion, this study provides strong evidence that foliar application of gibberellins or cytokinin effectively alleviates the salt stress adverse effects in faba bean plants. This mitigation is achieved through enhanced antioxidant enzyme activities and increased total phenol content, which collectively reduce oxidative stress. Additionally, both hormones contribute to maintaining osmotic balance by upregulating osmolyte accumulation. Gibberellins or cytokinin exhibited comparable effects in promoting growth and improving yield; however, CK demonstrated greater efficacy in mitigating the salinity negative impacts across all assessed growth and productivity traits. Moreover, both hormones play crucial roles in preserving reproductive success under stress, with GA delaying floral senescence and CK enhancing nutrient allocation to developing flowers. Their influence on physiological and biochemical pathways underscores their potential as effective tools for improving crop resilience under saline environments. Despite these promising findings, additional research is warranted to explore the potential synergistic effects of combined gibberellins and cytokinin applications at varying concentrations, in order to better understand and optimize their roles in salinity stress management.

## Authors' Contributions

Conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft & editing, statistical methods: M.F., E.A. and M.M.S. Conceptualization, methodology, investigation, supervision, writing review & editing: M.F. and M.M.S. Methodology, investigation, writing review & editing: M.F., E.A. and M.M.S. Methodology, investigation, writing review & editing: H.S. and A.M. Funding acquisition, writing-review & editing: H.S. Writing-review & editing: M.M.

All authors read and approved the final manuscript.

## Ethical approval (for researches involving animals or humans)

This work does not contain any studies involving human and animal subjects.

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## Conflict of Interests

Authors declare that they have no conflicts of interest.

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