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Bioaccumulation of cadmium in potato tuber grown on naturally high levels cadmium soils in Jamaica

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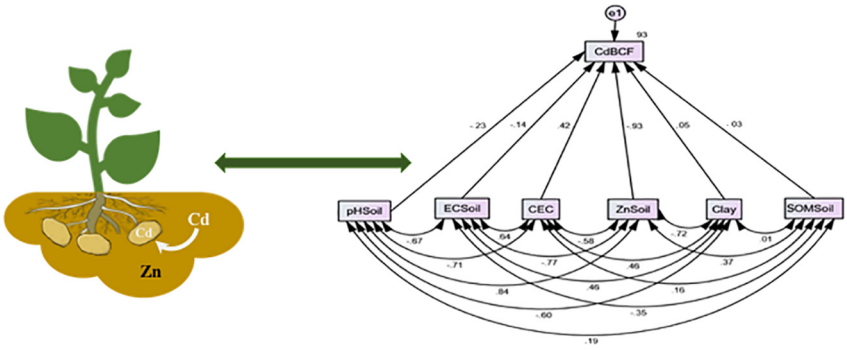
HIGHLIGHTS

- Level of cadmium in Jamaican soils was found medium to high.
- In potato, cadmium level was higher than the recommended limit.
- pH and Zn were the dominant factors influencing Cd accumulation in potato.
- Other soil properties did not influence cadmium bioaccumulation in potato.

GRAPHICAL ABSTRACT



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ABSTRACT

Jamaican soils have been reported to have naturally high level of cadmium (Cd), and its bioaccumulation in edible crops is of great concern for farmers, stakeholders, and public health authorities. The aim of this study was to determine the levels of Cd in soils in Jamaica and its bioaccumulation in potato tubers, and to determine the dominant soil factors influencing this bioaccumulation in potato. In addition, other soil factors were investigated such pH, electric conductivity (EC), cation exchange capacity (CEC), texture, organic matter content (OMC), and soil zinc (Zn) concentration. The soils' pH and Zn concentration were found to be the dominant factors influencing Cd accumulation in potato tubers, and this was confirmed by using a step-wise multiple regression analysis with the soil factors and tuber Cd ($P < 0.05$). With soil Cd ranging between 0.05 and 62.3 mg kg^{-1} and tuber Cd ranging between 0.01 and 0.22 mg kg^{-1} fresh weight, the bioaccumulation factor (BCF) of Cd in potato tuber gave a precise assessment of the influence of soil variables on Cd accumulation in potato tuber. The Cd concentration in potato tubers was found 50% higher than that recommended by the World Health Organization (WHO) regulation for potatoes (0.05 mg kg^{-1} fresh weight), and therefore, this should raise real concerns about the human health risk in Jamaica.

1. Introduction

Cadmium (Cd) was widely investigated because of its toxicity to plants and its effect on human health is also well documented (de Livera et al., 2011). Either in animal or plant organisms, Cd does

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not offer a known metabolic or physiological function towards their growth and development (Ondrasek et al., 2009). In Jamaican soils, Cd had been found in concentrations ranging from 0.3 mg kg^{-1} to over 400 mg kg^{-1} (Lalor et al., 1998). However, the levels of soil Cd over 400 mg kg^{-1} are very rare as Cd is only the 64th most abundant element with an average Cd concentration in the earth crust of 0.1 mg kg^{-1} (Tchounwou et al., 2012). The soil accumulates Cd from natural sources such as the weathering of parent rocks and anthropogenic sources such as mining activities and phosphate fertilizer application (de Livera et al., 2011).

As one of the mineral element in soil, Cd is uptaken and accumulated by plants, however, this uptake is influenced by intrinsic-crops species and cultivar and extrinsic-weather factors (Jönsson and Asp, 2011). Furthermore, soil factors such as pH, organic matter content (OMC), cation exchange capacity (CEC), electrical conductivity (EC), texture, and zinc (Zn) concentration also influence this uptake (Chavez et al., 2015; Leung and Mark, 2002; Liu et al., 2015; Ningning et al., 2015; Roberts, 2014). The pH is considered as the most important factor influencing Cd uptake, and a significant relationship was found between soil pH and extractable Cd and study showed that in soils with low pH, Cd uptake was higher (Muhammad et al., 2012). Cd and Zn share chemical similarities and as such, several hyper-accumulator plants are common for both Cd and Zn which highlights the similarity between their accumulations in plants (Reeves et al., 2017). Electrical conductivity was also found to be positively correlated to Cd uptake and chloride salinity of irrigation water has been found to increase Cd uptake in several edible crops (López-Chuken et al., 2011). In contrary, other factors such as such as cation exchange capacity (CEC) have been shown to be negatively correlated to Cd uptake (Nevel et al., 2011; Zhao et al., 2014). However, the total concentration of Cd in soil is not always a good indicator of its concentration in the edible tissues of plants (Perez and Anderson, 2009), and studies conducted in different regions of the world did not determine the dominant soil factor influencing Cd uptake.

In plants, accumulation of Cd causes a reduction in biomass, growth, a decrease in root growth chlorosis, and net CO_2 assimilation rate by reducing RUBISCO activity (Benavides et al., 2005; Dias et al., 2013). For example, increased Cd concentration caused a decrease of 30% in the strawberry plant growth (Muradoglu et al., 2015) and had a deleterious effect on the net photosynthetic rate in tomato seedling (Dong et al., 2005). However, some plants are more Cd-tolerant than other and accumulate less (Ci et al., 2009) but yet the mechanisms of Cd tolerance need still to be understood (Guo et al., 2016).

Although several studies reported on Cd uptake and bioaccumulation in plants, little is known on Cd uptake by edible crops in the tropics, while no study reported the case in Jamaica or the Caribbean. The aim of this study was to investigate Cd in Jamaican soils, and factors influencing its uptake and bioaccumulation by potato (*Solanum tuberosum*) which is one of the most consumed edible crops in Jamaica and the Caribbean.

2. Materials and methods

2.1. Site selection

Potato farms were selected in the parishes of St Elizabeth, Trelawney and Manchester where Cd levels have been reported higher than the island-wide average (Wright et al., 2010). These parishes are also traditional potato cultivating areas in Jamaica. A total of 20 farms were selected with two in St Elizabeth, two in Trelawney and 16 farms in Manchester where Cd levels in soils are over 5 folds higher than the first two selected ones (Fig. 1).

2.2. Potato and soil sampling

From each location, 1 kg of mature potato tubers were harvested and packed in polyethylene bags after using a nylon brush to carefully remove adhering soil and plant material. The tubers were transported to the lab, weighted and three potatoes were selected, placed in polyethylene bags, labeled and refrigerated before analysis. From each cultivating site, 5 kg of soil were sampled from 15 to 30 cm depth and sieved to discard plant material and stones as described by Wright et al. (2012). Soil samples were placed in polyethylene bags and transported to the laboratory for analysis.

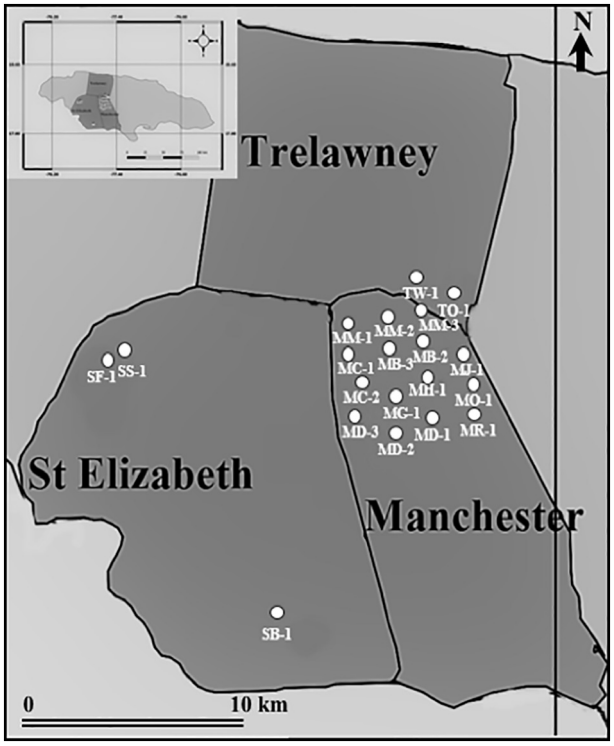

Fig. 1. Map of Jamaica illustrating potato farms used as study sites in the parishes of Manchester (M), Trelawney (T), and St Elizabeth (S).

2.3. Preparation soil samples for analysis

Soil samples air-dried at room temperature for five days. Dried soil samples were passed through a 2 mm nylon sieve and placed in polyethylene bags.

2.4. Preparation of potato samples for analysis

Potato tubers were peeled using a stainless-steel knife and washed first with tap water and then with deionized water. Peeled tuber samples were diced into small cubes of ca. 1 cm^3 and transferred into aluminium pans. Pans were placed in a pre-heated oven at 70 °C for 72 h until a constant dry weight was achieved for each sample. Then, the dried samples were ground using Fritsch Mortar Grinder Pulverisette 2, and the powder used for analysis.

2.5. Physiochemical properties of soils

The texture of the soil was determined using the hydrometer and sieve method as described by (Gee and Bauder, 1986). Soil pH was measured in a water suspension of 1:2.5 soil/solution ratio as described by (Gray et al., 1999). Soil organic matter (SOM) was measured by the method described by Sato et al. (2014) and Walkely and Black (1934), and the cation exchange capacity (CEC) was determined using the ammonium acetate method as described by (Ross and Kettering, 2011). For physicochemical properties of soils analysis, each sample was analyzed in duplicate (two biological repetitions).