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RESEARCH ARTICLE

Effect of composted organic amendments and zinc oxide nanoparticles on growth and cadmium accumulation by wheat; a life cycle study

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Abstract
Cadmium (Cd) availability in arable soils is a serious issue while little is known about the role of co-composted organic amendments and zinc oxide nanoparticles (ZnO-NPs) foliar spray on biomass and Cd accumulation in wheat grains. The current study investigated the soil application of organic amendment (composted biochar and farmyard manure) at a level of 0, 1, and 2% w/w and foliar spray of ZnO-NPs (0, 100, and 200 mg/L) on biomass, yield, and Cd in wheat grains cultivated in an aged Cd-contaminated agricultural soil. The results indicated that organic amendment increased the biomass, chlorophyll concentrations, yield, and activities of peroxidase and superoxide dismutase of wheat while decreased the electrolyte leakage and Cd concentrations in different parts of wheat such as shoots, roots, husks, and grains. This effect of organic amendment was further enhanced by the foliar spray of ZnO-NPs in a dose-additive manner. Cadmium concentration in grains was below threshold level (0.2 mg/kg DW) for cereals in combined application of 200 mg/L ZnO-NPs and 1% organic amendment as well as in higher treatment (2%) of organic amendment and NPs. Thus, combined use of organic materials and NPs might be a suitable way of reducing Cd and probably other toxic trace element concentrations in wheat and other cereals.

Keywords Biochar · Compost · Nanoparticles · Cadmium · Wheat

Introduction

Heavy metals make their way to ecosystem by human activities such as sewage sludge, mining, industrial processes, and vehicular emission (Gallego et al. 2012). Heavy metals caused negative effects on morphological, physiological and biochemical processes occurring in plants (Ali et al. 2015). The main route of toxic trace element entrance to the living organisms is via crops grown in contaminated soil (Gallego et al. 2012; Rizwan et al. 2015). Cadmium (Cd), among other heavy metals, is toxic trace element for crops as it has no known role in plants (Bayçu et al. 2017) and animals (Chaney 2015). Cadmium mainly accumulates in the human body through food chain (Beccaloni et al. 2013; Rizwan et al. 2019a) and results in various diseases in humans such as *Itai-Itai*, nephrotoxicity, and cancer (Khan et al. 2016). Cadmium also disturbs crop growth by altering ultra-structures and reducing chlorophyll biosynthesis (Wang et al. 2015) and gas exchange characteristics (Li et al. 2015). The Cd is the cause of oxidative burst in plants by generating reactive oxidative species (ROS) and caused electrolyte leakage through membrane burst (Nagajyoti et al. 2010) and weakens the defense system of plants which caused the reduction of enzymatic and nonenzymatic antioxidants (Abbas et al. 2018). The abovementioned effects of Cd on plants and humans force the management of

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Cd-contaminated soil for crop growth as contaminated soils should be cultivated to feed the ever-increasing population.

Wheat is staple food of half of the population of the world and is the most essential part of human diet. In 2013, the production of wheat was 318 MT in Asia and 713 MT in the whole world. The production of wheat was approximately 24.23 MT in Pakistan during the year 2013, which placed this country among top 10 wheat-producing countries (FAO 2014). Literature showed that wheat can uptake Cd, and it becomes part of the food chain via wheat and its products (Naeem et al. 2015; Abbas et al. 2018). Toxic effects of heavy metals mainly depend on their bioavailability to plants (Li et al. 2015; Abbas et al. 2018). There is crucial demand to alleviate Cd toxicity in crops by using environmental friendly techniques.

There are several organic amendments which can reduce availability of heavy metals to crops (Buss et al. 2012; Major et al. 2012; Rizwan et al. 2016). Biochar is organic in nature prepared from the dried biomass at higher temperature and limited oxygen (Ali et al. 2017). Biochar can enhance soil nutrients either by providing nutrients itself or by changing the nutrient cycle and improve the plant growth simultaneously (Haider et al. 2015; Rizwan et al. 2016). Biochar increased the soil pH and decreased the metal uptake by crops (Rehman et al. 2016). Biochar application decreased the heavy metals such as As in tomato (Waqas et al. 2015) and Zn in soybean (Waqas et al. 2014) and lead (Pb) in maize (Almaroai et al. 2014). Biochar may improve plant growth by improving physiochemical and biological properties (Rizwan et al. 2016; Seneviratne et al. 2017). Studies demonstrated that Cd mobility and Cd accumulation in grains reduced by biochar amendment in soil (Bian et al. 2016; Abbas et al. 2018). Biochar is efficient in minimizing heavy metals in crops but high cost of biochar production makes it less suitable amendment (Sohail et al. 2020) which may require more research related to biochar modification or its use in combination with other suitable amendments.

The application of compost as an organic soil amendment has been shown to increase the soil productivity and plant growth (Qayyum et al. 2017). The supply of biochar and compost improved the nutrient availability and peanut growth (Agegnehu et al. 2015). Biochar can be co-composted with other organic amendments such as farmyard manure (FYM) (Qayyum et al. 2017). Use of biochar and FYM after co-composting increased the yield while diminished the Cd concentrations in grains of wheat (Bashir et al. 2020). The findings of the study highlighted that the highest ratio of biochar in the compost was effective as compared to lower ratios of biochar in decreasing Cd concentration in grains (Bashir et al. 2020) which may increase the cost of production. Thus, a lower ratio of biochar in the composted material combined with other suitable materials might be a suitable amendment for using in metal-contaminated soils.

Zinc (Zn) is among the micronutrients required for proper growth of living organisms (Cakmak and Kutman 2018; Wang et al. 2018). Human deficits with Zn can face various health problems because about 10% protein in humans is based on Zn (Krężel and Maret 2016). Proper level of soil Zn is beneficial for adequate plant growth, and this Zn level could also minimize the Cd uptake by crops (Rizwan et al. 2019a). Zinc and Cd have similar properties and are antagonistic in nature (Rizwan et al. 2019a; Saifullah et al. 2016). Soil type and cultivar type along with soil pH affect availability of Zn and its toxicity (García-Gómez et al. 2018). Foliar treatment of micronutrients including Zn can increase the Zn concentrations in plants as the soil application of micronutrient might be less available to plants especially in high pH soils. Foliar treatment of Zn might be favorable in reducing Cd toxicity (Saifullah et al. 2016). Zinc can be applied through different forms and recently Zn in the form of nanoparticles (NPs) is of high attention due to their excessive use in the agriculture sector (Liu and Lal 2015; Sturikova et al. 2018). The NPs can be a source of nutrients for their controlled release in the medium, considerably micronutrients as the plants need only a minute portion of these nutrients which may restrict their entrance to the surrounding environmental partitions (Tripathi et al. 2015; Dimkpa et al. 2017). Zinc can be supplied to plants through different form including NPs (Sturikova et al. 2018; Taran et al. 2017). It has been described that zinc oxide nanoparticles (ZnO-NPs) minimized the Cd content in wheat tissues (Hussain et al. 2018) and minimized the oxidative burst in plant parts (Venkatachalam et al. 2017). In previous studies, ZnO-NPs combined with biochar decreased Cd concentration in rice (Ali et al. 2019) and maize (Rizwan et al. 2019b) in a short growth period. However, little is known about the role of ZnO-NPs and composted organic amendments on yield and Cd concentrations in tissues especially in grains. It was hypothesized that composted material of FYM and biochar along with foliar spray of ZnO-NPs might be a suitable approach in reducing Cd uptake by wheat. Thus, the experiment was designed to highlight the efficiency of organic amendments (co-composted biochar with FYM) and foliar spray of ZnO-NPs on growth, yield, and Cd concentrations in wheat grains in a complete life cycle study.

Materials and methods

Compost, ZnO-NPs, and soil

Garden peat feedstock was used for the preparation of biochar as described by Qayyum et al. (2017) and co-composting of biochar with FYM was done with 75% FYM and 25% biochar as reported by Qayyum et al. (2017). In brief, mixed ratio of biochar and FYM was placed as above ground piles and composting was performed for 2.5 months by mixing the materials at specific intervals. After this, the composted material was analyzed for pH, EC, ash and nitrogen (N) levels. The composted biochar and FYM has a pH, EC, ash, and N values of 8.81, 0.464 dS m^{-1}, 40.9%, and 3.73%, respectively. Commercially available ZnO-NPs were obtained from Alfa Aesar. The purity of these ZnO-NPs was 99% with a size of 20–30 nm APS powder and 5.606 g/cm^3 density.

Soil was sampled from arable field irrigated with sewage water since 30 years and contaminated mainly with Cd. Soil selected characteristics have been summarized in previous study (Khan et al. 2019). Soil pH, EC, total Cd, and available Cd were 7.71, 2.01 dS m^{-1}, 7.65 mg/kg, and 1.21 mg/kg, respectively.

Experimental setup

A trial was conducted in a botanical garden by using 5.0 kg of air-dried soil per pot under ambient conditions. Compost, as an organic amendment, was mixed (0, 1.0, and 2.0% w/w) in the soil before 1 week of seed sowing and soil was irrigated with water. Seeds were sown in the soil when the soil attained a proper soil moisture (about 65–75% WHC). Wheat (CV. Lasani-2008) seeds were first sterilized with hydrogen peroxide and carefully washed with dH_2O then was sown in a soil. Five seedlings were maintained in each pot after 7 days of germination. Fertilizers of N, potassium, and phosphorus were added in pots after thinning the seedlings. Different levels of ZnO-NPs (0, 100, and 200 mg/L) were applied through foliar spray after 4th, 6th, and 8th weeks of sowing the seeds. Control plants were sprayed with dH_2O and each time a fresh solution of NPs was prepared by mixing the calculated quantity of NPs through sonication. Total volume used per treatment for all four replicates was 1.0 L.

Plant harvesting and data collection

After 122 days of sowing, plants were harvested and separated into shoots, roots, husks, and grains. Physiological parameters such as plant height and length of spikes were noted before harvesting by meter-scale. After oven drying at 70 °C, the samples were weighted, ground, and stored for Cd measurement.

Determination of EL, antioxidant enzymes, and chlorophyll contents

After 10 weeks of sowing, the leaf samples were sampled for the estimation of electrolyte leakage (EL), peroxide (POD), superoxide dismutase (SOD) activities, and chlorophyll concentrations. For EL measurement, 1.0 g of leaves were cut and placed into 8.0 ml of deionized H_2O. Tubes with samples were put in water-bath for 2 h at 32 °C, and initial electrical conductivity (EC) denoted as EC1 was noted. At that point, cylinders were set in autoclave for 20 min at 121 °C, and EC termed as EC2 were noted. EL was measured by using following formulae (Dionisio-Sese and Tobita 1998).

$$EL = (EC1/EC2) \times 100$$

Fresh leaf samples were ground in cooled pestle motor and then placed in phosphate buffer (pH 7.8). The solution was centrifuged at 12,000 rpm for 20 min under 4 °C, and supernatant was collected and placed at 4 °C. Peroxide and SOD activities were measured by using Zhang (1992) method. To analyze the chlorophyll content, leaves were soaked in 10 ml of 85% v/v acetone by putting the samples without direct light. Supernatants were centrifuged at 4000 rpm for 10 min. After centrifugation, estimations were taken with the assistance of spectrophotometer at three absorbance wavelengths of 450, 650, and 663 nm (Lichtenthaler 1987).

Measurement of Cd concentration in wheat tissues, soil, and soil pH

The grinded plant material of 0.5 g each was placed in conical flask and added the acids with 1:3 ratios of $HClO_4$ and HNO_3 to the flasks and left for about 24 h. Flasks were transferred on hot plate for 2 h, and finally dH_2O was used for making required volume. Soil was collected from the pots after harvesting the plants and bioavailable Cd was extracted with AB-DTPA solution. Soil pH was estimated after mixing the soil in water with a ratio of 1:2.5 and shaking for 2 h. Determination of Cd concentration was done with atomic absorption spectrophotometer (novAA-350). Total Cd uptake by tissues was calculated by multiplying the biomass with the Cd concentration in that tissue.

Statistical analysis

The obtained data were analyzed by two-way ANOVA at 5.0% probability by using SPSS. The multiple comparisons of mean data were analyzed with Tukey's post hoc test.

Results

Plant growth and chlorophyll content

The results highlighting the impacts of compost and ZnO-NPs on growth and biomass have been reported in Figs. 1 and 2. Compost, ZnO-NPs and their combination greatly affected the plant growth parameters. The lowest values of all growth parameters (height of plants, length of spikes, and dry biomasses of shoot, root, husk, and grains) were observed in control treatment where no amendments were applied. The growth parameters were gradually increased with increasing concentration of the compost and foliar

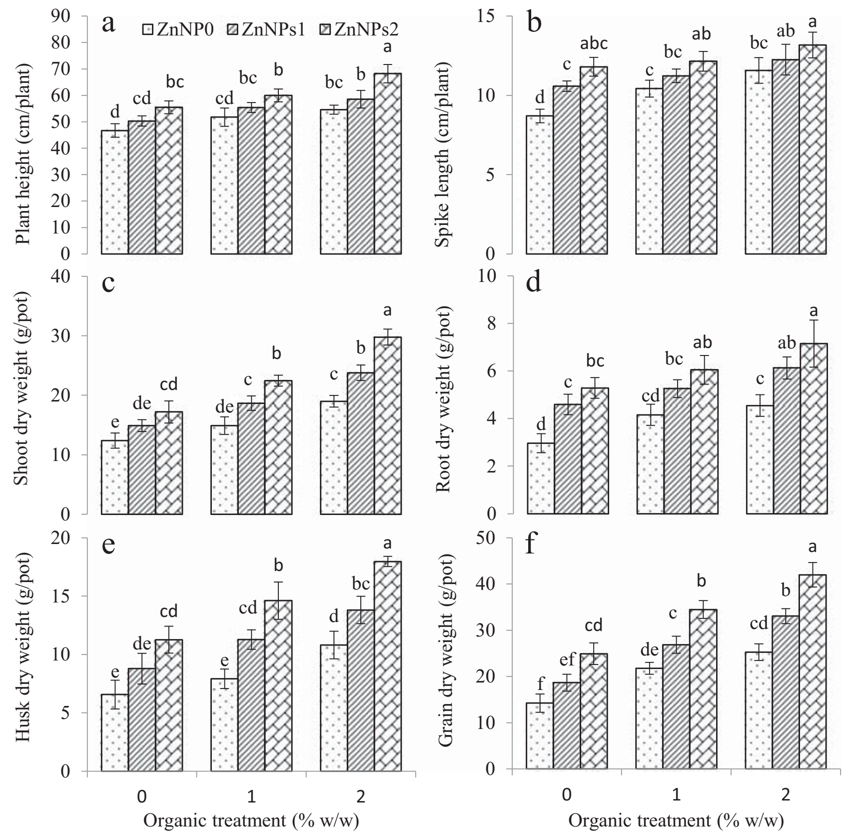

Fig. 1 Effect of soil applied organic amendment and foliar application of ZnO-NPs on plant height (**a**), spike length (**b**), and dry weights of shoots (**c**), roots (**d**), husk (**e**), and grains of wheat (**f**). The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

spray of ZnO-NPs. However, the maximum plant heights were seen in those pots which were amended with the highest level of compost and foliar spray of ZnO-NPs as compared to control. Compost significantly increased the spike length, root and shoot dry weight, whereas foliar spray of ZnO-NPs further increased the spike length and plant biomass than their respective treatment without NPs. Wheat husk and grain dry weight increased by 59.5% and 68.5% than control in those treatments which were amended with the highest level of compost (2%) and foliar application of ZnO (200 mg/L).

Chlorophyll and carotenoid content showed a significant increase either by application of compost alone or combined with ZnO-NPs in comparison with control (Fig. 2). The highest values of chlorophyll *a*, *b* and carotenoids were found in the highest level of compost (2%) and ZnO-NPs (200 mg/L) together and the lowest values of these attributes were reported in control. The concentration of chlorophyll *a* in both high levels of compost and ZnO NPs increased by 51.7% and 37%, respectively. Chlorophyll *b* was increased by 30% in the lowest level and 51.7% in the highest level of ZnO-NPs with no compost; however, carotenoids were increased by 83% in leaves amended with the highest level of both compost and ZnO-NPs (Fig. 2c).

Electrolyte leakage and SOD and POD activities

The effects of compost and ZnO-NPs on EL in leaves of wheat under Cd stress have been illustrated in Fig. 3a. The highest values of EL were recorded in control while the lowest values were recorded in plants grown in the highest compost and ZnO-NP treatments. The application of compost decreased the EL in leaves, and this decrease was further enhanced by applying foliar spray of NPs. The ZnO-NPs alone reduced EL by 35.2% while this reduction was pronounced with the increasing level of compost and NPs together in growth medium. The variation in POD and SOD activities are described in Fig. 3b, c. The SOD and POD activities were enhanced under different levels of compost and NPs. The activity of antioxidant enzymes was higher in plants grown in the highest level of compost and supplied with high levels of NPs. The SOD activity was increased by 50.3% in plants supplied with NPs alone, but it tends to increase by 71.7% in wheat plants grown in the highest level of compost and supplied with the highest level of NPs when compared with the control. Compost and NPs together showed a significant increase in POD in wheat plants relative to control. The negative correlation was recorded between EL and growth attributes and positive correlation was recorded between EL and Cd concentrations in various tissues (Table 1).

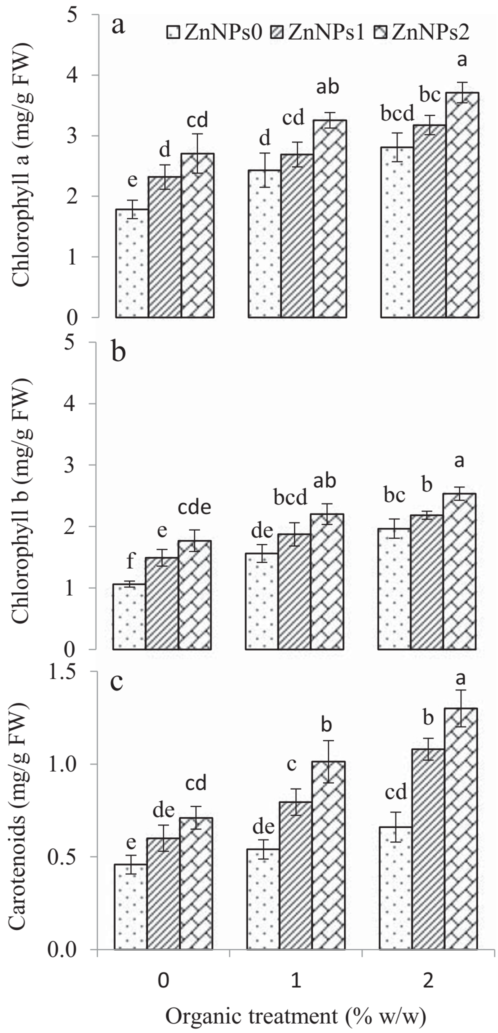

Fig. 2 Effect of soil applied organic amendment and foliar application of ZnO-NPs on chlorophyll *a* (**a**), chlorophyll *b* (**b**), and carotenoid (**c**) concentrations in leaves of wheat. The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

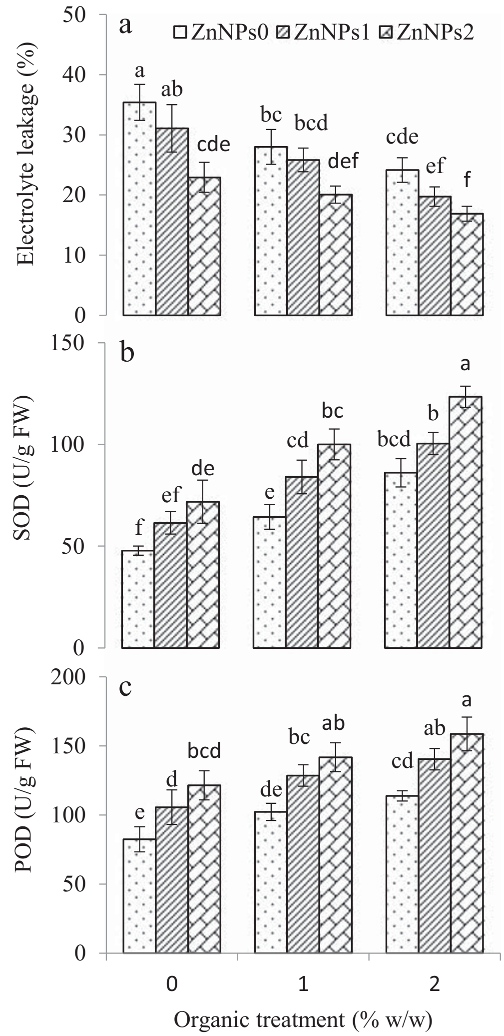

Fig. 3 Effect of soil applied organic amendment and foliar application of ZnO-NPs on electrolyte leakage (**a**), SOD (**b**), and POD (**c**) activities in leaves of wheat. The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

Cadmium concentration in wheat tissues

The results about effects of ZnO-NPs and compost on Cd contents in plants have been summarized in Fig. 4. The highest Cd concentration was recorded in control while the lowest Cd was observed in plants amended with the highest levels of both compost and NPs. Foliar application of ZnO-NPs (100 and 200 mg/L) minimized the Cd concentration in shoots by 14.5% and 26.2%, respectively. The application of 2% compost + 200 mg/L NPs decreased the Cd in shoots by 30.8% over the control. Similar trends were observed for the Cd concentrations in roots, grain and husk of wheat plants. The negative correlations were recorded between Cd concentrations in different tissues to the biomass of the respective tissues (Table 1).

Cadmium total uptake by different parts of the wheat varied with the applied amendments (Fig. 5). In general, total Cd uptake by shoot, root, and husks was higher in the applied treatments than control while grain total Cd uptake varied with the amendment levels. Shoot total Cd uptake did not significantly vary with the amendments. Root total Cd uptake increased with either NPs alone or in combination with compost. The highest shoot total Cd uptake was recorded in the highest NPs and compost treatment while the highest root Cd uptake was recorded in 1% compost + 200 mg/L NP treatment. Total Cd uptake by grains slightly decreased at the highest compost along with NPs treatments.

Table 1 Correlation coefficient between different parameters

Parameters	Plant height	Spike length	Shoot DW	Root DW	Husk DW	Grain DW	Chl a	Chl b	Car	Shoot Cd	Root Cd	Husk Cd
Plant height	1											
Spike length	0.787**	1										
Shoot DW	0.883**	0.781**	1									
Root DW	0.867**	0.774**	0.859**	1								
Husk DW	0.877**	0.802**	0.904**	0.853**	1							
Grain DW	0.913**	0.821**	0.945**	0.903**	0.925**	1						
Chl *a*	0.850**	0.782**	0.935**	0.844**	0.884**	0.924**	1					
Chl *b*	0.840**	0.834**	0.926**	0.864**	0.876**	0.933**	0.939**	1				
Car	0.854**	0.735**	0.940**	0.866**	0.924**	0.914**	0.887**	0.875**	1			
Shoot Cd	− 0.833**	− 0.789**	− 0.877**	− 0.836**	− 0.869**	− 0.891**	− 0.893**	− 0.894**	− 0.854**	1		
Root Cd	− 0.823**	− 0.813**	− 0.871**	− 0.771**	− 0.849**	− 0.843**	− 0.845**	− 0.827**	− 0.809**	0.835**	1	
Husk Cd	− 0.768**	− 0.762**	− 0.860**	− 0.728**	− 0.788**	− 0.864**	− 0.847**	− 0.856**	− 0.779**	0.790**	0.839**	1
Grain Cd	− 0.786**	− 0.842**	− 0.859**	− 0.810**	− 0.854**	− 0.855**	− 0.843**	− 0.877**	− 0.829**	0.812**	0.857**	0.836**
Shoot Cd uptake	0.414*	0.408*	0.576**	0.379*	0.390*	0.456**	0.473**	0.482**	0.485**	− 0.164	− 0.414*	− 0.552**
Root Cd uptake	0.496**	0.449**	0.414*	0.765**	0.458**	0.538**	0.470**	0.534**	0.498**	− 0.499**	− 0.215	− 0.32
Husk Cd uptake	0.154	0.231	0.037	0.242	0.342*	0.114	0.115	0.113	0.191	− 0.218	− 0.056	0.232
Grain Cd uptake	− 0.043	− 0.112	− 0.185	− 0.033	− 0.148	0.004	− 0.036	− 0.052	− 0.18	− 0.01	0.3	0.093
EL	−0.789**	− 0.811**	− 0.822**	− 0.819**	− 0.838**	− 0.875**	− 0.809**	− 0.846**	− 0.816**	0.807**	0.783**	0.792**
SOD	0.889**	0.811**	0.949**	0.869**	0.887**	0.936**	0.902**	0.953**	0.903**	− 0.876**	− 0.844**	− 0.832**
POD	0.817**	0.783**	0.908**	0.856**	0.888**	0.887**	0.914**	0.902**	0.949**	− 0.852**	− 0.756**	− 0.805**
Soil Cd	− 0.860**	− 0.855**	− 0.864**	− 0.862**	− 0.897**	− 0.930**	− 0.878**	− 0.873**	− 0.865**	0.891**	0.783**	0.786**
Soil pH	0.528**	0.576**	0.647**	0.527**	0.563**	0.660**	0.643**	0.721**	0.564**	− 0.699**	− 0.585**	− 0.682**

Parameters	Grain Cd	Shoot Cd Uptake	Root Cd Uptake	Husk Cd Uptake	Grain Cd Uptake	EL	SOD	POD	Soil Cd	Soil pH
Plant height										
Spike length										
Shoot DW										
Root DW										
Husk DW										
Grain DW										
Chl *a*										
Chl *b*										
Car										
Shoot Cd										
Root Cd										
Husk Cd										
Grain Cd	1									
Shoot Cd uptake	− 0.520**	1								
Root Cd uptake	− 0.433**	0.101	1							

Table 1 (continued)

Husk Cd uptake	−0.158	−0.312	.349*	1						
Grain Cd uptake	0.393*	−0.377*	0.307	−0.006	1					
EL	0.884**	−0.421*	−0.526**	−0.164	0.125	1				
SOD	−0.862**	0.515**	0.491**	0.104	−0.125	−0.838**	1			
POD	−0.831**	0.514**	0.581**	0.191	−0.077	−0.828**	0.894**	1		
Soil Cd	0.845**	−0.328	−0.569**	−0.268	0.01	0.838**	−0.868**	−0.867**	1	
Soil pH	−0.674**	0.29	0.289	−0.058	−0.036	−0.653**	0.724**	0.613**	−0.615**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Soil bioavailable Cd and pH

The data about postharvest soil Cd and pH of soil are illustrated in Fig. 6. The concentration of bioavailable Cd in soil decreased with application of compost and foliar application of ZnO-NPs. The highest and lowest concentrations of Cd were found in control and 2% compost + 200 mg/L ZnO-NP treatment, respectively. The spray of ZnO-NPs decreased bioavailable Cd in soil, but it was further decreased by application compost and NPs together. Foliar spray of NPs did not affect the soil pH while compost treatments significantly increased the soil pH compared to the amendment without compost irrespective of NP treatments. Soil bioavailable Cd negatively correlated between plant biomasses and positively correlated with the tissue Cd concentrations (Table 1).

Discussion

The main aim of this experiment was to explore the ameliorative efficiency of ZnO-NPs combined with compost which was prepared with FYM and biochar at a ratio of 75% and 25%, respectively. The lower biomass and growth were recorded in the control plants (Fig. 1). Excess of Cd may cause disorders in plants which may damage the photosynthetic machinery and resultantly reduced the plant growth (Rizwan et al. 2019a). However, the Cd contents in wheat tissues were not too high and the biomass was not much suffered while the higher dry weight under the amendments may be not only due to lower Cd contents in tissues (Fig. 4) but due to the provisions of nutrients by the compost (Rehman et al. 2016) and higher Zn contents in plants under the ZnO-NP treatments (Rizwan et al. 2019b). The foliar NPs alone improved the plant biomass (Fig. 1). The studies demonstrated that foliar spray of ZnO-NPs on foxtail millet at field level improved the plant physiological properties and nutritional parameters of grains (Kolencik et al. 2019). The compost application alone also improved the growth and yield of wheat (Fig. 1). Studies reported that co-composted biochar improved the growth of crops (Agegnehu et al. 2015, 2017; Kammann et al. 2015).

Our results demonstrated that co-application of NPs and composted material further enhanced the growth and yield of wheat over the control and NPs alone (Fig. 1). Previously reported that simultaneous supply of biochar and foliar ZnO-NPs improved the growth of rice (Ali et al. 2019) and maize (Rizwan et al. 2019b). In another study, composting of biochar with FYM was performed to enhance the efficiency of biochar and FYM and the results demonstrated that the highest biomass was observed in the treatment with the highest ratio of biochar in the compost (Bashir et al. 2020). To make the composting material more feasible, we have applied the composted material with lower ratio of biochar

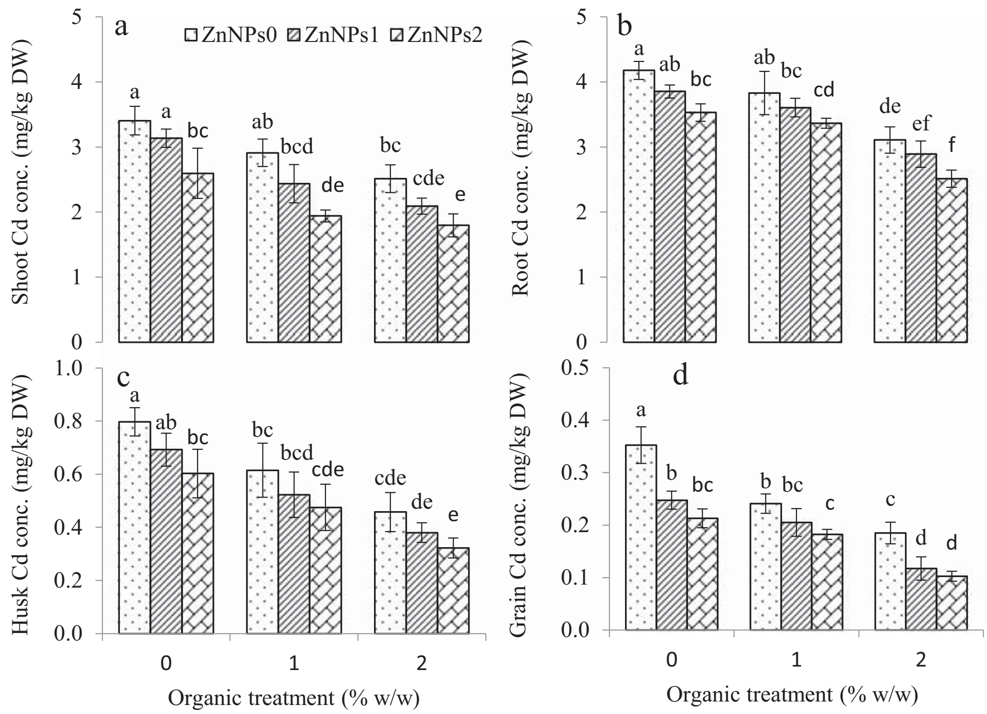

Fig. 4 Effect of soil applied organic amendment and foliar application of ZnO-NPs on Cd concentrations in shoots (**a**), roots (**b**), husk (**c**), and grains (**d**) of wheat. The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

along with ZnO-NPs for the reduction of Cd mobility in the soil by the compost and its competition with similar element Zn in the plants as Rizwan et al. (2019a) reviewed that Cd and Zn has antagonistic effects on each other in the plants and soil. The highest values of growth and biomass were observed in the highest levels of NPs and compost (Fig. 1) which depicted that this might be due to the provision of nutrients to the plant which favored the growth.

The level of chlorophyll contents in leaves of the plants is one of the important parameters under stressful environments (Rizwan et al. 2016). Our study demonstrated that amendments increased the chlorophyll contents in leaves under Cd

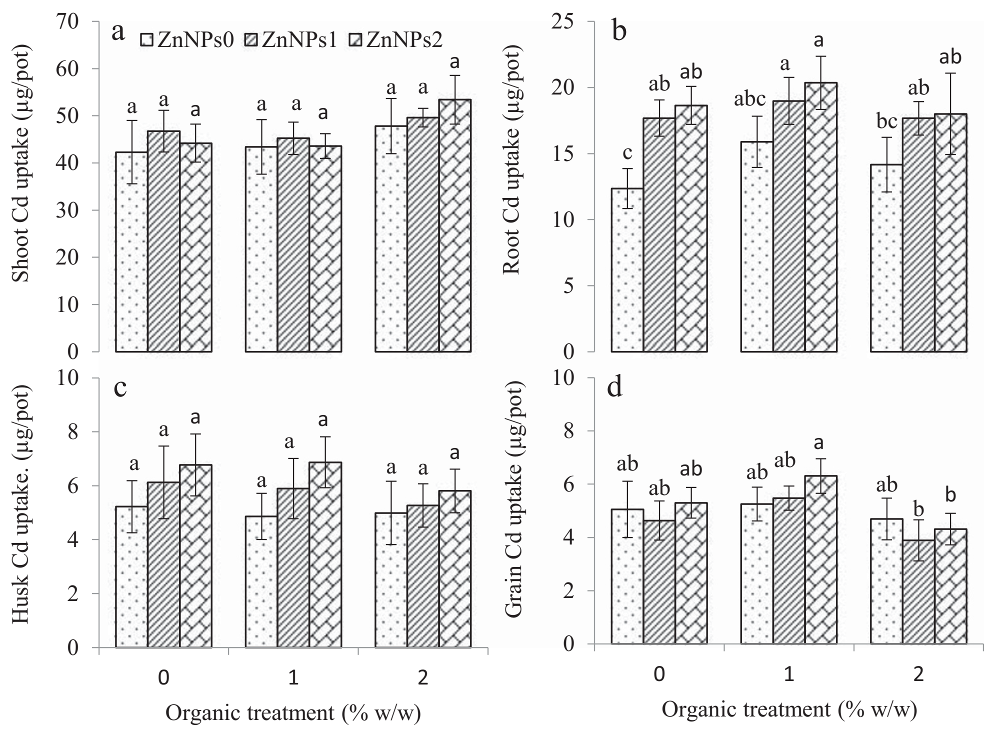

Fig. 5 Effect of soil applied organic amendment and foliar application of ZnO-NPs on Cd uptake by shoots (**a**), roots (**b**), husk (**c**), and grains (**d**) of wheat. The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

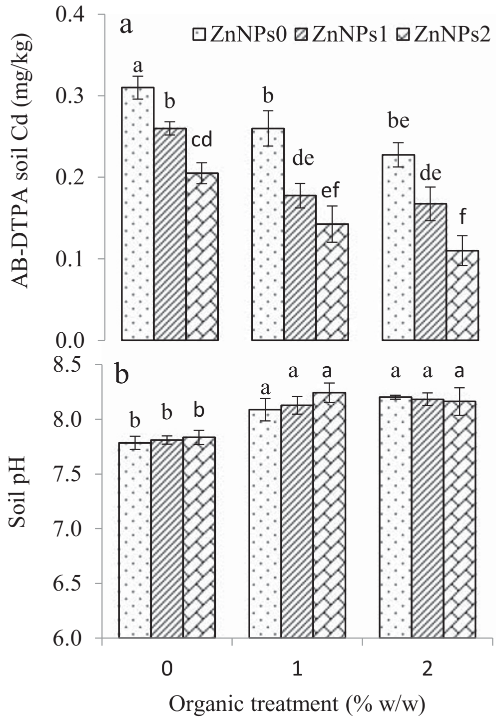

Fig. 6 Effect of soil applied biochar and foliar application of ZnO-NPs on postharvest soil AB-DTPA extractable Cd (**a**) and soil pH (**b**). The bars represent the mean values of four replicates ± standard deviation. The different letters on the bars represent the significant differences between treatments by Tukey's HSD test at $P \leq 0.05$. ZnNPs = 0, ZnNPs1 = 100 mg/L, and ZnNPs2 = 200 mg/L of ZnO-NP concentrations

stress (Fig. 2). Co-composted biochar and FYM improved the chlorophyll contents in Cd-stressed wheat (Bashir et al. 2020) and FYM and compost application improved the chlorophyll contents in Ni-stressed maize (Rehman et al. 2016). Foliar application of ZnO-NPs improved the chlorophyll contents in maize (Rizwan et al. 2019b). These higher contents of chlorophyll contents might be associated with the higher contents of nutrients in plant tissues under the applied amendments (Rehman et al. 2016) or lower Cd contents (Fig. 4).

The plants can cope with toxic metals by the stimulation of defense system. Our results depicted that the applied amendments decreased the leaf EL and improved the selected antioxidant enzyme activities in leaves (Fig. 3). Published studies reported that ZnO-NPs decreased the oxidative stress in plants (Venkatachalam et al. 2017; Rizwan et al. 2019b). The compost application diminished the oxidative stress in wheat under Cd (Bashir et al. 2020). This stimulation in defense system might be due to excess Cd in plants (Fig. 4).

Foliar spray of NPs minimized the Cd concentrations in wheat and this effect was further enhanced with the combined application of compost and NPs (Fig. 4). Published report highlighted that FYM, biochar, and compost application decreased the Ni concentration in maize (Rehman et al. 2016). The use of green waste compost and biochar decreased Pb and Cu mobility and their uptake by ryegrass (Karami et al. 2011). The biochar and compost mixture immobilized the heavy metals in the soil (Karer et al. 2015). Foliar spray of ZnO-NPs minimized the Cd in plants (Hussain et al. 2018; Ali et al. 2019). The reduced Cd in plant parts with the amendments may be due to the dual impacts of both amendments as the ZnO-NPs supplied Zn to plants (Rizwan et al. 2019b), and this increase in Zn contents may counteract Cd entrance in the plants and the compost application in the soil decreased the bioavailable Cd (Fig. 6a) which is due to rise in soil pH (Fig. 6b). Our results indicated that total Cd uptake by different parts was higher under the applied treatments than control except total Cd uptake in grains in the highest NPs and compost treatment (Fig. 5). This higher total Cd uptake by plants indicates a dilution effect which is due to the higher biomass production under the influence of treatments than control which reduced the per unit Cd concentrations while increased the total Cd uptake by plants. This higher Cd total uptake might also be the reason of lower bioavailable Cd in the soil along with other factors such as rise in soil pH.

Conclusion

The lower Cd concentrations in cereal grains are required as the grain Cd exceeds the limits without showing any toxicity symptoms in plants. To combat this problem the utilization of dual techniques required such as foliar spray of ZnO-NPs and soil application of compost presented in this study. The amendments increased the biomass and photosynthesis of wheat and decreased Cd in the plant parts and availability of Cd in the soil. The increase in yield of wheat with lower Cd concentrations in the grains proves the utilization of compost and ZnO-NPs in soils moderately contaminated with Cd. The further in-depth studies using different sizes of NPs and different composting techniques by using various organic materials such as organic wastes are required for better understanding the utilization of this approach at field levels.

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