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Uptake of metals by tomato plants (*Solanum lycopersicum*) and distribution inside the plant: Field experiments in Biscay (Basque Country)

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ABSTRACT

The concentration of several elements (Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, Sr, Ti, V and Zn) in soils and different parts (roots, stems, leaves and fruits) of tomato plants (*Solanum lycopersicum*) from 11 cultivars located in Biscay (Basque Country) was measured, in order to evaluate metal uptake, transportation, and accumulation in tomato plants. The analysis was carried out by Inductively Coupled Plasma-Mass Spectrometry, after microwave assisted acidic extraction of the samples. Principal Component Analysis and Correlation Analysis of the dataset were performed. Different bioaccumulation and translocation factors were calculated to estimate the efficiency to absorb metals from soil and to distribute them among the different parts of the plant. As expected, metal concentrations in soil were significantly higher than in tomato plant. Different accumulation rates were observed in each part of the plant. Accumulation of metals in fruits compared with any other compartment analyzed was low. In fact, the concentrations of the most toxic metals (Pb and Cd) found in the edible part of the plant were below the maximum permissible levels established by the European Commission, which confirms that, regarding toxic metals, consumption of these tomato fruits is not harmful for human health.

1. Introduction

Consumption of vegetables with unacceptable high concentrations of heavy metals may represent a threat to human health. For example, the World Health Organisation (WHO) has limited the weekly intake of metals like Cd, Pb, Al and Sn to 0.007, 0.025, 2 and 14 mg/kg of body weight, respectively, and the monthly intake of Cu, Fe and Zn to 0.5, 0.8 and 1 mg/kg of body weight, respectively (Codex Alimentarius Commission, 2012). The main inputs of metals to plants are i) from soil through roots and ii) by aerial deposition through leaves (Filipović-Trajković et al., 2012). It is well established that in crops and vegetables fumigation processes are the main source of certain trace elements through deposition processes, with a possible subsequent assimilation through the leaf stoma (Serbula et al., 2013).

There are many factors that influence the concentration of trace elements in crops, such as the type of cultivar, the cultivation method, the geographical and meteorological characteristics of the production region and the sampling season. For example, some authors have reported that the acidity of soil may affect metal uptake. Metals in acid soils are more available to plants than those in alkaline soils (Wang et al., 2000). All these factors act simultaneously and, therefore, it is difficult to come to clear conclusions about metal uptake and distribution inside the plant (Hernández-Suárez et al., 2007).

Different accumulation and translocation factors have been used to provide supporting and complementary information about the fate of metals in plants. The BioConcentration Factor (BCF, ratio of metal concentration in roots to that in soil) (Yoon et al., 2006), the BioAccumulation Coefficient (BAC, ratio of metal concentration in the whole plant to that in soil) (Zayed et al., 1998), and the

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Translocation Factor (TF, ratio of metal concentration in shoot, e.g. the aerial part of the plant, to that in roots) (Fayiga and Ma, 2006; Zhang et al., 2002) are the most popular ones. They help us to investigate the distribution of elements among the different parts of the plant and decide, for example, if a given plant species can be used as accumulator in phytoremediation or phytostabilisation processes.

A regular consumption of vegetables is important to assure an equilibrated diet and thereby to prologue lifetime. Tomato, *Solanum lycopersicum*, is the most consumed vegetable (about 60 g per day) in the Basque Country (Elika gidak 8, 2008) and one of the most consumed all over the world (Nuez, 2001). Cultivars of tomato can be affected by metallic pollution from different anthropogenic sources, e.g. industry, agriculture, livestock, waste management and road/air traffic (Groom et al., 1995). It has been observed that tomato plants absorb greater amounts of heavy metals, especially Cd, than other plants, such as maize. Furthermore, accumulation of heavy metals increases when tomato is intercropped with other plant species (Lingyao et al., 2001). Wang et al. (2000) observed that Co tends to accumulate in roots rather than in other parts of the tomato plant. Zn and Sr, however, showed maximum accumulation in leaves and stems. In tomatoes, special attention must be paid to the edible part of the plant, the fruit. Some authors concluded that there was no risk to consume the tomatoes they had analyzed (Luis et al., 2012; Rodriguez-Iruretagoiena et al., 2015; Trebolazabala et al., 2017), while others observed high concentrations of metals in fruits collected in cultivars next to industrial or other anthropogenic activities (Nwajei et al., 2012). The uptake and distribution of several elements in tomato plants cultivated under controlled conditions in open-air plots has already been recently investigated (Liñero et al., 2015).

The European Commission (EC) has defined the maximum allowed concentration of several toxins in foodstuff (European Commission, 2006). Following the recommendations of the WHO (Codex Alimentarius Commission, 2012), they have limited the concentration of Cd and Pb to 0.05 and 0.1 mg/kg (fresh weight), respectively, in fruiting vegetables. These metals can cause serious damage to human health, so their concentration in foodstuff must be carefully monitored.

The aim of this work was to investigate the distribution of metals within the different parts of the tomato plant and its relation (if any) with the concentration of metals in the cultivation soil. Thus, the concentration of fifteen elements (Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, Sr, Ti, V and Zn) in different parts of tomato plants (root, stem, leaf and fruit) collected at eleven different orchards located in Biscay (Basque Country), and in their cultivation soils were measured by Inductively Coupled Plasma/ Mass spectrometry (ICP-MS) after microwave-assisted acid digestion of the sample. The concentrations found were compared with the threshold valued given by the EC, the dataset was analyzed using chemometric techniques, and several accumulation factors were calculated.

2. Materials and methods

2.1. Sampling and sample pretreatment

Sampling was carried out at eleven orchards in Biscay (Basque Country): Artebakarra (ART), Gatika (GAT), Getxo (GET), Barrika (BAR), Butron (BUT), Elorrio (ELO), Plentzia (PLE), Dima (DIM), Leioa (LEI), Gorliz (GOR) and Zamudio (ZAM) (see Fig. 1). Sampling took place in September 2011. Samples were collected in sunny days without rain in, at least, the previous 96 h.

All glassware material in contact with samples or standards was firstly washed with soap and water, soaked in a 10% HNO_3 bath (prepared from HNO_3 65% Technical grade, Panreac, Castellar del Vallès, Catalonia) for at least 24 h, rinsed twice with Elix quality water (Millipore, Billerica, MA, USA) and once with Milli-Q water (18.2 MΩ cm, Milli-Q Element A10 purification system, Millipore, Billerica, MA, USA). Finally, the clean material was dried in a Heraeus oven D63450 model (Heraeus Holding, Hanau, Germany) at 100 °C for 24 h and stored in clean plastic bags until use.

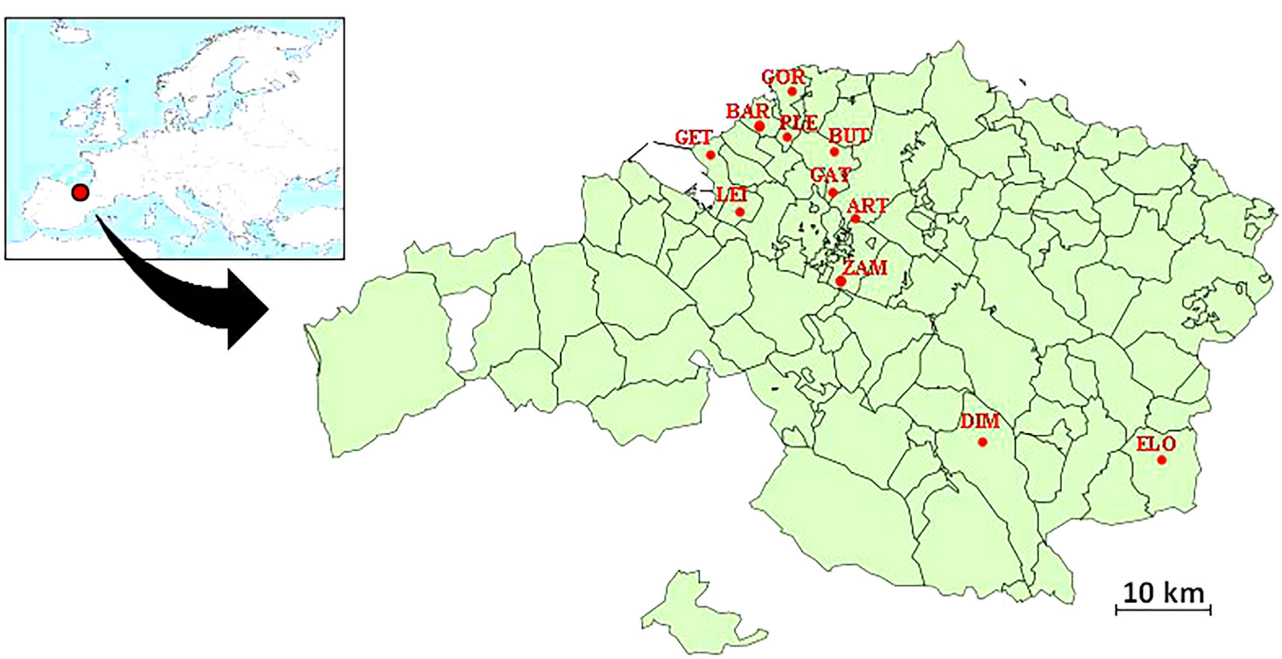

Fig. 1. Location of the orchards where samples were collected (Biscay, Basque Country).
Artebakarra (ART), Gatika (GAT), Getxo (GET), Barrika (BAR), Butron (BUT), Elorrio (ELO), Plentzia (PLE), Dima (DIM), Leioa (LEI), Gorliz (GOR) and Zamudio (ZAM).