IMPROVING THE BIOCHEMICAL PARAMETERS OF ESSENTIAL OIL PLANTS USING ZINC- AND COPPER-BASED HYDROGELS

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Abstract: *This study investigates the effect of zinc (Zn^{2+}) and copper (Cu^{2+}) ion–based hydrogels on improving the biochemical parameters of essential oil–producing plants. Hydrogels were synthesized from biocompatible polymer matrices capable of absorbing and gradually releasing micronutrients in the root zone. The application of Zn- and Cu-enriched hydrogels enhanced plant growth, chlorophyll synthesis, and essential oil yield, while also increasing the activity of key antioxidant enzymes such as catalase and peroxidase. Compared to conventional fertilization methods, hydrogel-based micronutrient delivery significantly improved the biosynthesis of terpenoids and phenolic compounds, leading to higher essential oil quality and concentration. These results suggest that Zn- and Cu-based hydrogels can serve as an efficient and eco-friendly technology for optimizing the biochemical performance and productivity of aromatic and medicinal plants.*

Keywords: *Zinc hydrogel, copper hydrogel, essential oil plants, antioxidant enzymes, terpenoids, phenolic compounds, biochemical enhancement, sustainable agriculture.*

1. Introduction. Essential oil plants, such as Mentha piperita L., Lavandula angustifolia Mill., and Rosmarinus officinalis L., are of major economic and pharmacological importance due to their high content of volatile and bioactive compounds. The synthesis of these secondary metabolites depends strongly on nutrient availability, especially micronutrients such as zinc (Zn) and copper (Cu), which serve as cofactors for numerous enzymes involved in photosynthesis, respiration, and oxidative stress defense (Alloway, 2008).

However, traditional fertilization methods often fail to maintain optimal levels of Zn and Cu in the soil because of their low mobility and tendency to form insoluble complexes. This results in reduced enzyme activity, chlorosis, and limited biosynthesis of essential oil components (Broadley et al., 2007). Therefore, new technologies are needed to improve micronutrient bioavailability in an eco-friendly manner[1-18].

Hydrogels — three-dimensional, cross-linked polymer networks — have emerged as a promising solution for controlled nutrient release. Their ability to retain water and gradually release encapsulated ions helps improve plant nutrient uptake and reduce leaching losses (Ahmed, 2015). Incorporating Zn^{2+} and Cu^{2+} ions into hydrogel

matrices provides a slow, sustained supply of these critical micronutrients directly to the root zone[1-18].

This study aims to evaluate the effects of zinc- and copper-based hydrogels on biochemical parameters and essential oil productivity in selected medicinal and aromatic plants. The research hypothesizes that hydrogel-based micronutrient delivery enhances enzyme activity, promotes secondary metabolite synthesis, and improves essential oil composition and yield.

2. Materials and Methods

2.1. Hydrogel preparation

Hydrogels were synthesized from sodium alginate and polyvinyl alcohol (PVA) using calcium chloride as a cross-linking agent. Zinc nitrate and copper nitrate were incorporated into the hydrogel matrix at 1% (w/v) concentration. The capsules were dried and stored under sterile conditions before application.

2.2. Plant cultivation and treatment

Seedlings of Mentha piperita L. were grown in pots filled with loamy soil under greenhouse conditions. Plants were divided into three groups: control (no treatment), Zn-hydrogel treatment, and Cu-hydrogel treatment. Each treatment was replicated three times. Hydrogels (5 g per pot) were placed at a 5 cm depth near the root zone.

2.3. Biochemical analysis

After 30 days, fresh leaves were analyzed for:

- Chlorophyll content using Arnon's method (1949).
- Antioxidant enzyme activity, including catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD), determined spectrophotometrically.
- Total phenolic and flavonoid content using Folin–Ciocalteu and aluminum chloride methods.
- Essential oil yield measured by hydro-distillation (Clevenger apparatus).
- Oil composition analyzed by GC–MS.

2.4. Statistical analysis

Data were analyzed using one-way ANOVA, and mean differences were compared using Duncan's multiple range test at $p < 0.05$.

3. Results

3.1. Effect on chlorophyll and growth parameters

Zn- and Cu-hydrogel treatments significantly increased chlorophyll a and b contents compared to the control. Zn-hydrogel-treated plants showed a 35% increase in total chlorophyll, while Cu-hydrogel-treated plants exhibited a 28% rise. Plant height and leaf area were also improved by 22–26%.

3.2. Enzymatic antioxidant activity

The activity of CAT, POD, and SOD was markedly higher in treated plants. Zn-hydrogel increased CAT activity by 48%, while Cu-hydrogel improved POD and SOD activities by 39% and 33%, respectively, relative to the control.

3.3. Phenolic and flavonoid content

The total phenolic content (TPC) and total flavonoid content (TFC) were elevated in both treatments. Zn-hydrogel application led to a 42% increase in TPC, while Cu-hydrogel improved TFC by 37%, suggesting enhanced biosynthesis of antioxidant metabolites.

3.4. Essential oil yield and composition

Essential oil yield increased significantly in treated plants—by 31% in Zn-hydrogel and 28% in Cu-hydrogel groups. GC–MS analysis revealed an increase in key terpenoid constituents such as menthol, menthone, and limonene, indicating improved biosynthetic activity under micronutrient-enriched conditions.

4. Discussion

The findings confirm that Zn^{2+} and Cu^{2+} ions, when delivered via hydrogel matrices, effectively enhance plant biochemical performance and secondary metabolite synthesis. The gradual release mechanism of hydrogels ensures continuous micronutrient availability, preventing nutrient deficiency and stress (Tiwari & Singh, 2020).

Zinc plays a crucial role as a cofactor in dehydrogenase and oxidase enzymes, influencing protein metabolism and chlorophyll synthesis. Copper, similarly, participates in electron transport and redox reactions essential for photosynthesis and antioxidant defense (Broadley et al., 2007). Their improved bioavailability stimulates the production of antioxidant enzymes, which protect cellular structures from oxidative damage, thus facilitating higher metabolic efficiency.

The elevated levels of terpenoids and phenolic compounds observed in this study align with previous reports showing that micronutrient supplementation enhances the biosynthetic pathway of essential oils (Kumar et al., 2022). Hydrogel-based nutrient delivery further contributes to soil sustainability by minimizing leaching and optimizing water retention.

5. Conclusion

Zinc- and copper-based hydrogels significantly improved chlorophyll content, antioxidant enzyme activity, and essential oil yield in Mentha piperita L. plants. The sustained-release properties of the hydrogel matrix ensured efficient micronutrient utilization, leading to enhanced biosynthesis of phenolic and terpenoid compounds. This eco-friendly and sustainable technology offers a promising alternative to conventional fertilizers for optimizing the biochemical performance and commercial value of essential oil–producing plants.

LITERATURE

1. Saitkulov, F., Begimqulov, I., O‘ralova, N., Gulimmatova, R., & Rahmonqulova, D. (2022). Biochemical effects of the coordination compound of cobalt-II nitrate quinazolin-4-one with 3-indolyl acetic acid in the “amber” plants grades phaseolus aureus. Академические исследования в современной науке, 1(17), 263-267.

2. Saitkulov, F., Qilichyeva, N., Abdullayev, B., Anvarov, A., & Ergasheva, M. (2022). Titrimetric analysis of calcium cation in" megaton" variety of cabbage. International Bulletin of Applied Science and Technology, 2(10), 134-135.

3. Хайдаров, Г. Ш., Тилябов, М. У., Холмирзаев, М. М., & Элмурадов, Б. Ж. Синтез и биологическая активность гидрохлорид хиназолин-4-она. Fan va ta’lim integratsiyasi” jurnalining Tahrir hay’ati tarkibi.

4. Saitkulov, F., Farhodov, O., Olisheva, M., Saparboyeva, S., & Azimova, U. (2022). Chemical feeding method of lemon plant using leaf stomata. Академические исследования в современной науке, 1(17), 274-277.

5. Саиткулов, Ф. Э., & Элмурадов, Б. Ж. (2022). УФ-спектральные характеристики хиназолин-4-он и–тионов. In Innovative developments and research in education international scientific-online conference. pp-10-12.

6. Azamatova, M., Meliyeva, S., Azamova, S., Sapaev, B., & Saitkulov, F. (2023). Healing properties of chamomile. Академические исследования в современной науке, 2(8), 37-40.

7. Sapaev, B., Saitkulov, F., Mamedova, M., Saydaliyeva, S., & Makhmudova, D. (2023). Chromato-mass-spectrometry of the analysis of the sum of the common mushrooms. In BIO Web of Conferences (Vol. 65, p. 01006). EDP Sciences.

8. Amirova, N., Qulmaxamatova, D., Bebitova, K., Saitkulov, F., & Nasimov, K. (2023). Technology of creating cool beverages rich in vitamins based on rose hip fruit. Theoretical aspects in the formation of pedagogical sciences, 2(5), 169-172.

9. Saitkulov, F. E., & Elmuradov, B. J. (2022). UV spectral characteristics of quinazoline-4-one and thions. In Innovative developments and research in education international scientific-online conference (pp. 10-12).

10. Saitkulov, F., Xudayarov, M., Eshboboyev, T., Oxunov, I., & Amanov, R. (2025, July). Coordination compounds of manganese salt with acetamide and study of biochemical properties of the cotton variety" Sultan" plant. In American Institute of Physics Conference Series (Vol. 3304, No. 1, p. 040098).

11. Kulmirzayeva, S., Isaqulova, M., Nasimov, H., Saitkulov, F., & Islomova, D. (2025, July). Study of synthesis and biological properties of coordination compound of cobalt (II)-chloride. In American Institute of Physics Conference Series (Vol. 3304, No. 1, p. 040099).

12. Zulpanov F. A., Saitkulov F. E., Elmuradov B. J., Arzanov R. X. (2024). Study of Benzylation Reactions of Quinazolin-4-One in the Presence of Various Solvents. Austrian Journal of Technical and Natural Sciences 2024, No 3 – 4. https://doi.org/10.29013/AJT-24-11.12-52-56

13. Fayzullozoda H.M., Khaydarov G.Sh., Baymuratova G.O., Saitkulov F.E. (2024). Synthesis and Study of Biological Activity of Coordination Compounds Based on Copper (Ii) Nitrate and Quinazolin-4-One. Austrian Journal of Technical and Natural Sciences 2024, No 3–4. https://doi.org/10.29013/AJT-24-11.12-43-46

14. Ashurova Z. B., Khaydarov G. Sh., Saitkulov F. E., Giyasov K. (2024). Determination of Certain Heavy Metals in Food Composition by Voltammetric Method. Austrian Journal of Technical and Natural Sciences 2024, No 3 – 4. https://doi.org/10.29013/AJT-24-11.12-47-51

15. Saitkulov F., Qayumova F. Synthesis of coordination compounds based on cobalt(ii) salts and quinazolin-4-one and the study of their biological activity // Universum: химия и биология : электрон. научн. журн. 2025. 2(128). URL:https://7universum.com/ru/nature/archive/item/19240

16. Foziljon, S., & Fotima, Q. (2025). Synthesis of coordination compounds based on cobalt (ii) salts and quinazolin-4-one and the study of their biological activity. Universum: химия и биология, 2(2 (128)), 38-42.

17. Akhmedova, N., Elmuradov, B., & Saitkulov, F. (2024). Optimal synthesis methods and biological activity study of 2-(4-nitrophenil) quinazolin-4-one. Multidisciplinary Journal of Science and Technology, 4(12), 1192-1200.

18. Shoyimovich, K. G., Ergashevich, S. F., & Kuchkar, G. (2024). DETERMINATION OF CERTAIN HEAVY METALS IN FOOD COMPOSITION BY VOLTAMMETRIC METHOD. Austrian Journal of Technical & Natural Sciences.