Shahrajabian *et al.*
Beni-Suef Univ J Basic Appl Sci (2022) 11:26
https://doi.org/10.1186/s43088-022-00210-6

Beni-Suef University Journal of Basic and Applied Sciences

REVIEW

Open Access

Foliar application of nutrients on medicinal and aromatic plants, the sustainable approaches for higher and better production

Mohamad Hesam Shahrajabian[1†], Wenli Sun[1*†] and Qi Cheng[2,3]

Abstract

Background: The most important advantages of foliar fertilization are to improve plant growth and crop quality, appropriately manage the nutritional status of plants, enhance disease resistance and regulate nutrient deficiencies.

Main body: The aim of this manuscript is to outline and emphasize the importance of foliar application of nutrients in order to increase both quality and yield of medicinal and aromatic plants. The searches focused on publications from 1980 to July 2021 using PubMed, Google Scholar, Science Direct and Scopus databases. The current manuscript presented many examples of potential of foliar application for medicinal and aromatic plants production systems. Foliar application of Fe and Zn on Anise; Se on Atractylodes; Zn sulfate on Basil, Costmary, Mint and Fenugreek; Se and Fe on Stevia; S and P on castor bean; Zn and Fe on Chamomile; Cu, Mg and $ZnSO_4$ on Damask rose; N and P on Fennel; Se on water spinach and tea; K^+ and Ca^{2+} on Thyme; Zn and K on Spearmint; Zn on Saffron, Ni on Pot marigold; Fe on peppermint, N and P on Mustard had positive and significant impacts.

Conclusion: Observed impacts of foliar fertilization consisted of significant increase of yield, enhanced resistance to insects, pests and diseases, improved drought tolerance and escalated crop quality.

Keywords: Nutrients, Foliar application, Medicinal herbs, Aromatic plants, Natural products, Chemical constituents

1 Background

The most aspects of complementary medicines are medicinal plants [1–3]. Traditional medicinal plants can be incorporated with herbal mixtures or single plant application as basic ingredients of medicines in various ways to treat different diseases in an organic life [4, 5], because medicinal plants are important natural sources of valuable chemical constituents [6, 7]. Foliar nutrition application has tremendous benefits, but the most notable ones include: rapid regulation of nutrient deficiencies, fast growth response of plants to foliar treatments and improved fixation of K and P. It can be beneficial and more effective than soil application of nutrients, especially when there is not enough moisture in top soil, while it can be integrated with other agrochemicals such as insecticides. It can also be effective when stressful conditions such as drought and root diseases affect the crops and is a cost-effective practice to improve yield, yield attributes and quality parameters of crops since usually only small amounts are needed, and the nutrients penetrate the stomata or the cuticle of the leaf, and then enter the cells [8].

Foliar application of magnesium retrieved plant growth, carbohydrates status and nutrients of banana [9]. Foliar calcium application had positive effects on quality of blueberry fruits [10], and foliar fertilizers including calcium chloride, such as Fruton Calcium and FOLANX@ Ca29, caused the significant increase in the calcium content of the fruits and foliage of banana [11].

*Correspondence: sunwenli@caas.cn
†Mohamad Hesam Shahrajabian and Wenli Sun have equally contributed to this work
[1] Biotechnology Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China
Full list of author information is available at the end of the article

Foliar Se utilization can alleviate abiotic stresses such as high temperatures induce to higher yield [12]. The application of K_2SO_4 had capability to boost the freezing tolerance of grapevine and applied as a prophylactic tool to alleviate freezing injury during the winter [13]. Foliar application of zinc, boron, calcium and potassium had significant effects on yield and yield attributes of guava [14]. Foliar spray of boron in the form of boric acid had effective impacts on fruit weight of mandarin orange [15]. Foliar application of Tecamin max® stimulated vegetative growth of okra in limited irrigation method [16]. Wang and Galletta [17] reported that foliar silicon application had positive effects on strawberry plant metabolism. Selenium application should be considered as the appropriate candidate for spinach production [18]. Foliar application of boric acid and zinc sulfate increased both the physiological traits of sesame and promoted its tolerance to drought stress [19]. Boron foliar application and spray of zinc had positive impacts on growth, yield and quality of onion [20]. Foliar application with $ZnSO_4.7H_2O$ improved Zn concentration in pakchoi leaves [21]. Foliar application of K in the form of KLMet-1 (K_2SO_4 together with lysine and lysine plus methionine) during nut filling is the best treatment to gain optimum yield and quality of pistachio [22]. Foliar Fe application was appropriate to inhibit Fe deficiencies in alkaline conditions in pepper cultivation [23]; moreover, foliar spray of Zn could be suggested for red pepper cultivation to increase plant development, yields and some quality properties in regions where Zn insufficiently is high [24]. Total chlorophyll, chlorophyll a and b, and total soluble sugars of olive notably improved as the boron application rate increased [25]. Boron foliar application promoted oleuropein levels and stimulated volatile compound composition in olive leaves [26]. Boric acid application positively influenced oil contents and its composition of olive [27]. Foliar application of phosphites inhibited the phosphate-starvation response in tomato plants [28]. Foliar spray of zinc can alleviate the adverse impacts of zinc deficiency of tomato plants [29], and foliar spray of K, Mg and Zn stimulated fruit number and yield of tomato plants [30]. The positive effects of foliar application of macro- and micro-nutrients on pomegranate have been reported in former studies [31–35].

Despite the benefits, the most important limitations of foliar applications are the cost of multiple applications when needed, foliar burn effects or scorching in high and inappropriate concentrations, while it may need specific requirements of climate conditions such as wind velocity, humidity and temperature, sticking agent and large leaf area to obtain good efficiency. This review article is aimed to introduce foliar application of nutrients in increasing final yield and chemical constituents of medicinal and aromatic plants as an important technique toward sustainable farming systems.

The literature search included review articles, randomized control experiments, analytical studies and observations, which have been gathered from different sources such as Google Scholar, Scopus, Science Direct and PubMed. Review of the literature was carried out using the keywords, foliar application, micro-nutrients, macro-nutrients, medicinal plants, aromatic plants, pharmaceutical benefits and natural products.

2 Main text

2.1 Foliar application on different plants

One of the most important sustainable management in enhancing crop yield and quality parameters is foliar application, which can also supplement soil fertilization, when oleuropein are utilized to the soil, and absorbed by roots and transfer to aerial parts. Foliar application of KH_2PO_4, $CaCl_2$ or NH_4NO_3 enhanced heat tolerance of creeping bentgrass by slowing leaf senescence and enhancing photosynthetic activities, and inhibition of lipid peroxidation, and keeping the scavenging capability may alleviate the negative impacts [36]. Potassium chloride foliar application to mature trees of cocoa may lead to increase in dry bean weight, bean weight, post and husk weight [36]. Urea foliar application at various stages, namely, tillering, anthesis, jointing and grain filling had positive impacts on plant height, the number of seeds per spike, grain weight and protein content of winter wheat [37]. A simple and sustainable technique to screen plant is foliar application which tolerate and accumulate As in *Chelidonium majus* cultivation [38]. For bio-fortification of soybean grains, Li_2SO_4 and LiOH are good sources [39]. Foliar treatment with $FeSO_4$ in eggplant lead to significant increase in quantum yield of photosystem (PS II), SPAD index, photochemistry (F_v/F_m) and performance index (PI) values of both old and young leaves [40]. The size of nodules may significantly increase after molybdenum foliar application as well as maintaining a longer duration of effective N_2 fixation [41]. Zn foliar application boosted the number of pods, pod shelling and yield and a hundred seed mass and seed zinc [42]. Foliar application of K and P alleviated the adverse impacts of salinity on plant growth and stimulated the concentrations of these nutrients in the grain and leaves of sorghum [43]. The supplementary Fe application mitigated Zn concentration in both roots and leaves of plant grown at high Zn [44]. Foliar application of Zn + Fe led to the maximum yield with a mean of 2613.84 kg ha^{-1} of soybean yield [45]. Foliar application of calcium and kinetin at the floral bud and full flowering stages did not significantly influence carbon dioxide (CO_2) assimilation, final yield and yield attributes of soybean [46].

Manganese foliar application may improve seed yield and the lint content of cotton [47]. Foliar application of silicon can significant stimulate resistance in wheat plants to drought condition, especially at the tiller and anthesis stages via increasing chlorophyll content, and keeping relative water content as well as maintaining cellular membrane integrity [48]. Foliar application of copper, iron, magnesium, manganese and zinc significantly improved their leaves, corresponding concentrations of aquaponic-treated tomato seedlings [49]. Foliar application of silicon has positive impacts on strawberry plant metabolism. Foliar application of the combination of salicylic acid and sodium nitroprusside to roots or leaves is more effective than its utilization to roots or spraying to leaves [50]. The effective influence of manganese sulfate on leaf proline content, and the significant impacts of zinc on stem proline, maximum root, oleic, linoleic and linolenic unsaturated fatty acids, and chlorophyll b is reported [51]. Foliar application P at low rates might promote mid-season P deficiency in winter wheat, and that may lead to higher P use efficiencies [52]. Combined foliar application of B^{3+} and K^{+} indicated higher plant growth and productivity of cotton at various level of salinity [53]. Foliar application of 1000 ppm Zinc (Zn) and 350 ppm Boron (B) can markedly increase seed yield and quality of safflower grown under terminal drought [54]. Application of urea (5000 mg L^{-1}) proved to be the most effective in boosting fresh and bulb dry weights and improved mineral uptake [55]. Zn foliar application in the form of complexed with amino acid caused positive increase of fresh mass of a hundred nut, total nut yield and spilled nuts of pistachio [56]. Foliar supplied of N and Zn are synergistically effectual on Zn bioavailability of winter wheat [57]. The glutathione content of vineyard was significantly improved after foliar organic nitrogen application [58]. Foliar urea application improved protein but higher concentrations reduced sugars and phenolics of escarole (*Cichorium endivia* L. var. latifolium) [59]. Selenite application at tuber bulking stage was effective for Se-rich potato production [60]. Zn and Se application improved photosynthesis and growth of Cd-stressed wheat and alleviated Cd and boosted Zn and Se concentrations in wheat, as well as up-regulating the antioxidant defense of wheat under Cd stress [61]. Foliar Zn application diminished Cd content in tobacco leaves while foliar Se application increase it; however, foliar Zn treatments were not as effective as soil amendments in decreasing Cd content of leaves [62]. Foliar nitrogen application helped to decrease the negative impacts of water-logging in Lulo plants (*Solanumquitoene* cv. *septentrionale*) [63]. Boron and zinc foliar application significantly increase the percentage of the olive oil, but in the warm climates, boric acid treatment improved olive oil quality such as increasing unsaturated fatty acid and reducing saturated fatty acid [64]. Sulfur nanoparticles had notable impacts on tomato growth by foliar spraying, at 200 ppm increased tomato growth compared to the control treatment [65]. Significant and positive influence was achieved by foliar application of manganese chloride and manganese on physiological characteristics of green gram at 200 and 300 mM salinity level which was appropriate in alleviating the adverse impacts of NaCl [66]. Foliar nutrition of magnesium oxide (MgO) nanoparticles had positive and significant effects on macronutrient concentration of cotton plants such as magnesium, potassium, phosphorus and nitrogen [67].

0.2% foliar spray of $NiSO_4.7H_2O$ markedly improved growth, yield and Cu, Mn, Fe and Zn status in barley [68]. Zn foliar application decreased Cd and increased Zn in rice grain, stimulated rice leaves, antioxidant system, increased enhanced Cd chelation onto cell wall of rice leaves, and maybe utilized as an additional measure to manage Cd accumulation in rice grains [69]. Under high As stress, foliar silica sol promoted As accumulation in cell walls of roots of rice [70]. Sulfur foliar application was appropriate method for alleviating Cd in rice and improving the grain yield, it can also decrease Cd toxicity on PSII reaction center and improved photosynthetic efficiency [71]. Foliar Si and Se application can alleviate Cd in soft wheat, decreased Cd-induced oxidative stress by increasing antioxidative systems, up-regulated influx transporter and down-regulate influx transporter expression [72]. Foliar application of selenium was found effective for agronomic biofortification of wheat, and the appropriate dose of Se for increase yield and biofortification was 21 g ha^{-1} [73]. The maximum flavonoid content of grape was related to iron foliar application with significant impact on grape physic-chemical characteristics [74]. Foliar Zn application increased the reduction impacts of Cd in rice after lime application, as well as significant increase in the transfer ration of Cd from rice straw to the grain [75]. Zn-amino acid complexes (ZnAAC) and $ZnSO_4$ foliar spray increased both yield and quality of grain wheat, and ZnAAC was a good agent to boost grain Fe, Zn and protein concentration [76]. NPK nanoparticle fertilizer foliar application indicated a significant increase in yield ad morphological traits [77]. The significant increase in antioxidant activity system of winter wheat and positive impacts on the uptake of nutrients under drought stress was reported after application of selenium [78]. In sunflower plants, Si fertilizer had a great ability to attenuate sodium toxicity [79]. Si foliar application decreased Cd uptake and translocation, enhanced Cd compartmentation onto root cell walls; moreover, both Se and Si foliar application increased

SOD in plant tissues [80]. Foliar application of potassium significantly influenced antioxidant activity and phenolic compounds in fig fruit, and potassium treatment is proved to increase fig quality [81]. NaHS and $CaCl_2$ combined application increased Ni tolerance by decreasing oxidative stress, improved growth, alleviated Ni stress by increasing the nitrate reductase activity in the leaves and enhancing the protein content [82].

Selenium application at the rate of 25 g ha^{-1} can be applied as an appropriate agent to increase Se content for consumption in broccoli production, as well as enhancing the major organic compounds of Se, like Se-methylselenocysteine (Se-MeSeCys), selenocystine (SeCys2), and selenomethionine (SeMet) [83]. Foliar boron application had significant influence of total dry matter of tomato and beet [84]. Zinc nanofertilizers foliar application enhanced vegetative trains such as internode length, plant height, shoot and root fresh and dry weight, the number of pods, grain weight, zinc content in grain of pinto bean cultivars [85]. Foliar Mn and Zn application can increase the seed yield and quality of safflower under drought stress condition [86]. Selenium foliar application (1 μM) and nano-Se (2 μM) significant enhanced leaf area, chlorophyll content, growth and yield of pomegranate [87]. Combined application of nitrogen (142.8 kg ha^{-1}) and K_2O (1.15 kg ha^{-1}) with mepiquat chloride (0.048 + 0.021 kg ha^{-1}) were reported as important treatment to increased seed yield, seed vigor and seed viability of cotton plants [88]. Zinc nanoparticle (ZnO NPs) and biochar significantly improve biomass of corn, alleviated the Cd content, enhanced the Zn concentration and decreased the oxidative stress and improved the enzyme activities [89]. Silicon foliar spray increased lignin biosynthetic enzyme activity, up-regulated lignin biosynthetic genes, increased photosynthesis by enhancing chlorophyll content and stomatal conductance, mitigated the drastic shading impacts on stem stability and could be beneficial in reducing soybean lodging [90]. B application noticeably enhanced maize growth through increasing photosynthetic capacity, tissue-B content, water-status, up-regulation of antioxidative defense-system; furthermore, mitigated negative impacts of B on corn was also reported [91]. Zinc foliar application (100 mg L^{-1}) and molybdenum (40 mg L^{-1}) stimulated growth and yield characteristics of sugar beet through balancing translocation and nutrients uptake [92]. Application of Ca, B and GA_3 increased quantitative and qualitative characteristics of pomegranate fruit, enhanced peel integrity and decreased sun-burning and cracking of pomegranate and increased fruit chemical composition and peel moisture [93]. Foliar spray of urea (2%) at flowering, and flowering + pod formation stages increased Fe and Zn concentration of chickpea's grain [94].

2.2 Foliar application of nutrients on medicinal and aromatic plants

Foliar application has tremendous beneficial effects on yield and yield attributes of medicinal and aromatic plants and herbs [94, 95]. Foliar applied urea at full-flowering and pod-setting gave acceptable outcomes but the appropriate stage of utilization was first flowering, full flowering and pod setting [95]. Foliar application of methanol had remarkable impacts on essential oil and physiological characteristics of *Lavandula stoechas* L. in NaCl salinity stress environment [96]. Zinc and iron foliar application had effective impact on agronomic traits in *Alyssum desertorum*, *Borago officinalis*, *Calendula officinalis* and *Thymus vulgaris* [97]. Zinc application had significant effects on the physiological characteristics of *Lavandula stoechas* L. plants growing under salinity stress conditions [98]. Silicon foliar application influenced green color index of orchids, nutrient absorption and improving concentrations of Si of *Phalaenopsis* and *Dendrobium* orchids [99]. Photosynthesis and grapy yield was increased by spray of mixture of Cu-Fe and alleviated the Cu accumulate in soil and plant [100]. Some of the most important examples of positive effect of foliar application of nutrients on aromatic and medicinal plants are indicated in Table 1.

3 Conclusions

Foliar application of nutrients is the best technique of sustainable agriculture and horticultural production systems to improve both quality and quantity of medicinal and aromatic plants. Foliar application of nutrients basically micronutrients is an age-old practice to rectify the deficiency symptoms. Foliar application may lead to quick growth of seedling after germination in annual crops, during tillering and grain filling stages, during flowering and fruit-set in deciduous crops, during rapid fruit expansion in many types of fruit crops and during bulking-up process in bulb or tuber crops. The positive effect of foliar application of Fe and Zn on anise and chamomile, Se on atractylodes, water spinach and tea, coffee and stevia, magnesium on banana, Zn on basil, saffron and fenugreek, calcium on blueberry, P and S on castor bean, iron on costmary, cooper, magnesium and zinc sulfate on damask rose, N and P on fennel and mustard, Zn, B, Ca and K on guava, Fe, Cu, Mn and Zn on lemon balm, B on mandarin orange and olive, sodium chloride on mint, B and Zn on onion and sesame, Fe on pepper, Fe on peppermint, K on pistachio, Ni on pot marigold, Si, Zn and K on spearmint, Se on spinach, Sin on strawberry, K and Ca on thyme, K, Zn and Mg on tomato have been reported in various studies. Foliar application is an appropriate technique of feeding medicinal plants, fruits and herbs by utilizing liquid fertilizer directly to

Table 1 The most notable impacts of foliar application of nutrients on medicinal and aromatic plants

Plant	Scientific name	Plant family	Key point	References
Anise	*Pimpinella anisum* L.	Apiaceae	Fe and Zn foliar spray improved the yield of anise, and the highest yield was obtained from 4 g L^{-1} Zn with 6 g L^{-1} Fe for biological yield, and from 2 to 4 g L^{-1} Zn with 6 g L^{-1} Fe for essential oils	[101]
Atractylodes	*Atractylodes macrocephala* Koidz	Asteraceae	Foliar application of 5.0–10.0 mg m^{-2} selenium was effective in growth of atractylodes	[102]
			Foliar application of 2.5–20.0 mg m^{-2} selenium could alleviate the pest damage of leaves	[102]
Basil	*Ocimum basilicum* L.	Lamiaceae	Foliar application of zinc sulfate is the appropriate candidate to improve essential oil	[103]
Candyleaf (Stevia)	*Stevia rebaudiana* Bertoni	Asteraceae	Application of selenium alone or mixed with iron boosted the growth characteristics of stevia	[104]
			KNO_3 application alleviated the adverse impacts of salinity on yield by up to 26%	[105]
			Foliar application of moringa leaf extract promoted growth, increased mineral content and nutraceutical and boosted stevioside contents of stevia leaves	[106]
Castor bean	*Ricinus communis* L.	Euphorbiaceae	Foliar application of S and P had important role in improving seed and oil yields as well as in boosting oil quality	[107]
Chamomile	*Matricaria chamomilla* L.	Asteraceae	Flower yield, essential oil percentage and essential oil yield improved by foliar application of Zn and Fe	[108]
Costmary	*Tanacetum balsamita* L.	Asteraceae	Growth parameters, total phenol content, protein, antioxidant capacity and chlorophyll index were stimulated by zinc supply	[109]
			Foliar spray of iron markedly influenced leaves fresh and dry weights, root fresh and dry weights and peroxidase content	[110]
Damask rose	*Rosa damascene* Mill	Rosaceae	Foliar spray of copper, magnesium and zinc sulfate modulated higher numbers of flowers, flower yield per plant and higher cintronellol + nerol content	[111]
Fenugreek	*Trigonellafoenum-graecum*	Fabaceae	Foliar spray of zinc oxide nanoparticles had positive impacts on some biochemical and physiological parameters	[112]
Fennel	*Foeniculum vulgare* Mill	Apiaceae	Foliar spray of N and P alleviated the anethole content of oil and boosted that of fenchone significantly	[113]
Lemon Balm	*Melissa officinalis* L.	Lamiaceae	Foliar application of Fe, Cu, Mn and Zn induced to significant impacts on morpho-physiological and essential oil content and composition of lemon balm	[114]
Mexican marigold	*Tagetes minuta* L.	Asteraceae	Essential oil content improved with increasing diammonium phosphate levels	[115]
Mint	*Mentha arvensis* L	Lamiaceae	Foliar spray of sodium chloride markedly alleviated the population of adult whitefly in menthol mint	[116]
			Application of zinc sulfate and iron sulfate promoted yield and yield attributes	[117]
Mustard	*Brassica juncea* L.	Brassicaceae	Foliar application of N and P boosted the performance of the crop and improved seed yield and oil yield	[118]
Peppermint	*Mentha piperita* L.	Lamiaceae	Foliar application of nano-iron (0.5 g L^{-1}) in flowering stage had positive effects on dry matter yield and essential oil content and composition of peppermint	[119]
Pot marigold	*Calendula officinalis* L.	Asteraceae	Nickel is the best candidate to improve plant growth parameters and antioxidant activity	[120]
Saffron	*Crocus sativus* L.	Iridaceae	Foliar application of nano-ZnO improved chlorophyll a	[121]
Spearmint	*Mentha spicata* L.	Lamiaceae	Foliar application of cations such as Si, Zn and K had effective impacts to mitigate the native impacts of salinity stress	[122]
Tea	*Camellia sinensis* (L.) Kuntze	Theaceae	Nano-Selenium (10 mg L^{-1}) application significantly increased catechins contents, tea polyphenols, the protein, soluble sugar and carotenoid	[123]
			Selenium-supplementation may stimulate tea leaves, secondary metabolism, boosting the accumulation of total phenols and flavonoids such as rutin, apigenin, myricetin, kaempferol and quercetin	[123]

Table 1 (continued)

Plant	Scientific name	Plant family	Key point	References
Thyme	*Thymus vulgaris* L.	Lamiaceae	Foliar application of K^+ and Ca^{2+} was able to lessen salinity stress	[124]
Water spinach	*Ipomoea aquatica* Forsk	Convolvulaceae	Foliar application of selenium alleviated the uptake of chromium, and decreased the distribution characteristics of chromium in organelles	[125]

their leaves, and essential elements can be absorb into the leaves directly, which is the proper method for small amounts of both micro- and macro-nutrients. Foliar applications of nutrients have tremendous benefits on medicinal and aromatic plants, but the most important advantages are increase resistance to insect, pests and diseases, increase drought tolerance, boost soil salinity tolerance and enhance resistance to physiological disorders, it may have positive effect for the immobilized nutrients like iron, better and rapid nutrient absorption in different plant growth stages, especially at early crop growth stages. The positive effects of feeding plant via foliar fertilizers directly to the leaves are reported in many studies, therefore foliar application can be considered as the best tool to give supplemental doses of both minor and major nutrients, stimulants and even plant hormones. Foliar application is advisable where additional benefits from the plant's activity can be obtained. The big advantage of foliar treatment is that they can address an urgent need within a relatively short time, and they are therefore specially efficient as a preventive and in some cases curative treatments. Foliar treatment is not generally intended to replace soil or fertigation applications, but to complement them. More researches are needed to survey the impacts of nutrient foliar application on final yield and quality of medicinal and aromatic plants and herbs.

Abbreviations
KLMet-1: K_2SO_4 complexed with lysine and lysine plus methionine; PI: Performance index; CO_2: Carbon dioxide; Zn: Zinc; B: Boron; MgO: Magnesium oxide; ZnAAC: Zn-amino acid complexes; Se-MeSeCys: Se-methylselenocysteine; SeCys2: Selenocystine; SeMet: Selenomethionine; ZnO NPs: Zinc nanoparticle.

Acknowledgements
Not applicable.

Authors' contributions
MHS: writing-original draft preparation; WS: writing-original draft preparation; QC: writing-review and editing. All authors have read and approved to the manuscript.

Funding
This work was supported by the National Key R&D Program of China (Research grant 2019YFA0904700). This research was also funded by the Natural Science Foundation of Beijing, China (Grant No. M21026).

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no potential competing interests.

Author details
[1] Biotechnology Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China. [2] College of Life Sciences, Hebei Agricultural University, Baoding 071000, Hebei, China. [3] Global Alliance of HeBAU-CLS&HeQiS for BioAl-Manufacturing, Baoding 071000, Hebei, China.

Received: 29 July 2021 Accepted: 1 February 2022
Published online: 15 February 2022

References
1. Shahrajabian MH, Sun W, Cheng Q (2020) Traditional herbal medicine for the prevention and treatment of cold and flu in the autumn of 2020, overlapped with Covid-19. Nat Prod Commun 15(8):1–10. https://doi.org/10.1177/1934578x20951431
2. Shahrajabian MH, Sun W (2020) Cheng Q (2020) Traditional herbal medicines to overcome stress, anxiety and improve mental health in outbreaks of human coronaviruses. Phytother Res 1:1–11. https://doi.org/10.1002/ptr.6888
3. Shahrajabian MH, Sun W, Cheng Q (2020) Exploring *Artemisia annua* L., artemisinin and its derivatives, from traditional Chinese wonder medicinal science. Not Bot Horti Agrobot Cluj Napoca 48(4):1719–1741. https://doi.org/10.15835/nbha48412002
4. Shahrajabian MH, Sun W, Cheng Q (2021) Asafoetida, a natural medicine for future. Curr Nutr Food Sci 17:1–10. https://doi.org/10.2174/1573401317666210222161609
5. Shahrajabian MH, Chaski C, Polyzos N, Petropoulos SA (2021) Biostimulants application: a low input cropping management tool for sustainable farming of vegetables. Biomolecules 11(5):698. https://doi.org/10.3390/biom11050698
6. Sun W, Shahrajabian MH, Cheng Q (2021) Health benefits of wolfberry (Gou Qi Zi) on the basis of ancient Chinese herbalism and Western modern medicine. Avicenna J Phytomed 11(2):109–119
7. Sun W, Shahrajabian MH, Cheng Q (2021) Fenugreek cultivation with emphasis on historical aspects and its uses in traditional medicine and modern pharmaceutical science. Mini Rev Med Chem 21(6):724–730. https://doi.org/10.2174/1389557520666201127104907
8. Fageria NK, Barbosa Filho MP, Moreira A, Guimaraes CM (2009) Foliar fertilization of crop plants. J Plant Nutr 32:1044–1064. https://doi.org/10.1080/01904160902872826
9. He H, Kin X, Ma H, Deng Y, Huang J, Yin L (2020) Changes of plant biomass partitioning, tissue nutrients and carbohydrates status in magnesium-deficient banana seedlings and remedy potential by foliar application of magnesium. Sci Hortic 268:109377. https://doi.org/10.1016/j.scienta.2020.109377
10. Stuckrath R, Quevedo R, Fuente LDl, Hernandez A, Spulveda V (2008) Effect of foliar application of calcium on the quality of blueberry fruits. J

Plant Nutr 31(7):1299–1312. https://doi.org/10.1080/01904160802135076
11. Ochmian I (2012) The impact of foliar application of calcium fertilizers on the quality of highbush blueberry fruits belonging to the "Duke" cultivar. Not Bot Horti Agrobot Cluj Napoca 40(2):163–169. https://doi.org/10.15835/nbha4028058
12. Mateus MPDB, Tavanti RFR, Tavanti TR, Santos EF, Jalal A, Reis ARD (2021) Selenium biofortification enhances ROS scavenge system increasing yield of coffee plants. Ecotoxicol Environ Saf 209:111772. https://doi.org/10.1016/j.ecoenv.2020.111772
13. Sarikhani H, Haghi H, Ershadi A, Esna-Ashari M, Pouya M (2014) Foliar application of potassium sulphate enhances the cold-hardiness of grapevine (*Vitis vinifera* L.). J Hortic Sci Biotechnol 89(2):141–146. https://doi.org/10.1080/14620316.2014.11513060
14. Kumar J, Kumar R, Rai R, Mishra DS, Singh SK, Nimbolkar PK (2017) Influence of foliar application of mineral nutrients at different growth stags of guava. J Plant Nutr 40(5):656–661. https://doi.org/10.1080/01904167.2016.1246568
15. Ullah S, Khan AS, Malik AU, Afzal I, Shahdi M, Razzaq K (2012) Foliar application of boron influences the leaf mineral status, vegetative and reproductive growth, yield and fruit quality of "KINNOW" Mandarin (*Citrus Reticulata* Blanco.). J Plant Nutr 35(13):2067–2079. https://doi.org/10.1080/01904167.2012.717661
16. Al-Shammari AM, Abood MA, Hamdi GJ (2019) Foliar application of Tecamin max® to alleviate water deficit on vegetative growth and yield of okra. Int J Veg Sci 25(3):278–284. https://doi.org/10.1080/19315260.2018.1509922
17. Wang SY, Galletta GJ (1998) Foliar application of potassium silicate induces metabolic changes in strawberry plants. J Plant Nutr 21(1):157–167. https://doi.org/10.1080/01904169809365390
18. Moteshare Zadeh B, Ghorbani S, Alikhani HA (2020) Spinach (*Spinaciaoleracea*) nutritional responses to selenium application. Commun Soil Sci Plant Anal 51(20):2537–2550. https://doi.org/10.1080/00103624.2020.1844729
19. Dehnavi MM, Misagh M, Yadavi A, Merajipoor M (2017) Physiological responses of sesame (*Sesamum indicum* L.) to foliar application of boron and zincunder drought stress. J Plant Process Funct 6(20):27–35
20. Manna D, Maity TK (2016) Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc. J Plant Nutr 39(3):438–441. https://doi.org/10.1080/01904167.2015.1109099
21. Han W, Huang L, Owojori OJ (2020) Foliar application of zinc alleviates the heat stress of pakchoi (*Brassica chinensis* L.). J Plant Nutr 43(2):194–213. https://doi.org/10.1080/01904167.2019.1659350
22. Hamze MR, Khoshgoftarmanesh AH, Shariatmadari H, Baninasab B (2018) The effects of foliar applied potassium in the mineral form and complexed with amino acids on pistachio nut yield and quality. Arch Agron Soil Sci 64(10):1432–1445. https://doi.org/10.1080/03650340.2018.1439580
23. Roosta HR, Mohsenian Y (2012) Effects of foliar spray of different Fe sources on pepper (*Capsicum annum* L.) plants in aquatic system. Sci Hortic 146:182–191. https://doi.org/10.1016/j.scienta.2012.08.018
24. Turhan A, Kuscu H, Ozmen N (2021) Response of red pepper (*Capsicum annuum* L.) to foliar applications of zinc. Commun Soil Sci Plant Anal. https://doi.org/10.1080/00103624.2021.1879123
25. Hegazi ES, El-Motaium RA, Yehia TA, Hashim ME (2018) Effect of foliar boron application on boron, chlorophyll, phenol, sugars and hormones concentration of olive (*Olea europaea* L.) buds, leaves and fruits. J Plant Nutr 41(6):749–765. https://doi.org/10.1080/01904167.2018.1425438
26. Paskovic I, Soldo B, Talhaoui N, Palcic I, Brkjaca M, Koprivnjak O, Germek VM, Ban D, Klanjac J, Franic M, Zurga P, Grozic K, Lukic I, Ban SG (2019) Boron foliar application enhances oleuropein level and modulates volatile compound compodition in olive leaves. Sci Hortic 257:108688. https://doi.org/10.1016/j.scienta.2019.108688
27. Rohi Vishekaii Z, Soleimani A, Fallahi E, Ghasemnezhad M, Hasani A (2019) The impact of foliar application of boron nano-chelated fertilizer and boric acid on fruit yield, oil content, and quality attributes in olive (*Olea europaea* L.). Sci Hortic 257:108689. https://doi.org/10.1016/j.scienta.2019.108689
28. Vinas M, Mendez JC, Jimenez VC (2020) Effect of foliar applications of phosphites on growth, nutritional status and defense responses in tomato plants. Sci Hortic 265:109200. https://doi.org/10.1016/j.scienta.2020.109200
29. Kaya C, Higgs D (2002) Response of tomato (*Lycopersicon esculentum* L.) cultivars to foliar application of zinc when grown in sand culture at low zinc. Sci Hortic 93(1):53–64. https://doi.org/10.1016/s0304-4238(01)00310-7
30. Roosta H, Hamidpour M (2011) Effects of foliar application of some macro- and micro-nutrients on tomato plants in aquaponic and hydroponic systems. Sci Hortic 129(3):396–402. https://doi.org/10.1016/j.scienta.2011.04.006
31. Mirzapour MH, Khoshgoftarmanesh AH (2013) Effect of soil and foliar application of iron and zinc on quantitative and qualitative yield of pomegranate. J Plant Nutr 36(1):55–66. https://doi.org/10.1080/01904167.2012.733049
32. Davarpanah S, Tehranifar A, Davarynejad Gh, Abadia J, Khorasani R (2016) Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punicagranatum* cv. Ardestani) fruit yield and quality. Sci Hortic 210:57–64. https://doi.org/10.1016/j.scienta.2016.07.003
33. Hasani M, Zamani Z, Savaghebi Gh, Sofla HS (2016) Effect of foliar and soil application of urea on leaf nutrients concentrations, yield and fruit quality of pomegranate. J Plant Nutr 39(6):749–755. https://doi.org/10.1080/01904167.2015.1047525
34. Chater JM, Garner LC (2019) Foliar nutrient applications Wonderful pomegranate (*Punica granatum* L.). I. effect on fruit mineral nutrient concentrations and internal quality. Sci Hortic 244:421–427. https://doi.org/10.1016/j.scienta.2018.04.022
35. Pathania S, Kumar A, Arora PK (2018) Response of different pomegranate cultivars to foliar application of potassium nitrate in arid irrigated region of Punjab. J Plant Nutr 41(20):2572–2580. https://doi.org/10.1080/01904167.2018.1497176
36. Ojeniyi SO, Egbe NE (1981) Effect of foliar application of potassium on cocoa yield. J Hortic Sci 56(3):267–269. https://doi.org/10.1080/00221589.1981.11515000
37. Gholami A, Akhlaghi S, Shahsavani S, Farrokhi N (2011) Effects of urea foliar application on grain yield and quality of winter wheat. Commun Soil Sci Plant Anal 42(6):719–727. https://doi.org/10.1080/00103624.2011.550377
38. Zhang Z, Sugawara K, Hatayama M, Huang Y, Inoue C (2014) Screening of As-accumulating plants using a foliar application and a native accumulation of As. Int J Phytoremediat 16(3):257–266. https://doi.org/10.1080/15226514.2013.773277
39. Santos ACMD, Marques KR, Rodrigues LU, Faria AJGD, Nascimento VL, Fidelis RR (2019) Biofortification of soybean grains with foliar application of Li sources. J Plant Nutr 42(19):2522–2531. https://doi.org/10.1080/01904167.2019.1659339
40. Roosta HR, Mohsenian Y (2015) Alleviation of alkalinity-induced Fe deficiency in eggplant (*Solanum melongena* L.) by foliar application of different Fe sources in recirculating system. J Plant Nutr 38(11):1768–1786. https://doi.org/10.1080/01904167.2015.1061542
41. Vieira RF, Cardoso EJBN, Vieira C, Cassini STA (1998) Foliar application of molybdenum in common bean. III. Effect on nodulation. J Plant Nutr 21(10):2153–2161. https://doi.org/10.1080/01904169809365551
42. Singh AL, Chaudhari V (2015) Zinc biofortification in sixty groundnut cultivars through foliar application of zinc sulphate. J Plant Nutr 38(11):1734–1753. https://doi.org/10.1080/01904167.2015.1042165
43. Hussein MM, Abdel-Kader AA, Kady KA, Youssef RA, Alva AK (2010) Sorghum response to foliar application of phosphorus and potassium with saline water irrigation. J Crop Improv 24(4):324–336. https://doi.org/10.1080/15427528.2010.499042
44. Kaya C, Higgs D, Burton A (1999) Foliar application of iron as a remedy for zinc toxic tomato plants. J Plant Nutr 22(12):1829–1837. https://doi.org/10.1080/01904169909365759
45. Vaghar MS, Sayfzadeh S, Zakerin HR, Kobraee S, Valadabadi SA (2020) Foliar application of iron, zinc, and manganese nano-chelates improves physiological indicators and soybean yield under water deficit stress. J Plant Nutr 43(18):2740–2756. https://doi.org/10.1080/01904167.2020.1793180
46. Fioreze SK, Carneiro JP, Pinto DD, Rodrigues JD (2017) Foliar application of calcium and kinetin on soybean at reproductive stage. J Plant Nutr 40(18):2602–2610. https://doi.org/10.1080/01904167.2017.1381120

47. Dordas C (2009) Foliar application of manganese increases seed yield and improves seed quality of cotton grown on calcareous soils. J Plant Nutr 32(1):160–176. https://doi.org/10.1080/01904160802609013
48. Maghsoudi K, Emam Y, Ashraf M (2016) Foliar application of silicon at different grown stages alters growth and yield of selected wheat cultivars. J Plant Nutr 39(8):1194–1203. https://doi.org/10.1080/01904167.2015.1115876
49. Roosta H, Hamidpour M (2013) Mineral nutrient content of tomato plants in aquaponic and hydroponic systems: effect of foliar application of some macro- and micro-nutrients. J Plant Nutr 36(13):2070–2083. https://doi.org/10.1080/01904167.2013.821707
50. Song Y, Dong Y, Kong J, Tian X, Bai Z, Xu L (2017) Effects of root addition and foliar application of nitric oxide and salicylic acid in alleviating iron deficiency induced chlorosis of peanut seedlings. J Plant Nutr 40(1):63–81. https://doi.org/10.1080/01904167.2016.1201491
51. Gheshlaghi MZ, Pasari B, Shams K, Rokhzadi A, Mohammadi K (2019) The effect of micronutrient foliar application yield, seed quality and some biochemical traits of soybean cultivars under drought stress. J Plant Nutr 42(50):2715–2730. https://doi.org/10.1080/01904167.2019.1655034
52. Mosali J, Desta K, Teal RK, Freeman KW, Martin KL, Lawles JW, Raun WR (2006) Effect of foliar application of phosphorus on winter wheat grain yield, phosphorus uptake, and use efficiency. J Plant Nutr 29(12):2147–2163. https://doi.org/10.1080/01904160600972811
53. Azeem M, Shoujun Y, Qasim M, Abbasi MW, Ahmed N, Hanif T, Adnan MY, Ahmad R, Dong R (2021) Foliar enrichment of potassium and boron overcomes salinity barriers to improve growth and yield potential of cotton (*Gossypium hirsutum* L.). J Plant Nutr 44(3):438–454. https://doi.org/10.1080/01904167.2020.1845365
54. Soheili-Movahhed S, Khomari S, Sheikhzadeh P, Alizadeh B (2019) Improvement in seed quantity and quality of spring safflower through foliar application of boron and zinc under end-season drought stress. J Plant Nutr 42(8):942–953. https://doi.org/10.1080/01904167.2019.1584214
55. Charbaji T, Arabi MIE, Jawhar M (2008) Urea foliar fertilization affects onion weight and nutrient content. Int J Veg Sci 14(3):198–204. https://doi.org/10.1080/19315260802164285
56. Najizadeh A, Khoshgoftarmanesh AH (2019) Effects of foliar applied zinc in the form of $ZnSO_4$ and Zn-amino acid complexes on pistachio nut yield and quality. J Plant Nutr 42(18):2299–2309. https://doi.org/10.1080/01904167.2019.1655043
57. Li M, Wang S, Tian X, Zhao J, Li H, Guo C, Chen Y, Zhao A (2015) Zn distribution and bioavailability in whole grain and grain fractions of winter wheat as affected by applications of soil N and foliar Zn combined with N or P. J Cereal Sci 61:26–32. https://doi.org/10.1016/j.jcs.2014.09.009
58. Gutierrez-Gamboa G, Garde-Cerdan T, Gonzalo-Diago A, Moreno-Simunovic Y, Martinez-Gil AM (2017) Effect of different foliar nitrogen applications on the must amino acids and glutathione composition in Cabernet Sauvignon vineyard. LWT 75:147–154. https://doi.org/10.1016/j.lwt.2016.08.039
59. Otalora G, Pinero MC, Lopez-Marin J, Varo P, Del Amor FM (2018) Effects of foliar nitrogen fertilization on the phenolic, mineral, and amino acid composition of escarole (*Cichorium endivia* L. var. latifolium). Sci Hortic 239:87–92. https://doi.org/10.1016/j.scienta.2018.05.031
60. Zhang H, Zhao Z, Zhang X, Zhang W, Huang L, Zhang Z, Yuan L, Liu X (2019) Effects of foliar application of selenate and selenite at different growth stages on Selenium accumulation and speciation in potato (*Solanum tuberosum* L.). Food Chem 286:550–556. https://doi.org/10.1016/j.foodchem.2019.01.185
61. Wu C, Dun Y, Zhang Z, Li M, Wu G (2020) Foliar application of selenium and zinc to alleviate wheat (*Triticum aestivum* L.) cadmium toxicity and uptake from cadmium-contaminated soil. Ecotoxicol Environ Saf 190:110091. https://doi.org/10.1016/j.ecoenv.2019.110091
62. Yun Y, Wan Y, Wang Q, Li H (2017) Effect of humic acid-based amendments with foliar application of Zn and Se on Cd accumulation in tobacco. Ecotoxicol Environ Saf 138:286–291. https://doi.org/10.1016/j.ecoenv.2017.01.011
63. Florez-Velasco N, Balaguera-Lopez HE, Restrepo-Diaz H (2015) Effects of foliar urea application on lulo (*Solanum quitoense* cv. *septentrionale*) plants grown under different waterlogging and nitrogen conditions. Sci Hortic 186:154–162. https://doi.org/10.1016/j.scienta.2015.02.021
64. Saadati S, Moallemi N, Mortazavi SMH, Seyyednejad SM (2013) Effects of zinc and boron foliar application on soluble carbohydrate and soil contents of three olive cultivars during fruit ripening. Sci Hortic 164:30–34. https://doi.org/10.1016/j.scienta.2013.08.033
65. Salem NM, Albanna LS, Awwad AM (2016) Green synthesis of sulfur nanoparticles using *Punica granatum* peels and the effects on the growth of tomato by foliar spray applications. Environ Nanotechnol Monit Manag 6:83–87. https://doi.org/10.1016/j.enmm.2016.06.006
66. Shahi S, Srivastava M (2018) Influence of foliar application of manganese on growth, pigment content, and nitrate reductase activity of *Vigna radiata* (L.) R. Wilczek under salinity. J Plant Nutr 41(11):1397–1404. https://doi.org/10.1080/01904167.2018.1454470
67. Kanjana D (2020) Foliar application of magnesium oxide nanoparticles on nutrient element concentrations, growth, physiological, and yield parameters of cotton. J Plant Nutr 43(20):3035–3049. https://doi.org/10.1080/01904167.2020.1799001
68. Kumar O, Singh SK, Latare AM, Yadav SN (2018) Foliar fertilization of nickel affects growth, yield component and micronutrient status of barley (*Hordeum vulgare* L.) grown on low nickel soil. Arch Agron Soil Sci 64(10):1407–1418. https://doi.org/10.1080/03650340.2018.1438600
69. Zhen S, Shuai H, Xu C, Lv G, Zhu X, Zhang Q, Zhu Q, Nunez-Delgado A, Conde-Cid M, Zhou Y, Huang D (2021) Foliar application of Zn reduces Cd accumulation in grains of late rice by regulating the antioxidant system, enhancing Cd chelation onto cell wall of leaves, and inhibiting Cd translocation in rice. Sci Total Environ Sci 770:145302. https://doi.org/10.1016/j.scitotenv.2021.145302
70. Pan D, Liu C, Yi J, Li X, Li F (2021) Different effects of foliar application of silica sol on arsenic translocation in rice under low and high arsenite stress. J Environ Sci 105:22–32. https://doi.org/10.1016/j.jes.2020.12.034
71. Liu J, Hou H, Zhao L, Sun Z, Li H (2020) Protective effect of foliar application of sulfur on photosynthesis and antioxidative defense system of rice under the stress of Cd. Sci Total Environ 710:136230. https://doi.org/10.1016/j.scitotenv.2019.136230
72. Zhou J, Zhang C, Du B, Cui H, Fan X, Zhou D, Zhou J (2021) Soil and foliar applications of silicon and selenium effects on cadmium accumulation and plant growth by modulation of antioxidant system and Cd translocation: comparison of soft vs. durum wheat varieties. J Hazard Mater 402:123546. https://doi.org/10.1016/j.jhazmat.2020.123546
73. Lara TS, Lessa JHDL, Souza KRDD, Corguinha APB, Martins FAD, Lopes G, Guilherme LRG (2019) Selenium biofortification of wheat grain via foliar application and its effects on plant metabolism. J Food Compos Anal 81:10–18. https://doi.org/10.1016/j.jfca.2019.05.002
74. Shi P, Song C, Chen H, Duan B, Zhang Z, Meng J (2018) Foliar applications of iron promote flabonoids accumulation in grape berry of *Vitis vinifera* cv. Merlot grown in the iron deficiency soil. Food Chem 253:164–170. https://doi.org/10.1016/j.foodchem.2018.01.109
75. Duan M-M, Wang S, Huang D-Y, Zhu Q-H, Liu S-L, Zhang Q, Zhu H-H, Xu C (2018) Effectiveness of simultaneous applications of lime and zinc/iron foliar sprays to minimize cadmium accumulation in rice. Ecotoxicol Environ Saf 165:510–515. https://doi.org/10.1016/j.ecoenv.2018.09.037
76. Ghasemi S, Khoshgoftarmanesh AH, Afyuni M, Hadadzadeh H (2013) The effectiveness of foliar applications of synthesized zinc-amino acid chelates in comparison with zinc sulfate to increase yield and grain nutritional quality of wheat. Eur J Agron 45:68–74. https://doi.org/10.1016/j.eja.2012.10.012
77. Abdelsalam NR, Kandil EE, Al-Msari MAF, Al-Jaddadi MAM, Ali HM, Salem MZM, Elshikh MS (2019) Effect of foliar application of NPK nanoparticle fertilization on yield and genotoxicity in wheat (*Triticum aestivum* L.). Sci Total Environ 653:1128–1139. https://doi.org/10.1016/j.scitotenv.2018.11.023
78. Nawaz F, Ahmad R, Ashraf MY, Waraich EA, Khan SZ (2015) Effect of selenium foliar spray on physiological and biochemical processes and chemical constituents of wheat under drought stress. Ecotoxicol Environ Saf 113:191–200. https://doi.org/10.1016/j.ecoenv.2014.12.003
79. Hurtado AC, Chiconato DA, Prado RDM, Sousa Junior GDS, Gratao PL, Felisberto G, Viciedo DO, Dos Santos DMM (2020) Different methods of silicon application attenuate salt stress in sorghum and sunflower by modifying the antioxidative defense mechanism. Ecotoxicol Environ Saf 203:110964. https://doi.org/10.1016/j.ecoenv.2020.110964
80. Wu Z, Xu S, Shi H, Zhao P, Liu X, Li F, Deng T, Du R, Wang X, Wang F (2018) Comparison of foliar silicon and selenium on cadmium

absorption, compartmentation, translocation and the antioxidant system in Chinese flowering cabbage. Ecotoxicol Environ Saf 166:157–164. https://doi.org/10.1016/j.ecoenv.2018.09.085
81. Gaaliche B, Ladhari A, Zarrelli A, Mimoun MB (2019) Impact of foliar potassium fertilization on biochemical composition and antioxidant activity of fig (*Ficus carica* L.). Sci Hortic 253:111–119. https://doi.org/10.1016/j.scienta.2019.04.024
82. Valivand M, Amooaghaie R (2021) Foliar spray with sodium hydrosulfide and calcium chloride advances dynamic of critical elements and efficiency of nitrogen metabolism in *Cucurbita pepo* L. under nickel stress. Sci Hortic 283:110052. https://doi.org/10.1016/j.scienta.2021.110052
83. Sindelarova K, Szakova J, Tremlova J, Mestek O, Praus L, Kana A, Najmanova J, Tlustos P (2015) The response of broccoli (*Brassica oleracea* convar. Italic) varieties on foliar application of selenium: uptake, translocation, and speciation. Food Addit Contam Part A 32(12):2027–2038. https://doi.org/10.1080/19440049.2015.1099744
84. Gondim ARDO, Prado RDM, Filho ABC, Alves AU, Correia MAR (2015) Boron foliar application in nutrition and yield of beet and tomato. J Plant Nutr 38(10):1573–1579. https://doi.org/10.1080/01904167.2015.1043373
85. Mahdieh M, Sangi MR, Bamdad F, Ghanem A (2018) Effect of seed and foliar application of nano-zinc oxide, zinc chelate, and zinc sulphate rates on yield and growth of pinto bean (*Phaseolus vulgaris*) cultivars. J Plant Nutr 41(18):2401–2412. https://doi.org/10.1080/01904167.2018.1510517
86. Movahhedy-Dehnavy M, Modarres-Sanavy SAM, Mokhtassi-Bidgoli A (2009) Foliar application of zinc and manganese improves seed yield and quality of safflower (*Carthamus tinctorius* L.) grown under water deficit stress. Ind Crops Prod 30(1):82–92. https://doi.org/10.1016/j.indcrop.2009.02.004
87. Zahedi SM, Hosseini MS, Hakimi Meybodi ND, Silva JATD (2019) Foliar application of selenium and nano-selenium affects pomegranate (*Punicagranatum* cv. Malase Saveh) fruit yield and quality. S Afr J Bot 124:350–358. https://doi.org/10.1016/j.sajb.2019.05.019
88. Sawan ZM, Fahmy AH, Yousef SE (2009) Direct and residual effects of nitrogen fertilization, foliar application of potassium and plant growth retardant on Egyptian cotton growth, seed yield, seed viability and seedling vigor. Acta Ecol Sin 29(2):116–123. https://doi.org/10.1016/j.chnaes.2009.05.008
89. Rizwan M, Ali S, Zia ur Rehman M, Adrees M, Arshad M, Qayyum MF, Ali L, Hussain A, Chatha SAS, Imran M (2019) Alleviating of cadmium accumulation in maize (*Zea mays* L.) by foliar spray of zinc oxide nanoparticles and biochar to contaminated soil. Environ Pollut 248:358–367. https://doi.org/10.1016/j.envpol.2019.02.031
90. Hussain S, Shuxian L, Mumtaz M, Shafiq I, Iqbal N, Brestic M, Shoaib M, Sisi Q, Li W, Mei X, Bing C, Zivcak M, Rastogi A, Skalicky M, Hejnak V, Weiguo L, Wenyu Y (2021) Foliar application of silicon improves stem strength under low light stress by regulating lignin biosynthesis genes in soybean (*Glycine max* (L.) Merr.). J Hazard Mater 401:123256. https://doi.org/10.1016/j.jhazmat.2020.123256
91. Naeem M, Naeem MS, Ahmad R, Ahmad R, Ashraf MY, Ihsan MZ, Nawaz F, Athar H-U-R, Ashraf M, Abbas HT, Abdullah M (2018) Improving drought tolerance in maize by foliar application of boron: water status, antioxidative defense and photosynthetic capacity. Arch Agron Soil Sci 64(5):626–639. https://doi.org/10.1080/03650340.2017.1370541
92. Zewail RMY, El-Gmal IS, Khaitov B, El-Desouky HSA (2020) Micronutrients through foliar application enhance growth, yield and quality of sugar beet (*Beta vulgaris* L.). J Plant Nutr 43(15):2275–2285. https://doi.org/10.1080/01904167.2020.1771580
93. Hosein-Beigi M, Zarei A, Rostaminia M, Erfani-Moghadam J (2019) Positive effects of foliar application of Ca, B and GA_3 on the qualitative and quantitative traits of pomegranate (*Punica granatum* L.) cv. "Malase-Torshe-Saveh." Sci Hortic 254:40–47. https://doi.org/10.1016/j.scienta.2019.04.081
94. Pal V, Singh G, Dhaliwal SS (2019) Field enhacement and biofortification of chickpea (*Cicer arietinum* L.) grain with iron and zinc through foliar application of ferrous sulfate and urea. J Plant Nutr 42(15):1789–1802. https://doi.org/10.1080/01904167.2019.1648675
95. Oko BFD, Eneji AE, Binang W, Irshad M, Yamamoto S, Honna T, Endo T (2003) Effect of foliar application of urea on reproductive abscission and grain yield of soybean. J Plant Nutr 26(6):1223–1234. https://doi.org/10.1081/pln-120020366
96. Valizadeh-Kamran R, Mehrabani LV, Pessarakli M (2019) Effects of foliar application of menthanol on some physiological characteristics of *Lavandula stoechas* L. under NaCl salinity conditions. J Plant Nutr 42(3):261–268. https://doi.org/10.1080/01904167.2018.1554677
97. Yadegari M (2017) Irrigation periods and Fe, Zn foliar application on agronomic characters of *Borago officinalis*, *Calendula officinalis*, *Thymus vulgaris* and *Alyssumdesertorum*. Commun Soil Sci Plant Anal 48(3):307–315. https://doi.org/10.1080/00103624.2016.1269796
98. Mehrabani LV, Kamran RV, Hassanpouraghdam MB, Pessarakli M (2017) Zinc sulfate foliar application effects on some physiological characteristics and phenolic and essential oil contents of *Lavandula stoechas* L. under sodium chloride (NaCl) salinity conditions. Commun Soil Sci Plant Anal 48(16):1860–1867. https://doi.org/10.1080/00103624.2017.1406105
99. Mantovani C, Prado RDM, Pivetta KFL (2018) Silicon foliar application on nutrition and growth of *Phalaenopsis* and *Dendrobium* orchids. Sci Hortic 241:83–92. https://doi.org/10.1016/j.scienta.2018.06.088
100. Ma J, Zhang M, Liu Z, Chen H, Li YC, Sun Y, Ma Q, Zhao C (2019) Effects of foliar application of the mixture of copper and chelated iron on the yield, quality, photosynthesis, and microelement concentration of table grape (*Vitis vinifera* L.). Sci Hortic 254:106–115. https://doi.org/10.1016/j.scienta.2019.04.075
101. Pirzad A, Barin M (2018) Iron and zinc interaction on leaf nutrients and the essential oil of *Pimpinella anisum* L. Iran J Plant Physiol 8(4):2507–2515
102. Zhou W, Duan Y, Zhang Y, Wang H, Huang D, Zhang M (2021) Effects of foliar selenium application on growth and rhizospheric soil micro-ecological environment of *Atractylodes macrocephala* Koidz. S Afr J Bot 137:98–109. https://doi.org/10.1016/j.sajb.2020.09.032
103. Moghimipour Z, Sourestani MM, Ansari NA, Ramezani Z (2017) The effect of foliar application of zinc on essential oil content and composition of holy basil (*Ocimumsanctum*) at first and second harvests. J Essent Oil-Bear Plants 20(2):449–458. https://doi.org/10.1080/0972060x.2017.1284609
104. Aghighi Shahverdi M, Omidi H, Tabatabaei SJ (2018) Plant growth and steviol glycosides as affected by foliar application of selenium, boron, and iron under naCl stress in *Stevia rebaudiana* Bertoni. Ind Crops Prod 125:408–415. https://doi.org/10.1016/j.indcrop.2018.09.029
105. Mahajan M, Sharma S, Kumar P, Kumar Pal P (2020) Foliar application of KNO_3 modulates the biomass yield, nutrient uptake and accumulation of secondary metabolites of *Stevia rebaudiana* under saline conditions. Ind Crops Prod 145:112102. https://doi.org/10.1016/j.indcrop.2020.112102
106. Sardar H, Nisae A, Anjum MA, Naz S, Ejaz S, Ali S, Javed MS, Ahmad R (2021) Foliar spray of moringa leaf extract improves growth and concentration of pigment, minerals and stevioside in stevia (*Stevia rebaudiana* Bertoni). Ind Crops Prod 166:113485. https://doi.org/10.1016/j.indcrop.2021.113485
107. Sadeghi-Bakhtavari AR, Hazrati S (2020) Growth, yield and fatty acids as affected by water-deficit and foliar application of nitrogen, phosphorus, and sulfur in castor bean. J Crop Improv. https://doi.org/10.1080/15427528.2020.1824953
108. Nasiri Y, Zehtab-Salmasi S, Nasrullahzaeh S, Najafi N, Ghassemi-Golezani K (2010) Effects of foliar application of micronutrients (Fe and Zn) on flower yield and essential oil of chamomile (*Matricaria chamomilla* L.). J Med Plant Res 4(17):1733–1737
109. Derakhshani Z, Hassani A, Sadaghiani MHR, Hassanpouraghdam MB, Hosseini Khalifani B, Dalkani M (2011) Effect of zinc application on growth and some biochemical characteristics of costmary (*Chrysanthemum balsamita* L.). Commun Soil Sci Plant Anal 42(20):2493–2503. https://doi.org/10.1080/00103624.2011.609257
110. Valizadeh-Kamran R, Mehrabani LV, Hassanpouraghdam MB, Pessarakli M (2017) Effects of foliar application of $FeSO_4$ and NaCl salinity on vegetative growth, antioxidant enzymes activity, and malondialdehyde content of *Tanacetum balsamita* L. Commun Soil Sci Plant Anal 48(16):1825–1859. https://doi.org/10.1080/00103624.2017.1406104
111. Kumar R, Sharma S, Kaundal M, Sharma S, Thakur M (2016) Response of damask rose (*Rosa damascene* Mill.) to foliar application of magnesium

(Mg), copper (Cu) and zinc (Zn) sulphate under western Himalayas. Ind Crops Prod 83:596–606. https://doi.org/10.1016/j.indcrop.2015.12.065
112. Noohpisheh Z, Amiri H, Mohammadi A, Farhadi S (2021) Effect of the foliar application of zinc oxide nanoparticles on some biochemical and physiological parameters of *Trigonella foenum-graecum* under salinity stress. Plant Biosyst Int J Deal Asp Plant Biol 155(2):267–280. https://doi.org/10.1080/11263504.2020.1739160
113. Khan MMA, Samiullah Afaq SH, Afridi MMRK (1992) Yield and quality of fennel (*Foeniculum vulgare* Mill.) in relation to basal and foliar application of nitrogen and phosphorus. J Plant Nutr 15(11):2505–2515. https://doi.org/10.1080/01904169209364490
114. Yadegari M (2017) Effects of Zn, Fe, Mn and Cu foliar application on essential oils and morpho-physiological traits of lemon balm (*Melissa officinalis* L.). J Essent Oil-Bear Plants 20(2):485–495. https://doi.org/10.1080/0972060x.2017.1325010
115. Saharkhiz MJ, Estahbanati MN, Rezaei M, Tafazoli E, Delavar H (2012) Foliar application of diammonium phosphate increase essential oil content and changes its compositions in Mexican Marigold (*Tagetes minuta* L.). J Essent Oil-Bear Plants 15(2):244–249. https://doi.org/10.1080/0972060x.2012.10644042
116. Prasad A, Wasnik K, Singh D (2014) Foliar application of metallic salts modulates yield, chemical composition of essential oil, whitefly population and rhizosphere properties of menthol mint. J Essent Oil-Bear Plants 17(2):176–185. https://doi.org/10.1080/0972060x.2014.895155
117. Lothe NB, Mazeed A, Pandey J, Patairiya V, Verma K, Semwal M, Verma RS, Verma RK (2021) Maximizing yields and economics by supplementing additional nutrients for commercially grown menthol mint (*Mentha arvensis* L.) cultivars. Ind Crops Prod 160:113110. https://doi.org/10.1016/j.indcrop.2020.113110
118. Kahn NA, Samiuilah AO (1993) Response of mustard to seed treatment with pyridioxine and basal and foliar application of nitrogen and phosphorus. J Plant Nutr 16(9):1651–1659. https://doi.org/10.1080/01904169309364640
119. Nemati Lafmejani Z, Jafari AA, Moradi P, Moghadam AL (2018) Impact of foliar application of iron-chelate and iron nano particles on some morpho-physiological traits and essential oil composition of peppermint (*Mentha piperita* L.). J Essent Oil-Bear Plants 21(5):1374–1384. https://doi.org/10.1080/0972060x.2018.1556122
120. Sobati-Nasab Z, Alirezalu A, Noruzi P (2021) Effect of foliar application of nickel on physiological and phytochemical characteristics of pot marigold (*Calendulaofficinalis*). J Agric Food Res 3:1001108. https://doi.org/10.1016/j.jafr.2021.100108
121. Rostami M, Talarposhti RM, Mohammadi H, Demyan MS (2019) Morpho-physiological response of saffron (*Crocus sativus* L.) to particle size and rates of zinc fertilizer. Commun Soil Sci Plant Anal 50(10):1250–1257. https://doi.org/10.1080/00103624.2019.1614602
122. Chrysargyris A, Solomou M, Petropoulos SA, Tzortzakis N (2019) Physiological and biochemical attributes of *Mentha spicata* when subjected to saline conditions and cation foliar application. J Plant Physiol 232:27–38. https://doi.org/10.1016/j.jplph.2018.10.024
123. Li D, Zhou C, Zou N, Wu Y, Zhang J, An Q, Li J-Q, Pan C (2021) Nanoselenium foliar application enhances biosynthesis of tea leaves in metabolic cycles and associated responsive pathways. Environ Pollut 273:116503. https://doi.org/10.1016/j.envpol.2021.116503
124. Zrig A, Ferreira JFS, Hamouda F, Tounekti T, Selim S, Al Jaouni S, Khemira H, Abdelgawad H (2019) The impact of foliar fertilizers on growth and biochemical responses of *Thymus vulgaris* to salinity stress. Arid Land Res Manag. https://doi.org/10.1080/15324982.2018.1551817
125. Guo X, Ji Q, Rizwan M, Li H, Li D, Chen G (2020) Effects of biochar and foliar application of selenium on the uptake and subcellular distribution of chromium in *Ipomoea aquatica* in chromium-polluted soils. Ecotoxicol Environ Saf 206:111184. https://doi.org/10.1016/j.ecoenv.2020.111184

Publisher's Note