Journal of Hazardous Materials 191 (2011) 373–379

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Municipal solid waste compost application improves productivity, polyphenol content, and antioxidant capacity of *Mesembryanthemum edule*

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ARTICLE INFO

Article history:
Received 1 December 2010
Received in revised form 22 April 2011
Accepted 23 April 2011
Available online 6 May 2011

Keywords:
Growth
Mesembryanthemum edule
Antioxidant activities
Phenolic compounds
Heavy metals

ABSTRACT

Organic wastes were successfully used as soil amendment to improve agrosystems productivity. Yet, the effectiveness of this practice to enhance plant antioxidant capacities has received little attention. Here, we assess the effect of municipal solid waste (MSW) compost (at 40 t ha^{-1}) on growth, polyphenol contents and antioxidant activities of *Mesembryanthemum edule*. MSW compost application significantly increased the soil contents of carbon, nitrogen, calcium, phosphorus and potassium. This was associated with higher nutrient (N, P, and K) uptake, which likely led to the significant improvement of the plant biomass and relative growth rate (RGR) (+93% on average) as compared to the control. In the same way, the fertilizing effect of the added organic matter significantly enhanced the antioxidant potential *M. edule*, assessed by radical scavenging activity, iron reducing power and β-carotene bleaching capacity. This was associated with significantly higher antioxidant contents, mainly total phenols and flavonoids. Heavy metal (Pb, Cd, Cu, and Zn) concentrations were slightly increased upon compost application, but remained lower than phytotoxic values. Overall, our results point out that short-term MSW compost application at 40 t ha^{-1} is efficient in enhancing the productivity together with the antioxidant potentiality of *M. edule* without any adverse environmental impact.

1. Introduction

Degraded soil quality, as poor surface soil aggregation, high bulk density, low porosity, and slow infiltration, is considered as a major environmental factor restricting plant growth and productivity [1]. This environmental issue, mainly observed in arid and semi-arid areas, is to a great extent due to the scarcity of precipitation and the intensive land exploration. Meanwhile, the growing global demand for food implies the need to increase crop production through specific agricultural fertilization practices. Therefore, there is growing interest in developing simple methodologies to increase the productivity in such affected areas. Various organic amendments, such as manures, have been investigated for their effectiveness in soil remediation [2]. Increasing soil organic matter content through the addition of organic amendments has proven to be a valuable practice for maintaining or restoring soil quality [3]. Interestingly, Hadas and Portnoy [4] showed that a 20-year compost application period (yearly average compost load 15 t ha^{-1}) led to the increase of humus content by 0.4–0.5%. Comparatively, the above-mentioned parameter decreased by 0.5% in the case of inorganic fertilization. Besides improving crop yield, the utilization of organic amendments could be extended to enhance the productivity of plant rich in active substances used as antioxidants, pharmaceutical, and cosmetic industries. Many spontaneous plants contain significant levels of biologically active compounds that provide health benefits and basic nutrition. In the biomedical area, these plants are highly attractive mainly for their bioactive substances used as antioxidant, antimicrobial, antiviral, and anti-tumor drugs [5].

Application of MSW compost has beneficial impacts on soil fertility and physico-chemical properties [6]. MSW compost utilization may promote nutrient availability, plant growth, stimulate respiration, photosynthesis, and chlorophyll content [2]. Interestingly, the yield of the essential oils and main components of medicinal plant *Origanum dictamnus* cultivated on soil amended with organic amendment was increased [7]. Recently, Jin et al. [8], reported higher antioxidant capacities, polyphenol and flavonoid contents of strawberries produced from organic culture compared to conventional culture. Hence, one may reasonably hypothesize that MSW compost could be beneficial for *Mesembryanthemum edule* (*M. edule*) (Aizoaceae family), an edible plant naturally rich in bioactive substances, commonly found in the semi-arid zones of Tunisia [5]. This species is known for its pharmacological potential, mainly as antiseptic poultices for sores, burns, scalds, and as gargled to treat mouth infections [5]. It can also been taken orally to treat dysentery and tuberculosis, and as a diuretic in South African traditional medicine [9]. It is also worth mentioning that a number

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doi:10.1016/j.jhazmat.2011.04.092

Table 1
The characteristics of MSW compost used (means and standard deviations calculated on 3 replications basis).

	MSW compost	Recommended levels[a] of heavy metals for agriculture practices
pH	7.9 ± 0.04	
EC (electrical conductivity) (μS cm^{-1})	$8.1 \times 10^3 \pm 40$	
C (%)	13.0 ± 2.2	
N (%)	1.14 ± 0.06	
C/N	11.4 ± 1.8	
Cu (μg g^{-1})	91.6 ± 13	1000–1750
Pb (μg g^{-1})	251.6 ± 12	750–1200
Cd (μg g^{-1})	3.4 ± 0.3	20–40
Zn	255.5 ± 33	2500–4000

[a] European Economic Community [10].

of phenolic compounds including rutin, hyperoside, quercitrin and kampferol were isolated from *M. edule* shoots [5].

However, the agricultural excessive application of composts and/or their low quality can be environmentally hazardous because of the accumulation of micro-pollutants such as heavy metals (Pb, Cd, Cu, . . .). This aspect must be taken into account to ensure a safe use of this byproduct as a soil conditioner [9].

Interestingly, data related to the impact of the supply of MSW compost on plant phenolic compounds and related risks are relatively scarce. Thus, the main objective of this study was to investigate the impact of MSW compost on the medicinal plant *M. edule*. Plant growth, mineral nutrition, polyphenol contents (total polyphenol, flavonoid, and condensed tannin), antioxidant activities, and Pb, Cd, Cu, and Zn concentrations were emphasized.

2. Material and methods

2.1. Culture conditions and sampling

M. edule plants were collected from Borj-Cedria seashore situated in the North-East of Tunisia (25 km from Tunis). Three cm long-stem segments with one node and two opposite leaves were taken from mother plants, and placed in pots (20 cm diameter and 30 cm height) filled with sandy soil added with 0 t ha^{-1} (control: C) or 40 t ha^{-1} MSW compost (MSW). The compost was prepared at the pilot composting station of Beja (100 km west of Tunis). Preparing MSW compost started by stoking the wastes on big piles for 2 months without any previous treatment. After the non-biodegradable coarse wastes were manually removed, the remaining wastes were crushed and sieved to 40 mm in order to decrease the waste heterogeneity. These wastes were then stocked during 3 months for stabilization. Temperature and humidity were daily controlled. Operations of turning and watering with tap water were generally performed twice monthly depending on the ambient temperature. Finally, the obtained compost was sieved to 10 mm and stored until its application as soil amendment. The characteristics of used compost are summarized in Table 1. The experiment was conducted in greenhouse with mean (night–day) temperatures of 18–25 °C and relative humidity 80–70%. Irrigation frequency was twice a week with tap water. The plants (shoots and roots) were harvested after two months. The fresh weight (FW) was measured immediately, and the dry weight (DW) after 48 h of desiccation in an oven at 60 °C.

2.2. Soil analysis

The soil pH and electric conductivity were determined on a soil suspension (2:5, w/v) by digital pH meter, standard LPH203T, and standard CDRV 62 conductimeter, respectively. Total nitrogen was determined by the Kjeldahl method as recommended by Brookes et al. [11], whereas organic C content was determined by the Anne method [12]. Phosphorus was determined as reported by Tandon et al. [13]. Soluble cation (Ca, Mg, and K) contents were assayed by flame photometry (flame photometer, Corning M410, UK).

2.3. Plant nutrient status and heavy metal accumulation

Shoot and root samples were dried at 60 °C until constant weight, ground, and then used for nutrient and heavy metal analyses. For Na, K, and heavy metals (Pb, Cd, Cu, and Zn), samples were digested in 4/1 (v/v) $HNO_3/HClO_4$ mixture and the element concentrations were determined by flame photometry (case of Na and K) atomic absorption spectrometry (Perkin-Elmer Analyzer) (case of heavy metals). Nitrogen and phosphorus contents were assayed following respectively Kjeldahl and vanado-molybdate [14] methods.

2.4. Measurement of phenolic compounds

2.4.1. Extract preparation

Extracts were obtained by magnetic stirring of 2.5 g dry powder with 25 ml pure methanol for 30 min. Extracts were kept for 24 h at 4 °C, filtered through a Whatman N° 4 filter paper, and were stored at 4 °C until analysis.

2.4.2. Total phenolics content

Total phenolics were assayed using the Folin–Ciocalteu reagent, following Singleton and Rosi's [15] method, based on the reduction of a phosphowolframate–phosphomolybdate complex by phenolics to blue reaction products and slightly modified by Dewanto et al. [16]. An aliquot of diluted sample extract was added to 0.5 ml of distilled water and 0.125 ml of the Folin–Ciocalteu reagent. The mixture was shaken and allowed to stand for 6 min, before addition of 1.25 ml of 7% Na_2CO_3. The solution was then adjusted with distilled water to a final volume of 3 ml and mixed thoroughly. After incubation in dark, the absorbance at 760 nm was read versus the prepared blank. Total phenolic content of plant shoots was expressed as milligrams of gallic acid equivalents per gram of dry weight (mg GAEg^{-1} DW) through the calibration curve with gallic acid. All samples were analyzed in three replications.

2.4.3. Total flavonoid content

Total flavonoids were measured using a colorimetric assay developed by Dewanto et al. [16]. An aliquot of diluted sample or standard solution of (+)-catechin was added to 75 μl of $NaNO_2$ solution (7%), and mixed for 6 min, before adding 0.15 ml $AlCl_3$ (10%). After 5 min, 0.5 ml of 1 M NaOH solution was added. The final volume was adjusted to 2.5 ml, thoroughly mixed, and the absorbance of the mixture was determined at 510 nm. Total flavonoids were expressed as mg (+)-catechin equivalent g^{-1} DW (mg CE g^{-1} DW), through the calibration curve of (+)-catechin (0–400 μg ml^{-1} range). All samples were analyzed in three replications.

2.4.4. Total condensed tannins

Procyanidins were measured using the modified vanillin assay described by Sun et al. [17]. Three millilitres of 4% methanol vanillin solution and 1.5 ml of concentrated H_2SO_4 were added to 50 μl of suitably diluted sample. The mixture was allowed to stand for 15 min, and the absorbance was measured at 500 nm against methanol as a blank. The amount of total condensed tannins was expressed as mg (+)-catechin equivalent g^{-1} DW. All samples were analyzed in three replications.

2.5. Plant antioxidant capacity

2.5.1. DPPH° radical scavenging activity

The diphenylpicrylhydrazyl radical (DPPH°) scavenging activity was estimated according to Hatano et al. [18]. The plant extract was diluted in pure methanol at different concentrations ranging from 1 to 100 μg ml^{-1}, and then 2 ml were added to 0.5 ml of DPPH° 0.2 M prepared in methanolic solution. The mixture was shaken vigorously and left standing at room temperature for 30 min in the dark, and then the absorbance was measured at 517 nm. For each dilution of the extract, the DPPH° scavenging activity was calculated as 100 $(A_0 - A_1)/A_0$, where A_0 is the absorbance of the control at 30 min, and A_1 is the absorbance of the sample at 30 min. The anti-radical activity was finally expressed as IC_{50} (μg ml^{-1}), the extract concentration required to cause a 50% inhibition. A lower IC_{50} value corresponds to a higher antioxidant activity of the plant extract. All samples were analyzed in three replications.

2.5.2. Iron reducing power

The reducing power of *M. edule* shoots was determined through the transformation of Fe^{3+} to Fe^{2+} inducing by plant extracts according to the method of Oyaizu [19]. Sample solutions at different concentrations were mixed with 2.5 ml of 0.2 M phosphate buffer (pH 6.6) and 2.5 ml of potassium ferricyanide (1%, w/v). The mixture was incubated at 50 °C for 20 min. Afterwards, 2.5 ml of trichloroacetic acid (TCA) (10%) were added and the mixture was centrifuged for 10 min at 1000 × g. Supernatant (2.5 ml) was mixed with distilled water (2.5 ml) and 0.5 ml of ferric chloride (0.1%, w/v), and the absorbance was read at 700 nm against ascorbic acid as authentic standard. Higher absorbance of the reaction mixture indicates greater reducing power. EC_{50} value (μg ml^{-1}) is the effective concentration of the extract at which the absorbance was 0.5 and it was obtained from linear regression analysis.

2.5.3. β-Carotene bleaching test (BCBT)

A slightly modified Koleva et al. [20] method was employed to estimate *M. edule* shoots capacity to inhibit the β-carotene bleaching. Two milligrams of β-carotene were dissolved in 20 ml chloroform and to 4 ml of this solution, linoleic acid (40 mg) and Tween 40 (400 mg) were added. Chloroform was evaporated under vacuum at 40 °C and 100 ml of oxygenated water was added, then the fresh emulsion was vigorously shaken. An aliquot (150 μl) of the β-carotene/linoleic acid emulsion was distributed in 96-well microtitre plates and methanolic solutions of the test samples or authentic standards (10 μl) were added. Three replicates were prepared for each concentration. The microtitre plates were incubated at 50 °C for 120 min, and the absorbance was measured using a model EAR 400 microtitre reader (Labsystems Multiskan MS) at 470 nm. Readings of all samples were performed immediately (t = 0 min) and after 120 min of incubation. The antioxidant activity of the extracts was evaluated in terms of bleaching inhibition of the β-carotene using the formula:

$$\beta\text{-carotene bleaching inhibition}\,(\%) = \left[\frac{S - C_{120}}{C_0 - C_{120}}\right] * 100$$

where C_0 and $C_{120,}$ are the absorbance values of the control at 0 and 120 min, respectively, and S the sample absorbance at 120 min. The results were expressed as IC_{50} values (μg ml^{-1}).

2.6. Plant growth activity

The relative growth rate (RGR) was calculated based on whole-plant dry weight production, as: $RGR = \ln W_2 - \ln W_1/(t_2 - t_1)$, where W_1 and W_2 were the dry matter at the beginning and the end of the treatment period, and $(t_2 - t_1)$ was the duration of the period [21].

Table 2
The characteristics of soil used after the experiment (means and standard deviations calculated on 3 replications basis).

	C	MSW
pH	7.0 ± 0.04a	6.7 ± 0.15b
EC (μS cm^{-1})	492.3 ± 37b	643.3 ± 90a
C (%)	0.54 ± 0.06b	0.77 ± 0.12a
N (%)	0.05 ± 0.01b	0.08 ± 0.01a
Ca (mg g^{-1})	16.8 ± 7.1b	20.7 ± 6.8a
Mg (mg g^{-1})	3.1 ± 0.3a	3.5 ± 0.8a
K (mg g^{-1})	5.3 ± 0.9b	6.9 ± 0.1a
P (mg g^{-1})	0.37 ± 0.1b	0.43 ± 0.05a

C: control treatment, MSW: soil amended of 40 t ha^{-1} of compost. Means (three replicates) followed by at least one same letter are not significantly different at $P < 0.05$.

2.7. Statistical analysis

The statistical analysis was achieved using the SPSS 16.0 software. Data were subjected to One-Way ANOVA test and means were compared using Duncan's Multiple Range Test at 5% significance level.

3. Results

3.1. Soil properties

MSW compost incorporation slightly reduced the soil pH in MSW treatment, while EC was significantly increased (Table 2). Carbon and nitrogen contents were significantly increased with the supply of MSW compost, as compared to control. Increases were also measured for soil soluble nutrient contents Ca, K, and P, however, no variation of Mg was recorded.

3.2. Plant growth and macro and micro-elements uptake

MSW compost application induced a significant increase of DW by more than 90%, as compared to the control (Fig. 1A). Similarly, RGR was highly enhanced (+97%) under MSW compost treatment (Fig. 1B).

Nitrogen concentration was significantly increased in shoots and roots of 40 t ha^{-1} MSW compost-amended plants as compared to the control (Fig. 2). The stimulation observed in phosphorus was much higher as compared to nitrogen, especially in shoots. Comparatively, no significant variation was observed in roots. Potassium contents showed approximately the same behaviour observed in nitrogen for shoots and roots (Fig. 2).

Regarding heavy metal accumulation, Pb contents increased under MSW treatment in both shoots and roots, reaching 1 and 4 mg kg^{-1}, respectively. Cd content was also significantly higher in roots of plants cultivated on compost-amended soil as compared to the control, reaching 0.5 mg kg^{-1}, while Cd was not accumulated in shoots. Higher Cu contents were recorded in roots following MSW compost supply (25.3 mg kg^{-1}) as compared to the control. Concerning Zn concentration, no significant variation was observed in both shoots and roots. As a whole, Pb, Cd, Cu and Zn concentrations were higher in roots than in shoots.

3.3. Shoot phenolic contents and antioxidant activities

MSW compost induced a significant increase in shoot total polyphenol contents (Table 3). Similarly, flavonoids and condensed tannins contents showed the highest values under MSW treatment (36.18 mg CE g^{-1} DW and 7.42 mg CE g^{-1} DW, respectively)

Table 3
Phenolic compounds (polyphenols, flavonoids, and condensed tannins) measured in *M. edule* shoots.

	Polyphenols (mg GAE g^{-1} DW)	Flavonoids (mg CE g^{-1} DW)	Condensed tannins (mg CE g^{-1} DW)
C	20.6b	34.0b	7.1a
MSW	22.1a	36.2a	7.4a

C: control treatment, MSW: soil amended of 40 t ha^{-1} of compost. Means (three replicates) followed by at least one same letter are not significantly different at $P < 0.05$. mg GAE g^{-1} DW: milligram gallic acid equivalent per gram dry weight; mg CE g^{-1} DW: milligram catechin equivalent per gram dry weight.

Table 4
DPPH$^{\circ}$ scavenging activity, reducing power, β-carotene bleaching activity measured in *M. edule* shoots.

	DPPH$^{\circ}$ scavenging activity IC$_{50}$ $\mu g\,ml^{-1}$	Reducing power EC$_{50}$ $\mu g\,ml^{-1}$	β-Carotene bleaching activity IC$_{50}$ $\mu g\,ml^{-1}$
C	9.3a	380*a*	282*a*
MSW	5.2b	340*b*	70*b*

C: control treatment, MSW: soil amended of 40 t ha^{-1} of compost. Means (three replicates) followed by at least one same letter are not significantly different at $P < 0.05$.

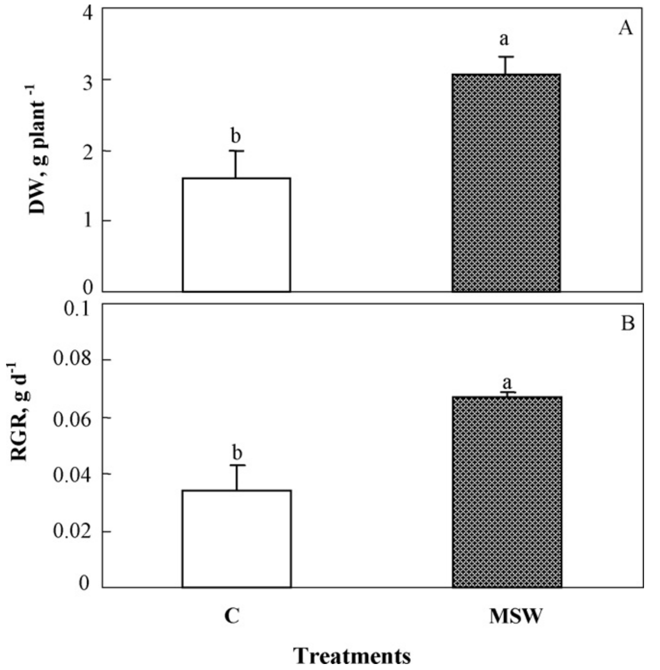

Fig. 1. (A) Dry matter production, (B) relative growth rate (RGR) of *M. edule* plant. C, control treatment; MSW, soil amended of 40 t ha^{-1} of compost. Means (four replicates) followed by at least one same letter are not significantly different at $P < 0.05$.

(Table 3). With respect to DPPH$^{\circ}$ scavenging, MSW compost application improved the free radical scavenging capacity measured with DPPH$^{\circ}$ (IC$_{50}$ values were 5.20 $\mu g\,ml^{-1}$ and 9.25 $\mu g\,ml^{-1}$ in MSW treatment and the control, respectively) (Table 4). The reducing power was also significantly improved in plants cultivated under MSW compost (EC$_{50}$: 340 $\mu g\,ml^{-1}$ in MSW treatment versus 380 $\mu g\,ml^{-1}$ in the control) (Table 4). In the β-carotene linoleate system, β-carotene undergoes rapid discolouration in the absence of antioxidants. Our data showed that the capacity of shoot extracts from *M. edule* to prevent the bleaching of β-carotene was significantly better in plants cultivated on MSW compost-amended soil as compared to the control (70 $\mu g\,ml^{-1}$ and 282 $\mu g\,ml^{-1}$, respectively) (Table 4).

4. Discussion

4.1. Effect of MSW compost on plant growth and nutrition

The present study showed a marked enhancement of biomass production when *M. edule* plants were grown on 40 t ha^{-1} MSW

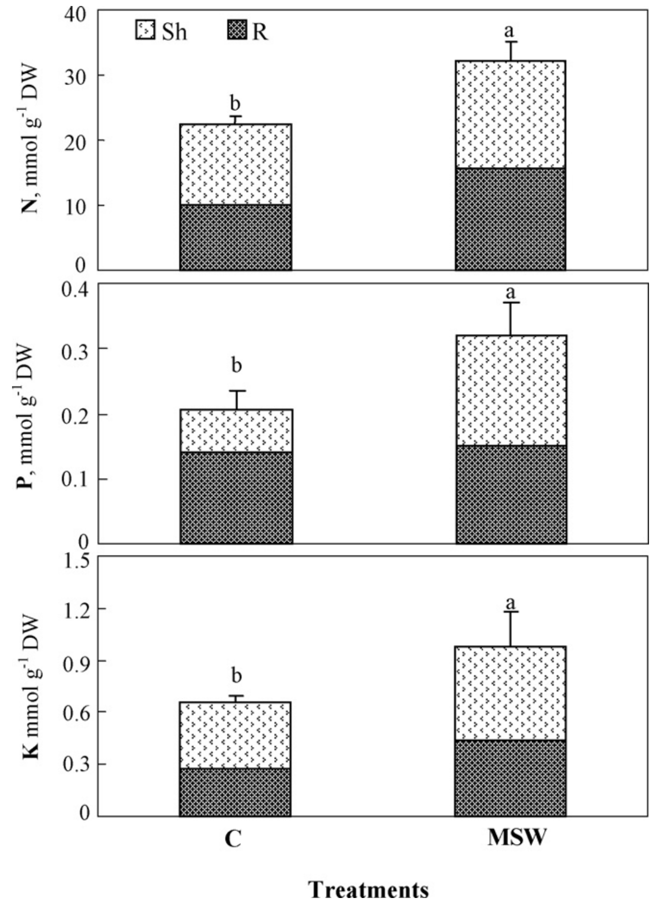

Fig. 2. Nitrogen, phosphorus and potassium contents of *M. edule* plant (Sh, shoots; R, roots). C, control treatment; MSW, soil amended of 40 t ha^{-1} of compost. Means (four replicates) followed by at least one same letter are not significantly different at $P < 0.05$.

compost amended soil (Fig. 1). This result is in agreement with recent findings [22], highlighting the positive impact of urban waste compost application on wheat growth. Several authors have shown that the application of mature compost at reasonable rates improves soil physico-chemical properties and enhances micro organism activity [2,6]. The observed decrease of pH plays an important role in the availability of plant nutrients [6]. Moreover, a significant increase of C and N contents was observed in MSW compost amended soil (Table 2), consisting with previous data of Dar et al. [23]. This amendment had also a positive effect on soil soluble Ca, K and P contents likely resulting in the mineralization of

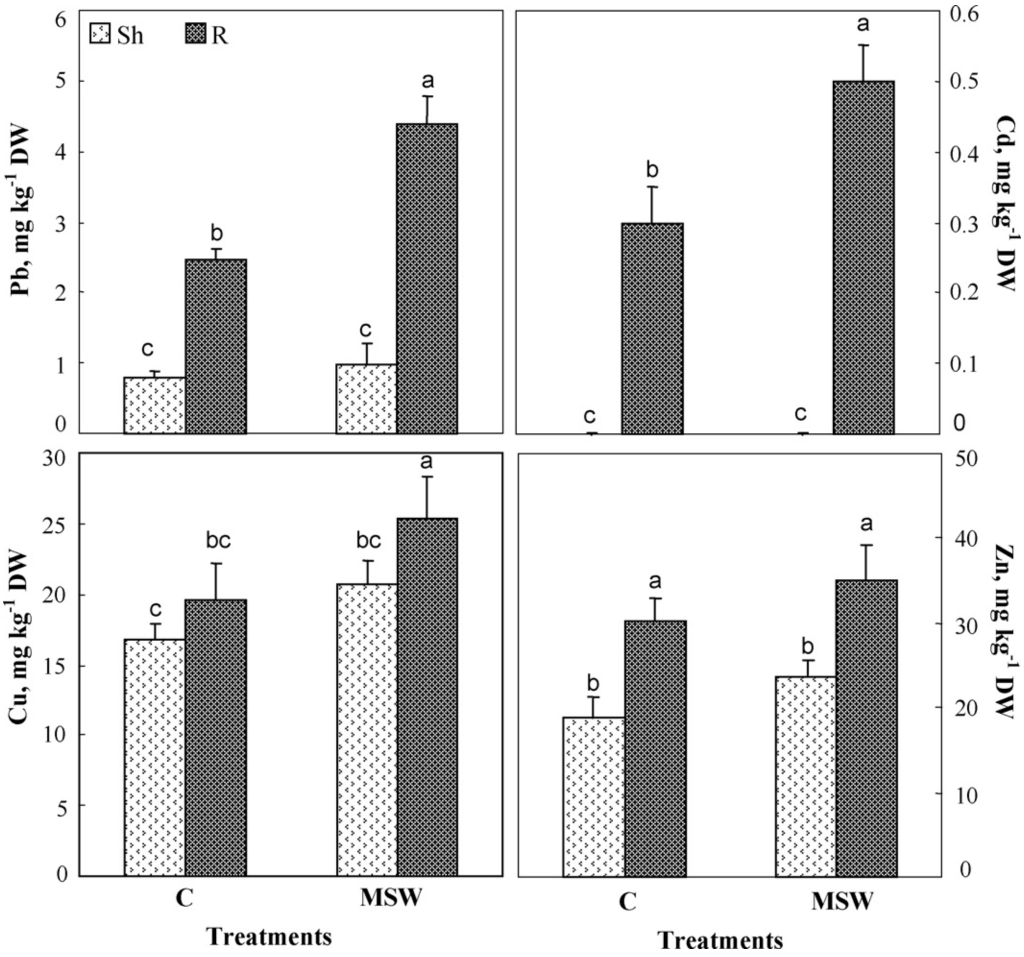

Fig. 3. Pb and Cd contents of *M. edule* plant (Sh, shoots; R, roots). C, control treatment; MSW, soil amended of 40 t ha^{-1} of compost. Cd was not detected in plant shoots. Means (four replicates) followed by at least one same letter are not significantly different at $P < 0.05$.

added organic matter [6]. This was clearly reflected by the relative plant growth rate (RGR) changes, which was markedly increased in the MSW compost based substrate at the end of the experimental period, as compared to the control (Fig. 1B).

Nitrogen uptake was significantly increased in both shoots and roots. Cordovil et al. [24] found a good correlation between compost mineralization and N uptake by wheat and ryegrass, reflecting growth dependence on nutrient availability. De Haan [25] estimates that only 10% to 30% of the nitrogen in these organic compounds will become available in one growing season. Some of the remaining nitrogen will become available in subsequent years and at much slower rates than in the first year. According to Singh and Jagadeesh [26], the response of crops to the compost supply depends on several factors such as C/N ratio, its degree of humification and nutrients content. Actually, good agronomic quality compost is characterized by C/N ratio under 25 [6]. C/N ratio of MSW compost used in the experiment was 11 indicating the good quality of this amendment. Previous studies have shown that compost enhance nutrient use efficiency by slow releasing of nutrients and reducing their losses. Dar et al. [23] also reported that well composted organic amendments with low C/N made N available synchrony with plant growth and give higher yields. Concerning phosphorus, despite some conflicting results about the effect of organic wastes on P availability, the positive effect of compost on *M. edule* P uptake was evident (Fig. 2). In fact, exogenous phosphorus application in the forms of compost to soil of intensive cropping systems often exceeds P uptake by paddy crops [27]. This surplus leads to P accumulation in soils as chemically stable and insoluble forms that may become available to plants in subsequent years. Potassium status showed approximately the same behaviour as observed in nitrogen with an increase of 58% and 32% in *M. edule* shoots and roots, respectively. This augmentation is likely due the high residual potassium in compost amended soil bounded by clay minerals and organic matter, which becomes more available due to the action of organic acids liberated during decomposition [28]. In addition, compost supply enriches soil with microorganisms which synthesize several different phytohormones that can act to enhance various stages of plant growth, and synthesize some less well characterized low molecular mass compounds or enzymes that can modulate plant growth and development [29].

4.2. Effect of MSW compost on polyphenols, antioxidant activities, and heavy metal risks

Reactive products of oxygen are amongst the most potent and omnipresent threats faced by any living organism. As reported by Falleh et al. [5], *M. edule* exhibited high potential in numerous antioxidants production. Differences in the management of soil fertility affect soil dynamics and plant metabolism, which may result in differences in plant composition [9]. The increase of soil organic matter content derived from MSW compost improved chemical and biological properties of the soil associated likely with positive impact on *M. edule* polyphenols, antioxidant activities. In this context, Ren et al. [30] demonstrated also that organically grown spinach contained 120% higher antioxidant activity and Welsh onion, and Chinese cabbage contained 20–50% higher antioxidant activity compared to their conventionally grown plants. Likewise, MSW compost application seems to have a positive effect on polyphenols status and antioxidant activities of *M. edule* (Table 3). The DPPH° assay has been widely used for evaluation of radical-scavenging activity of natural products and crude extracts. MSW compost supply improved by 44% the capacity of plant to scavenge the radical DPPH° (Table 4). In agreement with the findings of Taie et al. [31] the slow release of nutrients from compost amendment, due to microorganisms activity, *M. edule* photosynthetate were allocated for synthesis secondary compounds as phenolics, flavonoids and isoflavonoids. These results are in line also with those obtained by Khalil et al. [32] reporting a positive influence of compost in medicinal and aromatic plants such as *Calendula officinalis*, *Dracocephalum moldavica*, *Plantago afra* and *Salvia viridis* species. The high scavenging property of *M. edule* may be due to hydroxyl groups present in the phenolic compounds' chemical structure that can provide the necessary component as a radical scavenger. In fact, several authors reported a similar increase in the antioxidant potential in different crops amended with organic wastes, suggesting that compost causes changes that favour the accumulation of antioxidants [9]. As for DPPH°, reducing powers increased by 11% with the application of MSW compost as compared to the control (Table 4). Likewise, reducing potential was increased in methanol extracts of *Phyllanthus emblica* plants [33]. Such a result may be likely ascribed to the higher polyphenol content of *M. edule* species. In fact, the levels of total phenols, flavonoids, and condensed tannins also increased under 40 t ha^{-1} of MSW compost, consistent with the results of Mitchell et al. [34]. This was likely due to the high pathogenic pressure in organic methods, in which no pesticides were used, which in turn may have produced biotic and abiotic stresses and caused an increase in the levels of phenolics produced by the plants [31,34]. These data support earlier study reporting a high phenolic content in *M. edule* plants under natural conditions [35]. In addition, MSW compost cultivated plants showed a higher ability to inhibit β-carotene bleaching (Table 4).

With regard to heavy metal (Pb, Cd, Cu, and Zn) risk, Table 1 shows that the concentrations found in the applied MSW compost were within the normal range for agriculture practices. MSW compost application induced an increase of Pb and Cd concentration in *M. edule* roots, while no Cd was detected in shoots (Fig. 3). Yet, the values found in roots and shoots of both heavy metals were below the limit of phytotoxicity in plants ranging between 2 and 20 mg kg^{-1} for Cd and between 30 and 300 mg kg^{-1} for Pb [36]. MSW compost application led to the increase of Cu contents in roots, while non significant increase was detected in shoots. The critical concentration of Cu in plants varies from 20 to 100 mg kg^{-1} [36]. No significant increase was observed in shoots and roots Zn concentrations with the application of MSW compost as compared to control, and the recorded values were within safe limits ranged between 27 and 150 mg kg^{-1} [36]. Furthermore, heavy metal concentrations in *M. edule* were significantly higher in roots than in shoots (Fig. 3). Such a partitioning of metals between the plant organs is a common strategy to protect the photosynthesising tissues from heavy metal toxicity [2].

5. Conclusion

The present study revealed that the application of MSW compost at 40 t ha^{-1} as soil amendment improved *M. edule* biomass production along with the enhancement of polyphenol contents and antioxidant capacities. This behaviour can be attributed to the slow-release fertilizer effect of MSW compost constituting a promising approach for restoring sustaining soil properties and promoting productivity of plant source of bioactive substances. The levels of heavy metals (Pb, Cd, Cu, and Zn) in the MSW compost used in this experiment were below the allowed limits for its agronomic use, and their concentrations in shoots were far below toxic thresholds.

Acknowledgement

This work was supported by Tunisian Ministry of Higher Education, Scientific Research and technology (LR02CB02).

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