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Distribution of Cadmium in Sweet Corn Grown on a Peat Soil and Its Implication on Food Safety

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ABSTRACT

Cadmium (Cd) is a heavy metal that can contaminate agricultural soils, in which one of the sources of Cd in agricultural soils is the use of phosphate fertilizers. Some plant species are known to have the ability to accumulate large amounts of Cd in their organs despite the Cd content in soil is relatively small. Cadmium distribution in various organs of plants also shows a diverse variation. Maize is able to accumulate Cd in its organs, either in roots, leaves or grains. This study aims to determine the distribution of Cd in sweet corn plants grown on a peat soil. Samples of maize plants were taken from nine maize fields in the village of Rasau Jaya 1, Rasau Jaya subdistrict, Kubu Raya district, West Kalimantan. The cultivars of sweet corn planted were *Zea mays saccharata* cultivar Bonanza and *Zea mays saccharata* cultivar Secada. Samples for roots, leaves, stems and panicles were taken at the stage of early grain filling. Grain samples were taken at the phase of fresh pod consumption. The Cd contents in the plant organ tissues were determined using dry ashing method. The results showed that the distribution of Cd in plant organs of sweet corn cultivars Secada and Bonanza follows the pattern of Cd in leaves > roots > grains > panicles > stems. The leaves contain the highest concentration of Cd, while the stems contain the lowest amount of Cd. The Cd concentration in leaves is about 3.5 times higher than that in grains, and 1.5 times higher than that in roots. The average Cd content in grains of sweet corn is 0.037 mg kg^{-1}, which is still below the safe limit of Cd content in grains allowed by the *Standar Nasional Indonesia, i.e.* 0.2 mg kg^{-1}.

Keywords: Cadmium, food safety, peat soil, sweet corn

ABSTRAK

Kadmium (Cd) sering menjadi pencemar pada lahan pertanian, salah satu sumbernya adalah penggunaan pupuk fosfat. Beberapa spesies tanaman diketahui mampu mengakumulasi sejumlah besar Cd dalam jaringannya walaupun konsentrasi Cd di dalam tanah relatif kecil. Distribusi Cd pada berbagai organ tanaman juga menunjukkan variasi yang beragam. Jagung termasuk tanaman yang mampu mengakumulasi Cd pada jaringannya, baik pada akar, daun dan bijinya. Penelitian ini bertujuan untuk mengetahui distribusi Cd pada tanaman jagung manis yang ditanam pada lahan gambut. Sampel tanaman jagung diambil dari 9 kebun petani di Desa Rasau Jaya 1, Kecamatan Rasau Jaya, Kabupaten Kubu Raya, Kalimantan Barat. Kultivar jagung manis yang ditanam adalah Bonanza dan Secada. Sampel tanaman diambil pada fase awal pematangan biji untuk organ akar, daun, batang dan malai. Sampel biji jagung diambil dari tongkol jagung pada fase matang untuk konsumsi segar. Metode penentuan kandungan total Cd pada organ tanaman menggunakan metoda destruksi kering (pengabuan) dan konsentrasi Cd diukur menggunakan AAS. Hasil penelitian menunjukkan bahwa distribusi Cd pada organ tanaman jagung manis kultivar Secada dan Bonanza mengikuti pola berikut: Cd di daun > akar > biji > malai > batang. Daun mengandung Cd paling besar sedangkan batang mengandung Cd dalam jumlah paling kecil. Konsentrasi Cd di daun 3,5 kali konsentrasi Cd pada biji dan 1,5 kali dari Cd pada akar. Konsentrasi Cd pada biji jagung manis rata-rata 0,037 mg kg^{-1}, masih berada dibawah batas aman yang diperbolehkan oleh SNI untuk bahan pangan biji-bijian yaitu 0,2 mg kg^{-1}.

Kata kunci: Jagung manis, kadmium, keamanan pangan, tanah gambut

INTRODUCTION

Soils derived from igneous rocks contain cadmium (Cd) of 0.1-0.3 mg kg^{-1}, those from metamorphic rocks contain 0.1-1.0 mg kg^{-1}, and those from sedimentary rocks contain 0.3 to 11 mg kg^{-1}. In general, most soils can be expected to contain Cd <1 mg kg^{-1} (Page and Bingham *in* Alloway 1997). According to Hasset and Banwart (1992), besides from the parent rocks, Cd in agricultural soils can be derived from industrial waste or domestic waste (sewage sludge) that contaminate farmland. According to Singer and Munns (2006), other sources of Cd in soils are from the use of phosphate fertilizers during crop cultivation. The use of phosphate fertilizers intensively in the long term will increase the concentration of Cd in agricultural soils.

In Thailand, there is a number of studies that documented the Cd contamination to environment including foods produced in the contaminated areas. There have been some concerns about the potential health effects on human resulting from the consumption of the contaminated foods by local people in the polluted area and people who get the foods from the distributed markets (Chunhabundit 2016). According to Bernard (2008), Cd is a heavy metal with high toxicity. Its toxicity is due to its divalent ion bond with the sulfihydryl (-SH) group of an enzyme thus reducing the activity of the enzyme. The research of Niu *et al.* (2013) showed that in all farmland in China, Cd is a heavy metal with the highest pollution index, *i.e.* 5.28, and according to Liu et al. (2009) Cd is a heavy metal with the top priority for monitoring on agricultural soils compared to other heavy metals due to its toxicity.

A field sampling conducted in Rasau Jaya 1 village, Rasau Jaya sub-district, West Kalimantan indicates that the Contamination/Pollution Index (C/P Index) of Cd of the soils in that area is at very slight and slight contamination levels, thus the fields are still relatively safe for crop cultivation (Susana and Suswati 2015). The Contamination-Pollution Index of Cd of the peatland cultivated between 4-5 years is relatively the same as the peatland cultivated for 7-8 years and 12-14 years. The peat soils sampled in Rasau Jaya 1 village contain Cd of 0.20-0.32 mg kg^{-1}. The use of phosphate-containing fertilizers and chicken manure has contributed to the content of Cd in the soils of that area.

The ability of plants to accumulate Cd is determined by plant genetics, diversity not only among the species but also in the varieties, thus different maize varieties will accumulate different amounts of heavy metals in their tissues. Some plant species are known to tend to accumulate large amounts of Cd in their tissues despite the amount of Cd in the soils is relatively small. The study of Romkens *et al.* (2009) conducted in Taiwan showed that the soil Cd content is below the critical limit proposed by Taiwan Soil Quality Standard (SQS), but the concentrations of Cd in the grains of the 2 varieties of rice, *i.e.* Japonica and Indica are above the critical limit proposed by WHO Food Quality Standard (0.2 mg kg^{-1}) and Japan/Taiwan Food Quality Standard (0.4 mg kg^{-1}).

Maize is able to accumulate heavy metals in its tissue, including in the roots, leaves and seeds. Maize is a heavy metal accumulator plant (Neugschwandtner *et al.* 2008) and according to Wang *et al.* (2007), maize is often used in the studies of phytoremediation. The soils contaminated by Cd, even in a small amount would be dangerous if planted with heavy metal accumulator food crops such as maize.

Cadmium is a mobile heavy metal in soil that is easily absorbed by plants and transferred to the shoots, while the poorly mobile element such as Pb generally distributes with a similar pattern in plants, in which the uptake in roots > shoots > leaves > fruits > seeds (Sekara *et al.* 2005). Cadmium accumulation in various plant species has been extensively studied and showed various results.

Greger and Lofstedt (2004) examined the concentration and distribution of Cd in roots, leaves and seeds of various cultivars of wheat, and the results showed that the distribution pattern of Cd in the winter wheat, spring wheat and durum wheat is roots > flag leaves > seeds. The results of the study of Sekara *et al.* (2005) showed that the red beet is able to accumulate a large amount of Cd in the leaves, while the Cd accumulation in roots are 2.8 times smaller than that in the leaves. In pumpkin, the largest Cd accumulation is in the leaves, which is less than that in the stems and fruits. Cadmium accumulation in roots of barley is 4 times greater than that in the panicles, and 7 times greater than that in the seeds. The results of this study also concluded that the red beets, pumpkin, chicory, common bean, white-cabbage and parsnip accumulate Cd the most in their leaves.

The study of Wang *et al.* (2007) examined 2 cultivars of maize namely Nongda 108 and Liyu 6, and the results showed that although the uptake and concentration of Cd in the roots and shoots of both cultivars are different but both cultivars accumulate Cd in roots greater than that in the shoots. Cultivar Liyu 6 has a greater ability to accumulate Cd than

Nongda 108. The study of Sharma *et al.* (2010) found that the Cd accumulation in the roots of *Pisum sativum* is greater than that in the shoots. The study of Susana and Suswati (2013) about the 3 spesies of Brassicaceae found that mustard, chicory and Chinese kale are able to accumulate a large amount of Cd in their roots and shoots, but the Cd concentration in the roots is higher than that in the shoots. The study by Chai *et al.* (2013) and Susana *et al.* (2014) on *Aloe vera* showed that the Cd concentration in roots > leaf skin > mesophyll tissue.

The purpose of this study is to determine the distribution of Cd in sweet corn (roots, stems, leaves, panicles and grains) grown on a peat soil in the Rasau Jaya subdistrict, Kubu Raya district, West Kalimantan.

MATERIALS AND METHODS

Soil and Plant Sampling

Soil samples were obtained from 9 maize fields in the village of Rasau Jaya 1, Rasau Jaya subdistrict, Kubu Raya district, West Kalimantan. The soil samples were taken in each sampling site using composite methode. The soil samples were taken from 5 sampling points in each sampling site at a depth of 0-20 cm, then the samples were composited into one sample. The soil samples were put into plastic bags and labeled. The coordinates of the sampling sites were recorded using GPS (Table 1).

Maize plant samples were taken from the same fields as used for soil sampling. The cultivars of the sweet corn planted were cultivar Secada and Bonanza. In each field, 3 plant samples were taken randomly, so in total there were 27 plant samples. The plant samples were taken as a whole plant in the early grain filling phase (2-3 weeks before harvesting), and the grain samples were taken in the phase of fresh pod consumption.

Soil Analysis

Total Cd content in the soil samples was determined using a wet destruction method by applying a concentrated acid mixture of HNO_3 and $HClO_4$. The dry soil sample as much as 1 g was put in a test tube, then 5 ml concentrated HNO_3 and 1 ml concentrated $HClO_4$ were added to the soil sample and left for one night. The next day, the soil suspension was heated using a digestion block at 100^{o}C for 1 hour 30 minutes, then the heating temperature was risen to 130^{o}C for 2 hours 30 minutes until the yellow smoke was run out. After that, the heating temperature was risen again to 200^{o}C for 1 hour until the white smoke was formed. The destruction process was completed when the white precipitataton was formed or the clear solution was remained about 1 ml. The clear solution was then cooled and diluted using ion free water to 10 ml, then the solution was shaken. The Cd concentration in the clear solution was then measured using Atomic Absorption Spectrophometer. The soil pH was measured using a pH meter. The amount of available-P in soil was determined using Bray methods, and the soil organic-C content was determined using Walkey and Black method. The characteristics of the soils, including pH, organic-C content, organic matter content and total Cd content are presented in Table 1.

Plant Analysis

The plant samples were separated into roots, leaves, panicles and stems. The roots were cleaned from soil residue and other debris using clean water, then the roots were dried before being cut into small pieces. The root tissue was taken as a whole. The corn stems were separated from the leaves. The corn stems were taken from the segment 2, 3 and 4 from the base of the stems, then the stems were cut into small pieces. The leaf samples were taken from leaf 3, 4 and 5 of the top of the plant, then the leaves were cleaned up from dirt in advance using a clean damp cloth, then the leaves were cut into small pieces. The panicles were taken as a whole and cut into small pieces. The grains were separated from the cob, then placed in a container of aluminum foil, then the grains were dried at 85^{o}C for 48 hours. The pieces of roots, stems, leaves, and panicles were then placed into brown paper bags and also dried at 85^{o}C for 48 hours. The tissues of roots, stems, leaves, panicles and grains that have been dried then ground using a grinder.

The Cd content in each plant organ (roots, stems, leaves, panicles, and grains) were determined using dry ashing method. The dried plant tissues that have been ground was weighed as much as 2 up to 2.5 g. The dried materials then were put in a porcelain dish, and ashed at 600 ^{o}C for 7 hours. Then, the ash was dissolved into 10 ml of 30% HNO_3 solution and a few drops of H_2O_2, then heated using a hot-plate until all the ash was dissolved. After that, the solution was filtered to remove the insoluble ash materials, then the clear filtrate was diluted using distilled water to a volume of 25 ml using a volumetric flask. The Cd concentration in the filtrate was measured using AAS (SHIMADZU Type AA-6300 series).

Data Analysis

The data were statistically analysed using analysis of variance. The significant differences between means were analysed using the student t-test at 5% significance level. The pattern of Cd distribution in each plant organ was determined based on the order from highest concentration to the lowest concentration. The Cd concentration in the grains was then compared to Cd levels permitted in food grains proposed by SNI 7387: 2009.

RESULTS AND DISCUSSION

Soil Characteristics and Total Cd Content

The pHs of the soils sampled from all maize fields range from 3.5 to 4.6, and the soil pHs are classified as very acid to acid according to the criteria proposed by the Soil Research Institute (2005). According to Alloway (1997), soil acidity is a very important factor determining the availability of Cd, because the soil pH affects the mechanical adsorption and specification of the metal in soil solution. The correlation between soil acidity (pH) and the availability of Cd can be seen from the uptake of Cd by plants at different pH levels. The study of Page *et al.* (1981) *in* Alloway (1997) suggests that the Cd uptake by plant is inversely proportional to soil pH. The Cd content in the Swiss chard leaves increases about 2 to 3.9 folds when the soil pH decreases from 7.4 to 4.5. The Cd uptake in rice decreases with increasing pH from 5.5 to 7.5.

The organic-C contents in the soils range from 35.96% to 52.78%, which are classified as very high according to the criteria proposed by the Soil Research Institute (2005). The presence of organic matter in soil can reduce the solubility of heavy metals such as Cd because Cd is bound to soil organic compounds, thereby reducing the Cd uptake by plants. According to Tan (1988), a number of organic compounds including humic acid and fulvate acid are able to form complexes with metal ions. Stevenson (1982) indicated that organic compounds can bind the metal ions such as Cd^{2+} in soil solution. The organic compounds that bind the metal ions are commonly called as ligands.

The amounts of available-P in the soils sampled from the maize fields are in the range of 296 mg kg^{-1} up to 1028 mg kg^{-1}, which are considered as very high according to the criteria proposed by the Soil Research Institute (2005). The varying amounts of available- P in the soils at the sampling sites depend on the variation of the dosages and the types of P fertilizers used by the farmers.

The total Cd contents in the soils of the maize fields range from 0.20 to 0.32 mg kg^{-1}. These concentrations are considered as low for agricultural soils. According to Darmono (2008), the concentrations of Cd in the clean agricultural soils (no contamination) is 0.1 mg kg^{-1} up to 1 mg kg^{-1}.

Table 1. Sampling site coordinates, total Cd content, and characteristics of the soils sampled at the study sites.

Field Code	Coordinate		Total Cd (mg kg^{-1})	Organic Carbon (%)	Organic Matter (%)	Available-P (mg kg^{-1})	pH H_2O
L3**)	S 00°13'35.0"	E 109°23'16.6"	0.20	50.75	87.49	413	4.1
L5**)	S 00°13'31.2"	E 109°23'15.0"	0.18	35.96	62.00	296	4.6
L6**)	S 00°13'35.9"	E 109°23'23.0"	0.32	50.46	86.99	1,028	3.5
L7**)	S 00°13'36.9"	E 109°23'24.7"	0.22	49.88	85.99	446	4.3
L11**)	S 00°13'47.2"	E 109°23'42.9"	0.24	52.78	90.99	415	4.2
L12**)	S 00°13'48.8"	E 109°23'41.9"	0.18	51.91	89.49	516	4.5
L13*)	S 00°13'47.9"	E 109°23'44.3"	0.15	53.36	91.99	523	4.1
L14*)	S 00°13'44.4"	E 109°23'39.2"	0.26	52.20	89.99	681	4.2
L15**)	S 00°13'45.0"	E 109°23'36.6"	0.28	51.91	89.49	856	4.3

Notes: *) Cultivar Bonanza **) Cultivar Secada. Source: Susana and Suswati (2015).

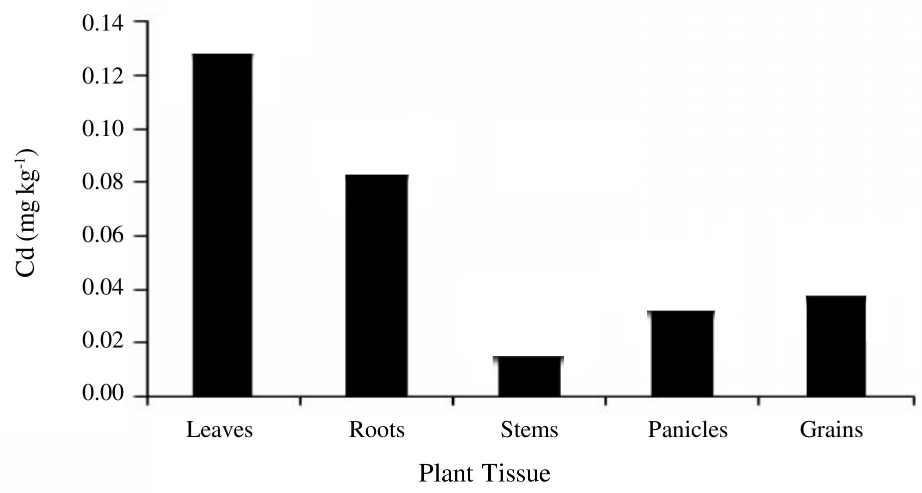

Figure 1. Average Cd Concentrations in leaves, roots, stems, panicles and grains of sweet corn.

Distribution of Cd in Organs of Maize Plants

The mean concentrations of Cd in the roots, stems, leaves, grains and panicles of sweet corn plants taken from 9 maize fields can be seen in Figure 1. The Cd concentrations in the plant organs are in the order of leaves > roots> grains> panicles> stems. The highest Cd concentration was measured in the leaves while the lowest Cd concentration was measured in the stems. The concentration of Cd in the leaves is 1.5 times Cd concentration in the roots. The results of analysis of variance showed that the plant organs significantly affect the concentration of Cd accumulated.

A previous research on two cultivars of maize showed that in general the concentrations of Cd in the roots of the 2-4 weeks aged maize seedlings was higher than that in the leaves, although the amounts of the Cd accumulated were different between the two cultivars (Wang *et al.* 2007). The leaf samples in this study were taken at the early grain filling stage. This result suggests that at this phase, most of Cd in the roots were transferred to the leaves around the cobs, and further translocated to other parts of cobs including grains.

The high Cd concentration measured in the leaves than that in the roots of sweet corn plants indicates a high ability of sweet corn plants to translocate Cd from the roots to the top of the plants, especially the leaves. According to Smith (1996) *in* Sharma *et al.* (2010), Translocation Factor (TF) is the accretion of heavy metals in the plant parts, also known as transfer coefficient. Translocation Factor (TF) is the ratio of the concentration of heavy metals in the shoots to that in the roots, demonstrating the ability of plants to transfer Cd from roots to shoots. The TF of each organ can also be calculated by finding the ratio of Cd concentration in each organ to Cd concentration in the roots. The TFs of leaves, grains, panicles and stems are as follow: leaves (1.54) > grains (0.44) > panicles (0.38) > stems (0.18). The TF of leaves of sweet corn plants is high (1.54), meaning that most of the Cd is transferred from roots to the leaves of sweet corn plants. The study of Li *et al* (2008) stated that the cadmium TF of maize shoots grown intercropping with chickpea is relatively large, *i.e.* 0.55. The study of Sekara *et al.* (2005) shows that the cadmium TF from roots to shoots of maize plants is 0.33, while Cd TF from roots to shoots of the red beet reaches 2.81 and it is 1.50 for alfalfa.

The ability of plants to accumulate Cd and the distribution of Cd in plants vary not only at the species level but also to the level of varieties and cultivars. The results of current study showed that the distribution of Cd in two cultivars of sweet corn plants (*i.e.* Secada and Bonanza) is similar. The distribution of Cd is in the order of leaves > roots > grains > panicles > stems. The Bonanza cultivar was planted in two maize fields (L13 and L14), while Scada cultivar was planted in other seven maize fields (Table 1).

The implications of the Cd contents in Maize Plant Organs on Food Safety

Foods should be free of Cd, but there is a safe limit of Cd content in foods that has been set by the Indonesian government (written in the SNI 7387: 2009). For example, the safe limit of Cd content in grains based on SNI 7387: 2009 is 0.2 mg kg^{-1}. According to WHO (2011), the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established a safe level of Cd intake as provisional tolerable monthly intake (PTMI) of 25 µg kg^{-1} body weight. The major food groups that contribute the most to the Cd exposure are rice and grains, shellfish and seafood, meat including edible offal, and vegetables. Table 1 showed that all the sweet corn grain samples taken from 9 maize fields in the current study contain Cd below the threshold value allowed by SNI 7387: 2009.

The leaves and stems of maize plants are often used by the farmers to feed cattle and goats. The Cd concentration in the leaves of sweet corn plants measured in the current study is 8.6 times the concentration of Cd in stems, and 3.5 times Cd contained in grains. The average value of Cd in the leaves of sweet corn plants is 0.129 mg kg^{-1}. The implication of high Cd concentration in the leaves of sweet corn plants for animal feed is the use of large amounts of leaves potentially causes the increase of accumulation of Cd in the cattle tissues. The safety limit of Cd in meat and meat products according to SNI 7387: 2009 is 0.3 mg kg^{-1}.

Another implication of the relatively high Cd concentration in the leaves of sweet corn plants is the corn plants can be potentially used for phytoremediation of Cd contaminated agricultural soils. Plant biomass derived from the leaves and stems is much larger than the root biomass, therefore, the greater the plant biomass and the higher the ability of leaf biomass to accumulate Cd will result in the greater amount of Cd that can be taken up from the soil, thereby resulting in more efficient phytoremediation. According to Ebbs *et al.* (1997) and Opeolu *et al.* (2005), the successful phytoremediation requires plants that have large biomass in addition to the ability to accumulate contaminants in large quantities. Plants that have high biomass can be used efficiently for phytoremediation of heavy metal contaminated soils although the concentrations of heavy metals that can be absorbed by the plants are not too high, because the total concentrations of heavy metals that can be transported from soils to plants is expressed as the total uptake by the entire plant biomass. The greater the biomass, the higher amount of Cd that can be absorbed by the plants.

CONCLUSIONS

The distribution of Cd in the plant organs of sweet corn cultivars Scada and Bonanza follows the order of Cd in leaves > roots > grains > panicles > stems. The leaves contain the highest amount of Cd, while the stems contain the lowest amount of Cd. The Cd concentration in the leaves is 3.5 times the concentration of Cd in grains, and 1.5 times Cd concentration in the roots. The average Cd concentration in grains is 0.037 mg kg^{-1}, which is still below the safe limit of Cd content in grains allowed by SNI 7387: 2009, *i.e.* 0.2 mg kg^{-1}.

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