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Variation of Some Plant Growth Parameters in Coriander (*Coriandrum sativum* L.) with Copper Application

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Abstract: This study was carried out to investigate the effect of different copper (Cu) concentrations on some plant growth parameters in coriander (*Coriandrum sativum* L.). The study was perfomed at the Agricultural Biotechnology growth room, Faculty of Agriculture, Siirt University (Turkey). In the study, the coriander Mardin province population was used as plant material. Five different doses of Cu (0, 100, 200, 300, and 400 ppm) were applied to plants. Plant height (cm), stem diameter (mm), the number of branches per plant, the number of umbel per plant, the number of seeds in the main umbel, plant fresh, and dry weights (g) were determined. According to the results, the effect of different Cu concentrations in all growth parameters except stem diameter and number of branches were found to be significant. In the current study, plant height, stem diameter, number of branches, number of umbel, number of seeds in the main umbel, and plant fresh weight and dry weights were ranged between 41.31-52.79 cm, 1.57-2.18 mm, 3.07-5.71 per plant, 2.57-4.86 per plant, 13.36-37.86 per plant, 2.33-4.12 g and 0.239-0.550 g, respectively. In the study, it was concluded that coriander can be included in phytoremediation programs in Cu-contaminated areas.

Keywords: Copper, *Coriandrum sativum* L., plant height, fresh weight, dry weight

1. Introduction

The coriander (*Coriandrum sativum* L.) belonging to the Umbelliferae family is one of the oldest known spice plants (Bashir and Safdar, 2020). Today, the largest coriander producer countries are India, Russia, Morocco, Canada, Romania, and Ukraine, while Iran, Turkey, Israel, Egypt, China, the United States, Argentina, and Mexico are smaller producers (Satyal and Setzer, 2020). The leaves and fruits of the coriander have a pleasant aromatic scent, and coriander essential oil is among the top 20 essential oils in the world (Silva et al., 2020). Coriander essential oil is rich in linalool, limonene, α-pinene, camphene, geranyl acetate, and linalyl acetate. In addition to essential oil ingredients, oleoresins, which are new value-added products obtained from coriander seeds, are also in high demand in international markets (Sharma and Sharma, 2012). Coriander exhibits a wide variety of biological effects as an antioxidant, anti-inflammatory, analgesic, antiedemic, antiseptic and antimicrobial effects. For these reasons, coriander is a popular ingredient in the preparation of home remedies. In recent studies, coriander oils or extracts have been reported to exhibit broad antimicrobial activity against Gram-positive and Gram-negative bacteria, yeasts, molds, and parasites (Darughe et al., 2012; Zeb, 2016; Silva et al., 2020). Moreover, coriander contains the fixed oil, which is one of the fatty acids not found in the oils of other oil plants, its content is very rich (55-90%) in petroselinic acid, and can be used both as edible and industrial oil (Keskin and Baydar, 2016; Bashir and Safdar, 2020).

Cultivation of medicinal and aromatic plants is becoming increasingly important to supply high-quality raw materials required for the food, pharmaceutical, and cosmetic industries (Canter et al., 2005; Varlı et al., 2020). The yield and quality of products in agricultural farming depend on genetic and environmental (climate and soil, etc.) factors. It is known that some cultural practices affect the yield and quality of products. In this sense, considering that macro and microelements increase the herbal properties and phenolic substance content of medicinal plants (Matlok et al., 2021), balanced fertilization is important in terms of many nutrients.

Copper (Cu) has roles in plant growth, photosynthesis, respiration, carbon, and nitrogen metabolism, and provides protection against oxidative stress (Broadley et al., 2012; Ghorbanpour et al., 2016; Rajput et al., 2018; Shams et al., 2019; Chrysargyris et al., 2021). It is an important element with significant roles in carbohydrate and lipid metabolisms, DNA and RNA synthesis, and resistance against diseases and pests (Yerli et al., 2020). It is also important in plant performance and development, especially in field crops. On the other hand, the increasing use of various phytochemicals (fungicides, insecticides, etc.) in agriculture (Panou-Filotheou and Bosabalidis, 2004) and urban and industrial wastes (Vassell et al., 2019) are gradually causing excessive Cu accumulation in the soil. High Cu concentrations can cause changes in photosynthesis and respiration processes, enzyme activity, DNA, membrane integrity, and may cause growth restriction in plants (Zvezdanović et al., 2007; Küpper et al., 2009; Ghorbanpour et al., 2016; Abbasifar et al., 2020). Although it is known that Cu is necessary as a cofactor for normal plant growth and development, its indirect effects on some physiological events make it difficult to determine the amount needed by plants (Okcu et al., 2009).

It has been reported that low Cu concentrations (50 ppm) cause a significant increase in overall growth, dry matter accumulation, and nutrient content, while high concentrations (100-250 ppm) decrease growth, nutrient content, and dry matter in mung bean (*Vigna radiata* L.) (Manivasagaperumal et al., 2011). In *Suaeda fruticosa,* the application of a high concentration of Cu does not affect the shoot growth of the plant, on the contrary, it stimulated growth of the root system. It has been suggested that *S. fruticosa* may be a Cu hyperaccumulator, and this species can be used in the decontamination of Cu-contaminated soils (Bankaji et al., 2015). Foliar fertilizer containing 4000 ppm zinc (Zn) and 2000 ppm Cu applied to the basil (*Ocimum basilicum* L.) caused a significant increase in most of the morphological parameters (Abbasifar et al., 2020), while improved growth in rice, maize, and wheat (Jyothi and Hebsur, 2017) has been reported with the use of Cu.

Medicinal and aromatic plants have significant phytoextraction potential. Therefore, they can be grown in heavy metal contaminated soils as an alternative to products used as human and animal food (Stancheva et al., 2014). According to previous reports; dill (*Anethum graveolens*), field mint (Mentha x piperita), basil (*Ocimum basilicum*) (Zheljazkov et al., 2006), mayasıl otu (*Marrubium vulgare*), lemon balm (*Melissa officinalis*), İzmir oregano (*Origanum heracleoticum*) (Zheljazkov et al., 2008), coriander (*C. sativum* L.) (Matic et al., 2019) and black cumin (*Nigella sativa*) (Marichali et al., 2014, 2016) have the potential to tolerate and accumulate excessive heavy metal concentrations. However, there was almost no study on the effect of Cu on the morphological characteristics of the coriander. Therefore, in this study, it was aimed to investigate the effect of different Cu concentrations on some morphological parameters of coriander (*C. sativum* L.).

2. Materials and Methods

The study was carried out at the Agricultural Biotechnology growth room in the Faculty of Agriculture, Siirt University (Turkey). In the study, coriander (*C. sativum* L.) seeds from the Mardin province population were used as plant material. Four different Cu doses (100, 200, 300, and 400 ppm) and water (0 ppm) as control treatments were considered as research subjects. A total of 7 pots were used per dose according to randomized complete blocks design with seven replications. In the experiment, peat: sand: soil mixture (2:2:1 ratio) was used as the plant growth medium. Some physico-chemical properties of the growth material used are given in Table 1. The soil of the plant growth medium was clayey-loamy textured, slightly alkaline, and salt-free. Lime content was "medium calcareous", organic matter content was

Table 1. Some physical and chemical properties of soil used in the research*

Soil Property	Value
Clay, %	36.63
Silt, %	43.10
Sand, %	20.27
pH	7.82
Electrical conductivity, mS cm^{-1}	0.818
Lime ($CaCO_3$), %	7.5
Organic matter, %	2.40
Available phosphorus (P), ppm	7.95
Exchangeable potassium (K), meq 100 g^{-1}	0.94
Available iron (Fe), ppm	19.63
Available copper (Cu), ppm	4.89
Available zinc (Zn), ppm	0.48
Available manganese (Mn), ppm	13.76

*: Analyzes were made in the Soil and Water Analysis Laboratory of the Black Sea Agricultural Research Institute

"moderate", and available P and available K contents were "adequate". The available Fe content of the soil was "high", the Cu content was "adequate", and the Zn and Mn content were "low" (Table 1).

The temperature of the growth environment was 25-27 °C, relative humidity was between 60-70%, and the plants were grown in a 16 h/8 h light/dark regime for 7 weeks. Non-heating white fluorescent was used as the ambient light source. In the study, copper sulfate ($CuSO_4.5H_2O$) containing 24.9% Cu was used as a Cu source. Seeds were surface-sterilized with 70% ethyl alcohol (C_2H_5OH) and 5% sodium hypochlorite (NaCIO) for 5 minutes each before sowing. Seeds were rinsed under running water for 1 minute and placed in pots with a 2:2:1 mixture of peat: sand: soil. Before planting, the pots were watered, the soil was brought to field capacity, and the weight of each pot at field capacity was equalized. Two seeds per pot were sown on 05.02.2019 and the first seedlings emerged on 14.02.2019.

Different doses (0, 100, 200, 300, and 400 ppm) of copper were applied to plants in three parts with the final volume of 100 ml in three days intervals at 20, 23, and 26th of February 2019, starting 6 days after the seedling emergence. The water was applied to the control group with the final volume of 100 ml in parallel with Cu- experimental groups.

During the growth and development of the plants, foliar fertilizer was applied to each pot to ensure normal development. 50 ml of water was given daily using tap water to keep the soil at field capacity.

At the end of the 7th week, fruit setting occurred in coriander plants, and the plants were harvested after initial measurements before the fruits were ripe. In the current study, plant height (cm), stem diameter (mm), the number of branches per plant, the number of umbel per plant, the number of fruit in the main umbel, and plant fresh and dry weights (g) were measured.

The data obtained from the study were subjected to analysis of variance (ANOVA) according to randomized complete blocks experimental design. According to the results of the F test, the differences between the groups were determined by the Tukey's HSD (Honestly Significant Difference) multiple comparison test (Açıkgöz and Açıkgöz, 2001).

3. Results and Discussion

3.1. Plant height

The effects of Cu application on the plant height of the coriander were statistically significant at the $p<0.05$ level. Accordingly, although the highest plant height was obtained at the 300 ppm Cu (52.79 cm), significant differences were observed between the control and all other Cu concentrations (Figure 1). In similar previous studies, Kalidasu et al. (2008), reported that 0.25% (2500 ppm) $CuSO_4$ applied to coriander from the leaves increased the plant height compared to the control, while it decreased in 0.5% (5000 ppm) application. On the other hand, Mounika et al. (2017), reported that 0.5% $CuSO_4$ application from the leaves increased plant height in coriander compared to the control. In some other previous studies on different plant species such as *Mentha pulegium* L. (Lajayer et al., 2017) and *Carthamus tinctorius* L. (Li et al., 2015), Cu doses significantly affected plant heights, and significant growth inhibition was reported at the higher doses (Li et al., 2015). In a previous study conducted with *Hymenaea courbaril* L. (Caesalpinioideae), Marques et al. (2018), reported that the plant height increased accordingly until 200

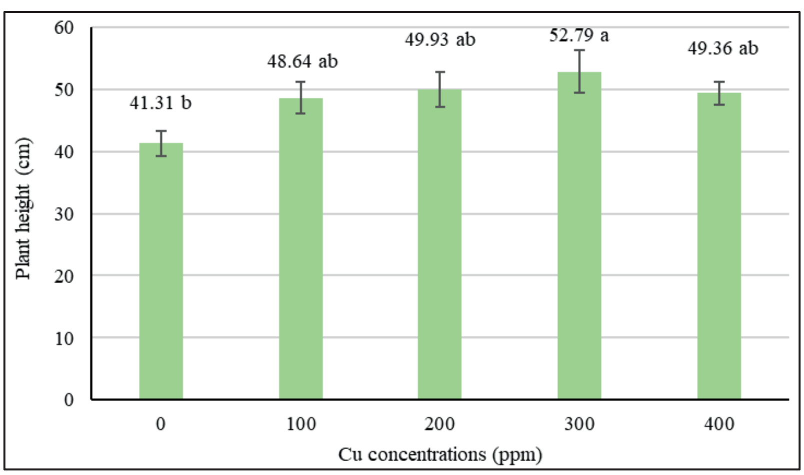

Figure 1. Plant height of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

ppm Cu dose, and it was negatively affected at 400 and 800 ppm Cu doses. The response of various plants to high Cu concentrations varies according to the nature of the plant and the cultivars used (Adrees et al., 2015). Since copper is a micronutrient, it is expected that positive effects on plant growth and development would be within certain limits.

3.2. Stem thickness

The difference between the applied Cu doses and stem thickness of the coriander was not statistically significant. Despite the insignificant results, there was a numerical difference between Cu applied plants and control, and stem thickness values varied between 1.57-2.18 mm (Figure 2). Especially stem diameter was higher on Cu applied plants up to 200 ppm and gradual decreases were observed at higher doses. Although copper is a micronutrient, excess Cu concentration in the soil can limit plant growth due to its potential toxicity when applied at high concentrations (DalCorso et al., 2014; Adrees et al., 2015). Hojati et al. (2017) reported decreased stem thickness with rising Cu concentrations in *Tanacetum parthenium*, on the other hand, Marques et al. (2018) reported that stem thickness of *Hymenaea courbaril* L. was affected positively at 0, 100, 200, and 400 ppm, and negatively at 800 ppm Cu concentrations. These results also indicated that the concentration of Cu is crucial for its activity.

3.3. Number of branches per plant

In this study, the effects of Cu concentrations on the number of branches per plant were found to be statistically insignificant. The number of branches varied between 3.07 and 5.71 per plant. Even though there was no significant effect of Cu doses, a significant decrease is observed in the number of branches at the highest Cu dose (Figure 3).

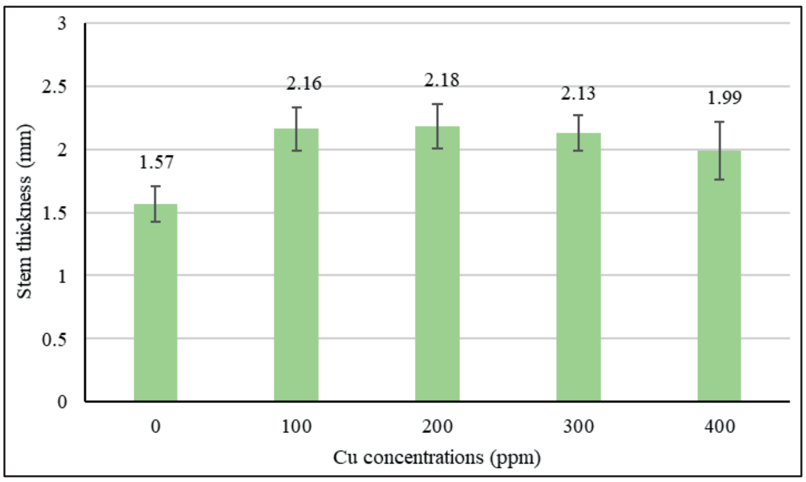

Figure 2. Stem thickness of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

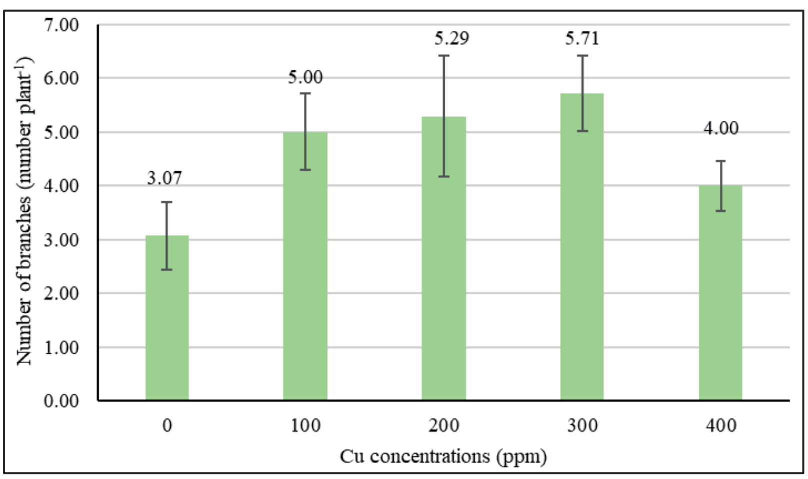

Figure 3. Number of branches per plant of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

Kalidasu et al. (2008), reported an increased number of primary and secondary branches with Cu application in coriander, while Huang et al. (2011) examined the phenology and reproduction of *Rumex dentatus* in Cu-contaminated and non-Cu-contaminated areas, and reported that the number of branches increased in 500 ppm Cu application compared to the control. While it has been reported that foliar-applied Cu concentrations increased the number of branches in broad bean (*Vicia faba* L.) (Alhasany et al., 2019), it was stated that higher Cu doses decreased the number of branches in Crambe (*Crambe abyssinica* H.) (Tito et al., 2014). In another previous study, it was reported that up to a certain Cu concentration (200 ppm), the number of branches increased in beans, and at higher doses, the number of branches decreased as a result of the decrease in cytokinin levels in seedlings (Bildirici, 2020).

3.4. Number of umbel per plant

The effects of Cu concentrations on the number of umbel were found to be statistically significant ($p<0.05$). The highest number of umbel per plant was obtained at 300 ppm Cu (4.86 plant^{-1}) and 200 ppm Cu (4.64 plant^{-1}), however, at the 400 ppm Cu concentration, the positive effect of Cu started to decline. In this study, the lowest number of umbel was obtained in the control group (0 ppm Cu) with 2.57 per plant (Figure 4). Kapoor et al. (2017) evaluated the effects of different microelement applications in coriander and reported that soil and foliar applications of copper sulfate increased the number of umbel in coriander. This result could be the positive effect of Cu on pollen viability and productivity which cause higher number of umbel in coriander (Mahendran et al., 2021).

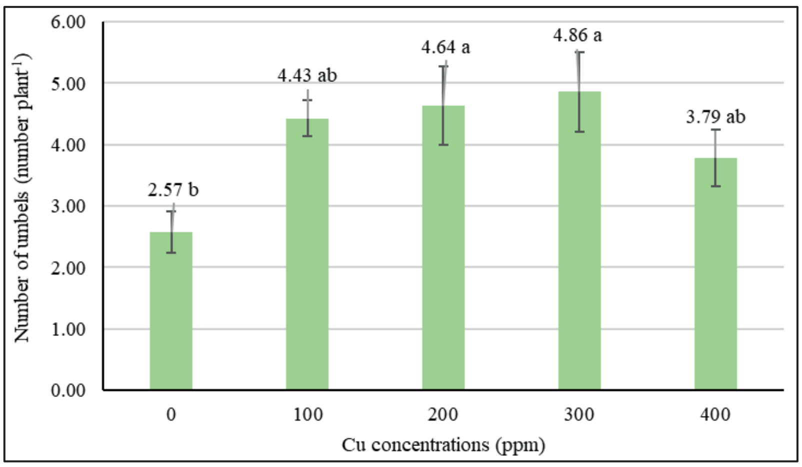

Figure 4. Number of umbels per plant of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

3.5. Number of fruit in the main umbel

According to the results, the effects of Cu concentrations on the number of fruit in the main umbel were statistically significant at the $p<0.01$ level. With the gradually increasing Cu doses, the number of fruit in the main umbel also increased (37.86) on 300 ppm Cu. Similar to other parameters, at 400 ppm Cu, the number of fruit in the main umbel was also started to decrease (28.79) (Figure 5). Sönmez et al. (2008), reported a decrease in the number of fruits in tomato with increased application of Cu in the soil, while, Moreira et al. (2019a), reported that increasing Cu doses (0, 1, 2, 4, and 8 kg ha^{-1}) had significant effects on the number of pod per plant in soybean and the highest value was obtained from the application of 4 kg Cu ha^{-1}. Mahendran et al. (2021), evaluated *Oryza sativa* with Cu and reported similar results to ours. The researchers stated that Cu concentrations increased the number of grains compared to control, and this was due to the positive effect of Cu on pollen viability and productivity which also implicated the importance of dose assessment on Cu application.

Not only excess Cu, but also Cu deficiency affects the development of the plant, causes a decrease in the number of flowering, and prevents the blooming of flowers (Broadley et al., 2012). Reuters et al. (1981) reported that copper deficiency indirectly causes a decrease in polyphenol oxidase activity and affects plant development. Additionally, Broadley et al. (2012) reported that Cu deficiency affects grain, seed, and fruit formation more strongly than vegetative growth, and the main reason for this is the lack of viability of pollen that causes a decrease in the formation of generative organs in Cu-deficient plants. While as an element, Cu is required by plants in very small

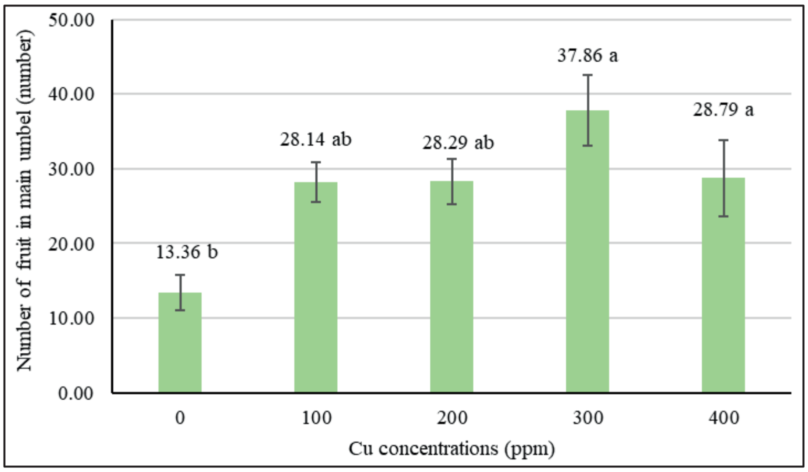

Figure 5. Number of fruit in main umbel of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

amounts, it is important in regulating plant growth and development, including chlorophyll formation and seed production (Nguyen et al., 2021).

3.6. Plant fresh weight

In the current study, the highest plant fresh weight was obtained with 4.12 g in 300 ppm Cu application, followed by 3.36 g on 200 ppm Cu and 3.19 g on 100 ppm Cu. The lowest plant fresh weight values (2.33 g) were obtained on control plants (0 ppm Cu). The difference between Cu doses was found to be statistically significant at the $p<0.05$ level (Figure 6). In previous reports, shoot and root biomass were decreased with increasing Cu concentration in tomato (*Solanum lycopersicum*) (Karataglis and Babalonas, 1985). Hydroponically applied Cu (for five days) decreased the fresh plant weight (Thounaojam et al., 2012) in rice (*Oryza sativa* L.), and in coriander, it hasbeen reported that copper sulfate applied to the soil at different rates (0, 100, 200 ppm) reduced the fresh above-ground biomass (Bayraktar, 2012). When we compared previous reports with our findings, it is clear that the effects of Cu is different depending on Cu doses, application methods as well as plant species. Indeed, Raskin and Ensley (1999), Gharbi et al. (2005), and Verma et al. (2011) reported that metal tolerance and mechanisms of action vary according to plant species.

3.7. Plant dry weight

In this study, the dry weight of the above-ground parts of the coriander showed statistically significant variation at the $p<0.01$ level, compared to the control. While the mean dry weight of the plants was 0.239 g in the control, the dry weight of Cu applied plants were varied between 0.435-0.550 g per plant depending on the Cu doses (Figure 7). Previous reports with rice and beans (Fageria, 2002), sweet basil (Ghorbanpour et al., 2016), and

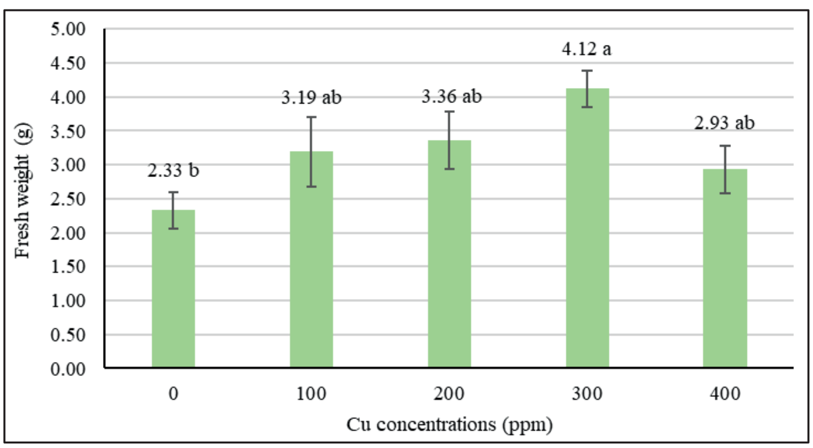

Figure 6. Fresh weight of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

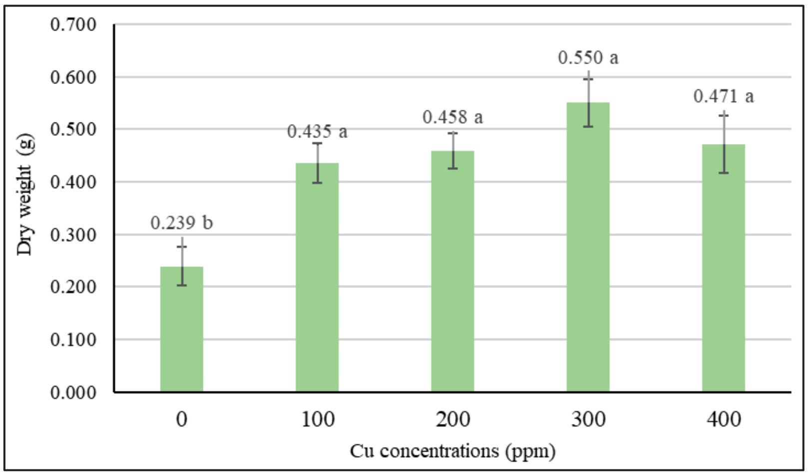

Figure 7. Dry weight of coriander exposed to different Cu concentrations*

*: Results are means±standard deviation

soybean (Moreira et al., 2019b), showed that up to a certain Cu dose, increasing concentrations improved shoot dry weight, however, biomass accumulation was reduced at higher doses. The study conducted with *Brassica juncea* reported that increased Cu applications increased shoot dry weight as well (Chigbo et al., 2013).

As a micronutrient, Cu is required for plants at an optimum level; while Its high concentrations reduce plant growth and development, and inhibit photosynthesis and reduce root and leaf growth (Kafkasyalı, 2021). On the other hand, Cu deficiency can affect plant development negatively. Since copper is considered an essential micronutrient at low doses and does not have toxic effects within acceptable limits, therefore, it is important to establish adequate limits for Cu in soil (Okcu et al., 2009).

4. Conclusions

In current study, coriander was exposed to different Cu doses, and according to the results; the application of various Cu concentrations affected plant height, number of umbrellas per plant, number of fruits in the main umbrella, and plant fresh and dry weight values significantly compared to control. In these parameters, Cu had positive and significant effects up to 300 ppm, and after this dose, a slight decrease occurred at 400 ppm Cu dose. While control and Cu applications showed distinct differences for these parameters, in different Cu doses, the differences were not sharp. This may arise from the soil's available Cu levels and tolerance of the plant. Our findings are also important to show that coriander can tolerate Cu application up to 300 ppm dose and can be subjected to phytoremediation programs in Cu-contaminated areas.

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