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Original article

Cadmium contamination on potatoes (*Solanum tuberosum* L.) in intensive production

Contaminación por cadmio en la producción intensiva de papa (*Solanum tuberosum* L.)

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ABSTRACT : Cadmium (Cd) is an element with no known biological function for plants, animals and man, however, due to its chemical similarity with other essential elements, it can be absorbed by plants and thus enter the food chain, causing severe damage. Potato cultivation is known to be a hyperaccumulator of Cd and other heavy metals, so it represents a risk for the food chain if this plant is grown in areas contaminated by these elements. For this reason, the objective of this research was to evaluate the concentration of Cd in potatoes for consumption, from two units in intensive production, as possible risk factors for the food chain and the environment. For this, the concentration of Cd was evaluated in the soil, the propagule (agamic seed), the plant and the potato tuber produced for consumption. As a result, contamination could be observed, since the concentrations of Cd in the different samples evaluated exceeded the maximum permissible limits, mainly due to the use of cultivation technology in Cuba, with numerous applications of pesticides, preventively to the cultivation and high doses of fertilizers. Although this contamination could also have been influenced by various contaminating sources of the studied sites, such as: the burning of sugarcane in neighboring areas, the existence of a solid waste dump near the field and the proximity of roads with high vehicular traffic. Based on the results, a Technological Surveillance System was proposed that will mitigate the risks in the agroecosystems that were contaminated with Cd.

Key words: Heavy metals, contaminant sources, toxicity, Technological Surveillance System.

RESUMEN : El cadmio (Cd) es un elemento sin función biológica conocida para las plantas, animales y el hombre, sin embargo, por su semejanza química con otros elementos esenciales puede ser absorbido por las plantas y de esta manera entrar a la cadena trófica provocando daños severos. El cultivo de la papa es conocido por ser hiperacumulador de Cd y otros metales pesados, por lo que representa un riesgo para la cadena trófica que esta planta se cultive en áreas contaminadas por estos elementos. Por esa razón, la presente investigación tuvo como objetivo evaluar la concentración de Cd en papa para el consumo, procedentes de dos unidades en producción intensiva, como posibles factores de riesgo para la cadena trófica y el medio ambiente. Para ello se evaluó, a partir de muestreos aleatorios, la concentración de Cd, en el suelo, el propágulo (semilla agámica), la planta y el tubérculo producido de papa para el consumo. Como resultado se pudo observar contaminación, ya que las concentraciones de Cd en las diferentes muestras evaluadas sobrepasaron los límites máximos permisibles debido, fundamentalmente, al uso de la tecnología del cultivo en Cuba, con numerosas aplicaciones de plaguicidas, de forma preventiva al cultivo y elevadas dosis de fertilizantes. Aunque también, esta contaminación pudo haber sido influenciada por varias fuentes contaminantes de los sitios estudiados, como fueron: la quema de caña de azúcar de áreas colindantes, la existencia de un vertedero de residuos sólidos cerca del campo y la cercanía de carreteras de alto tráfico vehicular. A partir de los resultados, se propuso un Sistema de Vigilancia Tecnológica que permitirá mitigar los riesgos en los agroecosistemas que resultaron contaminados con Cd.

Palabras clave: metales pesados, contaminantes, toxicidad, vigilancia de contaminantes.

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INTRODUCTION

Heavy metals are defined as those that are toxic to health and the environment, and when they come into contact they damage health and the environment where they are found. The most toxic metals are lead, mercury, cadmium and arsenic. These heavy metals are found in the parent material of the soil (1). Heavy metals such as lead, cadmium, chromium, zinc, mercury and others are released into aquatic ecosystems as well as soils mainly due to various anthropogenic activities and pose a serious threat to plants, animals and even humans due to their persistence, bioaccumulation, non-biodegradable property and toxicity even at low concentrations (2).

For some time now, heavy metal contamination has been of particular interest to researchers around the world, mainly because of the damage it can cause to human and animal health. Several studies have addressed the subject, due to the risk that this implies for the trophic chain, especially when the causes of soil and water contamination can be various, from the excessive use of chemical products to the influence of aerosols from motor vehicles and fires (3). This implies that some plants, including those of agricultural interest, have developed evolutionary mechanisms that allow them to survive in these stressful conditions, even removing large quantities of these elements from the soil; these plants are known as heavy metal accumulators or hyperaccumulators (4,5). Among this type of plant is the potato (*Solanum tuberosum* L.) as a hyperaccumulator of Cd and Cr (6).

Every year, the Cuban state invests considerable financial resources in potato cultivation, since it requires high-input technology and agrochemicals to achieve acceptable yields in tropical conditions, for which the most productive soils are used (7), which can sometimes be affected by contaminating sources. This crop can accumulate in tubers: 0.021 mg kg^{-1} of Cd; although it can also store other metallic elements such as Cu, Pb, Ni and Zn (7). Cd cannot be found pure in the environment; it is found in the form of complex oxides, sulfides and carbonates of zinc, lead and copper (8). However, its presence in nature is minimal, ranging between 0.1 - 0.5 mg kg^{-1} of the earth's crust, its presence in the organism is between 10 and 30 years, presenting a great variety of negative effects in humans (9). It is not an essential element for plants, animals or man, but as it has chemical similarities with other elements, it can enter the plant through common transporters. Its effect on plants is due to the fact that it interferes in the entry and transport of nutrients, causing reduction of Mn, Zn, Cu, Fe and Ca in roots, stems and leaves (10).

For this reason, the objective of this research was to evaluate the concentration of Cd in the soil, the propagule (seed), the plant and the potato tuber in intensive production, in two productive units in Güines municipality in Mayabeque province, Cuba.

MATERIALS AND METHODS

Location and Characterization of the study sites:

The present research was carried out at the Miguel Soneira Ríos Assorted Crops Enterprise in Mayabeque province, Cuba, in two production units in Güines municipality, the CAP (Cooperative of Agricultural Production) Cuban-Bulgarian Friendship and El Marqués Farm, located in Río Seco town. These sites have been dedicated to the production of various crops for many years and have Red Ferrallitic soils. CAP borders the Güines-Melena del Sur highway, with high vehicular traffic, and is located at coordinates 22°50'47.04'' north latitude and 82°0.3'45.03'' west longitude. The farm borders other agricultural units belonging to the Ministry of Agriculture and AZCUBA; the surrounding area is historically a sugarcane area where it was observed that some blocks were burned and that a few meters from the field under study is the town's domestic garbage dump. This area is geographically located between 22º 47' 53" north latitude and 81º 58' 45" west longitude.

In both places, agricultural production is intensive, with center pivot machines. It is important to point out that in our country a technological package is established for this crop (8) that makes use of large quantities of chemical products, which the Cuban state prioritizes each year to achieve high yields that satisfy the country's demand. The technological package can be found by consulting the field history of the phytosanitary specialist.

In these production areas, the methodology for the Agroecological Diagnosis of areas with possible risk of contamination (11) was used, for which workshops were held with phytosanitary specialists, potato crop specialists and other social actors involved, also using the Action-Participation Method, after which a SWOT matrix (12) was made with the results of the workshops.

Sampling and analysis performed

The soil samples were dried at room temperature and macerated, while the plant tissue samples were dried in an oven at 80 ºC for 3 days, until a constant mass was reached. Subsequently, the digestions described in Table 1 were carried out and then the Cd concentration was determined using a flame Atomic Absorption Spectrophotometer (Spectrometer-NovAA 350, Analytik jena), at the Physiology Laboratory of the Institute of Animal Science (ICA), located in Catalina de Güines, Mayabeque, Cuba.

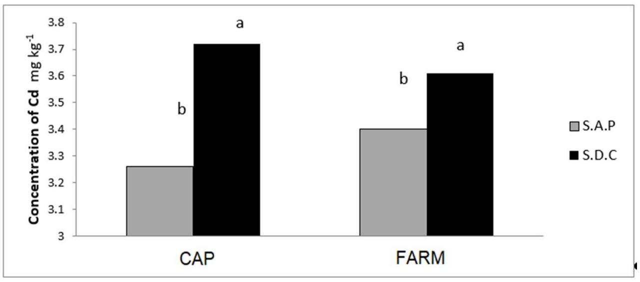
Statistical analysis

A simple analysis of variance (ANOVA) was applied with five replicates per treatment or sample taken and then, in the cases where differences were found between treatments, a comparison of means was made using Duncan's multiple range test ($p<0.05$). The Statgraphics Centurion program was used for statistical processing.

RESULTS AND DISCUSSION

Evaluation of Cd concentration in the soil

Figure 1 shows the Cd concentration in the soil of the two production units. It can be observed that there are significant differences between the sampling times, with higher values found after harvest, which leads us to think that this increase may be mainly due to the technology used in the crop. In this regard, some authors suggest that the numerous applications of chemical products made to the crop, in the Ferrallitic Red soils of Mayabeque, Cuba, have increased the concentrations of heavy metals in the soil in the last years (11).



S.A.P: sample taken before potato planting. S.D.C: sample taken after potato harvest. Means with common letters in each bar do not differ significantly for $p \leq 0.05$

Figure 1. Comparison of Cd concentrations in soil, at two sampling times, in the two production units

Other authors refer as possible causes of soil contamination, heavy metals from agrochemicals applied in weed and pest control (15). The intensive use of pesticides, pesticides and chemical fertilizers is also mentioned as part of the anthropic contamination (16).

In Cuba, the Red Ferrallitic soils can naturally have 0.6 mg kg^{-1} of Cd, so the values found, higher than 3 mg kg^{-1}, are considered very high values, that is, with these levels of Cd in the soil, remediation measures should be taken (14).

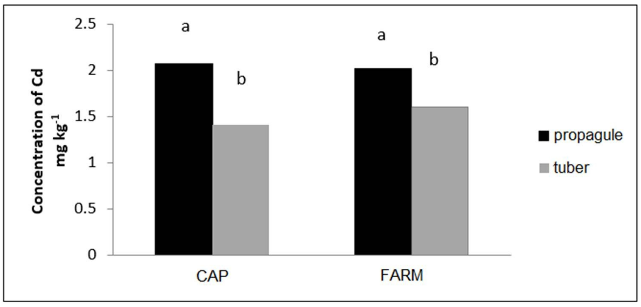
Other sources of Cd contaminants may have played a role. In the case of the Farm, it could be the aerosols emitted by the burning of sugar cane near the field studied and also the fact that there is a domestic waste landfill a few meters from the area. In this sense, some research has identified domestic waste landfills as a contaminating source of heavy metals, not only in soils, but also in vegetables that have been treated with organic amendments from domestic waste (17). In the case of the CAP, the other contaminating source could be Güines-Melena del Sur highway that borders the field. In this regard, it has been suggested in the international literature, as a summary, that one of the causes of soil contamination is the heavy metals that come out with the smoke from car exhaust pipes (16).

Other authors have reported higher levels of Cd than the maximum permissible limit in the chard crop and the environmental quality standards for agricultural soils, which may be influenced by the discharge of tributaries to the river from mining and the application of fertilizers and phytosanitary products (18).

Results have been obtained in soils in Peru (19) with average Cd concentrations above the established standards, indicating that a gradual increase in the application of phosphate fertilizers could result in an increase in the cadmium content of the soil and, therefore, damage to people's health could be expected.

Evaluation of Cd concentration in propagules and tubers

Figure 2 shows that there is a significant difference in Cd concentrations between propagules and tubers at each location, with the highest values for propagules. These results in tubers correspond with those reported by other authors (11) in other farms for this same crop; however, they did not study the propagule or seed.



Propagule: agamic seed used to plant the potato. Tuber: Agricultural fruit that is consumed. Means with common letters in each bar do not differ significantly for $p \leq 0.05$

Figure 2. Comparison of Cd concentrations in potato propagules and tubers at the two sites studied

Table 1. Description of sample collection (treatments) and analytical techniques employed

Samples	Sampling method	Sampling time	Analytical technique for digestion
Soil	Random, taking 5 samples per quadrant for a total of 20 samples.	Before planting and after harvesting	Extraction with aqua regia (6 mL of nitric acid and 2 mL of hydrochloric acid) (13)
Propagule (seed)	Random, taking 5 samples directly from the seed store for a total of 20 samples.	Before planting	Wet digestion: (HNO_3 and $HClO_4$) (3:1 v/v)(14)
Plant (aerial part)	Random, taking 5 samples per quadrant for a total of 20 samples.	At harvest	Wet digestion: (HNO_3 and $HClO_4$) (3:1 v/v)(14).
Tuber	Random, taking 5 samples per quadrant for a total of 20 samples.	At harvest	Wet digestion: (HNO_3 and $HClO_4$) (3:1 v/v) (14).

High values obtained in potato tubers, as can be observed in Figure 2, exceed the permissible limit of Cd in roots and tubers of 0.1 mg kg^{-1}, according to the Cuban Standard for metallic contaminants in food (20), as well as the CODEX Alimentarius of the FAO (21), which can constitute a risk for the trophic chain and a serious danger for the people who consume the food, since Cd can cause serious health problems fundamentally in the long term (22).

Evaluation of Cd concentration in plant (aerial part)

The concentration of Cd in potato plants from both experimental sites (Table 2) did not show significant differences, which corroborates, as mentioned in the introduction, that this crop is a plant that hyperaccumulates the metals Cd and Cr (7). The existence of this element in the plant can be highly toxic, altering its photosystem, inhibiting the flow of electrons and the photosynthetic apparatus, creating oxidative stress, instability of the cell walls and structural damage, decreasing the tolerance to stress, which opens the doors to the attack of undesirable microorganisms (23). However, in the research it was observed throughout the crop cycle that there were no symptoms of visible toxicity in any phenological stage, coinciding with other researches.

Table 2. Comparison of Cd concentrations in the aerial part of the potato plant in the two areas studied

Productive Area	Cd concentration (mg kg^{-1})
CAP	1.90 a
Farm	1.95 a
CV (%)	13.50

Means with common letters in the same column do not differ significantly at $p < 0.05$

In a study carried out with *Rumex cet*osa, a plant tolerant to heavy metals, no symptoms of visible Cd toxicity were observed; however, some anomalies were observed in the ultrastructure of chloroplasts (24).

The results generally coincide with the research developed in xxxxxxx in the potato crop, it was found that the Cd content in the plant, tuber and final soil exceeded the LMP for the crop (25).

An influential factor in contamination is the application of chemicals such as pesticides and mineral fertilizers. Research shows that pesticides contain trace elements and can contribute 1.38 - 1.94 mg kg^{-1} of Cd; phosphate and nitrogen fertilizers can contribute 0.1 - 170 mg kg^{-1} and 0.05 - 8.5 mg kg^{-1} of Cd, respectively (26).

From the analysis of the field history of each studied site and the exchange with producers, it was observed that several applications of pesticides were made preventively with the same objective, that although they attack pests and diseases, they can compromise the food safety, even contaminate soils and phreatic mantles (26,27).

In Cuba, the Technical Instructions for potato cultivation (7) establishes a strategy for the prevention of pests and diseases, which was identified as a Threat according to the Action-Participation method, since the application of this technological package is mandatory. Through this same method, the lack of knowledge on the subject of contamination by the producers of CAP Amistad Cubano-Bulgara was identified as a Weakness, but as a Strength, the producers of El Marqués farm were aware of it, since research was previously carried out at this site. From this arises as an Opportunity a Technological Surveillance System that proposes:

- To evaluate the concentrations of heavy metals in the soil, irrigation water, propagule, tuber and potato plant.
- Strictly comply with the cultural control measures set out in the technical instructions.
- Control contaminant sources throughout the crop cycle and apply pesticides only when harmful organisms exceed the level of economic damage.
- Conduct training workshops with producers, agricultural managers and public health specialists on the issue of heavy metal contamination in food and the risks involved.

CONCLUSIONS

- The different samples evaluated showed cadmium contamination, with concentrations that exceeded the maximum permissible limits, mainly due to the use of propagules or agamic seed already contaminated and to the use of cultivation technology in Cuba, with high doses of mineral fertilizers and numerous preventive applications of pesticides to the crop.
- It is inferred that the contamination could have been influenced by other contaminating sources present in the areas studied, as has been pointed out in the literature, such as: the burning of sugar cane in adjacent areas, the existence of a solid waste landfill near the field and the proximity of high vehicular traffic highways.
- A Technological Surveillance System was proposed that will allow productive units to mitigate the risks in these agroecosystems contaminated with cadmium.

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