Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Response of red Cabbage to foliar spraying with potassium and nano-calcium under hydroponic conditions

Worood Adnan

worudadnan@uodiyala.edu.iq

[illegible]

Hassan Alalawy

[illegible]

[illegible]

[illegible]

Research Article

Keywords: foliar spray, nano-calcium, potassium, hydroponics, red cabbage

Posted Date: September 25th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11144208/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Response of red Cabbage to foliar spraying with potassium and nano-calcium under hydroponic conditions

Abstract

The experiment was conducted at the research station affiliated with the Department of Horticulture and Landscape Architecture, College of Agriculture, University of Diyala, during the autumn season of 2025. The aim of this study was to evaluate the effect of foliar spraying with potassium and nano-calcium, and the interaction between them, on certain growth characteristics and chemical composition of the red cabbage. The experiment was conducted using a completely randomized block design with three replicates, and included treatments with conventional potassium at a concentration of 0, 250 and 500 mg L^{-1} and with nano-calcium at concentrations of 0, 1 and 2 mg L^{-1}, as well as the interaction between them.

The results showed that the spray treatments outperformed the control treatment in most of the traits studied, as the treatments led to a significant increase in plant height, number of leaves, chlorophyll content and anthocyanin pigment, as well as an increase in the leaf content of the nutrients nitrogen, phosphorus and potassium. Furthermore, the interaction treatment between potassium and nano-calcium at a concentration of 2 ml/L recorded the highest values for most of the traits studied.

Keywords: foliar spray, nano-calcium, potassium, hydroponics, red cabbage

Introduction

Red cabbage (*Brassica oleracea var. capitata f. rubra)* is a cruciferous crop of high nutritional importance due to its content of natural antioxidants such as anthocyanins and vitamin C, in addition to its role in promoting general health. Mineral nutrition management is one of the most important determinants of its yield and quality, particularly in hydroponic systems that rely on precise control of the nutrient solution (Savvas & Gruda, 2018; Gruda, 2019).

Potassium (K) is one of the major elements essential for plant growth, as it participates in regulating osmotic pressure, activating more than 60 enzymes, regulating stomatal opening and closing, and promoting the transport of carbohydrates from the leaves to storage organs (Wang et al., 2013). Recent studies have indicated that improving potassium supply in hydroponic systems leads to increased photosynthetic efficiency and improved crop quality in leafy vegetable crops (Zörb et al., 2014; Amtmann et al., 2022).

Calcium (Ca), on the other hand, is both a structural and signaling element; it forms part of cell walls, maintains the integrity of cell membranes, and acts as a second messenger in stress-related signaling pathways (Hepler, 2005; White & Broadley, 2003). Calcium deficiency is a common problem in hydroponic systems due to its limited mobility within the plant and its dependence on transpiration flux (Saure, 2014).

In recent years, agricultural nanotechnology applications have emerged as a promising tool for improving nutrient use efficiency. Nano-fertilizers were characterized by a high surface area and their ability to improve foliar uptake and reduce losses, thereby enhancing plant nutrient efficiency compared to conventional sources (Dimkpa & Bindraban, 2018). The application of nutrient nanoparticles has been shown to improve plant physiological performance and upregulate antioxidant defense systems under abiotic stress conditions (Shang et al., 2023).

Studies have also shown that foliar spraying with nano-calcium led to improved vegetative growth, increased calcium uptake and reduced symptoms of calcium deficiency in leafy vegetables compared to traditional sources (El-Saadony et al., 2024). In the context of hydroponic systems, has shown that combining nutrient solution control with foliar feeding can enhance physiological efficiency and production quality in cruciferous crops (Rouphael & Colla, 2020).

Despite advances in the study of nano-fertilizers, studies addressing the interactive effect of conventional potassium and nano-calcium in hydroponic systems on red cabbage remain limited, necessitating an experimental study to evaluate the vegetative, physiological, chemical and yield responses of this crop under these treatments.

Materials and Methods

The experiment was conducted at the research station of the Department of Horticulture and Landscape Architecture, College of Agriculture, University of Diyala, during the autumn season of 2025, with the aim of studying the effect of spraying with nano-calcium and potassium on the growth and yield of red cabbage. The seedlings were planted on 25 October 2025. Conventional potassium spray was applied at concentration of 0, 250 and 500 mg L^{-1} and the second treatment involved spraying with nano-calcium at concentrations of 0, 1 and 2 mg L^{-1}. The plants were sprayed 20 days after planting and the second spraying taking place one month after the first. The experimental design was a completely randomized block design (RCBD) with 9 treatments and 3 replicates. The data were analyzed using SAS software, and the arithmetic means were compared using Duncan's multiple range test at a significance level of 0.05.

Parameters studied:

Plant height (cm): The length of the plant was measured from their point of contact with the peat moss to the growing tip using a measuring tape for five plants in each experimental unit and then averaged was calculated.

Number of leaves (leaf plant^{-1}): The number of leaves was counted for the five randomly selected plants and the average was calculated.

Relative chlorophyll content (SPAD): The chlorophyll content in the leaves was measured 60 days after planting using a SPAD 502 Plus Chlorophyll Meter.

Estimation of total anthocyanins

Total anthocyanins content was determined using the pH differential method according to Lee et al. (2005). Fresh plant tissue (0.5 g) was finely ground and extracted with 10 mL of acidified ethanol (1% HCl). The extract was stored in the dark at 4°C for 24 h and then filtered. An aliquot of the extract was diluted separately with 0.025 M KCl buffer (pH 1.0) and 0.4 M sodium acetate buffer (pH 4.5). Absorbance was measured at 520 and 700 nm using a UV–Vis spectrophotometer. The absorbance and total monomeric anthocyanin concentration were calculated according to the pH differential.

Estimation of nutrients (N P K) in the leaves:

After collecting leaf samples from the plant, the leaves were washed to remove dust, then dried in an oven at 65 °C until constant weight was achieved. Wet digestion was then carried out according to the method proposed by (Cresser and Parsons 1979), using 200 mg of dry, ground material. The samples were placed in digestion flasks, to which 3 ml of concentrated sulfuric acid was added, and left for 24 hours. Then 1 ml of a mixture of concentrated sulfuric acid and perchloric acid was added, and the digestion flasks were placed on a hot plate. Fumes were observed to rise and the color of the samples gradually changed until a clear, colorless solution was obtained. After the samples had cooled, the volume of each sample was made up to 50 ml by adding distilled water, then stored in labelled glass bottles.

Results and Discussion:

Plant height:

The results shown in table 1 indicate an increase in the height of red cabbage plants following treatment with conventional potassium and nano-calcium, as well as the interaction between the two. The control treatment without spraying recorded the lowest plant height of 9.773 cm, whilst the treatments involving spraying with potassium and nano-calcium showed significant increases in this trait. Furthermore, the interaction treatment between conventional potassium at a concentration of 500 mg/L and nano-calcium at a concentration of 2 mg/L recorded the highest plant height value of 11.66 cm.

This increase is attributed to the important physiological role of potassium in regulating vital processes in plants, as it activates numerous enzymes and contributes to the regulation of intracellular osmotic pressure,

leading to increased cell division and elongation and, consequently, increased vegetative growth of the plant. Furthermore, nano-calcium contributes to improving cell wall structure and increasing the efficiency of nutrient uptake, which has a positive effect on plant growth (Taiz et al., 2022; Raliya et al., 2021).

Plant height

The results showed a gradual increase in plant height with increasing potassium levels, where the mean plant height increased from 10.77 cm in the K0 treatment to 11.29 cm in the K500 treatment. Nano Calcium treatments also resulted in a noticeable increase, reaching 11.36 cm at the Ca2 level compared with 10.51 cm in the control treatment (Ca0). The interaction treatments K500Ca1 and K500Ca2 recorded the highest plant height, reaching 11.66 cm.This increase can be attributed to the vital role of potassium in activating numerous enzymes involved in photosynthesis and carbohydrate translocation within the plant, thereby enhancing vegetative growth and cell elongation. Calcium also contributes to cell wall formation, membrane integrity maintenance, and regulation of cell division, which positively influences plant growth. (Johnson et al., 2022; Baez et al., 2022).

Number of Leaves

The K500 treatment produced the highest number of leaves, reaching 12.84 leaves plant^{-1} compared with 11.29 leaves plant^{-1} in the K0 treatment. Nano Calcium application also increased leaf number, reaching 12.55 leaves plant^{-1} under the Ca2 treatment. The highest value was recorded in the interaction treatment K500Ca2, which reached 13.77 leaves plant^{-1}.This response may be attributed to the role of potassium in improving photosynthetic efficiency and regulating stomatal opening and closing, thereby enhancing water and nutrient use efficiency and stimulating the formation of new leaves. Calcium is also essential for meristematic cell division and the development of young tissues, leading to increased vegetative growth. (Mostofa et al., 2022; Feng et al., 2023).

Chlorophyll Content

The results indicated an increase in chlorophyll content with increasing levels of potassium and calcium. Chlorophyll content increased from 44.25 SPAD in the K0 treatment to 45.57 SPAD in the K500 treatment, while it increased from 43.28 SPAD in the Ca0 treatment to 46.17 SPAD in the Ca2 treatment. The interaction treatments K500Ca1 and K500Ca2 recorded the highest values (46.63 SPAD).This increase is associated with the role of potassium in enhancing photosynthetic processes and improving the transport efficiency of sugars and energy within the plant, as well as maintaining chloroplast activity. Calcium contributes to the stabilization of cellular and plastid membranes and reduces chlorophyll degradation, thereby increasing leaf chlorophyll content.(Wang et al., 2022; Hasanuzzaman et al., 2021).

Anthocyanin Content

The results showed a significant increase in anthocyanin concentration with increasing potassium and calcium levels. Anthocyanin content increased from 23.43 mg g^{-1} in the K0 treatment to 36.96 mg g^{-1} in the K500 treatment, and from 24.52 mg g^{-1} in the Ca0 treatment to 35.52 mg g^{-1} in the Ca2 treatment. The K500Ca2 treatment achieved the highest value, reaching 43.63 mg g^{-1}.This increase may be explained by the role of potassium in enhancing photosynthetic efficiency and carbohydrate production, which serve as precursors for the synthesis of phenolic compounds and anthocyanins. In addition, calcium acts as an important cellular signal regulating various metabolic pathways associated with the production of secondary metabolites and antioxidants.(Johnson et al., 2022; Liu & Liao, 2022).

Table 1. Response of Vegetative Growth Characteristics to Potassium and Nano-Calcium Spray

Treatment	Plant height (cm)	Number of leaves (Leaf plant^{-1})	Chlorophyll index (SPAD)
K_0	10.77 a	11.29 b	44.25 a
K_{250}	11.10 a	12.03 ab	45.28 a
K_{500}	11.29 a	12.84 a	45.57 a
Ca_0	10.51 a	11.36 b	43.28 b
Ca_1	11.25 a	12.25 ab	45.65 ab
Ca_2	11.36 a	12.55 a	46.17 a
K_0Ca_0	9.773 a	10.55 c	39.50 b
K_0Ca_1	10.33 a	10.99 bc	44.90 a
K_0Ca_2	10.77 a	11.44 bc	45.03 a
$K_{250}Ca_0$	11.10 a	11.44 bc	45.33 a
$K_{250}Ca_1$	11.33 a	12.10 abc	45.40 a
$K_{250}Ca_2$	11.33 a	12.66 ab	45.43 a
$K_{500}Ca_0$	11.44 a	12.66 ab	46.50 a
$K_{500}Ca_1$	11.66 a	12.88 ab	46.63 a
$K_{500}Ca_2$	11.66 a	13.77 a	46.63 a

Nitrogen Content (N)

The results presented in Table 2 demonstrated a gradual increase in nitrogen content with increasing potassium and calcium levels. Nitrogen concentration increased from 1.315% in the K0 treatment to 1.360% in the K500 treatment and reached 1.372% in the interaction treatment K500Ca2. The results showed a clear gradient in the recorded values of the studied trait, where treatment C recorded the highest value (1.344), followed by treatment B (1.336), while treatment A showed the lowest value (1.328). These results indicate an inverse response between the treatment level and the value of the studied trait.

Overall, these findings demonstrate that the best response was achieved in treatment C, suggesting that it was the most suitable for improving the studied trait compared to the other treatments. This may be attributed to a better balance between nutrient availability and their efficient utilization within the plant This increase may be attributed to the role of potassium in enhancing nutrient uptake and translocation within the plant, while calcium helps maintain cellular membrane efficiency and root activity, thereby improving the plant's ability to absorb and utilize nitrogen for protein and enzyme synthesis.(Mostofa et al., 2022; Johnson et al., 2022).

Phosphorus Content (P)

The results showed a clear increase in phosphorus content with increasing treatment levels. Phosphorus concentration increased from 0.371% in the K0 treatment to 0.473% in the K500 treatment, while the highest value (0.484%) was recorded in the K500Ca2 treatmen This response may be attributed to improved root growth and enhanced nutrient uptake efficiency resulting from the availability of potassium and calcium, as well as improved metabolic activity and energy supply required for nutrient transport within the plant. The results showed a slight but clear increase in the studied trait with nano-calcium treatments, where

treatment A recorded the highest value (2.324) compared to treatment B (2.315) and treatment C (2.300). This increase indicates the positive role of nano-calcium in improving the physiological performance of the plant.

Overall, these findings are consistent with recent studies reporting that foliar application of nano-calcium enhances the efficiency of physiological processes and plant growth compared to conventional calcium sources, due to higher bioavailability and faster absorption.

Potassium Content (K)

Leaf potassium content increased from 2.285% in the K0 treatment to 2.347% in the K500 treatment, while the interaction treatment K500Ca2 recorded the highest value of 2.367%.

These results indicate that increasing potassium application enhanced the availability of this nutrient in the root zone, thereby promoting its uptake and accumulation in plant tissues. Furthermore, calcium improved nutrient absorption efficiency and maintained membrane integrity, which facilitated potassium transport and accumulation within the plan.

Table 2. Response of Nutrients concentration to Potassium and Nano-Calcium Foliar Spray

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Anthocyanin content (mg g^{-1})		
		K_0	1.315 c	0.371 c	2.285 c	23.43 c
		K_{250}	1.333 b	0.432 b	2.308 b	30.67 b
		K_{500}	1.360 a	0.473 a	2.347 a	36.96 a
		Ca_0	1.328 a	0.412 c	2.300 c	24.52 c
		Ca_1	1.336 b	0.427 b	2.315 b	31.03 b
		Ca_2	1.344 c	0.437 d	2.324 a	35.52 a
		K_0Ca_0	1.308 g	0.359 g	2.279 g	19.50 i
		K_0Ca_1	1.314 fg	0.374 fg	2.286 f	23.43 h
		K_0Ca_2	1.322 f	0.380 f	2.290 f	25.03 g
		$K_{250}Ca_0$	1.325 ef	0.414 e	2.298 e	27.36 f
		$K_{250}Ca_1$	1.335 de	0.432 d	2.310 d	29.03 e
		$K_{250}Ca_2$	1.339 cd	0.449 cd	2.315 d	31.43 d
		$K_{500}Ca_0$	1.351 bc	0.463 b	2.324 c	35.56 c
		$K_{500}Ca_1$	1.358 b	0.473 ab	2.351 b	38.23 b
		$K_{500}Ca_2$	1.372 a	0.484 a	2.367 a	43.63 a

Conclusion

The results indicate a significant positive effect of potassium and calcium applications, both individually and in combination, on improving vegetative growth and the chemical composition of the plant. The interaction treatment K500Ca2 outperformed the other treatments in most of the studied traits, suggesting a synergistic effect between the two elements in enhancing physiological processes, increasing nutrient uptake efficiency,

and promoting the synthesis of plant pigments. This was directly reflected in improved plant growth and nutritional status

References

Al-Sahaf, F. H. (1989). Applied Plant Nutrition. Ministry of Higher Education and Scientific Research, University of Baghdad, Iraq.

Amtmann, A., Armengaud, P., & Volkov, V. (2022). Potassium nutrition and signalling in plants. Journal of Experimental Botany.

Baez, L. A., Tichá, T., & Hamann, T. (2022). Cell wall integrity regulation across plant species. Plant Molecular Biology, 109, 483–504. https://doi.org/10.1007/s11103-022-01284-7

Cresser, M. S., & Parsons, J. W. (1979). Sulphuric–perchloric acid digestion of plant material for the determination of nitrogen, phosphorus, potassium, calcium and magnesium. Analytica Chimica Acta, 109(2), 431–436. https://doi.org/10.1016/S0003-2670(01)84273-2.

Dimkpa, C. O., & Bindraban, P. S. (2018). Nanofertilisers: new products for the industry. Journal of Agricultural and Food Chemistry, 66, 6462–6473.

El-Shewy, A. A., et al. (2022). Role of calcium nanoparticles in improving plant growth and physiological traits. Plants, 11(3), 321.

Exogenous calcium: Its mechanisms and research advances involved in plant stress tolerance. Frontiers in Plant Science, 14, 1143963. https://doi.org/10.3389/fpls.2023.1143963

Feng, D., Wang, X., Gao, J., et al. (2023). Exogenous calcium: Its mechanisms and research advances involved in plant stress tolerance. Frontiers in Plant Science, 14, 1143963. https://doi.org/10.3389/fpls.2023.1143963

Liu, H., Liu, P., & Sun, X. (2023). Exogenous calcium: Its mechanisms and research advances involved in plant stress tolerance. Frontiers in Plant Science, 14, 1143963. https://doi.org/10.3389/fpls.2023.1143963

Gruda, N. (2019). Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. Agronomy, 9(6), 298. https://doi.org/10.3390/agronomy9060298

Hasanuzzaman, M., Bhuyan, M. H. M. B., Zulfiqar, F., Raza, A., Mohsin, S. M., Mahmud, J. A., Fujita, M., & Fotopoulos, V. (2021). Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. Antioxidants, 10(1), 156.

Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., & Hawrylak-Nowak, B. (Eds.). (2018). Plant Nutrients and Abiotic Stress Tolerance. Springer, Singapore. https://doi.org/10.1007/978-981-10-9044-8

Hepler, P. K. (2005). Calcium: A Central Regulator of Plant Growth and Development. The Plant Cell, 17(8), 2142–2155.https://doi.org/10.1105/tpc.105.032508

Johnson, R., Vishwakarma, K., Hossen, M. S., et al. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. Plant Physiology and Biochemistry, 172, 56–69. https://doi.org/10.1016/j.plaphy.2022.01.001

Lee, J., Durst, R. W., & Wrolstad, R. E. (2005). Determination of Total Monomeric Anthocyanin Pigment Content by the pH Differential Method. Current Protocols in Food Analytical Chemistry, F1.2.1–F1.2.13.

Liu, C., & Liao, W. (2022). Potassium signaling in plant abiotic responses: Crosstalk with calcium and reactive oxygen species/reactive nitrogen species. Plant Physiology and Biochemistry, 173, 110–121. https://doi.org/10.1016/j.plaphy.2022.01.016

Mostofa, M. G., Rahman, M. M., Ghosh, T. K., Kabir, A. H., Abdelrahman, M., Khan, M. A. R., Mochida, K., & Tran, L.-S. P. (2022). Potassium in plant physiological adaptation to abiotic stresses. Plant Physiology and Biochemistry, 186, 279–289. https://doi.org/10.1016/j.plaphy.2022.07.011

Raliya, R., Saharan, V., Dimkpa, C. O., & Biswas, P. (2018). Nanofertilizer for Precision and Sustainable Agriculture: Current State and Future Perspectives. Journal of Agricultural and Food Chemistry, 66(26), 6487–6503. https://doi.org/10.1021/acs.jafc.7b02178

Rouphael, Y., & Colla, G. (2020). Editorial: Biostimulants in Agriculture. Frontiers in Plant Science, 11, 40. https://doi.org/10.3389/fpls.2020.00040

Saadony, M. T., Desoky, E. S. M., El-Tarabily, K. A., AbuQamar, S. F., & Saad, A. M. (2024). Exploiting the role of plant growth promoting rhizobacteria in reducing heavy metal toxicity of pepper (Capsicum annuum L.). Environmental Science and Pollution Research, 31(18), 27465–27484

Sardans, J., & Peñuelas, J. (2021). Potassium Control of Plant Functions: Ecological and Agricultural Implications. Plants, 10(2), 419. https://doi.org/10.3390/plants10020419

Sarker, U., & Oba, S. (2020). Nutritional and antioxidant components in leafy vegetables. Journal of Plant Growth Regulation, 39, 1387–1404.

Saure, M. C. (2014). Why calcium deficiency is not always the cause of blossom-end rot. Journal of Plant Nutrition and Soil Science.

Savvas, D., & Gruda, N. (2018). Application of soilless culture technologies in greenhouse vegetable production. European Journal of Horticultural Science.

Shang, Y., et al. (2023). Nano-enabled fertilisers and plant responses. Frontiers in Plant Science.

Taiz, L., Zeiger, E., Møller, I., & Murphy, A. (2022). Plant Physiology and Development (7th ed.). Sinauer Associates.The critical role of potassium in plant stress responses and growth regulation. International Journal of Molecular Sciences, 23(4), 2033. https://doi.org/10.3390/ijms23042033

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. International Journal of Molecular Sciences, 14(4), 7370–7390. https://doi.org/10.3390/ijms14047370

White, P. J., & Broadley, M. R. (2003).

Zhang et al., 2023/2024. Exogenous calcium: Its mechanisms and research advances involved in plant stress tolerance.

Zhang, Y., et al. (2021). Simultaneous changes in anthocyanin, chlorophyll, and carotenoid contents produce green variegation in pink-leaved ornamental kale. BMC Plant Biology, 21, 283.

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture – Status and perspectives. Journal of Plant Physiology