ISSN 2709–3662 (Print)
ISSN 2709–3670 (Online)
https://doi.org/10.52587/JAF060101
Journal of Agriculture and Food
2025, Volume 6, No.1, pp. 1-19

A Case Study in Quinoa (*Chenopodium quinoa* Willd): Combine use of Sunflower Leaf Extract with Nitrogen improve Quinoa Plant Architecture

Nabeel Ahmad Ikram[1], Mudassar Ayub[1], Shahid Iqbal[2], Abid Hussain[3], Khuram Mubeen[1], Abdul Ghaffar[1], Mudassir Aziz[1], Muhammad Asif Shehzad[2], Waseem Hassan[4], Abdul Khaliq[5], M. Naazir Khan Niazi[6], M. Rohan Naveed[7]

Abstract

Quinoa (*Chenopodium quinoa* Willd) is a climate resilient crop, but grain yield is a complex trait highly effect by excessive vegetative growth. To overcome problem, study was carried out to evaluate the effect of foliar application of sunflower leaf extract as a plant growth retardant of quinoa observe with different nitrogen (N_2) levels. Experiment was carried out in randomize complete block design. Main experimental unit included different levels of nitrogen (N_1= 50 kg ha^{-1}, N_2= 75 kg ha^{-1} and N_3=100 kg ha^{-1}), and sub plots included control (without extract spray and water spray) and sunflower water extract foliar applications of different four concentrations (3%, 6%, 9%, 12%). Foliar application of sunflower leaf water extract and nitrogen application significantly enhanced yield and harvest index of quinoa crop. Maximum seed yield and harvest index was recorded by foliar application of sunflower water extract at 9% under higher dose of nitrogen 100 kg ha^{-1}.There was no harmful impact seen of sunflower water extract on seed quality attributes especially under higher nitrogen regimes. It is therefore concluded that foliar application of sunflower water extract at 9% under higher nitrogen regime improved physiological growth, yield, harvest index and seed quality attributes of quinoa.

Keywords: Growth retardant, Allelopathy, Physiological growth

[1]Department of Agronomy, MNS University of Agriculture Multan, Punjab Pakistan; [2]Institute of Plant Breeding and Biotechnology, MNS University of Agriculture Multan, Punjab Pakistan; [3]Manager Industrial Linkages and Technology Transfer, MNS University of Agriculture Multan, Punjab Pakistan; [4]Department of Soil and Environmental Sciences, MNS University of Agriculture Multan, Punjab Pakistan; 5Soil and Water Testing Laboratory, Kotla Ahmad Road, Rajanpur, Punjab Pakistan; [6]Technical Education and Vocational Training Authority, Lahore, Punjab Pakistan;[7]NFC Institute of Engineering and Technology Multan, Punjab Pakistan; [1]Corresponding Author: khurram.mubeen@mnsuam.edu.pk

Article History: 8th January, 2025 **Received:** 24th January, 2025; **Revised:** 29th January, 2025
Accepted:

Introduction

Changing climate is severely affecting the growth and yield of crops and threatening the global food security. Rise in global warming temperature is not suitable for plant production as it decreases the soil potential and degrades fertility (Gonzalez et al., 2015). Quinoa is the finest instance of unutilized crop that belongs to Andean region. It is seeking attention due to its ability to survive under stressful conditions like salinity, drought and frost (Gomez-Pando et al., 2010). The low agricultural productivity is due to these abiotic stresses causing food losses.

Quinoa is a C3 facultative halophytic plant and belongs to Amaranthaceae family. It is self-pollinated annual herbaceous plant. Its seed has two cotyledons (Jacobsen et al., 2003). Quinoa has superior nutrition profile than rice, wheat and maize. Protein contents of its seeds vary from 14% to 16.5% and fat contents vary from 5.2% to 9.7% (Valcárcel-Yamani and Lannes, 2012). As it is gluten free so it is safely used by celiac patients (Berti et al., 2004). Leaves and stem of quinoa can be used as fodder and grains can be used in making breads like multigrain breads, biscuits and beer in food industry. The nutrient profile of quinoa leaves is comparable to mustard and spinach which is used as salad (Valcarcel-Yamani and Lannes, 2012). Hence Quinoa has many nutritional benefits and uses.

Nitrogen application improve the yield, harvest index, protein contents and amino acid profile. Application of nitrogen improve the yield of pseudo cereal (Iqbal et al., 2014). Quinoa and amaranth showed significant improvement in protein contents of seed, plant height, grain yield per plant, harvest index, kernel weight, amino acid profile by the application of nitrogen (Thanapornpoonpong, 2008). Issue in quinoa production in Pakistan is that during high temperature it gains more height. Excessive vegetative growth further aggravated with the application of nitrogen. Due to this reason yield and harvest index is less (Basra et al., 2014). Although, quinoa has been successfully introduced in Pakistan, but it grows more vegetatively when day length increases. But some scientists manipulated vegetative growth by use of growth retardant paclobutrazol but this is synthetic chemical and residual effect of its spray may persist in food crop Quinoa (Desta and Amare, 2021). Some organic extracts like sunflower water extract can be utilized as a growth retardant.

Furthermore, quinoa also responds to Nitrogen supplementation, raise in quantity of application of nitrogen from 40 to 160 kg N ha^{-1} grain yield also increase significantly (Kaul et al., 2005). But increase in nitrogen also causes lodging due to extra plant height, therefore it is suggested to control vegetative growth and increase harvest index, for this purpose allelopathy can be utilized. Allelopathy has been suggested as a possible weed management tool in agro-ecosystems (Rehman et al., 2018). Sunflower allelochemicals have potential to weed control (Anjum and Bajwa, 2005). Sunflower extract prevented germination, shoot and root length of wheat and weeds (Shahid et al., 2006). Thus, sunflower may also retard extra vegetative growth and increase harvest index. Hence the present study was undertaken to see the effects of priming sunflower water extracts and nitrogen levels on growth, physiology and yield of quinoa.

Materials and Methods

Sunflower aqueous extract preparation

The plant material was dipped in distilled water in a 1: 20 ratio and stored for 24 hours. A muslin cloth was used to filter an aqueous extract of the plant. The filtrate was classified as a 100 percent concentration stock solution. Other concentrates of 3, 6, and 9 percent were produced from this stock solution by diluting it with distilled water, whereas the control contained just water.

Experimental site

Experiment was conducted at Research Farm of MNS-University of Agriculture, Multan. Experiment was carried out in RCB design having split plot arrangement with 4 replications. Quinoa variety UAF-Q7 was sown on first week of November 2020.

Crop husbandry

Seed of quinoa genotype, UAF-Q7 was obtained from University of Agriculture, Faisalabad. The seed bed was prepared by tractor driven cultivator 2-3 times followed by planking and 2.5 ft apart ridges were made. The crop was sown on one side of the ridges through dibbling using seed rate of 10 kg ha^{-1}. Crop was harvested on 27th March 2021**.** Total 2 irrigations were applied. Urea fertilizer (46% N) was the source for addition of selected amount of nitrogen. Foliar application of sunflower water extract was done at Four different concentrations while one treatment was assigned as control or water spray. Before foliar application spraying machine was washed properly then sunflower water extract was measured with the help of graduated cylinder. First foliar application of sunflower water extract was done at bud initiation stage. Second foliar spray was done at fortnight interval.

Apparatus Used

Plant height and main panicle length were measured using centimeter scale while the main stem diameter was measured by using digital vernier caliper. Chlorophyll content was measured using SPAD-502 at physiological maturity stage. Gas exchange parameters were measured using CIRAS-3.

Results and Discussions

Seed quality parameters

Seed quality in terms of emergence percentage improved significantly as a result of application foliar application of sunflower water extract. Maximum seed emergence percentage (86 %) was given by the seeds produced under lower nitrogen regimes (50 kg ha^{-1}) and foliar application of sunflower water extract at12% concentration. While minimum emergence percentage (71 %) was recorded where nitrogen was applied @ 50 kg ha^{-1} and 3% concentration of sunflower water extract application (Fig. 1).

Seed vigor was assessed by measuring electrical conductivity of seed leachates. EC of seed leachates was more for the seeds produced under high nitrogen regimes along where no foliar spray of Sunflower water extract. Lowest values of seed leachate's electrical conductivity were recorded in the treatment where nitrogen was applied @ 100 kg ha^{-1} and sunflower water extract was applied at 3% concentration (Fig. 2).

Growth parameters

Application of nitrogen significantly increased plant height of quinoa. Foliar spray of sunflower water extract resulted in decreased plant height. Individual effect of nitrogen doses and sunflower water extract foliar spray was significant. Maximum plant

height (125 cm) was recorded for the plants where nitrogen was applied @100 kg ha^{-1} and no sunflower water extract was applied (Fig. 3)

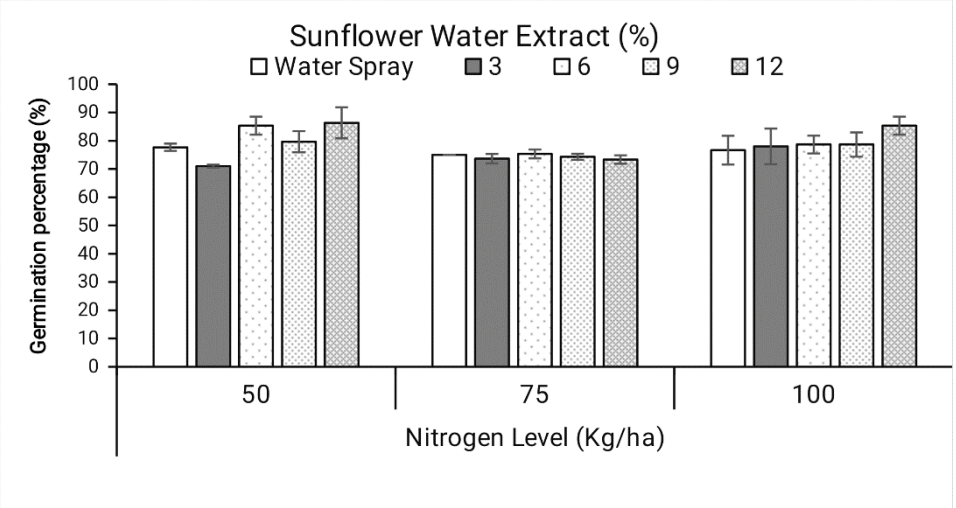

Figure.1. Influence of nitrogen level and foliar application of sunflower water extract on emergence percentage of quinoa

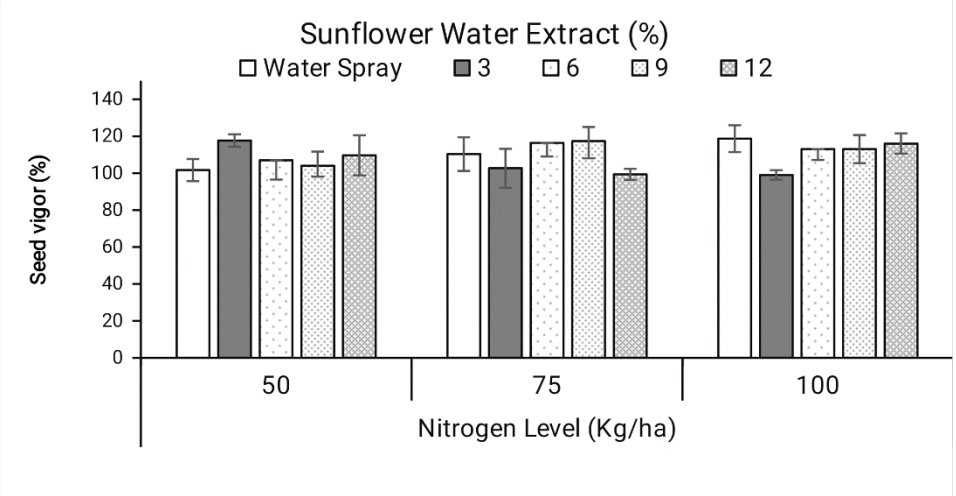

Figure 2. Influence of nitrogen level and foliar application of sunflower water extract on seed vigor of quinoa

Minimum plant height (68 cm) was recorded where nitrogen was applied @50 kg ha^{-1} and foliar spray of sunflower water extract was applied at 12% concentration (Fig. 1). Plant height was positively linked with increasing doses of nitrogen whereas negatively linked with increasing concentration of sunflower water extract.

Higher dose of nitrogen application increased stem diameter of quinoa. Maximum stem diameter (16.3 mm) was observed where nitrogen was applied @75 kg $ha^{-1}$and foliar spray of sunflower water extract was applied at 9% concentration (Fig. 4). Minimum stem diameter (10.6 mm) was measured from the plots where nitrogen was applied @100 kg ha^{-1} and sunflower water extract was applied at 3% concentration. Interactive effect of Sunflower water extract foliar spray and nitrogen application was significant effect on stem diameter of quinoa. Application of nitrogen improved the panicle length of quinoa. Individual effect of nitrogen doses and sunflower water extract foliar spray was significant. Maximum panicle length (32 cm) was observed where nitrogen was applied @ 100 kg ha^{-1} and sunflower water extract was applied at 6% concentration. Minimum main panicle length (19.3 cm) was measured from the plots where nitrogen was applied @ 50 kg ha^{-1} and water spray was applied (Fig. 5).

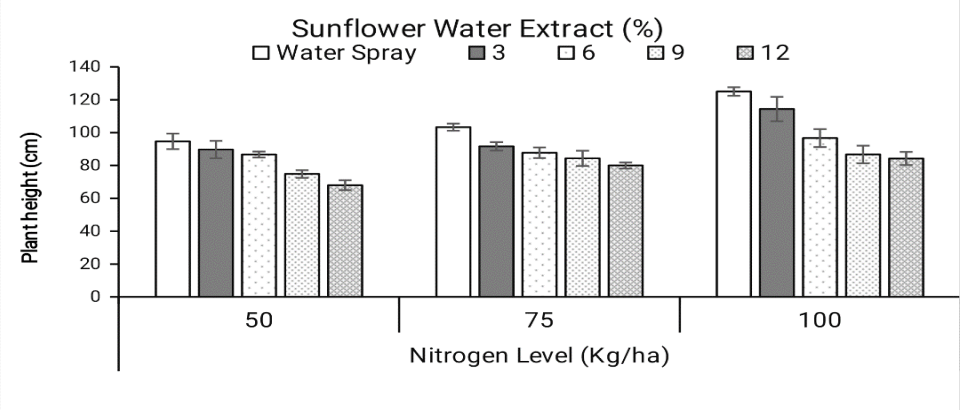

Figure 3. Influence of nitrogen level and foliar application of sunflower water extract on plant height of quinoa

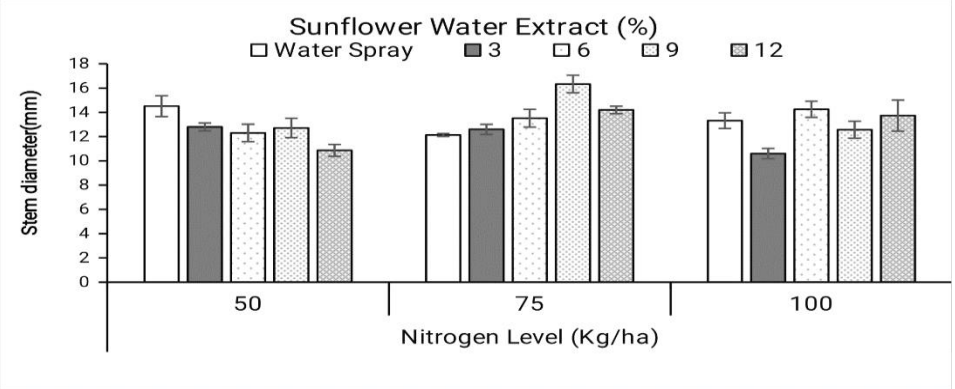

Figure 4. Influence of nitrogen level and foliar application of sunflower water extract on stem diameter of quinoa

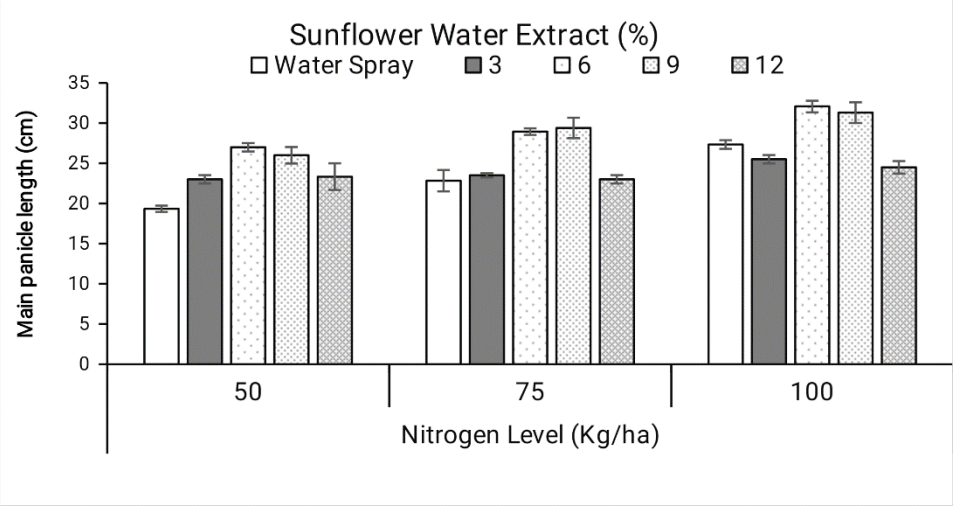

Figure 5. Influence of nitrogen level and foliar application of sunflower water extract on main panicle length of quinoa

Application of nitrogen improved the number of sub panicle of quinoa. Individual effect of nitrogen doses and sunflower water extract foliar spray was significant. Maximum number of sub panicle or inflorescence (33) was observed where nitrogen was applied @ 100 kg ha^{-1} and sunflower water extract was applied at 3% concentration. Number of sub panicle is positively linked with increasing doses of nitrogen. Minimum number of sub panicle (14) was recorded from the plots where nitrogen was applied @ 50 kg ha^{-1} and 12% concentration of sunflower water extract was applied (Fig. 6).

Nitrogen application enhanced panicle weight of quinoa crop. Interactive effect of sunflower water extract foliar spray and nitrogen application was non-significant effect on panicle weight of quinoa. Individual effect of sunflower water extract and nitrogen doses was significant. Maximum panicle weight (35 g) was observed in the treatment where nitrogen was applied @ 100 kg ha^{-1} and 6% concentration of sunflower water extract was applied. Minimum panicle weight (18.3 g) was recorded where nitrogen was applied @ 50 kg ha^{-1} and water spray was applied (Fig. 7). Panicle dry weight was absolutely connected with higher level of nitrogen whereas sunflower water extract application improved panicle weight up to a certain limit.

Interactive effect of sunflower water extract foliar spray and nitrogen application was non-significant effect on main panicle seed weight of quinoa. Individual effect of sunflower water extract and nitrogen doses was significant. Nitrogen application enhanced main panicle seed weight of quinoa crop. Maximum main panicle seed weight (24.6 g) was observed in the treatment where nitrogen was applied @ 100 kg ha^{-1} and 6% concentration of sunflower water extract was applied. Minimum main panicle seed weight (12.4 g) was recorded where nitrogen was applied @ 50 kg ha^{-1} and water spray was applied (Fig. 8). Main panicle seed weight was absolutely connected with higher level of nitrogen whereas sunflower water extract application improved main panicle seed weight up to a certain limit.

Physiological parameters

Photosynthesis rate

Interactive effect of sunflower water extract foliar spray and nitrogen application was significant effect on photosynthesis rate of quinoa. Individual effects of nitrogen doses and different concentrations of sunflower water extract was also significant. Maximum photosynthesis rate (15.1µ mol m^{-2} s^{-1}) was recorded where nitrogen was applied @ 100 kg ha^{-1} and sunflower water extract was applied at 3% concentration. Minimum photosynthesis rate (5 µ mol m^{-2} s^{-1}) was recorded where nitrogen was applied @ 100 kg ha^{-1} and 12% concentration of sunflower water extract application (Fig. 9). Increasing dose of nitrogen exhibit improved photosynthesis rate of quinoa whereas lower concentration of sunflower water extract also improved photosynthesis rate.

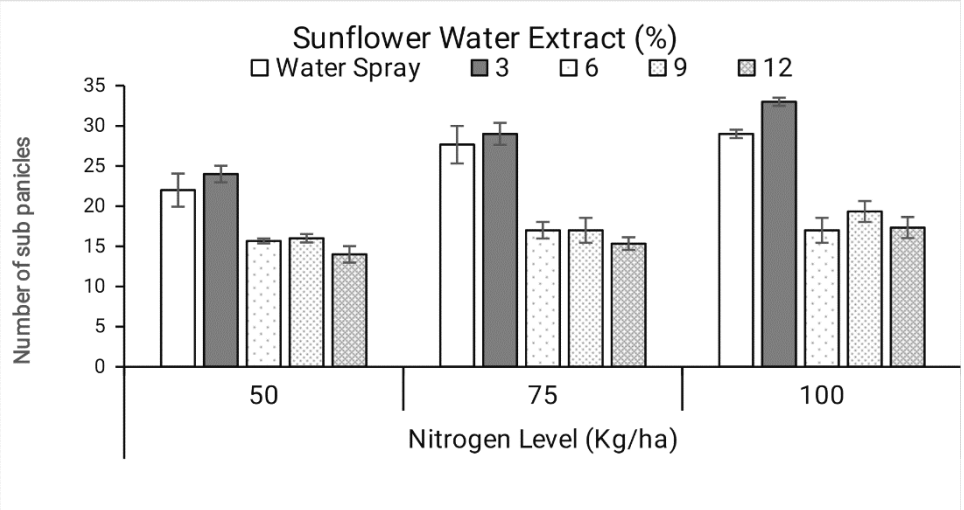

Figure 6. Influence of nitrogen level and foliar application of sunflower water extract on number of sub panicles of quinoa

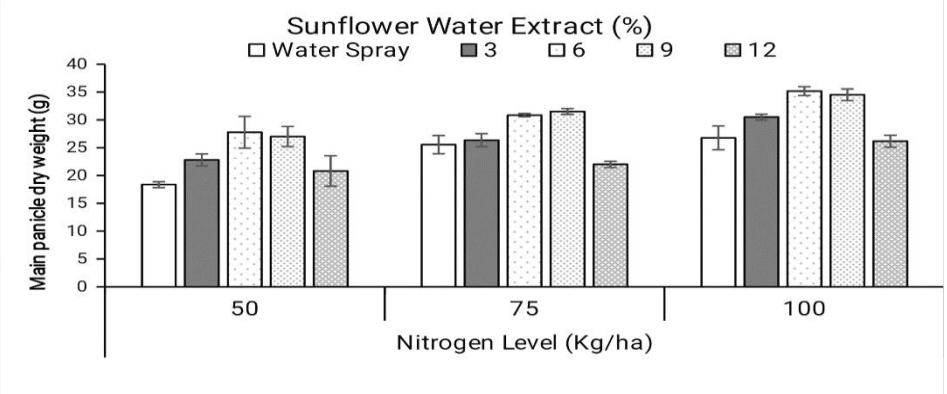

Figure 7. Influence of nitrogen level and foliar application of sunflower water extract on main panicle dry weight of quinoa

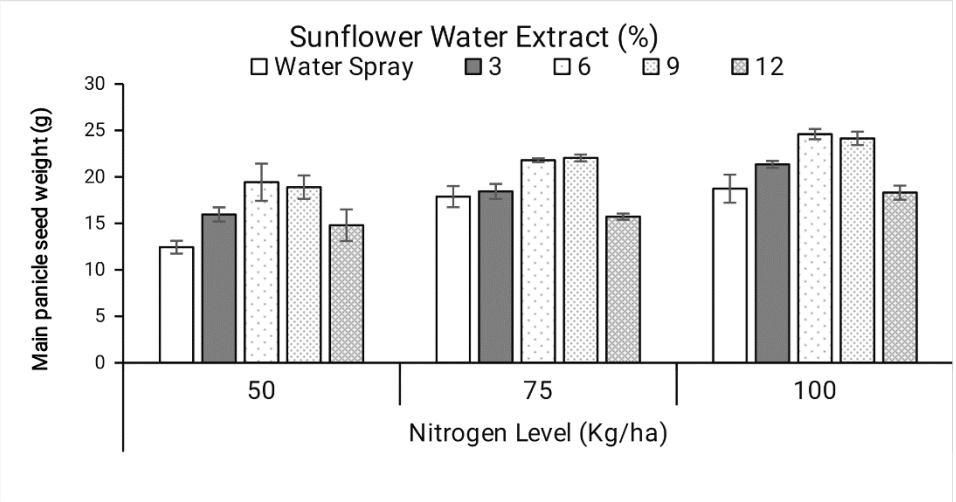

Figure 8. Influence of nitrogen level and foliar application of sunflower water extract on main panicle seed weight of quinoa

Transpiration rate

Interactive effect of sunflower water extract foliar spray and nitrogen application was non-significant effect on transpiration rate of quinoa. Individual effects of nitrogen doses and different concentrations of sunflower water extract was also non-significant. Transpiration rate was higher (6.1 m mole m^{-2} s^{-1}) in plants sprayed with sunflower water extract at 3% concentration and nitrogen was applied @ 75 kg ha^{-1}. Minimum transpiration rate (4.8 m mole m^{-2} s^{-1}) was recorded where nitrogen was applied @ 100 kg ha^{-1} and 3% concentration sunflower water extract was applied (Fig. 10).

Water use efficiency

Application of sunflower water extract significantly affected the water use efficiency of quinoa. For different nitrogen doses, highest water use efficiency was recorded where nitrogen was applied @100 kg ha^{-1}. Highest water use efficiency (6 kg m^{-3}) was recorded in the treatment where sunflower water extract was applied at 9% concentration and nitrogen was applied @ 100 kg ha^{-1}. Minimum water use efficiency (2.8 kg m^{-3}) was measured where sunflower water extract was applied at 12% concentration and nitrogen @ 50 kg ha^{-1} (Fig. 11).

Chlorophyll content

Nitrogen application increased the chlorophyll content of quinoa. Individual effect of sunflower water extract and nitrogen doses was significant. Maximum chlorophyll content (90.3) was measured where sunflower water extract was applied at 3% concentration and nitrogen @ 100 kg ha^{-1}. Minimum chlorophyll content (57) was recorded where nitrogen was applied @ 50 kg ha^{-1} and 12% concentration of sunflower water extract was applied (Fig. 12).

Yield parameters

1000-Seed Weight

Nitrogen application significantly increased the 1000-seed weight of quinoa. Maximum 1000-seed weight was found in the treatment where nitrogen was applied @ 75 kg ha^{-1} and sunflower water extract was applied 12% concentration. While where nitrogen was applied @ 50 kg ha^{-1} along with foliar spray of sunflower water extract at 3% concentration showed the minimum value of 1000-seed weight (Fig. 13).

Biological Yield

Nitrogen application improved the biological yield of quinoa. Highest biological yield (8450 kg ha^{-1}) was observed where nitrogen was applied @ 100 kg ha^{-1} and water spray was applied. Lowest plant dry biomass (5059 kg ha^{-1}) was noticed where nitrogen was applied @ 50 kg $ha^{-1}$and sunflower water extract was applied at 12% concentration (Fig. 14). Biological yield was positively linked to application of nitrogen fertilizer whereas negatively related to sunflower water extract application.

Grain Yield

Nitrogen application and foliar spray of sunflower water extract improved the grain yield of quinoa. Individual effects of nitrogen doses and different concentrations of sunflower water extract was significant. Highest seed yield (3877 kg ha^{-1}) was recorded from the experimental units where nitrogen was applied @ 100 kg $ha^{-1}$and sunflower water extract was applied at 9% concentration. While minimum seed yield (966 kg ha^{-1}) was observed in the treatment where nitrogen was applied @ 50 kg ha^{-1} and water spray was applied (Fig. 12). Increasing concentration of sunflower water extract beyond 9% negatively impacted the grain yield (Fig. 15).

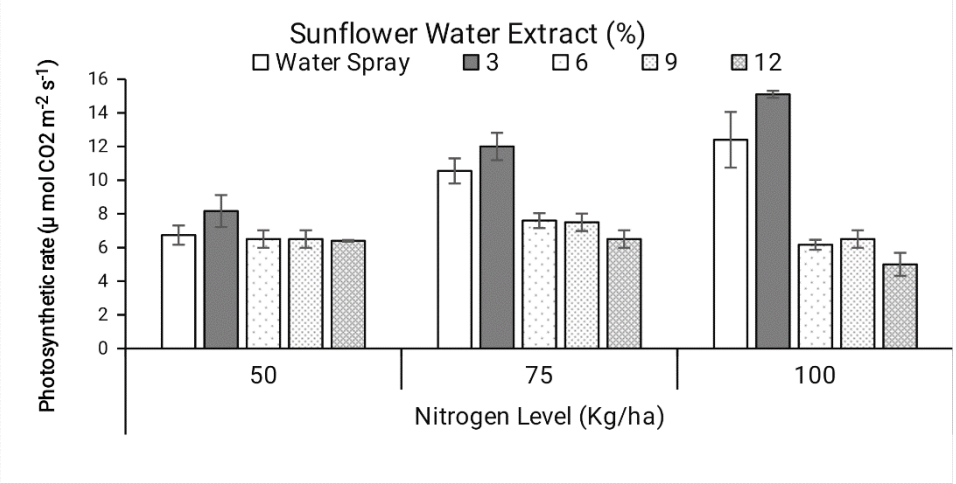

Figure 9. Influence of nitrogen level and foliar application of sunflower water extract on photosynthetic rate of quinoa

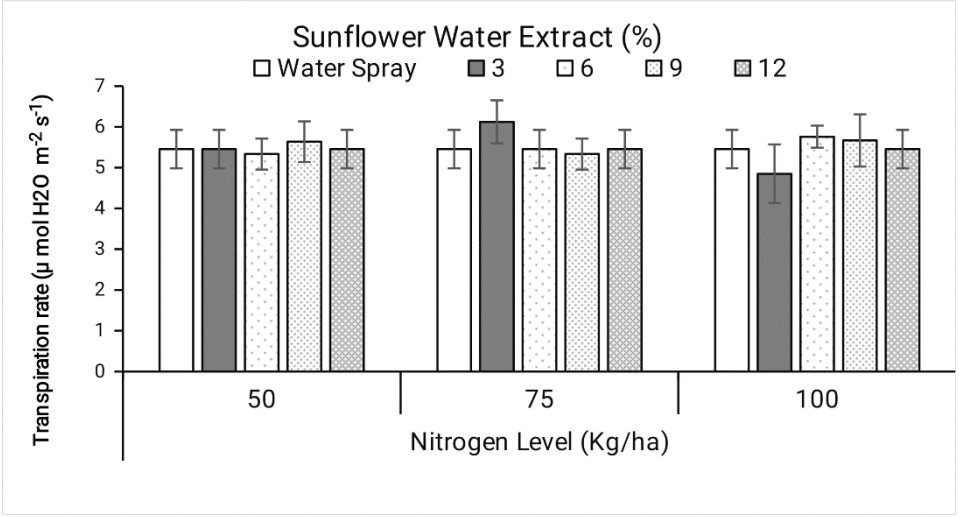

Figure 10. Influence of nitrogen level and foliar application of sunflower water extract on transpiration rate of quinoa

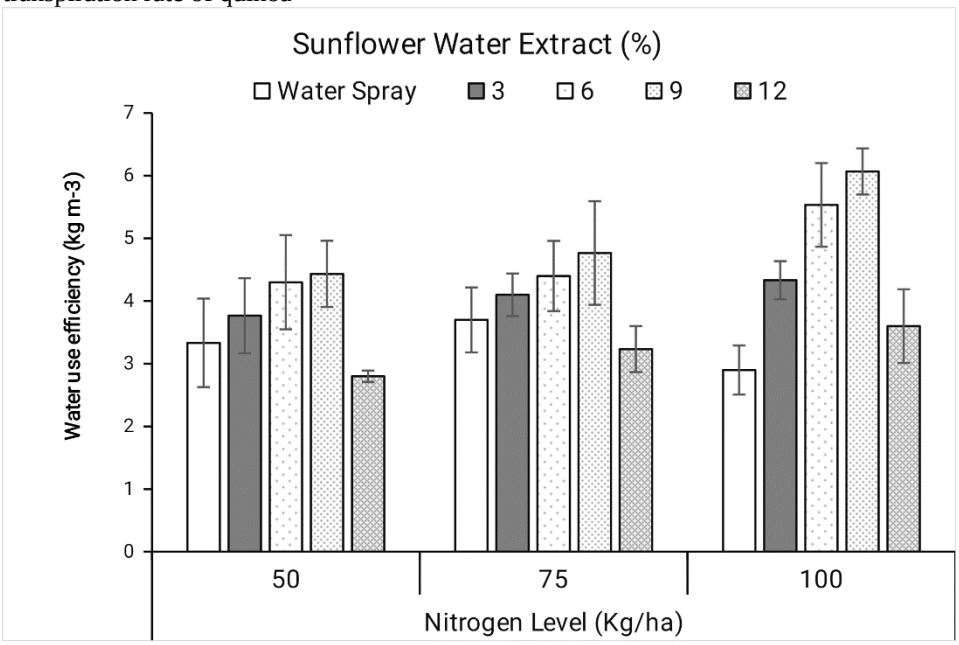

Figure 11. Influence of nitrogen level and foliar application of sunflower water extract on water use efficiency of quinoa

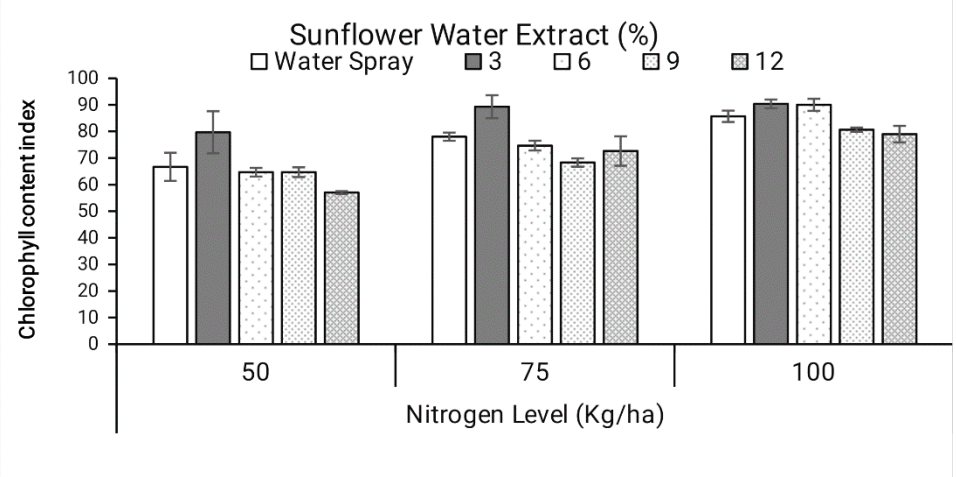

Figure 12. Influence of nitrogen level and foliar application of sunflower water extract on chlorophyll content of quinoa

Grain yield

Harvest Index

Individual effect of nitrogen doses and sunflower water extract foliar spray was significant. Highest values of harvest index (0.55) were recorded from the experimental units where nitrogen was applied @ 100 kg ha^{-1} and sunflower water extract was applied 9% concentration. Minimum harvest index (0.12) was observed where nitrogen was applied @ 50 kg ha^{-1} with water spray (Fig. 16).

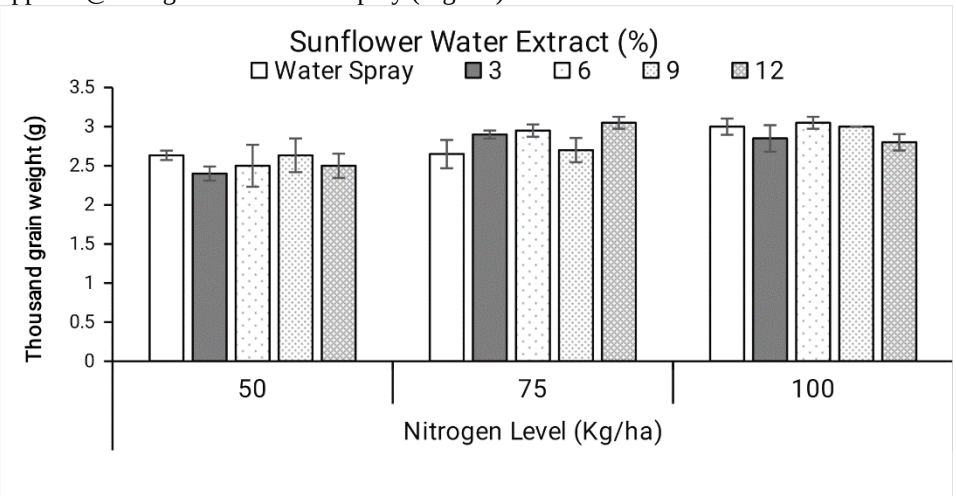

Figure 13. Influence of nitrogen level and foliar application of sunflower water extract on thousand grain weight of quinoa

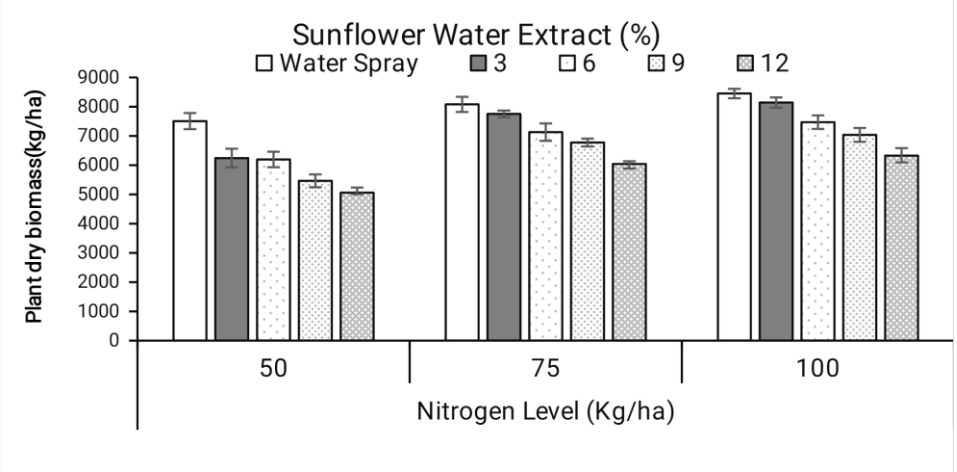

Figure 14. Influence of nitrogen level and foliar application of sunflower water extract on biological yield of quinoa

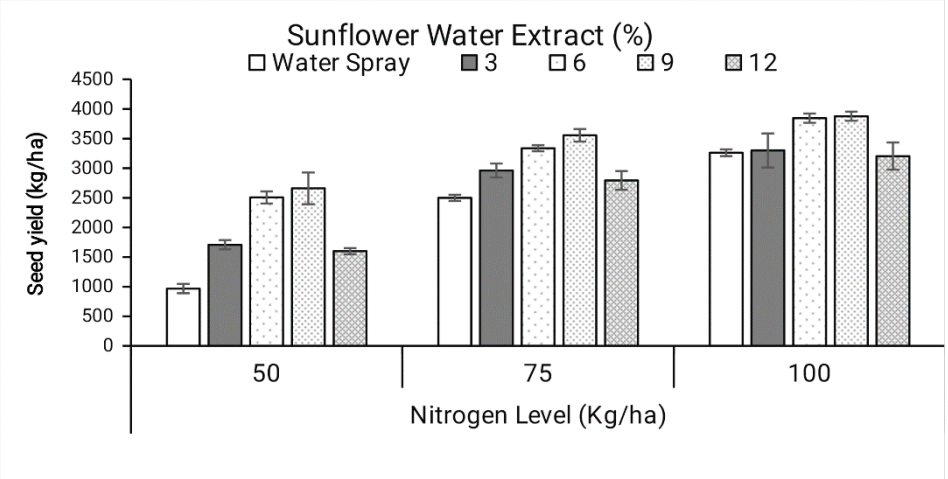

Figure 15. Influence of nitrogen level and foliar application of sunflower water extract on seed yield of quinoa

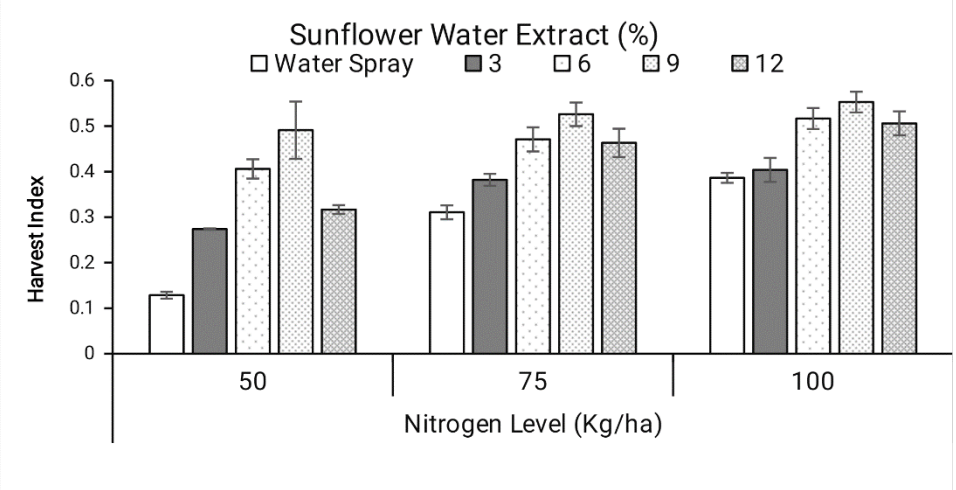

Figure 16. Influence of nitrogen level and foliar application of sunflower water extract on harvest index of quinoa

Discussion

Nitrogen application increased all growth related traits like plant height, stem diameter and biological yield. Increasing concentration of sunflower water extract reduced the plant height (Sadeghi et al., 2010). Sunflower water extract application suppresses the vegetative growth of the plant and promote to reproductive growth (Sadeghi et al., 2010), which resulted in early harvest maturity. In current study higher nitrogen doses increased plant height and plants where sunflower water extract was applied at higher concentration resulted in prominent reduction in plant height. Difference between treated and controlled plants was clear. Interactive effect of sunflower water extract foliar spray and nitrogen application was significant effect on photosynthesis rate of quinoa. Individual effects of nitrogen doses and different concentrations of sunflower water extract was also significant on chlorophyll content and photosynthesis rate of quinoa genotype UAF-Q7. Photosynthetic rate and chlorophyll content were higher where sunflower water extract was applied at lower concentration (3%).

Photosynthetic rate and yield have direct association at grain filling stage (Gonzalez et al., 2010). Photosynthetic rate also improved because plants exhibit more green color which in turn resulted in improved photosynthetic rate in higher dose of nitrogen treated plants as compared to non-treated plants (Amaliotis et al., 2004). Increased number of chloroplasts linked with high chlorophyll content which ultimately resulted in high photosynthetic rate. Because it is the main component in photosynthetic reaction that helps plant to capture sun light. Current study results show that combined application of sunflower water extract and high level of nitrogen improved seed yield of quinoa as compared to control. Nitrogen application and foliar spray of sunflower water extract increased the seed weight (Fig. 13). In this experimentation nitrogen fertilization especially higher dose of 100 kg ha^{-1} N and 6% concentration of sunflower water extract maximally improved main panicle length, main panicle dry weight and main panicle seed weight in quinoa, which ultimately results in increased seed yield of quinoa crop. Plant

treated with sunflower water extract showed improved grain yield in wheat (Cheema et al., 1997).

Increased grain yield ultimately resulted in higher values of harvest index. Significantly, increase in the panicle length was observed by nitrogen application (Muchow, 1988; Bhargava et al., 2006). The increase in seed yield by nitrogen treatments might be due to fact that N is a part of Rubisco (Fredeen et al., 1991). Current study results show that no negative effect of nitrogen and sunflower water extract application on seed quality. In present study seed emergence and vigor was positively influenced by nitrogen fertilization and foliar application of sunflower water extract. Seed emergence of quinoa crop improved up to some extent in treatment where nitrogen was applied @ 50 kg ha^{-1} and sunflower water extract was applied at 12% concentration. Seed vigor was higher for the seed harvested from the plots where higher nitrogen dose was applied. Sunflower water extract has also been used as priming agent to promote seed germination (Kamal and Bano, 2008).

Conclusion

Foliar application of sunflower water extract and nitrogen application significantly enhanced yield and harvest index of quinoa crop. Maximum seed yield and harvest index was recorded by foliar application of sunflower water extract at 9% under higher dose of nitrogen i.e.100 kg ha^{-1}. There was no harmful impact of sunflower water extract on seed quality attributes especially under higher nitrogen regimes. It is therefore concluded that foliar application of sunflower water extract at 9% under higher nitrogen regime improved physiological growth, yield, harvest index and seed quality attributes of quinoa.

COMPETING OF INTEREST

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgement: Not applicable.
Funding: Not applicable.

Ethical statement: This article does not contain any studies regarding human or Animal.
Code availability: Not applicable.
Consent to participate: All authors participated in this research study.
Consent for publication: All authors submitted consent to publish this research.
Data availability statement: The data presented in this study are available on request.

References

Abadin, H. (2007). Agency for Toxic Substances and Disease Registry. 2005. Toxicological Profile for Lead, Atlanta. US Department of Health and Human Services. *Public Health Service*, 43–59.

Adie, P., Afu, S., Olim, D., Beshel, S., & Ofem, V. (2022). Heavy Metals Concentration In Soils And Bioaccumulation In Earthworm (Lumbricus Terrestris) At Lemna Solid Wastes Dumpsite, Calabar, Cross River State. *Global Journal of Pure and Applied Sciences*, 28(2), 131–139.

Ahmad, S. A., Hussain, S., Aziz, H., & Riaz, M. (2022). Cadmium Investigations in Lahore Soil and Other Regions of Pakistan: Cadmium Concentration in Lahore, Pakistan. *Pakistan Journal of Scientific & Industrial Research Series A: Physical Sciences*, 65(1), 64–73.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M.-Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: *Ecological risks and human health implications. Toxics*, 9(3), 42.

Ali, A., Aasim, M., Çelik, K., Nadeem, M. A., & Baloch, F. S. (2024a). Frontiers in bacterial-based green synthesized nanoparticles (nps): a sustainable strategy for combating infectious plant pathogens. *Biocatalysis and Agricultural Biotechnology*, 103293. https://doi.org/10.1016/j.bcab.2024.103293

Ali, A., Ölmez, F., Zeshan, M. A., Mubeen, M., Iftikhar, Y., Sajid, A., ... & Solanki, M. K. (2024b). Yeast-Based Solutions in Controlling Plant Pathogens. *Biocatalysis and Agricultural Biotechnology*, 103199. https://doi.org/10.1016/j.bcab.2024.103199

Alves, C., Galon, L., Winter, F., Basso, F., Holz, C., Kaizer, R., & Perin, G. (2019). Winter species promote phytoremediation of soil contaminated with protox-inhibiting herbicides. *Planta Daninha*, 37.

Azizi, A., Lim, M., Noor, Z., & Abdullah, N. (2013). Vermiremoval of heavy metal in sewage sludge by utilising Lumbricus rubellus. *Ecotoxicology and Environmental Safety*, 90, 13–20.

Bahadar, H., Mostafalou, S., & Abdollahi, M. (2014). Growing burden of diabetes in Pakistan and the possible role of arsenic and pesticides. *Journal of Diabetes & Metabolic Disorders*, 13, 1–8.

Brar, A. S., Kaur, K., Sindhu, V. K., Tsolakis, N., & Srai, J. S. (2022). Sustainable water use through multiple cropping systems and precision irrigation. *Journal of Cleaner Production*, 333, 130117.

Chandanshive, V. V., Rane, N. R., Tamboli, A. S., Gholave, A. R., Khandare, R. V., & Govindwar, S. P. (2017). Co-plantation of aquatic macrophytes Typha angustifolia and Paspalum scrobiculatum for effective treatment of textile industry effluent. *Journal of Hazardous Materials*, 338, 47–56.

Dandan, W., Huixin, L., Feng, H., & Xia, W. (2007). Role of earthworm-straw interactions on phytoremediation of Cu contaminated soil by ryegrass. *Acta Ecologica Sinica*, 27(4), 1292–1298.

Datta, S., Singh, J., Singh, S., & Singh, J. (2016). Earthworms, pesticides and sustainable agriculture: a review. *Environmental Science and Pollution Research*, 23(9), 8227–8243.

Eevers, N., White, J. C., Vangronsveld, J., & Weyens, N. (2017). Bio-and phytoremediation of pesticide-contaminated environments: a review. *Advances in Botanical Research*, 83, 277–318.

Garg, G., & Kataria, S. K. (2009). Phytoremediation potential of Raphanus sativus (L.), Brassica juncea (L.) and Triticum aestivum (L.) for copper contaminated soil. Proceedings of the 53rd Annual Meeting of the ISSS-2009, Brisbane, Australia,

Gupta, S., & Gupta, K. (2020). Bioaccumulation of pesticides and its impact on biological systems. *Pesticides in Crop Production: Physiological and Biochemical Action*, 55–67.

Hwang, J.-I., Kwak, S.-Y., Lee, S.-H., Kang, M.-S., Ryu, J.-S., Kang, J.-G., Kim, J.E. (2016). Establishment of safe management guideline based on uptake pattern of pesticide residue from soil by radish. *Korean Journal of Environmental Agriculture*, 35(4), 278–285.

Iftikhar, Y., Mubeen, M., Shakeel, Q., Lalarukh, I., Ali, A., Aasim, M., ... & Al-Shuraym, L. A. (2024). Spatial Distribution and Molecular Characterization of Huanglongbing and its Vector in Various Citrus Cultivars. Pakistan Journal of Agricultural Sciences, 61(2): 685–694. https://doi.org/10.21162/PAKJAS/24.155

Jehan, S., Muhammad, S., Ali, W., & Hussain, M. L. (2022). Potential risks assessment of heavy metal (loid) s contaminated vegetables in Pakistan: a review. Geocarto International, 37(24), 7287–7302.

Jusselme, M. D., Miambi, E., Lebeau, T., & Rouland-Lefevre, C. (2015). Role of earthworms on phytoremediation of heavy metal-polluted soils. Heavy Metal Contamination of Soils: Monitoring and Remediation, 279–298.

Kanwal, I., Iffat, A., Shaukat, M. B., Shafique, T., Majeed, Y., Zafar, M. I., & Seemab, F. (2024). Insights into Fusarium wilt of tomato (Fusarium oxysporum f. sp. lycopersici) and its management strategies. *Journal of Agriculture and Biology*, 2(1), 31–42. https://doi.org/10.55627/agribiol.002.01.0837

Kashem, M. A., Singh, B. R., Huq, S. I., & Kawai, S. (2008). Cadmium phytoextraction efficiency of arum (Colocasia antiquorum), radish (Raphanus sativus L.) and water spinach (Ipomoea aquatica) grown in hydroponics. *Water, air, and soil Pollution*, 192, 273–279.

Khan, M. U., Malik, R. N., & Muhammad, S. (2013). Human health risk from heavy metal via food crops consumption with wastewater irrigation practices in Pakistan. *Chemosphere*, 93(10), 2230–2238.

Lakhani, K., & Satchell, J. (1970). Production by Lumbricus terrestris (L.). The Journal of Animal Ecology, 473–492.

Li, Y., Luo, J., Yu, J., Xia, L., Zhou, C., Cai, L., & Ma, X. (2018). Improvement of the phytoremediation efficiency of Neyraudia reynaudiana for lead-zinc mine-contaminated soil under the interactive effect of earthworms and EDTA. *Scientific Reports*, 8(1), 6417.

Mahurpawar, M. (2015). Effects of heavy metals on human health. *International Journal of Research Granthaalayah*, 530, 1–7.

Marchiol, L., Assolari, S., Sacco, P., & Zerbi, G. (2004). Phytoextraction of heavy metals by canola (Brassica napus) and radish (Raphanus sativus) grown on multicontaminated soil. *Environmental pollution*, 132(1), 21–27.

Mikes, O., Cupr, P., Trapp, S., & Klanova, J. (2009). Uptake of polychlorinated biphenyls and organochlorine pesticides from soil and air into radishes (Raphanus sativus). *Environmental Pollution*, 157(2), 488–496.

Naqvi, S. A. H., Abbas, A., Farhan, M., Kiran, R., Hassan, Z., Mehmood, Y., & Baloch, F. S. (2024b). Unveiling the Genetic Tapestry: Exploring Rhizoctonia solani AG-3 Anastomosis Groups in Potato Crops across Borders. *Plants*, 13(5), 715. https://doi.org/10.3390/plants13050715

Naqvi, S. A. H., Farhan, M., Ahmad, M., Kiran, R., Fatima, N., Shahbaz, M., & Ahmad, S. (2024a). Deciphering fungicide resistance in Phytophthora: mechanisms, prevalence, and sustainable management approaches. *World Journal of Microbiology and Biotechnology*, 40(10), 1–17. https://doi.org/10.1007/s11274-024-04108-6

Nayak, P., & Solanki, H. (2021). Pesticides and Indian agriculture—a review. International Journal of Research Granthaalayah, 9, 250–263.

Niti, C., Sunita, S., Kamlesh, K., & Rakesh, K. (2013). Bioremediation: An emerging technology for remediation of pesticides. *Research Journal of Chemistry and Environment*, 17, 4.

Odjegba, V., & Fasidi, I. (2004). Accumulation of trace elements by Pistia stratiotes: implications for phytoremediation. *Ecotoxicology*, 13, 637–646.

Parveen, A., Anjum, M., Mahmood, S., Nawaz, R., & Khalid, A. (2023). Environmental implication and cancer risk assessment of residual pollutants in cotton crop: a case study of Multan District, Pakistan. *Environmental monitoring and Assessment*, 195(9), 1100.

Patel, J., Kumar, G., Deviprasad, S., Deepika, S., & Qureshi, M. S. (2011). Phytochemical and anthelmintic evaluation of Lantana camara (l.) var. aculeate leaves against Pheretima posthuma. *Journal of Global Trends in Pharmaceutical Sciences*, 2(1), 11–20.

Raskin, I., Smith, R. D., & Salt, D. E. (1997). Phytoremediation of metals: using plants to remove pollutants from the environment. *Current opinion in Biotechnology*, 8(2), 221–226.

Rehman, A. U., Rauf, A., Ali, A., Taimoor Shakeel, M., Hasan Naqvi, S. A., Shahid, M., & Umar, U. U. D. (2023). First report of Fusarium equiseti causing leaf spots of Bitter gourd (Momordica charantia) in Pakistan. *Plant Disease*, 107(2), 584. https://doi.org/10.1094/PDIS-04-22-0786-PDN

Saeed, M. F., Shaheen, M., Ahmad, I., Zakir, A., Nadeem, M., Chishti, A. A., Damalas, C. A. (2017). Pesticide exposure in the local community of Vehari District in Pakistan: an assessment of knowledge and residues in human blood. *Science of the Total Environment*, 587, 137–144.

Sarwar, T., Shahid, M., Khalid, S., Shah, A. H., Ahmad, N., Naeem, M. A., Bakhat, H. F. (2020). Quantification and risk assessment of heavy metal build-up in soil–plant system after irrigation with untreated city wastewater in Vehari, Pakistan. Environmental geochemistry and health, 42(12), 4281–4297.

Shahid, M., Ahmad, A., Khalid, S., Siddique, H. F., Saeed, M. F., Ashraf, M. R., Naqvi, S.T.A. (2016). Pesticides pollution in agricultural soils of Pakistan. *Soil science: Agricultural and environmental Prospective*, 199–229.

Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2011). Heavy metals and living systems: An overview. *Indian Journal of Pharmacology*, 43(3), 246.

Singh, S. I., Singh, S., & Vig, A. P. (2020). Earthworm-assisted bioremediation of agrochemicals. In Agrochemicals detection, treatment and remediation (pp. 307-327). Elsevier.

Sinha, R. K., Bharambe, G., & Ryan, D. (2008). Converting wasteland into wonderland by earthworms—a low-cost nature's technology for soil remediation: a case study of vermiremediation of PAHs contaminated soil. *The Environmentalist*, 28, 466–475.

Sinha, R. K., Herat, S., Valani, D., & Chauhan, K. (2010). Earthworms–the environmental engineers: review of vermiculture technologies for environmental management and resource development. *International Journal of Global Environmental Issues*, 10(3-4), 265–292.

Tariq, M. I., Afzal, S., Hussain, I., & Sultana, N. (2007). Pesticides exposure in Pakistan: a review. *Environment international*, 33(8), 1107–1122.

Tong, S., Li, H., Wang, L., Tudi, M., & Yang, L. (2020). Concentration, spatial distribution, contamination degree and human health risk assessment of heavy metals in urban soils across China between 2003 and 2019—a systematic review. *International Journal of Environmental Research and Public Health*, 17(9), 3099.

Upatham, E. S., Boonyapookana, B., Kruatrachue, M., Pokethitiyook, P., & Parkpoomkamol, K. (2002). Biosorption of cadmium and chromium in duckweed Wolffia globosa. *International journal of phytoremediation*, 4(2), 73–86.

Uwizeyimana, H., Wang, M., Chen, W., & Khan, K. (2017). The eco-toxic effects of pesticide and heavy metal mixtures towards earthworms in soil. *Environmental toxicology and pharmacology*, 55, 20–29.

Xu, Z., Yang, Z., Zhu, T., Shu, W., & Geng, L. (2021). Ecological improvement of antimony and cadmium contaminated soil by earthworm Eisenia fetida: Soil enzyme and microorganism diversity. Chemosphere, 273, 129496.

Yao, X., Zhang, F., Qiao, Z., Yu, H., Sun, S., Li, X., Jiang, X. (2020). Toxicity of thifluzamide in earthworm (Eisenia fetida). *Ecotoxicology and Environmental Safety*, 188, 109880.

Zhang, H., Yuan, X., Xiong, T., Wang, H., & Jiang, L. (2020). Bioremediation of co-contaminated soil with heavy metals and pesticides: Influence factors, mechanisms and evaluation methods. *Chemical Engineering Journal*, 398, 125657.

Citation

Ikram, N.A., Ayub, M., Iqbal, S., Hussain, A., Mubeen, K., Ghaffar, A., Aziz, M., Shehzad[2], A., Hassan, W., Khaliq, A., Niazi, M.N.K. M., Naveed, R. (2025). A Case Study in Quinoa (*Chenopodium quinoa* Willd): Combine use of Sunflower Leaf Extract with Nitrogen improve Quinoa Plant Architecture. *Journal of Agriculture and Food, 6(1),* 1–18.