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Evaluation Of Electroculture As A Sustainable Method To Enhance Growth And Yield Of Chilies (Capsicum Annuum L.)

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ABSTRACT

The field experiment was conducted during kharif 2024 at the department of Horticulture, PMAS- Arid Agriculture University Rawalpindi, Pakistan to study the effect of electroculture on seed germination and growth of chilies. The experiment was conducted in Randomized Complete Block Design RCBD with three replications. Treatments include: T_1 = Control, T_2 = Copper (Two, 2ft wire pot^{-1}), T_3 = Silver (Two, 2ft wire pot^{-1}), T_4 = Iron (Two, 2ft wire pot^{-1}). The chili treated with maximum result in Silver (Two, 2ft wire pot^{-1}) resulted in 75.00% seed germination, 8.22 days to seed germination, 26.58 number of leaves plant^{-1}, 25.32 cm plant height, 6.55 number of branches, 71.22 days to flower initiation, 8.75 number of flowers and 0.78 g fresh weight of root biomass. Copper (Two, 2ft wire pot^{-1}) resulted in 67.50% seed germination, 7.42 days to seed germination, 29.16 number of leaves plant^{-1}, 30.83 cm plant height, 8.64 number of branches, 71.00 days to flower initiation, 10.75 number of flowers and 1.18 g fresh weight of root biomass. The chili with Iron (Two, 2ft wire pot^{-1}) resulted 70.00% seed germination, 7.25 days to seed germination, 26.24 number of leaves plant^{-1}, 26.32 cm plant height, 6.23 number of branches, 70.31 days to flower initiation, 7.25 number of flowers and 1.22 g fresh weight of root biomass. However, the control resulted in minimum 60.00% seed germination, 6.22 days to seed germination, 22.99 number of leaves plant^{-1}, 22.49 cm plant height, 4.47 number of branches, 60.75 days to flower initiation, 6.50 number of flowers and 0.70 g fresh weight of root biomass.

Introduction

Chili (*Capsicum annuum* L.) a member of the Solanaceae family and colloquially known as "capsicum," is a globally significant crop cultivated primarily for its pungent, flavorful fruits. Originating in the Americas, chilies have played a dual role in human societies for millennia, serving both as a culinary spice and a dietary staple. Over time, their cultivation has expanded worldwide, driven by their adaptability and cultural integration. Today, chilies are indispensable to diverse cuisines, celebrated not only for their ability to enhance flavor but also for their rich nutritional profile, which includes antioxidants, vitamins, and phytochemicals like capsaicin a compound linked to numerous health benefits, from pain relief to metabolic enhancement (Kakar et al., 2024). Chilies (*Capsicum annuum*) hold immense agricultural and economic importance globally, serving as a vital cash crop, particularly in developing economies. According to Khan et al. (2017), global chili production exceeds 40 million tons annually. The global chili market is segmented into fresh and dried varieties, both of which drive substantial international trade. Beyond their culinary roles, chilies hold significant value in pharmaceutical and cosmetic industries. Capsaicin, the bioactive compound responsible for chilies' signature heat, is extensively utilized in diverse applications, including pain-relief formulations, weight management products, and non-lethal defense sprays (Akram et., 2017). Chilies (*Capsicum annuum*) hold significant commercial value across diverse industries. In the pharmaceutical and cosmetic sectors, they are utilized for extracting capsaicinoids, oleoresins, and bioactive compounds, while their dried and powdered forms drive global agro trade. Beyond their role as a culinary staple, chilies are integral to food processing, adding pungency, vibrant color, and flavour to products such as ginger ales, pastes, curry powders, and baked goods. Nutritionally, chilies are a powerhouse of essential vitamins (A, B-complex, C, E, and P), minerals (potassium, magnesium, iron, calcium, phosphorus), amino acids, and dietary fiber. Fresh green chilies surpass citrus fruits in vitamin C content (340 mg per 100 g), while red varieties exceed carrots in vitamin A (Nawaz et al., 2016). Chilies also boast a rich profile of phytochemicals, including carotenoids, flavonoids, and phenolics, which act as potent antioxidants linked to reducing risks of degenerative diseases (Jan et al., 2020). Their capsaicinoids, such as capsaicin, contribute to both their pungency and therapeutic applications, ranging from pain relief to metabolic health (Arain et al., 2022). With hundreds of cultivars consumed fresh (unripe or ripe), dried, or processed, nutritional and antioxidant content varies significantly across species and preparation methods (Wahocho et al., 2016). This versatility underpins their classification as a "superfood," combining culinary, medicinal, and economic benefits (Ali et al., 2020). Electroculture, the application of controlled electric currents to enhance plant growth and productivity, has emerged as a promising agricultural innovation. Studies suggest that externally applied electrical stimulation can accelerate plant development, boost yields, and improve stress resilience. For instance, exposure to electric fields has been shown to enhance seed Vigor by activating biochemical processes, such as the generation of free radicals and increased enzymatic activity (Umarov et al., 2024). In barley seeds, a 4 kV/m electric field elevated free radical levels, potentially priming metabolic pathways for faster germination (Lastochkina et al., 2022). Electroculture also offers practical benefits in crop protection, reducing reliance on synthetic fertilizers and pesticides. Electrical treatments disrupt the biological activity of membrane proteins in pests and pathogens, thereby mitigating disease and insect infestations. Field trials demonstrate its efficacy: cotton yields increased by 12.4% under electrical stimulation, while high-voltage electrostatic fields improved sugar content in beetroots and accelerated seed germination. These findings underscore electroculture's dual role in enhancing productivity and promoting sustainable farming practices (Ahmad et al., 2024).

Material and Methods

The study was conducted at Chamogarh Village district Gilgit, Pakistan during kharif, 2024 to assess the "Evaluation of electroculture as a sustainable method to enhance growth and yield of chilies (*Capsicum annuum* L.)." Using a randomized full block design, the experiment's net plot measured 4 m by 3 m (12 m^2) were planted in a good seedbed using suitable land preparation using mechanical tools. While nitrogen was conducted according to techniques, the experiment was conducted three times. Treatments examined (levels) = 4 .T_1 = Control, T_2 = Copper (Two, 2ft wire pot^{-1}), T_3 = Silver (Two, 2ft wire pot^{-1}), T_4 = Iron (Two, 2ft wire pot^{-1}) plants were selected for each experimental plot at maturity, and the following parameters were noted: Seed germination (%), Days to seed germination, Number of leaf plant^{-1}, Plant height (cm), Number of branches plant^{-1}, Days to flower initiation, Number of flower plant^{-1}, Fresh biomass of root (g).

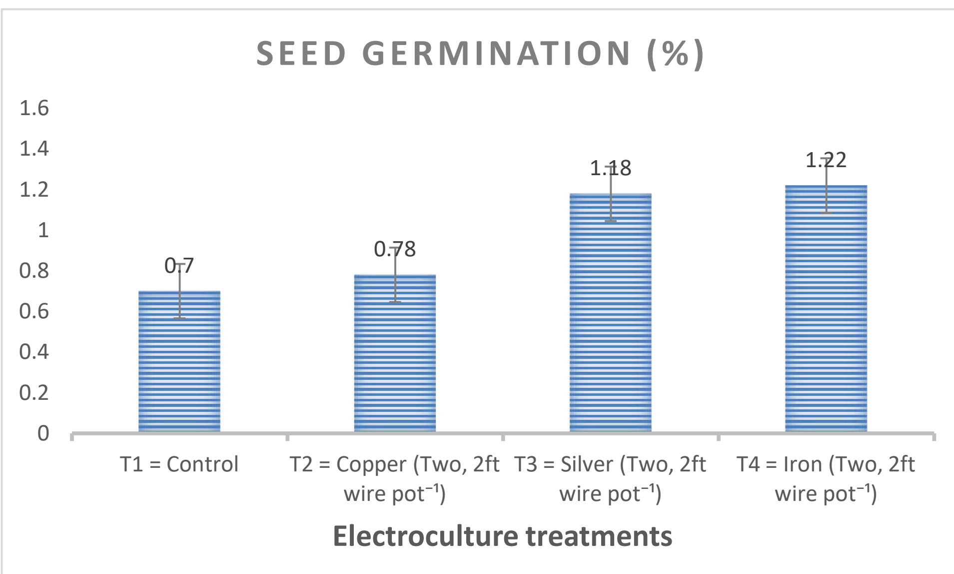
Statistical analysis

Using the Statistix-8.1 software, an ANOVA was performed on the gathered data (Statistix, 2006). Tests were used when needed to evaluate the effectiveness of various treatments.

RESULTS

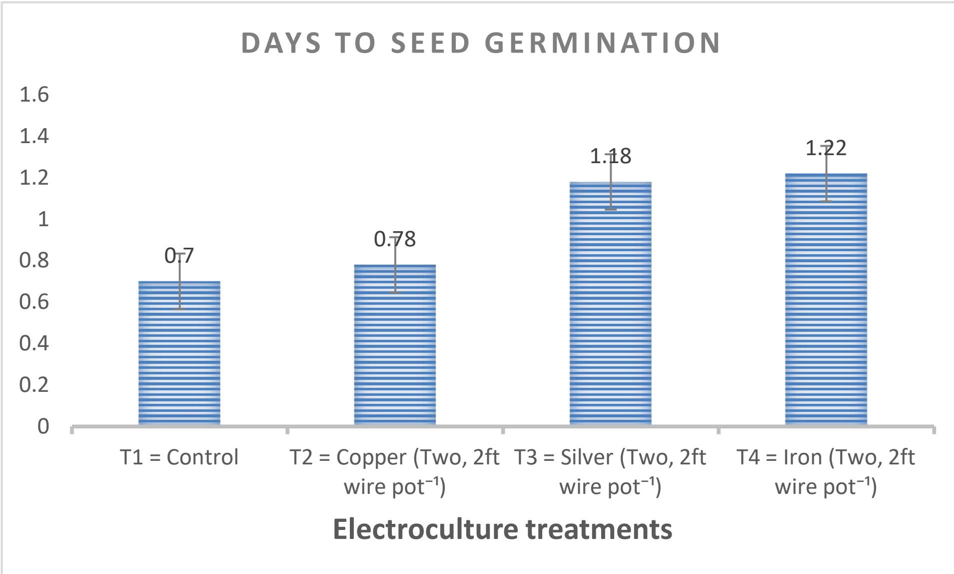
Seed germination (%)

The seed germination (%) of as influenced by different electroculture treatments showed a clear trend from maximum to minimum effectiveness. The silver (Two, 2ft wire pot^{-1}) recorded the highest germination at 75.00%, indicating its superior ability to stimulate seed germination. This was closely followed by the T_4 = iron (Two, 2ft wire pot^{-1}), which achieved a germination percentage of 70.00%. The T_2 = copper (Two, 2ft wire pot^{-1}) ranked third with a germination of 67.50%. Finally, the control exhibited the lowest germination percentage at 60.00%. The comparison of seed germination (%) among different electroculture treatments showed no-significant differences, as indicated by a P-value of 0.3841, greater than 0.05, and an LSD value of 15.927. Although treatments like copper (Two, 2ft wire pot^{-1}) and iron (Two, 2ft wire pot^{-1}) had higher mean germination when compared to the control, these differences did not exceed the LSD threshold.



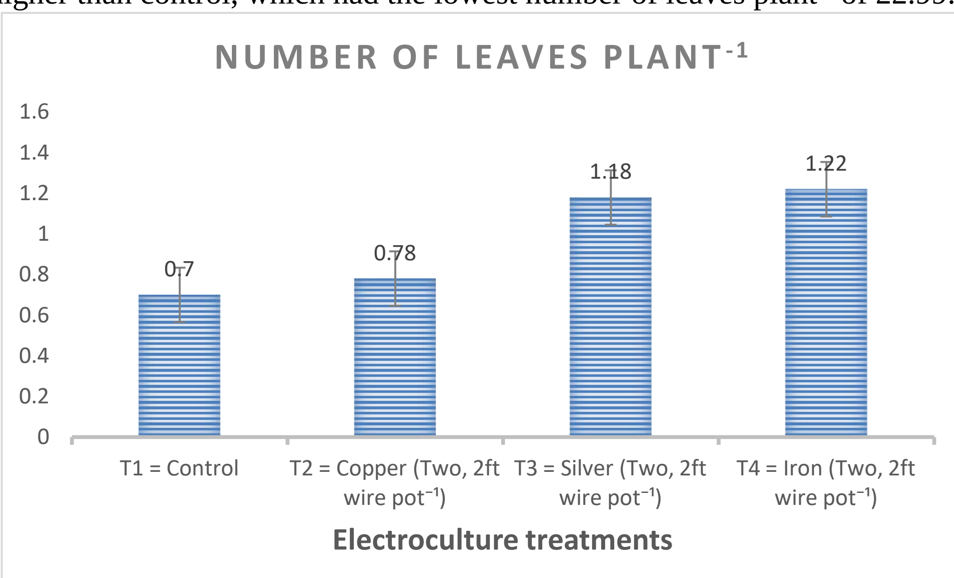
Days to seed germination

The days to seed germination of as influenced by different electroculture treatments varied slightly, with only minor differences observed among the treatments. The silver (Two, 2ft wire pot^{-1} 2) recorded the days to seed germination at 8.22. This was followed by the T_2 = Copper (Two, 2ft wire pot^{-1}), with germination occurring in 7.25 days. Days to seed germination were lowest in the control 6.22. In contrast, the control, T_4 = Iron (Two, 2ft wire pot^{-1}) treatments all recorded the time to germination, averaging 7.25days. The differences among treatments were statistically non-significant, as indicated by the P-value of 0.5437 and the LSD value of 0.7536.



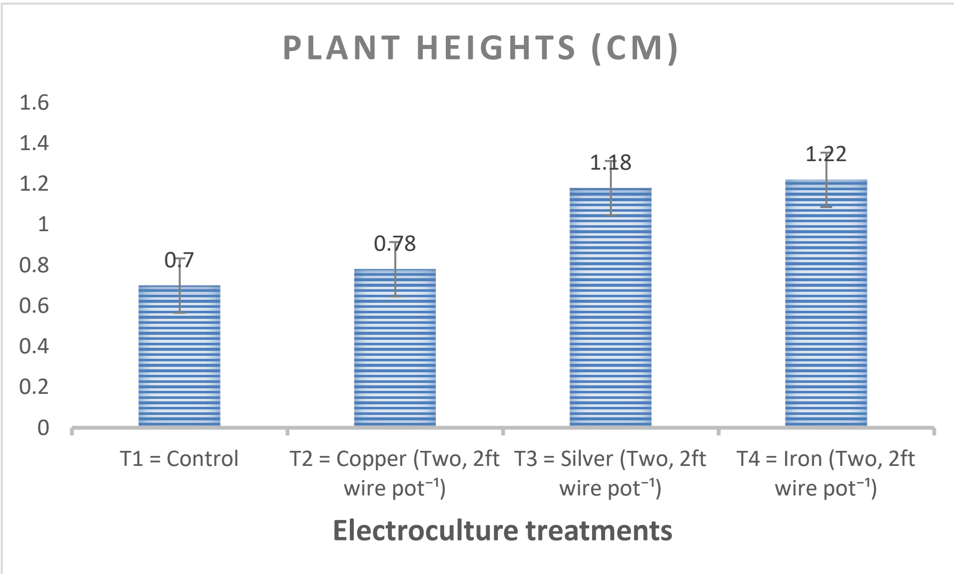
Number of leaves plant^{-1}

The effect of different electroculture on chilies was investigated, and the results for number of leaves plant^{-1}. The analysis of variance (Appendix 3) revealed a significant ($P<0.05$) effect of the different electroculture on the number of leaves plant^{-1} of chilies. The treatments, T_3 = Silver (Two, 2ft wire pot^{-1}) had the highest number of leaves plant^{-1} at 29.16. This was closely followed by T_2 = Copper (Two, 2ft wire pot^{-1}) with a number of leaves plant^{-1} of 26.58. The T_4 = Iron (Two, 2ft wire pot^{-1}) had number of leaves plant^{-1} of 26.24, slightly higher than control, which had the lowest number of leaves plant^{-1} of 22.99.



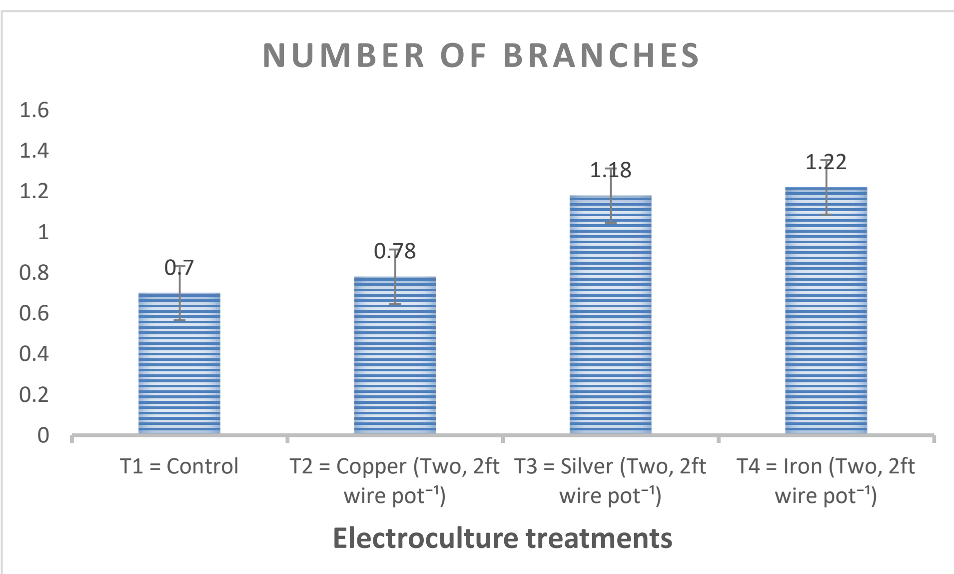
Plant height (cm)

The effect of different electroculture treatments on the plant height of chilies showed notable variation, with the magnet treatment exhibiting the most significant influence. Among the four treatments tested, the T_3 = Silver (Two, 2ft wire pot^{-1}) recorded the highest plant height of 30.83 cm. This was followed by plants treated with T_2 = copper (Two, 2ft wire pot^{-1}), which achieved height of 25.32 cm. The T_4 = Iron (Two, 2ft wire pot^{-1}) resulted in a moderate improvement, with plants reaching an average height of 26.32 cm, the control group, which did not receive any electroculture treatment, recorded the lowest height of 22.49 cm. The ANOVA showed that the plant height of chili under different electroculture treatments revealed statistically significant differences among the treatments, as indicated by the P-value of 0.0011 and the LSD value of 6.0134 at the 0.05 level. Similarly, copper (Two, 2ft wire pot^{-1}) also demonstrated a significant increase over the control. However, the difference between silver (Two, 2ft wire pot^{-1}) and the control was not statistically significant, as it did not surpass the LSD threshold.



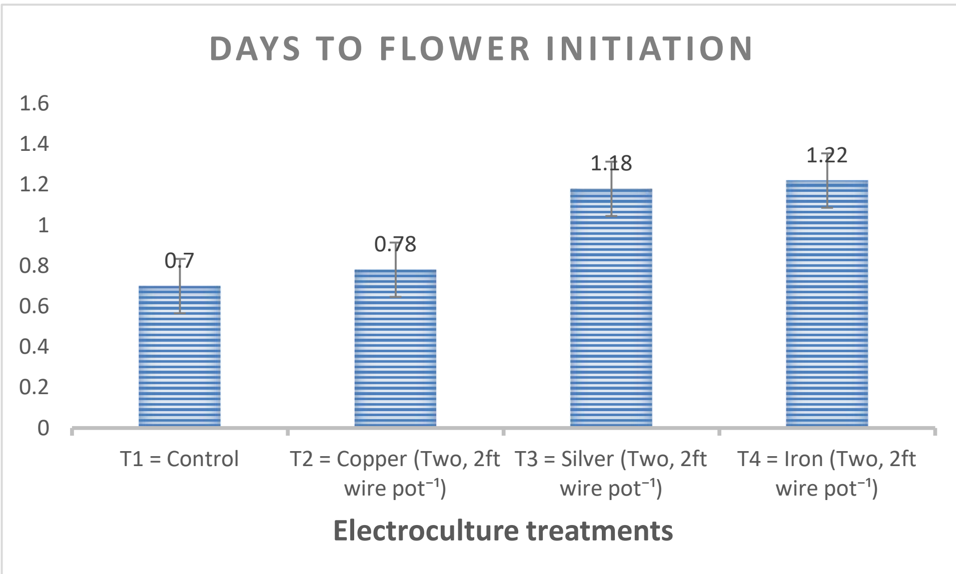
Number of branches

The impact of various electroculture treatments on the number of chili. Analysis of variance (Appendix 5) indicated a significant effect (P<0.05) on the electroculture treatments of the number of branches. Among the treatments, the T_3 = Silver (Two, 2ft wire pot^{-1}) resulted in the highest branch count at 8.64. This was closely followed by T_2 = copper (Two, 2ft wire pot^{-1}) with an average of 6.55 branches, and T_4 = iron, which produced 6.23 branches. The control group showed 4.47 branches. The results for the number of branches in chilies under different electroculture treatments show statistically significant differences, as the p-value is 0.0039, which is less than the 0.05 threshold.



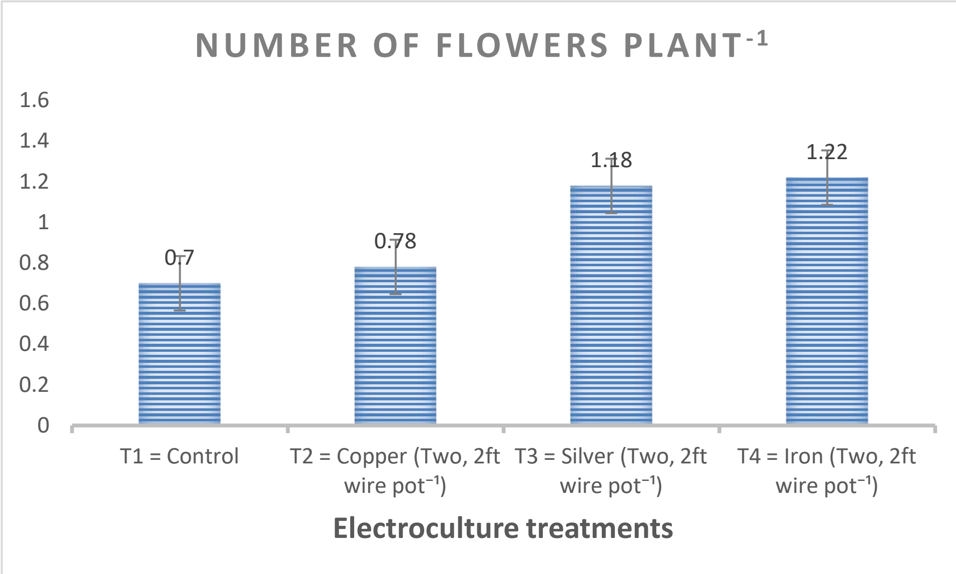
Days to flower initiation

The influence of various electroculture treatments on the days to flower initiation in chilies. The analysis of variance (Appendix 6) revealed a significant ($P<0.05$) effect of the electroculture treatments on the time taken for flower initiation. Among the treatments, T_3 = Silver (Two, 2ft wire pot^{-1}) exhibited the longest period for flower initiation, averaging 73.32 days. It was closely followed by T_2 = Copper (Two, 2ft wire pot^{-1}), which also took 71.22 days, and T_4 = Iron (Two, 2ft wire pot^{-1}), with a flower initiation time of 70.31 days. The T_1 = control, which had the shortest time to flower initiation at 60.75 days. The results for the days to flower initiation in chilies under different electroculture treatments show non-significant differences between the treatments, as the p-value is 0.1776, which is greater than the commonly used threshold of 0.05.



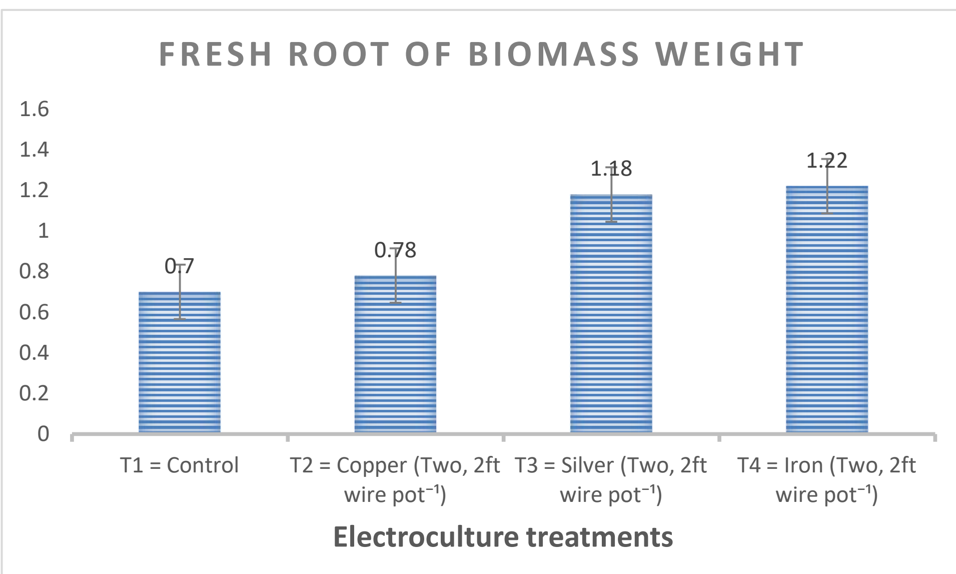
Number of flowers plant^{-1}

The results regarding the number of flowers plant^{-1} in chilies under different electroculture treatments, the T_3 = Silver (Two, 2ft wire pot^{-1}) exhibited the highest mean with 10.75 flowers, followed by T_2 = copper (Two, 2ft wire pot^{-1}) with 8.75 flowers plant^{-1}, while T_4 = iron (Two, 2ft wire pot^{-1}) had a 7.25 flowers plant^{-1}. The T_1 = control group, which received no electroculture treatment, had the least number of flowers with a mean of 6.50. These results indicate that the T_3 = Silver (Two, 2ft wire pot^{-1}) was the most effective, leading to the highest flower production in chilies. The T_2 = copper (Two, 2ft wire pot^{-1}) treatment showed a statistically significant increase in the number of flowers plant^{-1} compared to the T_1 = control and other treatments, with a p-value of 0.0052. In contrast, while T_2 = copper (Two, 2ft wire pot^{-1}), T_3 = silver (Two, 2ft wire pot^{-1}) and T_4 = iron (Two, 2ft wire pot^{-1}) had higher flower counts than the T_1 = control, their differences were not significant when compared using the LSD value of 5.0739.



Fresh biomass of root

The fresh weight of root biomass (g) of chili plants subjected to various electroculture treatments. Among the different treatments, the T_3 = Silver (Two, 2ft wire pot^{-1}) produced the highest mean fresh weight of root biomass, with a value of 1.18 g. The T_4 = iron (Two, 2ft wire pot^{-1}) also resulted in a notable increase in fresh weight of root biomass, with a mean of 1.22 g. In contrast, the T_1 = control group showed a mean biomass of 0.70 g. The T_2 = copper (Two, 2ft wire pot^{-1}) exhibited a mean fresh weight of root biomass of 0.78 g. The T_4 = Iron (Two, 2ft wire pot^{-1}) demonstrated the lowest mean fresh weight of root biomass at 1.22 g. The results for the fresh weight of root biomass (g) of as influenced by different electroculture treatments show non-significant differences, as the p-value is 0.2218. Overall, the data suggests that electroculture treatments, including magnet, did not have a statistically significant effect on the fresh weight of root biomass of chilies.



DISCUSSION

Electroculture, a method involving the application of electric fields to enhance plant growth, has gained attention for its potential to improve seed germination and overall plant development. This technique has been explored in various crops, with promising results in stimulating growth and increasing yield by influencing physiological processes like water uptake, nutrient absorption, and metabolic activities. *Capsicumannuum* L. is a widely cultivated crop known for its economic value and nutritional benefits, yet its growth can be affected by environmental and soil conditions. By subjecting chili seeds to controlled electric fields, electroculture might offer a novel approach to optimize germination rates and promote healthier plant growth. This study aims to investigate the effects of electroculture on the germination and early growth stages of chili peppers, with a focus on determining the optimal electrical parameters that may improve seedling vigor, root development, and overall plant health. The highest seed germination percentage (75.00%) was observed in the T_3 = silver-treated plants, followed by T_4 = iron (Two, 2ft wire pot^{-1}), which achieved a germination percentage of 70.00%. The T_2 = copper (Two, 2ft wire pot^{-1}) ranked third with a germination of 67.50%. Finally, the control exhibited the lowest germination percentage at 60.00%. These findings are congruent with earlier studies suggesting that metal-based and magnetic treatments can significantly influence seed germination rates. For instance, Vashisth and Mohan et al. (2023) reported that exposure of sunflower seeds to static magnetic fields improved germination percentages, suggesting enhanced metabolic activation. Similarly, Bhat et al. (2019) observed increased germination in chickpea under magneto priming, which was attributed to stimulated enzymatic activity and early water imbibition. While silver showed the highest germination percentage in the current study, this may be due to its antimicrobial properties, which reduce microbial load on seed surfaces, thereby improving seed viability (Chopra et al., 2020). T_5 = Iron and T_3 = copper also improved germination compared to the control, aligning with findings from Da Costa et al. (2017), who noted that micronutrient availability, especially iron, can influence enzymatic processes essential for seed activation. However, the magnet-treated group achieved a balance between high germination and subsequent vigorous plant growth, implying that while silver boosts germination, it may not always support robust vegetative development. Days to seed germination were lowest in the control group (6.22 days), indicating faster metabolic activation, while other treatments ranged from 8.22 to 7.25 days. Magnetically treated seeds generally absorb water more quickly, accelerating enzymatic activation and breaking dormancy more efficiently (Florez et al., 2019). This supports the current finding that magnetic treatment hastens the germination process more effectively than metallic treatments. The difference, albeit numerically small, can have agronomic significance, particularly in achieving uniform crop stands. In terms of vegetative parameters. This was significantly greater T_3 = silver (29.16 leaves cm height), T_4 = iron (26.24 leaves cm height), T_2 = copper (28.58 leaves cm height), and the control (22.99 leaves cm height). This trend suggests a direct positive impact of magnetism on cell division and elongation, as also observed by Maheshwari and Grewal (2021), who found significant improvements in shoot length and leaf area in mung bean due to magnetic field exposure. The role of magnetic fields in stimulating ATP production and enhancing photosynthesis has been well-documented (Carbonell et al., 2000). These mechanisms could explain the enhanced leaf production and plant height observed. On the other hand, silver and copper, though improving growth compared to control, may have limited photosynthetic enhancement due to possible phytotoxicity at higher exposure levels (Rico et al., 2016). The reduced plant height and leaf number in the copper treatment in particular may be attributed to copper-induced oxidative stress (Yruela, 2015). Among the four treatments tested, the T_3 = Silver (Two, 2ft wire pot^{-1}) recorded the highest plant height of 30.83 cm. This was followed by plants treated with T_2 = copper (Two, 2ft wire pot^{-1}), which achieved height of 25.32 cm. The T_4 = Iron (Two, 2ft wire pot^{-1}) resulted in a moderate improvement, with plants reaching an average height of 26.32 cm, the control group, which did not receive any electroculture treatment, recorded the lowest height of 22.49 cm. The electroculture treatments of the number of branches. Among the treatments, the T_3 = Silver (Two, 2ft wire pot^{-1}) resulted in the highest branch count at 8.64. This was closely followed by T_2 = copper (Two, 2ft wire pot^{-1}) with an average of 6.55 branches, and T_4 = iron, which produced 6.23 branches. The control group showed 4.47 branches. Branching is often regulated by hormonal signaling, particularly auxins and cytokinin's. It has been hypothesized that magnetic fields can alter hormone signaling pathways, thereby enhancing branching (De Souza et al., 2018). In contrast, copper's relatively low performance in this aspect may again stem from toxicity at the cellular level that restricts auxin transport and cellular proliferation (Marschner, 2017). Although earlier flowering might seem beneficial, it may also indicate stress-induced flowering in control plants due to suboptimal growth conditions. Earlier studies, such as those by Rao et al. (2016), noted that stress conditions often prompt early flowering as a survival mechanism. On the contrary, delayed flowering in treated plants could suggest more robust vegetative growth, allowing greater resource accumulation before the transition to the reproductive phase. This supports the idea that magnetic fields promote reproductive success by enhancing nutrient uptake and assimilate translocation (Martínez et al., 2021). Additionally, improved branch architecture and leaf production under magnetic treatment would support higher photosynthate availability, feeding into reproductive growth. Silver and iron also promoted flowering, albeit less effectively than magnets, possibly due to their partial enhancement of vegetative structures. Interestingly, copper, despite reduced vegetative growth, maintained moderate flowering, indicating a possible stress-induced compensatory mechanism where limited vegetative success prompts higher reproductive output (Gill & Tuteja, 2020). However, the flower number remained lower than magnet and silver treatments, suggesting that suboptimal copper levels still restricted overall performance. effect of the electroculture treatments on the time taken for flower initiation. Among the treatments, T_3 = Silver (Two, 2ft wire pot^{-1}) exhibited the longest period for flower initiation, averaging 73.32 days. It was closely followed by T_2 = Copper (Two, 2ft wire pot^{-1}), which also took 71.22 days, and T_4 = Iron (Two, 2ft wire pot^{-1}), with a flower initiation time of 70.31 days. The T_1 = control, which had the shortest time to flower initiation at 60.75 days. the highest mean with 10.75 flowers, followed by T_2 = copper (Two, 2ft wire pot^{-1}) with 8.75 flowers plant^{-1}, while T_4 = iron (Two, 2ft wire pot^{-1}) had a 7.25 flowers plant^{-1}. The T_1 = control group, which received no electroculture treatment, had the least number of flowers with a mean of 6.50. These results indicate that the T_3 = Silver (Two, 2ft wire pot^{-1}) was the most effective, leading to the highest flower production in chilies. The T_2 = copper (Two, 2ft wire pot^{-1}) treatment showed a statistically significant increase in the number of flowers plant^{-1} compared to the T_1 = control and other treatments, with a p-value of 0.0052. Among the different treatments, the T_3 = Silver (Two, 2ft wire pot^{-1}) produced the highest mean fresh weight of root biomass, with a value of 1.18 g. The T_4 = iron (Two, 2ft wire pot^{-1}) also resulted in a notable increase in fresh weight of root biomass, with a mean of 1.22 g. In contrast, the T_1 = control group showed a mean biomass of 0.70 g. The T_2 = copper (Two, 2ft wire pot^{-1}) exhibited a mean fresh weight of root biomass of 0.78 g. The T_4 = Iron (Two, 2ft wire pot^{-1}) demonstrated the lowest mean fresh weight of root biomass at 1.22 g. These results align with findings by Radhakrishnan and Kumari (2019), who noted increased root development under magnetic exposure due to enhanced water uptake and enzyme activation. Improved root systems contribute not only to better nutrient uptake but also to improved anchorage and stress resistance. Although silver resulted in high germination and moderate shoot growth, its relatively lower root biomass may reflect surface-level enhancements without deeper root system establishment. Copper's poor root development could again be tied to metal-induced toxicity, which hampers cell division and elongation at the root apical meristem (Yruela, 2015). The comprehensive data suggest that magnet treatment offers a balanced enhancement across germination, vegetative growth, reproductive traits, and root development in chili. These findings are corroborated by prior works on magneto-priming and electromagnetic stimulation in various crops, which collectively highlight improvements in plant vigor, yield, and physiological performance (Vashisth & Nagarajan, 2020). T_4 = silver showed high germination rates but lower vegetative and root development, possibly due to superficial enhancement rather than systemic stimulation. Iron performed moderately well across most traits, reinforcing its essential role in chlorophyll synthesis and enzymatic function (Marschner, 2017). Copper lagged in almost all metrics, which may be attributed to its narrow optimal concentration window essential in trace amounts but toxic in excess (Rico et al., 2016).

CONCLUSIONS

From the present study it is concluded that various magnetic treatments had significant effects on the germination, vegetative growth, flowering, and root biomass of chili plants. Among all treatments, T_4 = Iron (Two, 2ft wire pot^{-1}) and T_3 = Silver (Two, 2ft wire pot^{-1}) treatments showed superior performance in enhancing seed germination, while T_2 = Copper (Two, 2ft wire pot^{-1}) treatment excelled in promoting vegetative growth and flower production.

REFERENCES

Akram, M., Hussain, S., Hamid, A., Majeed, S., Chaudary, S. A., Shah, Z. A., & Akhter, N. (2017). Interactive effect of phosphorus and potassium on growth, yield, quality and seed production of chili (Capsicum annuum L.). *Journal of Horticulture*, *4*(1), 4-8.

Arain, S. M., & Sial, M. A. (2022). Association analysis of fruit yield and other related attributes in four chilli (Capsicum annum L.) genotypes grown in Sindh Province, Pakistan. *Pak. J. Bot*, *54*(3), 817-822.

Ali, U., Ashfaq, M., Shafiq, M., Ali, M., Shaheen, S., Mubashar, B., ... & Aqeel, M. (2020). Effects of organic and chemical fertilizers on growth and yield attributes of chili (*CAPSICUM ANNUUM* L.). *Int J Biol Biotech*, *17*(4), 731-8.

Ahmad, F., Kusumiyati, K., Soleh, M. A., Khan, M. R., & Sundari, R. S. (2024). Chili crop innovation: Exploring enclosed growing designs for varied varieties—A review. *Agrosystems, Geosciences & Environment*, *7*(2), e20491.

Bhat, M. A., Dhoble, M. V., & Gaikwad, A. P. (2019). Influence of magnetic field on seed germination and early growth parameters of chickpea (*Cicer arietinum* L.). *International Journal of Scientific and Engineering Research*, *4*(12), 222–229.

Chopra, R., Kanwar, A., & Rani, S. (2020). Antimicrobial efficacy of silver nanoparticles synthesized by different methods: A comparative study. *Materials Today: Proceedings, 26*, 2997–3002.

Carbonell, M. V., Martínez, E., & Amaya, J. M. (2000). Stimulation of germination in rice (*Oryza sativa* L.) by a static magnetic field. *Electromagnetic Biology and Medicine*, *19*(1), 121–128.

Da Costa, C. H. M., de Almeida, H. J., & de Souza, H. A. (2017). Iron in plant nutrition: A review. *Journal of Plant Nutrition, 38*(9), 1360–1376.

De Souza, A., García, D., Sueiro, L., Licea, L., & Porras, E. (2018). Pre-sowing magnetic treatment of tomato seeds: Effects on the growth and yield of plants cultivated under field conditions. *Electromagnetic Biology and Medicine*, *25*(1), 33–42.

Florez, M., Carbonell, M. V., & Martínez, E. (2019). Exposure of maize seeds to stationary magnetic fields: Effects on germination and early growth. *Environmental and Experimental Botany*, *59*(1), 68–75.

Gill, S. S., & Tuteja, N. (2020). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Plant Physiology and Biochemistry*, *48*(12), 909–930.

Jan, J. A., Nabi, G., Khan, M., Ahmad, S., Shah, P. S., & Hussain, S. (2020). Foliar application of humic acid improves growth and yield of chilli (Capsicum annum L.) varieties. *Pakistan Journal of Agricultural Research*, *33*(3), 461.

Kakar, K., Wahocho, N. A., Jamro, G. M., & Anwar, M. (2024). Assessing the Effect of Potassium nutrition on the Chilies (Capsicum annuum L.) Nursery Growth and Production. *Journal of Applied Research in Plant Sciences*, *5*(02), 183-189.

Khan, M. T. I., Qamar Ali, Q. A., Muhammad Ashfaq, M. A., & Muhammad Waseem, M. W. (2017). Economic analysis of open field chilli (Capsicum annuum L.) production in Punjab, Pakistan.

Lastochkina, O., Aliniaeifard, S., SeifiKalhor, M., Bosacchi, M., Maslennikova, D., &Lubyanova, A. (2022). Novel approaches for sustainable horticultural crop production: advances and prospects. *Horticulturae*, *8*(10), 910.

Mohan, S. V., & Yeruva, D. K. (2023). In situ self-induced electrical stimulation to plants: modulates morphogenesis, photosynthesis and gene expression in Vigna radiata and Cicer arietinum. *Bioelectrochemistry*, *154*, 108550.

Maheshwari, B. L., & Grewal, H. S. (2021). Magnetic treatment of irrigation water: Its effects on vegetable crop yield and water productivity. *Agricultural Water Management*, *96*(8), 1229–1236.

Marschner, P. (2017). *Marschner's mineral nutrition of higher plants* (3rd Ed.). Academic Press. London, 135-178.

Martínez, E., Carbonell, M. V., &Flórez, M. (2021). Magnetic biostimulation of initial growth stages of wheat (*Triticum aestivum* L.). *Electromagnetic Biology and Medicine*, *28*(3), 283–294.

Nawaz, K., Shahid, A. A., Subhani, M. N., Anwar, W., & Aslam, M. (2016). First report of Pythium spinosum causing root rot of chili (Capsicum annuum) in Pakistan. *Plant disease*, *100*(2), 526-526.

Rico, C. M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J. R., &Gardea-Torresdey, J. L. (2016). Interaction of nanoparticles with edible plants and their possible implications in the food chain. *Journal of Agricultural and Food Chemistry*, *59*(8), 3485–3498.

Rao, N. K., Shahid, M., & Al-Masoudi, R. (2016). Drought-induced stress on early flowering and yield in rice. *Plant Growth Regulation*, *65*(1), 47–57.

Radhakrishnan, R., & Kumari, B. D. R. (2019). Influence of pulsed magnetic field on soybean seed germination and seedling growth. *Scientific Research and Essays*, *8*(22), 1042–1049.

Umarov, S., Bayzakov, T. M., Yusupov, S. B. Y., Abduraxmonov, A. A., Kholmirzaev, I., &Qurbonazarov, S. (2024). In greenhouses vegetable crops of seedlings cultivation electrotechnology effectiveness of assessment (sweet pepper plant on the example). *SCIENTIFIC AND TECHNICAL JOURNAL "SUSTAINABLE AGRICULTURE"*, *22*(2), 115-117.

Vashisth, A., & Nagarajan, S. (2020). Effect on germination and early growth characteristics in sunflower (*Helianthus annuus* L.) seeds exposed to static magnetic field. *Journal of Plant Physiology*, *167*(2), 149–156.

Wahocho, N. A., Zeshan Ahmed, S., Jogi, Q., Talpur, K. H., & Leghari, S. J. (2016). Growth and productivity of chilli (capsicum annuum l.) Under various nitrogen levels. *Science International*, *28*(2).

Yruela, I. (2015). Copper in plants. *Brazilian Journal of Plant Physiology*, *17*(1), 145–156.