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Natural enrichment of *Solanum tuberosum* L. with Calcium – monitorization of mineral interactions in plant tissues

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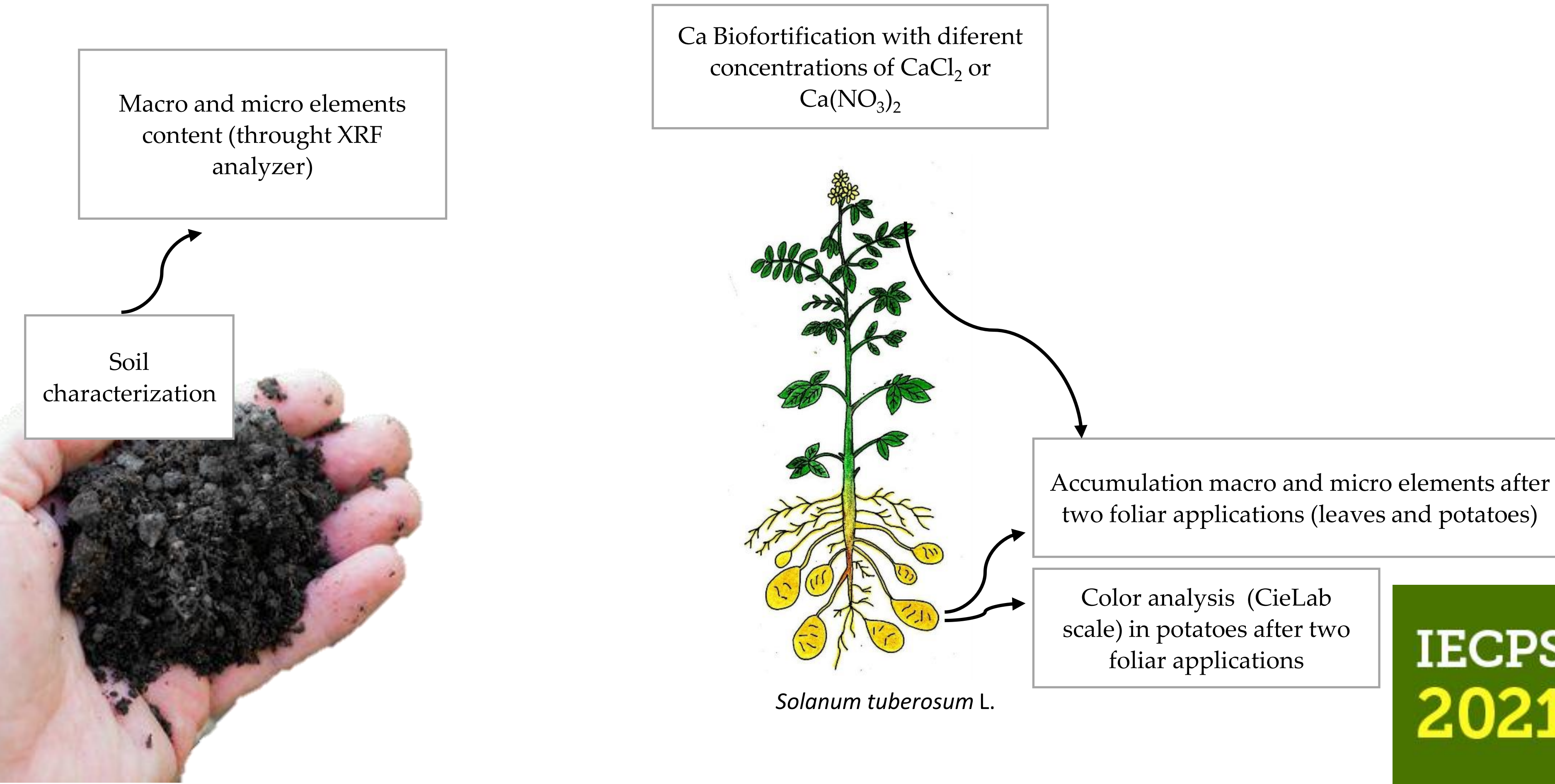

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Abstract: Calcium is an essential nutrient for plants, being required for several structural roles (such as in the membranes and in the cell wall). Although most of the Ca is obtained via the xylem (taken up by roots from the soil), in potatoes the accumulation of minerals also depends on phloem. So, it's crucial to understand the mechanisms of Ca and its interaction with other minerals in plant tissues of tubers. In this context, this study aimed to monitor the mineral interactions in tubers and leaves of *Solanum tuberosum* L. (Agria variety) after two foliar sprays with solutions of calcium chloride (1,3,6 and 12 kg.ha-1) and calcium nitrate (0.5,1,2 and 4 kg.ha-1), in order to improve naturally the Ca content. It was found different increases of Ca in the two fertilizers, with a higher content in the leaves with calcium nitrate 2 kg.ha-1 and in the tubers with calcium chloride 12 kg.ha-1. Moreover, Ca accumulation showed (in some treatments) a synergetic interaction with Mg in leaves, and with P, K and S in tubers. It was concluded that in the middle of Ca enrichment process in tubers plants there was a heterogeneous interaction between other minerals both in tubers and in leaves.

Keywords: Calcium biofortification; Mineral interactions; Natural enrichment with calcium; *Solanum tuberosum* L.

Materials and Methods

- Biofortification Itinerary – Foliar spraying with $CaCl_2$ and $Ca(NO_3)_2$
- Mineral contents in soils, potato tubers and leaves (throught XRF analyzer)
- Colorimetric parameters in potatoes (using a Minolta CR 400 colorimeter)
- Data analysis using One-Way ANOVA

Introdution

Calcium's one of the most abundant mineral elements in the human body (Peacock, 2010) and plays an important role in bone and teeth development, skeletal mineralization, muscle contraction, fluid balance within cells and it's crucial for the normal functioning of the circulatory system (Peacock, 2010;.IOM, 2011; Pravina et al., 2013;Buchowski, 2015; Sharma et al., 2017)

In plants, Ca is also an essential nutrient (White & Broadley, 2003), is required as Ca^{2+} and has a central task in stress responses (Hocking et al., 2016), plays an indispensable role in structural (such as in the membranes and in the cell wall) (White & Broadley, 2003; Sharma et al., 2017) and signaling (Sharma et al., 2017). In plants the accumulation of minerals (including Ca) is mainly obtained via the xylem (taken up by roots from the soil solution) (Subramanian et al., 2011), however, in low-transpiring organs such as potato tubers (Busse & Palta, 2006), they receive minerals and other nutrients mainly through redistribution from above-ground tissues via phloem [Baker & Moorby, 1969; Subramanian et al., 2011). However, the most mobile minerals in phloem tissue are Mg, S, P, and K, having Zn and Cu intermediate mobility and Ca, Fe, and Mn low mobility (Subramanian et al., 2011). In this context, the aim of this study is to monitor the mineral interactions in potato tubers and leaves of *Solanum tuberosum* L. (Agria variety) after two foliar sprays with calcium solutions (calcium chloride and calcium nitrate) with different concentrations, to improve naturally the Ca content.

Results and Discussion

To understand the mineral interactions in potato plants, it's important to perform a soil analysis. In this context, chemical composition (macro and microelements) of the potato-growing field soil was determined (Fig. 1 A,B). It was found that K had the highest content in soil followed by Fe and Ca. Among microelements, Mn presented the highest content.

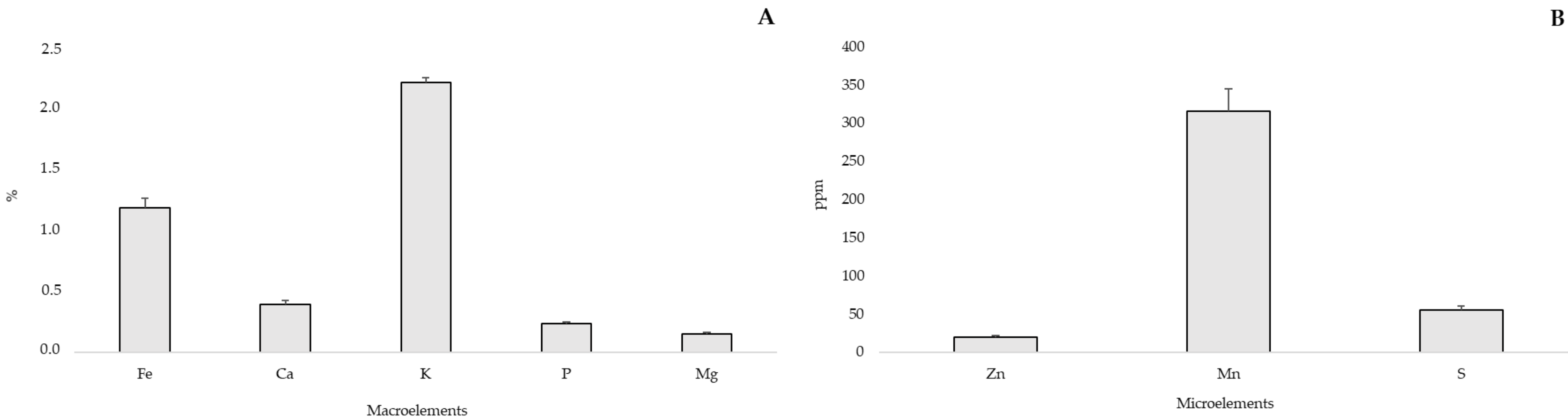

Figure 1 A,B. Mean values (n = 9) of macroelements (**A**) and microelements (**B**) of the soil of the experimental potato-growing field selected for Ca biofortification of *Solanum tuberosum* L., Agria variety.

In potato plants, mineral elements uptake occurs mainly from the soil solution (Subramanian et al., 2011). As such, it's important to correlate nutrients accumulation with the soil composition. In this context, as can be seen in Fig. 1-A, Ca it's the third most available nutrient in soil (D'Imperio et la., 2016), being its delivery dependent of xylem workflow (Weinl et al., 2008).

Results and Discussion

In potato tubers, Ca, P, K and S showed a higher content in the highest treatment in $CaCl_2$ (Table 2). Regarding Ca and P, both displayed a lower content in $CaCl_2$ 6 $kg.ha^{-1}$ treatment. Yet, Ca accumulation showed a synergetic interaction with P, K and S in some treatments, namely in $CaCl_2$ 12 $kg.ha^{-1}$ and $Ca(NO_3)_2$ 0.5 treatment. Moreover, Ca biofortification index after two foliar sprays (in the middle of biofortification process and plant development) varied between 6.4 % ($Ca(NO_3)_2$ 2 $kg.ha^{-1}$) and 35.3 % ($CaCl_2$ 12 $kg.ha^{-1}$).

Table 2. Mean values ± S.E. (n = 4) of Ca, P, K and S contents in dry tubers of *Solanum tuberosum* L., Agria variety after the 2nd foliar application. Different letters indicate significant differences, of each parameter, between treatments ($P \leq 0.05$). Foliar spray was carried out with four concentrations of $Ca(NO_3)_2$ (0.5, 1, 2 and 4 $kg.ha^{-1}$) and $CaCl_2$ (1,3,6 and 12 $kg.ha^{-1}$). Control was not sprayed.

Treatments		Ca (%)	P (%)	K (%)	S (%)
Control		0.122 ± 0.006 cd	0.204 ± 0.006abc	3.36 ± 0.099ab	0.173 ± 0.005ab
$Ca(NO_3)_2$	**0.5 kg ha^{-1}**	0.143 ± 0.012abc	0.218 ± 0.005ab	3.45 ± 0.086a	0.186 ± 0.005a
	1 kg ha^{-1}	0.159 ± 0.005ab	0.181 ± 0.004c	3.35 ± 0.025ab	0.182 ± 0.008a
	2 kg ha^{-1}	0.130 ± 0.007bcd	0.205 ± 0.009abc	3.22 ± 0.060ab	0.180 ± 0.002ab
	4 kg ha^{-1}	0.136 ± 0.007abcd	0.185 ± 0.006bc	3.31 ± 0.238ab	0.179 ± 0.006ab
$CaCl_2$	**1 kg ha^{-1}**	0.120 ± 0.007cd	0.186 ± 0.011bc	2.83 ± 0.086b	0.157 ± 0.006ab
	3 kg ha^{-1}	0.113 ± 0.000cd	0.176 ± 0.006c	3.27 ± 0.067ab	0.148 ± 0.004b
	6 kg ha^{-1}	0.107 ± 0.006d	0.170 ± 0.002c	3.16 ± 0.035ab	0.163 ± 0.004ab
	12 kg ha^{-1}	0.165 ± 0.001a	0.237 ± 0.011a	3.58 ± 0.157a	0.188 ± 0.013a

In tubers (Table 2), K is one of the main minerals (Navarre et al., 2009), showing similar values to another study carried out in the same variety with Ca enrichment (at harvest) (Coelho et al., 2021). After K, P is the main mineral in tubers (Navarre et al., 2009) and present higher values compared to other study carried out at harvest (Coelho et al., 2021). Moreover, Ca accumulation showed (in some treatments, namely in $CaCl_2$ 12$kg.ha^{-1}$ and $Ca(NO_3)_2$ 0.5 kg ha^{-1}) a synergetic interaction with P, K, and S. Being previously reported by Aulakh et al. (1978) that when Ca content increase, S content also increased. Also, in another study (Coelho et al., 2021) K and P also increased in potatoes with the increased of Ca content, observed in our study (Table 2).

Conclusions

Through the monitorization of mineral interactions in leaves and potato tubers, was possible to identify that natural enrichment of Ca (after two foliar sprays with calcium chloride or calcium nitrate) showed different relationships between minerals. In our study (at this stage of development of potato tubers) didn't occurred any cationic antagonism between Ca and Mg or K. In fact, in some treatments, was possible to identify a synergetic relationship between Ca and Mg in potato leaves at this stage. Additionally, in some treatments, synergetic relationship also occurred with P, K and S in tubers tissues. Nevertheless, the concentrations of mineral elements in potato tubers are influenced by Ca supply and Ca accumulation occurred through xylem mass flow and phloem redistribution, as seen in more phloem mobile elements (Mg, S, P, and K). Furthermore, mineral interactions and Ca natural enrichment did not show relevant changes in colorimetric paraments in tubers' pulp.

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