Effect of soil organic matter on cadmium toxicity in papaya (Carica papaya L.)

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Abstract

The morphological and physiological response of papaya plants exposed to cadmium (Cd) contaminated soil was evaluated using 2 and 10% organic matter (OM), low organic matter (LPOM) and high organic matter (HPOM) soil, respectively. Cadmium chloride ($CdCl_2$) was added weekly at doses of 50, 100 and 150 mg/L and a control treatment. Height, stem thickness, number of leaves, chlorophyll, Cd accumulation in root, stem and leaf were evaluated and the translocation factor (TF) was determined. The results showed that growth inhibition was proportional to the increase in the concentration of added Cd. Plant height in LPOM soil was reduced by 13, 23 and 27% compared to the control group in HPOM soil. Chlorophyll content was reduced by 19, 23 and 36% in the LPOM soil relative to the HPOM treatment. TF results in all treatments were less than 1, indicating that the root did not allow Cd transport to the aerial part of the plant. It was also found that the presence of a higher OM concentration in the soil decreased the metal uptake by the plant; this suggests that the application of organic amendments is a technological alternative to reduce the risk of Cd uptake in agricultural crop soils.

1 Introduction

The presence of heavy metals in soil has become an environmental concern, due to the long-term persistence of these elements and the harmful effects they can cause to living organisms. There are no effective controls to regulate the impact of anthropogenic activities on the environment and on agricultural soils, where metals can be absorbed during crop development, and concentrate to levels toxic to plants with the risk of entering the food chain (Kumar et al. 2015). Cadmium is considered a highly toxic metal, as it is not part of the biological function in organisms; its high solubility in water makes it readily available for uptake, and achieves bioaccumulation to toxic levels (De Paiva Magalhães et al. 2015; Kumar et al. 2015).

The entry of Cd into the plant occurs through nutrient uptake mechanisms, this is because they do not have a selective process to uptake essential elements from the soil (Järup and Åkesson 2009). Thus, the root absorbs Cd found as free ions in the soil, where it accumulates in the apoplast and is subsequently transported to the aerial part of the plant (Uraguchi and Fujiwara 2012; Lux et al. 2011). In the cell, Cd will preferentially bind to nitrogen (N) and sulphur (S) donors of functional groups of macromolecules and low molecular weight ligands (Gramlich et al. 2017; Hu and Cheng 2013). The interaction between Cd ions and cellular components is initiated within seconds with a significant number of metabolic responses that can cause permanent alterations in plant development (Choppala et al. 2014). Previous studies have reported that Cd interferes with the uptake and transport of essential elements, so it can directly or indirectly inhibit various metabolic processes that are important for plant development such as photosynthesis, respiration, gas exchange and the water system (Balen et al. 2011; Song et al. 2015) reported a decrease in Mn, Fe and Mg concentrations in leaves of cabbage crops caused by metal stress, causing a decrease in chlorophyll and plant growth. Bertoli et al. (2015) reported that the presence of Cd decreased K, Ca, Mn and Zn contents in the root and aerial part of tomato plants. Cd can compete with the entry and transport of Ca, Mg or Fe through the membranes, cause stomata closure and consequently lower transpiration rate and inhibition of photosynthesis, considerably affecting plant growth (Nazar et al. 2012).

Cd inputs in agricultural soils are related to the application of phosphate and nitrogen fertilizers, which contribute concentrations of Cd and Pb, either as an active ingredient or in the form of impurities (Kooner et al. 2014; Yadav 2010). Martí et al. (2002) found concentrations of 10.97 mg/kg Pb and 10.43 mg/kg Cd in phosphate fertilizers, with values of 4.65 mg/kg Pb and 2.03 mg/kg Cd in nitrogen fertilizers. On the other hand, Rodriguez Ortiz et al. (2018) reported levels of 3.7 and 8.7 mg/kg Cd in diammonium phosphate and triple superphosphate fertilizers, respectively. Several agricultural crops are exposed to intensive inorganic fertilization systems, such as papaya (*Carica papaya* L.). Papaya is a tropical fruit belonging to the genus Carica, which includes 22 species; it is appreciated for its nutritional and digestive properties (Madrigal and Boza 2013). It stands out for being the most economically important fruit for Mexico and Central America. Papaya is considered a fast-growing crop with an early and continuous production that requires high amounts of nutrients for its development; its fruit is a commercially important product at national and international level (García et al. 2003; García and Escobar 2010). During the crop cycle, excessive applications of nitrogen and phosphate fertilizers are made, with the risk of increasing heavy metal concentrations in the soil and uptake by crop plants.

However, techniques have been implemented to immobilize Cd in the soil, based on the application of organic amendments. Organic amendments have diverse functional groups that influence the physicochemical properties of the soil and help immobilize Cd (Park et al. 2011; Jiang et al. 2012). Organic wastes such as manure, compost, biosolids, household waste, straw and others can be used as amendments to reduce Cd availability in soil (Hao et al. 2012). He et al. (2015) demonstrated that the application of 5% and 10% biochar in soil decreased the concentrations of Cd, Zn and Pb for 56 days after application. Hamid et al. (2019) observed a decreased in Cd translocation in wheat shoots when using manure and clay minerals. Sato et al. (2010) reported up to 38% decrease in Cd uptake in spinach crop in soils with addition of organic matter of animal origin. Dong et al. (2021) reported that the application of the combination of organic amendments inhibited the accumulation of cadmium in amaranth shoots. The present investigation aimed to evaluate the effect of soil organic matter on Cd toxicity in papaya (*Carica papaya* L.). Plant growth, stem thickness, number of leaves, chlorophyll content and cadmium accumulation in root, stem and leaves were evaluated.

2 Materials And Methods

2.1 Plant cultivation and treatments

The study was conducted at the experimental facilities of the Technological institute of Boca del Río, in Veracruz, Mexico; it is characterized by a warm sub-humid climate, temperature of 24 – 26°C, mean annual rainfall of 1500 – 2000 mm. The study started on 01 April 2020. Certified maradol papaya seeds (*Carica papaya* L.) from Semillas del Caribe® were used. To promote germination, the seeds were immersed in distilled water for a period of 48 h, with replacements every 8 h. The seeds were then placed between two moist, sterile cloths and allowed to rest in a warm place. Germination was achieved within 7 to 10 days with the emergence of 1 – 2 cm radicle. Sandy loam soil was used for the experiments where 10% of HPOM, which corresponds to soil with high organic matter content, and 2% LPOM, which corresponds to soil with low organic matter content, were added separately to the cultivation soil. For this purpose, commercial organic matter at 58.71%, pH 3.98, 4.18% nitrogen, 0.70% total phosphorus and 11.15% potassium were used. It was homogenized together with the soil and subsequently the percentage of organic matter was analyzed by the ignition method in both the 2 and 10% soil treatments (Schulte and Hopkins 1996).

The seeds were sown 3 cm deep in plastic bags and kept protected from direct sunlight with the use of shade netting. After 45 days, the plants were transplanted into 15 kg containers, and the nutrients nitrogen (N), phosphate (P) and potassium (P) were added monthly in a ratio of 16:31:19. Two weeks after transplanting, the treatment was started with the addition of Cd. Cadmium chloride $CdCl_2$ was used as a contaminant agent at concentrations of 50, 100 and 150 mg/L (T2, T3 and T4 respectively) and 10 ml/kg^{-1} of soil was added weekly through irrigation water (Iannacone and Alvariño, 2009). A control treatment without metal addition was included for the two soil types (T1).

2.2 Measurement of morphological and physiological variables

The measurement of variables was carried out every 30 days for 10 months, starting from the addition of metal. The growth variables evaluated were plant height, stem thickness and number of leaves. Chlorophyll content was determined using a non-destructive test with a portable SPAD-502 meter (Minolta Co. Japan). The SPAD – 502 meter uses two light emitting diodes (650 and 940 nm) and a photodiode detector to measure the transmission of red and infrared light through the leaves, so that the values obtained are proportional to the chlorophyll content (Chang and Robinson 2003). For the measurement, 3 mature leaves per plant were selected and 3 readings per leaf were taken, resulting in 9 readings per plant and the average per plant (Azia and Stewart 2001).

2.3 Evaluation of Cd concentration

Cd concentration was analyzed by atomic absorption spectrophotometry according to the specifications of NOM-117-SSA1-1994 (DO 1995). The structural parts of the plant (leaves, stem and root) were separated, washed with distilled water and oven-dried at 65°C; they were then sieved to obtain the finest particles. We weighed 0.5 g of the sieved sample and added 10 ml of 70% reagent grade nitric acid (HNO_3) (suprapure) J.T. Baker®. They were placed in Teflon cups and placed in a CEM Mars 5 microwave oven (CEM, Corporation Mathews, NC, USA). After digestion, the samples were filtered using a Nalgene bottle with a 0.45 µm Millipore HAWP04700 filter and a vacuum pump. The filtrate was transferred to a 25 ml volumetric flask and volumetrically filled with deionized distilled water (1 µmho/cm at 25°C). The samples were transferred to pre-labelled amber glass bottles and kept refrigerated until analysis. A control sample was taken at the same time, using 45 ml of double distilled water and 5 ml of HNO_3. Cd quantification was performed on a Thermo Scientific iCE 3500 AAS spectrometer (Thermo Scientific®, China). For the calibration curve, certified High Purity Standards® (Charleston, SC) was used at a concentration of 1000 µg/mL in 2% HNO_3; with a range adjusted from low to high, close to the analyte to obtain a correlation coefficient above 0.95. Graphite furnace and argon gas (5.0 ultra high purity) Praxair® at a wavelength of 228.8 nm were used in the analysis of the Cd readings.

2.4 Translocation Factor (TF)

The translocation factor was evaluated in each of the treatments, the TF is the measure of the internal transport of a metal, it indicates the relationship between the accumulated concentration in the aerial part and in the root of a plant (Mattina et al. 2003). It is calculated by dividing the concentration of the metal in the aerial part by the concentration in the root of the plant according (Zhang et al. 2002; Olivares and Pena 2009).

2.5 Statistical analysis

A completely randomized experimental design was used, five plants were used for each treatment, as well as for each trial with soil with high and low organic matter content (HPOM and LPOM, respectively). Physiological variations over time were plotted for each treatment and soil type. A one-way analysis of variance and Tukey’s mean comparison ($p < 0.05$) were performed to determine the significant differences in the physiological results, Cd accumulation and the translocation factor. A Pearson correlation between HPOM and LPOM experiments was performed using Statistic 7.0 (StatSoft, Inc. Tulsa, USA).

3 Results

3.1. Morphological and physiological variation by cadmium addition

Table 1 shows the results of the variables of growth and chlorophyll content in the papaya crop (*Carica papaya* L.), these data correspond to the average of the treatments 10 months after the end of the experiment. The effect of Cd immobilization by the application of organic matter in the cultivation soil was observed. It was found that plants cultivated in soil with high organic matter content (HPOM) had a higher growth than plants cultivated in soil with low organic matter content (LPOM). Nevertheless, plants in soil with HPOM did not show a better response in the treatment with the highest concentration of added Cd (150 mg/L) compared to the other treatments, and this was because the organic matter content was insufficient to immobilize Cd, due to the time the plants were exposed to metal contamination.

Table 1
Results of the variables height, stem thickness, number of leaves and chlorophyll by treatment and by type of soil at the end of the experiment (mean values ± SD). Different letters indicate statistical differences according to test ($p < 0.05$). Inhibition of growth in height, stem thickness and number of leaves; decrease in chlorophyll content (%).

Treatment		**OM (%)**	**Plant height (cm)**		**Stem thickness (cm)**		**Number of Leaves**		**Chlorophyll (SPAD units)**	
				GI (%)		GI (%)		GI (%)		GI (%)
Control	T1	HPOM	73.80 ± 1.09 a	-	31.22 ± 1.48 a	-	16.20 ± 0.84 a	-	61.04 ± 4.26 a	-
		LPOM	69.50 ± 1.01 a	29.1	27.40 ± 1.62 a	12.2	15.20 ± 0.84 a	6.2	57.84 ± 5.41 a	3.6
50 mg/L	T2	HPOM	76.40 ± 4.13 a	-3.9	29.62 ± 2.00 ab	19.0	15.40 ± 1.14 a	4.9	54.22 ± 5.74 a	11.2
		LPOM	64.00 ± 3.95 b	13.0	23.62 ± 0.98 b	24.4	14.60 ± 0.89 a	9.9	41.76 ± 5.90 a	31.6
100 mg/L	T3	HPOM	73.11 ± 3.82 a	0.9	28.34 ± 1.10 bc	6.5	15.00 ± 1.00 ab	16.7	58.48 ± 2.52 a	4.2
		LPOM	56.90 ± 2.11 c	22.6	23.62 ± 0.56 b	24.4	12.20 ± 0.84 b	24.7	42.7 ± 5.54 a	30.0
150 mg/L	T4	HPOM	64.62 ± 5.82 b	12.4	26.01 ± 0.38 c	8.6	13.00 ± 1.14 b	14.8	46.46 ± 7.20 b	23.9
		LPOM	54.04 ± 3.07 c	26.8	21.22 ± 1.23 c	32.1	12.80 ± 0.84 b	21.0	34.46 ± 5.77 b	43.5

OM: Organic matter; HPOM: High organic matter content; LPOM: Low organic matter content; GI: Growth inhibition

Growth variables in plants grown in soil with high organic matter content (10%), where the highest growth was observed in the treatment with addition of 50 mg/L of Cd (T2). Significant differences were found in T4 with respect to all treatments. Stem thickness significant differences were found between T1 and T3 and T4. In relation to the number of leaves in plants, they were found to vary between 13 ± 1.14 and 16.2 ± 0.84; significant differences were shown between T1 and the treatment with the highest concentration of Cd (T4). Chlorophyll content in plants with HPOM significant differences were observed between the T4 and the rest of the treatments.

On the other hand, plants grown in soil with LPOM showed the greatest height was observed in the control group T1. Significant differences were found between T1 and the rest of the treatments. Thickness significant differences were found between the control T1 with respect to T3 and T4. In the measurement of leaf number, the results indicated a variation from 12.8 ± 0.84 to 15.2 ± 0.84; significant differences were observed between the T4 with respect to T1 and T2. The chlorophyll content in the soil with LPOM was found between 34.46 ± 5.77 to 5784 ± 5.41 SPAD units, significant differences were observed between the T4 and the rest of the treatments.

A correlation analysis was performed between treatments grown in soil with HPOM and LPOM, observing a significant correlation of $r = 0.782$ $p < 0.01$ in stem thickness growth and in chlorophyll content of $r = 0.758$ $p < 0.01$, which indicated that the addition of organic matter showed no changes between both treatments for these variables. However, the height and number of leaves in soil with high organic matter content (HPOM) was decreasing as the treatment dose increased (Table 2).

Table 2
Correlation matrix of the variables of height, stem thickness, number of leaves and chlorophyll, in the treatment of 0, 50, 100 and 150 mg/L of Cd added in soil with high and low organic matter content.

		HPOM				**LPOM**			
		Height	**Stem T.**	**Chlorophyll**	**Leaves**	**Height**	**Stem T.**	**Chlorophyll**	**Leaves**
HPOM	Height	1							
	Stem T.	0.447*	1						
	Chlorophyll	0.408	0.588**	1					
	Leaves	0.331	0.829**	0.505*	1				
LPOM	Height	0.425	0.727**	0.471*	0.681**	1			
	Stem T.	0.338	0.782**	0.611**	0.729**	0.778**	1		
	Chlorophyll	0.409	0.667**	0.758**	0.645**	0.679**	0.754**	1	
	Leaves	0.337	0.630**	0.230	0.375	0.675**	0.548*	0.452*	1

*Correlation is significant at the 0.05 level **Correlation is significant at the 0.01 level; HPOM: High organic matter content; LPOM: Low organic matter content

3.2. Bioconcentration and translocation of cadmium

Cd accumulation in plants grown in soil with 10% organic matter (HPOM) showed a root > stem > leaves sequence (Table 3), Cd accumulation in root was 62 – 68%, 22 – 34% in stem and 4 – 9% in leaves. In root and stem there were significant differences between each of the treatments; yet, in leaves, differences were observed between T1 and T2 with respect to T3 and T4. Conversely, plants in soil with low organic matter content (LPOM). It was observed that the accumulation showed a sequence of root > stem > leaves, where the concentration was 51 – 60% in root, 34 – 40% in stem and 5 – 15% in leaves. In root and stem significant differences were found among all treatments, while in leaves differences were observed between the T4 and the rest of the treatments. Pearson's correlation analysis between treatments showed significant differences of $r = 0.996$ $p < 0.01$ in root, $r = 0.967$ $p < 0.01$ in stem and $r = 0.775$ $p < 0.01$ in leaves (Table 4).

In the calculation of the translocation factor, which indicates the transfer capacity of Cd from the root to the aerial part of the plant; the results of TF in papaya plants grown in soil with high organic matter content (HPOM), showing significant differences between the control group T1 with respect to all treatments with Cd addition. Since the TF values were less than 1, it indicates that the plant limited to a greater extent the transport of the metal to the aerial part. On the other hand, in the case of plants in soil with LPOM, TF values were significant differences between the control group and the treatments with Cd addition, as well as statistical differences between T2 and T3 with respect to T4. Similarly, the TF values were less than 1, which shows the characteristic of the plant in minimizing the passage of metal from the root to the aerial part.

Table 3

Results of the concentration of Cd in the structural part of the plant by treatment and by type of soil at the end of the experiment (mean values ± SD) (mg/kg). Different letters indicate statistical differences according to Tukey's test ($p < 0.05$). Percentage of cadmium accumulation in root, stem and leaves.

Treatment		**OM**	**Leaves**		**Stem**		**Root**		**TF**
				BAC (%)		BAC (%)		BAC (%)	
Control	T1	HPOM	0.020 ± 0.003 a	-	0.022 ± 0.005 a	-	0.046 ± 0.014 a	-	0.98 ± 0.44 a
		LPOM	0.022 ± 0.003 a	-	0.029 ± 0.003 a	-	0.038 ± 0.002 a	-	1.32 ± 0.11 a
50 mg/L	T2	HPOM	0.035 ± 0.009 a	9.2	0.085 ± 0.009 b	22.4	0.260 ± 0.026 b	68.4	0.47 ± 0.07 b
		LPOM	0.049 ± 0.007 b	15.2	0.109 ± 0.012 b	34.0	0.164 ± 0.010 b	50.8	0.97 ± 0.11 b
100 mg/L	T3	HPOM	0.051 ± 0.009 a	6.5	0.225 ± 0.012 c	28.9	0.502 ± 0.042 c	64.5	0.55 ± 0.05 b
		LPOM	0.043 ± 0.006 b	5.7	0.301 ± 0.046 c	40.2	0.406 ± 0.014 c	54.1	0.85 ± 0.12 b
150 mg/L	T4	HPOM	0.053 ± 0.006 b	4.0	0.451 ± 0.043 d	33.5	0.841 ± 0.045 d	62.5	0.60 ± 0.05 ab
		LPOM	0.065 ± 0.007 c	4.9	0.462 ± 0.007 d	34.6	0.806 ± 0.028 d	60.5	0.65 ± 0.02 c
HPOM: High organic matter content; LPOM: Low organic matter content; BAC: bioaccumulation									

Table 4

Correlation matrix of Cd uptake in root, stem and leaves, in treatments of 0, 50, 100 and 150 mg/L of Cd added in soil with high and low organic matter content.

		HPOM			**LPOM**		
		Leaves	Stem	Root	Leaves	Stem	Root
HPOM	Leaves	1					
	Stem	0.787**	1				
	Root	0.794**	0.991**	1			
LPOM	Leaves	0.755**	0.827**	0.820**	1		
	Stem	0.766**	0.967**	0.982**	0.763**	1	
	Root	0.792**	0.989**	0.996**	0.810**	0.977**	1
** Correlation is significant at the 0.01 level; HPOM: High organic matter content; LPOM: Low organic matter content							

4 Discussion

The influence of organic matter addition contributes to soil nutrition for agricultural crops, it is reported that the application of organic amendments in soil contaminated with heavy metals, can reduce the availability for uptake by crop plants (Angelova et al. 2013; Gul et al. 2015). The results on the growth of papaya (*Carica papaya* L.) plants grown in soil with high organic matter content (HPOM) showed higher growth in height, stem thickness and leaf number relative to plants grown in soil with low organic matter content (LPOM) (Table 1). Nonetheless, in both cases the plants that were exposed to the highest concentration of Cd (T4), showed a higher stress in growth, it is likely that the organic matter content was not sufficient, since it was only added at the beginning of the experiment and an effective immobilization of the metal was not achieved after 10 months of the experiment (Table 2).

The above was observed in height, stem thickness and number of leaves, where plants in HPOM showed better growth in the T2, indicating immobilization of the metal in contaminated soil at low concentrations with respect to T3 and T4. On the contrary, plants with soil in LPOM, showed a decrease in growth as the concentration of Cd treatment increased, indicating an inhibition of 13, 23 and 27% in height, 25, 24 and 32% in stem thickness and 10, 25 and 21% in the number of leaves in T2, T3 and T4 respectively with respect to the control group (T1) of plants in soil with HPOM.

Higher growth stress was observed in soil with LPOM relative to plants grown in soil with HPOM. The above, was similar to that reported by (Yingang et al. 2018) who indicated that Cd caused 40.1% decrease in growth in tobacco (*Nicotiana tabacum* L.) plants; so also cases of the decrease in growth have been reported in alfalfa *Medicago sativa* L. (Yang et al. 2019); in tomato *Solanum lycopersicum* L. (Hédiji et al. 2010), soybean *Glycine max* L. (Chen et al. 2003), maize *Zea mays* L. (Rizwan et al. 2016) and lettuce *Lactuca sativa* L. (Yazdi et al. 2019), which are in agreement with the present study.

Adrees et al. (2015) mentioned that growth inhibition in plants is one of the prominent symptoms of metal-induced stress. Aidid and Okamoto (1993) indicated that the growth rate in the stem is inhibited by the presence of heavy metals due to cell wall suppression caused by toxicity. However, organic amendment applications can alleviate the stress caused by Cd. Yen et al. (2021) indicated that amendment applications decreased growth by 30 to 50% in lettuce height. Singh and Prasad (2014) reported improved crop yield by addition of organic amendments.

In relation to chlorophyll content, this was the first visible symptom of stress caused by Cd in papaya plants, which was presented by the appearance of chlorosis in all treatments related by chlorophyll depletions. Because photosynthesis is linked to many metabolic pathways in plants, these alterations can represent the physiological state of the plant and is indirectly affected by the accumulation of toxic metals in leaves that influences the functioning of stomata (Chen et al. 2019). Heavy metals have a strong inhibitory effect on biosynthesis and on pigment accumulation due to enzymatic degradation (Parmar et al. 2013). It has been reported that the appearance of chlorosis in leaves is related to iron (Fe) deficiency, which is responsible for chlorophyll production and acts as a catalyst in the transport of oxygen in leaves and in chlorophyll synthesis (Das et al. 1997; Furcal and Torres 2020). It has also been reported that Cd is related to the reduction and transport of Mn, which acts as an energy catalyst in the photosynthetic process (Rodriguez 2007).

In the results, plants grown in soil with HPOM and LPOM showed a decrease in chlorophyll content as Cd concentrations increased in each treatment, and where the greatest decrease in chlorophyll content was found was at T4 for both cases (Table 1). Yet, a more significant chlorophyll decrease was observed in plants in soil with LPOM of 25, 29 and 41% was observed in T2, T3 and T4 with respect to the control group T1 of plants in soil with HPOM. The present study was similar to that reported by Abou et al. (2011), who observed a decrease in chlorophyll content and stem length in spinach (*Spinacia oleracea* L.) due to the presence of Cd. Likewise, Zengin and Munzuroglu (2005) observed a progressive decrease in chlorophyll with increasing concentrations of heavy metals in bean seedlings. Xin et al. (2020) indicated that at concentrations lower than 25 mg/L of Cd, chlorophyll content decreases due to metallic stress, causing alterations in the photosynthetic process. Hédiji et al. (2015) reported that Cd stress, reduced chlorophyll contents in shoots and root, reduced Fe content and showed a significant reduction of K and Mg in all organs of tomato plant. Li et al. (2016) observed damage in chloroplast structure and a reduction in chlorophyll production in Onion (*Allium fistulosum* L.) crop caused by Cd.

On the other hand, Cd bioaccumulation in the papaya plant (*C. papaya*), showed a sequence of accumulation in decreasing order up to the aerial part of the plant root > stem > leaves for all treatments in studies in soil with high (HPOM) and low (LPOM) organic matter content. Chan and Hale (2004) noted that Cd accumulates mainly in plant roots and decreases towards the aerial part, showing a decreasing order of root > stems > leaves > fruits. Seregin and Kozhevnikova (2008) indicated that Cd concentrations are often higher in roots than in shoots, suggesting that Cd transport to the xylem is restricted in most plants and will be lower in seeds, fruits and tubers, suggesting that Cd is not easily translocated in the phloem. Moreno-Caselles et al. (2010) mentioned that the accumulation gradient of heavy metals is higher in the root, where metal ions are retained and only small concentrations are transported to the other organs, but this will depend on the plant species, as well as the degree of contamination and time of exposure.

The results indicated that the highest uptake of Cd occurred in the root for both treatments. Plants in soil with HPOM accumulated more concentration of the metal in relation to plants in LPOM. Probably because the plants, being present in a soil rich in nutrients due to the organic amendments present, absorbed a greater amount of essential and non-essential elements. Despite this, plants in soil with HPOM significantly inhibited the transport of Cd to the aerial part of the plant by 69% at T2, 64% at T3 and 62% at T4, compared to plants in soil with LPOM, which inhibited transport by 51% at T2, 54% at T3 and 60% at T4 (Table 3). Similar to that reported with Pandit et al. (2012) who observed a 71% decrease in Cd uptake in spinach crop, in soils with addition of organic matter and lime; as well as Meng et al. (2019) who reported the application of organic amendments to rice crop, which decreased from 55 – 88% Cd uptake.

This was demonstrated with the Translocation Factor (TF), as it is an indicator of heavy metal accumulation in plants, since it indicates the relationship between the concentration of a metallic element in the aerial part of the plant and the concentration in the root (Zakira et al. 2021). The results showed that the root reduced the transport to the aerial part of the plant. In the particular case of the control group, the TF value is discarded due to the low concentrations reported.

It was reflected in the TF results giving values < 1, which indicated that the papaya plant (*C. papaya*), has the ability to reduce the passage of metal from the root to the aerial part of the plant. Plants can adopt different physiological strategies to counteract metal toxicity, allowing to restrict the transport of metal ions from the root to the aerial part (Medina and Montano 2013). It has been reported that the doses of amendments used for the immobilization of metals in the soil, is one of the key factors to reduce the availability of uptake (Janoš et al. 2010; Hao et al. 2012).

Liu et al. (2009) observed that the root reduced the translocation of metals to the rice stem and grain, thus mentioning that the root functioned as a protective barrier. Liu et al. (2020) performed biochar applications observing an increase in maize growth due to the reduction of Cd uptake, as well as a reduction in metal translocation. Ahmad et al. (2015) reported that the application of organic amendments significantly reduced Cd uptake in maize and wheat, and observed increased translocation to the plant. Huaraca-Fernández et al. (2020) stated that the application of organic amendments improves Cd immobilization in Cd-contaminated soils, this is due to the formation of chelates capable of retaining the metal cations in the soil, making them less available for uptake. OM can increase soil pH, leading to the formation of stable complexes and / or precipitates with the toxic metals present, reducing uptake by plants (Porter et al. 2004; Li et al. 2008). Mohamed et al. (2010) reported that pig manure and rice straw increased soil pH and decreased Cd bioavailability in peanut plants.

The effects of soil organic matter application are considered favorable in reducing the uptake of metal elements by plants. Some studies have reported that soils with a higher organic matter content can effectively reduce Cd uptake by plants (Shahid et al. 2012). Mainly because organic matter provides a high amount of functional groups (carboxyl, hydroxyl and phenoxyl) that interact with the heavy metals present in the soil forming stable complexes which prevents toxic metals from reaching the plant (Mahmood 2010). This indicates that OM has a strong cation exchange capacity, and thus metals can be retained on OM surfaces through electrostatic forces and form exchange complexes and chelates (Guo et al. 2006; Sauveä et al. 2000).

5 Conclusions

The results of the present study showed that Cd in soil has effects on the development during the cultivation of papaya plants (*Carica papaya* L.). In them it is shown that plants exposed to Cd-contaminated soil inhibit growth, indicating that as the concentration of the metal in the soil increases, the inhibition in height, stem thickness and number of leaves increases, it was also notorious a decrease in chlorophyll content. However, plants grown in soil with high organic matter content (HPOM) showed higher growth and higher chlorophyll content compared to plants grown in soil with low organic matter content (LPOM), suggesting that Cd ions were retained in the chelating complexes of the soil organic matter, decreasing the possibility of plant uptake.

Plant Cd uptake was observed to decrease, with accumulation decreasing from the root to the aerial part (leaves < stem < root) in all trials. It was observed that the plant absorbed a higher concentration of Cd as the dose of the treatments increased. Plants grown in soil with HPOM absorbed higher concentration in the root and reduced the transfer to the aerial part of the plant, so the value of the translocation factor (TF) was lower than plants grown in LPOM soil, which absorbed higher concentration of Cd.

In spite of this, the TF in all treatments indicated that the papaya plant (*C. papaya*) had the capacity to reduce the passage of the metal from the root to the aerial part of the plant, the addition of organic matter to the soil favored the restriction in the absorption of the metal in the root, a reduction of the toxic effects in the plant was achieved. Therefore, it is concluded that the application of high contents of organic matter in crop soils can favor the reduction of Cd absorption, making it a strategic and economical technological alternative in agricultural soils to reduce the risk of metal toxicity and accumulation of Cd in plants, which can reach the edible parts.

Statements And Declarations

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Isabel Araceli Amaro Espejo, Ana María Fernandez Martínez. Supervision and project management were by Maria del Refugio Castañeda Chávez, Joaquin Murguía González, Karina Patricia Bañuelos Hernández and María Elena Galindo Tovar. Preparation of the manuscript document was by Isabel Araceli Amaro Espejo, Maria del Refugio Castañeda Chávez and Fabiola Lango Reynoso. All authors read and accepted the final manuscript.

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Ethics approval

Not applicable: our manuscript does not report on or involve the use of any animal or human data or tissue.

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