Toxic and potentially toxic element uptake and translocation in durum wheat (*Triticum turgidum L. subsp. durum*) cultivars under real field conditions

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Abstract

Soil contamination from toxic and potentially toxic elements is a global environmental concern, due to the toxicity in the ecosystem, and for the potential risk of contamination of the food chain. Cd is one of the most important in terms of food chain contamination. Durum wheat has the capacity to accumulate more Cd than other cereals. The study aims at assessing the uptake and translocation of toxic and potentially toxic elements in five different durum wheat cultivars in two different experimental fields, harvested at the end of the vegetative cycle, under real field conditions.

Keywords: Toxic and potentially toxic elements, Triticum turgidum L. subsp. durum, Cultivars, Translocation

Introduction

Food quality depends on the quality of the production environment and in particular of the growing soil. High levels of toxic or potentially toxic elements (such as As, Be, Cd, Co, Cr, Ni, Pb, Cu, Se, V and Zn) in the soil can compromise food safety due to the risk of translocation to the edible parts and/or potential bioaccumulation along the food chain. It can affect also food security, in relation to phytotoxic effects with a consequent reduction of crop yield. Among the toxic elements, cadmium (Cd) is one of the most important in terms of contamination of the food chain, as it is readily absorbed by the cells of different plant species. Several authors have studied the bioaccumulation capacity of toxic and potentially toxic elements and their subsequent translocation in the various parts of the plant. They noted that these depend mainly on the characteristics of the soil, the plant species and the type of cultivar and the element considered (Figure 1).

Durum wheat (*Triticum turgidum L. subsp. durum*) has the capacity to accumulate more Cd than other cereals, moreover, some cultivars seem to accumulate this element more easily in the edible part.

The genotypic variation that determines the accumulation of Cd in durum wheat grains is attributable to the gene Cdu1 (Cadmium uptake 1), an important Quantitative Trait Locus (QTL) that controls the accumulation of Cd in wheat, the absence of this gene gives the phenotype "High Grain Cd cultivar". This gene controls the translocation of the Cd from roots to grains by xylematic and phlohematic transport in the stem. Since the accumulation of Cd and Pb in Durum Wheat constitutes a risk for human health, the European Commission, by Regulation No 1881/2006, set maximum levels of Cd and Pb in cereals, which must not exceed 0.2 mg/kg.

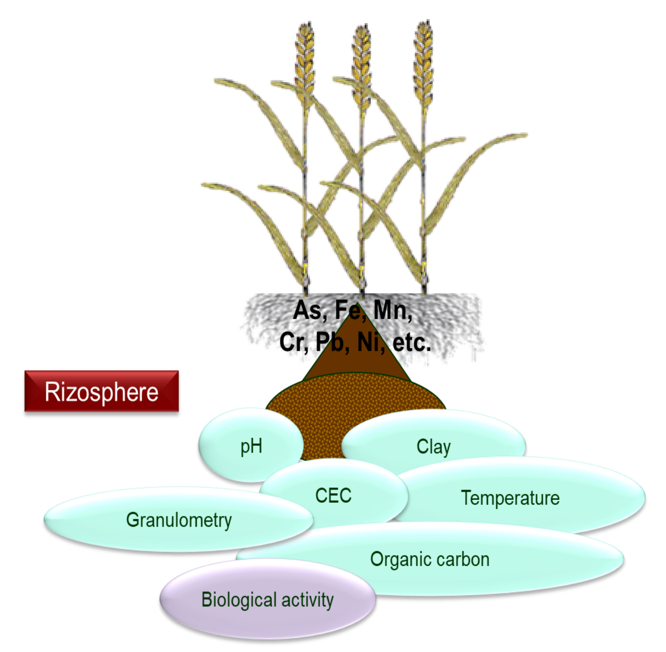


Figure 1 *Factors that influence the bioavailability of elements in the plant soil system*

The study aims to assess the uptake and translocation of toxic and potentially toxic elements in different durum wheat cultivars under real field conditions.

Methodology

The crop samples were collected at two different experimental fields of CREA - Research Center for Agro-Food Engineering and Transformations (Rome) of *"Inviolatella"* in 2018 and *"La castellaccia"* in 2019 (Figure 2).

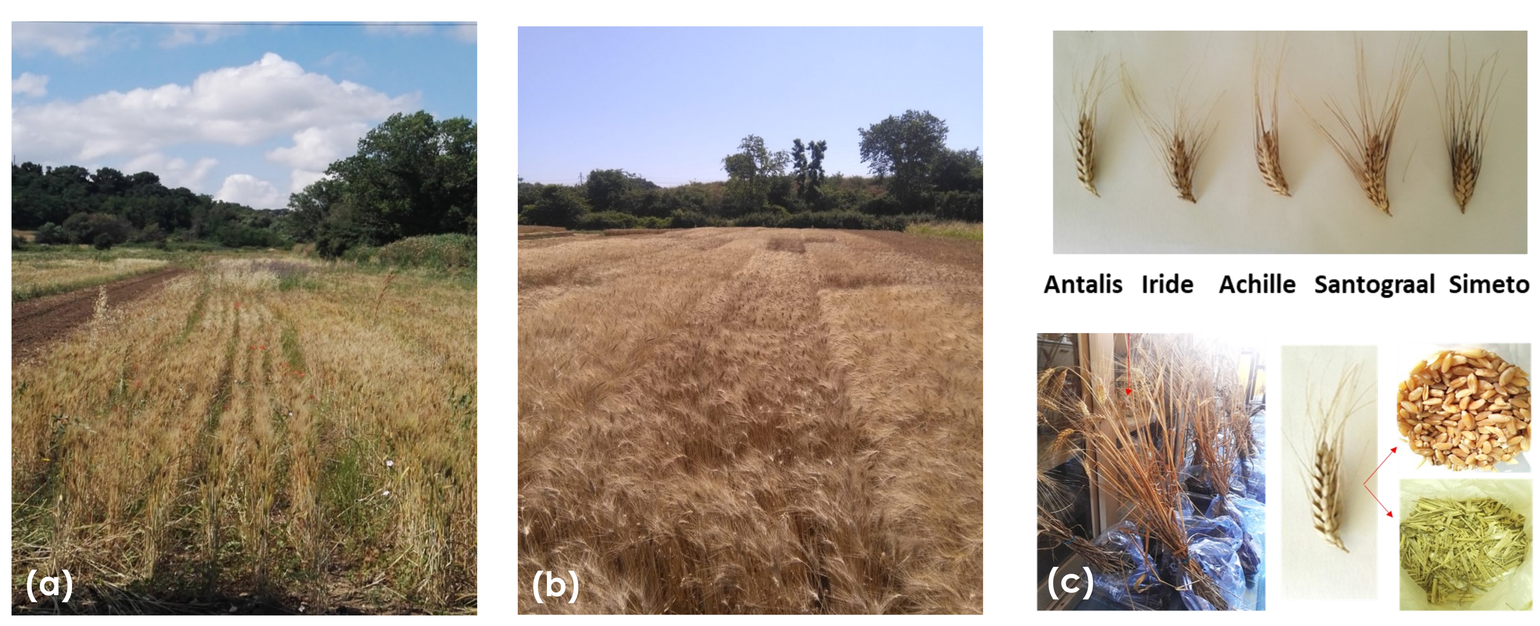


Figure 2 *Experimental fields of CREA (Rome)and crop samples. "Inviolatella" experimental field (a) and "La castellaccia" experimental field (b), crop samples (c)*

The study was carried out on durum wheat plants (*Triticum turgidum L. subsp. Durum*) of 5 different cultivars: Simeto, Iride, Achille, Antalis, and Santograal, harvested at the end of the vegetative cycle (from February to July).

For each cultivar, the samplings were carried out in triplicate (3 plots per cultivar) and at different points of the field with diverse exposure to possibly highlight any differences for each cultivar considered. In addition, five samples of "bulk soil" were taken for each field.

The sampling of the single durum wheat plant (composed of roots, shoots and grains) and its soil made it possible to assess in detail the uptake capacity (elements concentrations in roots) and the translocation capacity (concentration of elements in shoots and grains) of toxic and potentially toxic elements in the different plant parts.

The development and application of specific sampling and sample pretreatment procedures and the analytical methodologies (ICP-MS and ICP-AES) optimized for each type of matrix, make it possible to quantify the elemental total content in soils and the different plant parts. Specifically, the following elements were evaluated: Cd, Cr, Cu, Pb, Sr, Ti, V, and Zn.

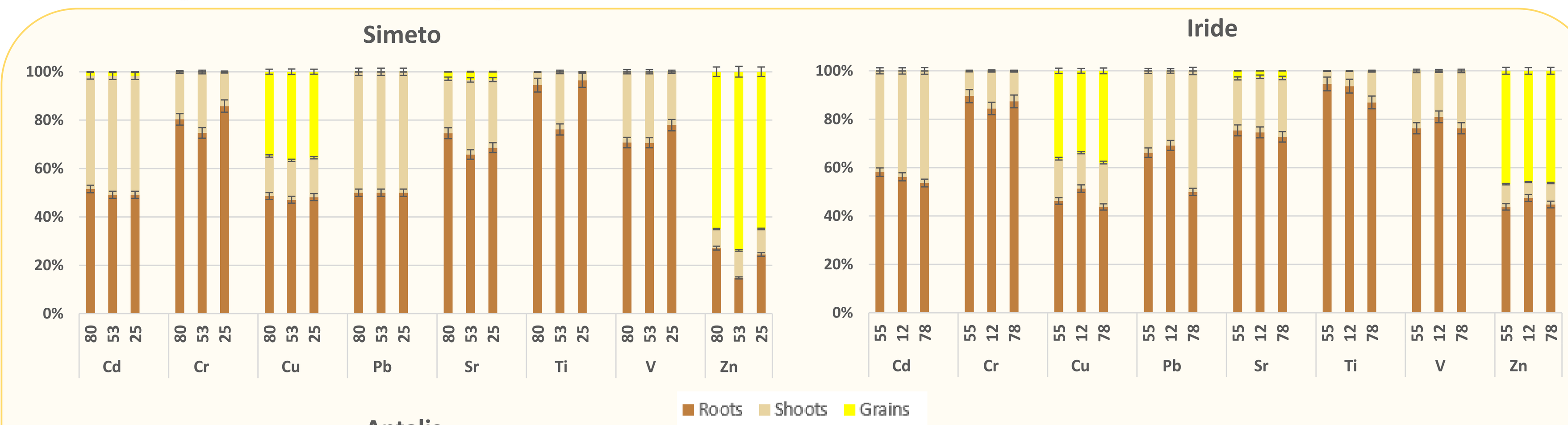
The availability of different cultivars in the same field has limited the variability due to the pedoclimatic and agronomic conditions. That allowed us to focus only on the effects dependent on the cultivar itself. The availability of the same cultivars in two different experimental fields made it possible to evaluate the effects related to the soil itself.

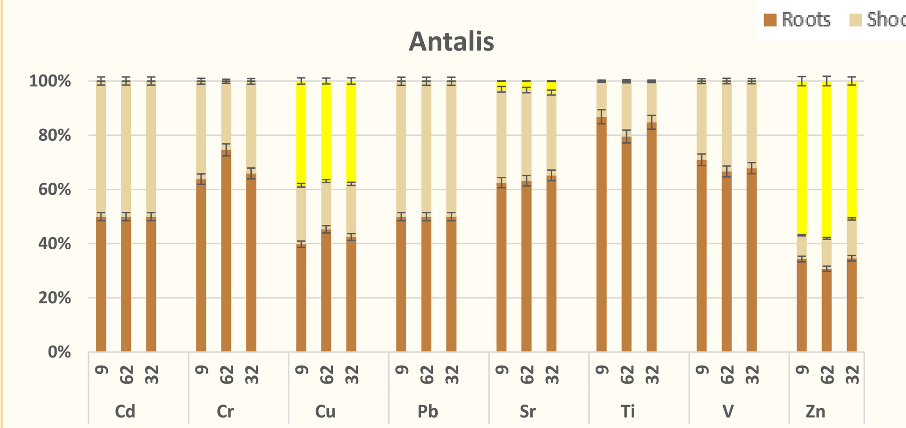
Furthermore, the ability to translocate elements from the roots to the aerial portions of the plant (shoots and grains) was evaluated for each element by calculating the Translocation Factor (TF) defined as "element concentration in the aerial parts"/"element concentration in the roots". The uptake of the elements from soil to roots was evaluated for each element by calculating the biological absorption coefficient (BAC), defined as "element concentration in the roots"/"element concentration in the soil".

Statistical analysis was performed using MATLAB R2015b software. To highlight significant differences in the elemental profile of grains, shoots and roots among the cultivars of the same field, or among the different fields, a one-way ANOVA test was carried out, and when there was a difference between the mean values, Tukey's test ($p < 0.05$) followed. The Analysis of the Principal Components (PCA) was then performed.

Results and discussion

The distribution of the elements in the different plant parts (Roots, Shoots and Grains) are shown in figure 3 (a) for the *"Inviolatella"* experimental field and in figure 3 (b) for the *"La castellaccia"* experimental field. Only common cultivars in both fields are shown. The calculation of the biological absorption coefficient (BAC) showed that nutrients such as Cu and Zn are easily absorbed by the roots, as well as Cd (especially for the experimental field "*La Castelaccia*") despite not being a nutrient and can be toxic even at low concentrations. The calculation of the translocation factor (TF) showed that Cu and Zn, are easily translocated to the shoots and grains; for other non-essential elements such as Cr, Pb, Sr, Ti, V, there is always a barrier effect at the root level. For these elements, the same behaviour was found in all cultivars, in both experimental fields. Differences between the cultivars emerged in the translocation of the Cd to the grains. Specifically, the Simeto cultivar seems to translocate more Cd in grains (in any case the total content of this element was always lower than the limit imposed by current legislation - not of concern in terms of food safety). The cultivars Iride and Antalis seem to store cadmium at a radical level and this is in agreement with other studies that have shown that the cultivar Iride is able to store even large quantities of Cd in the roots, preventing its translocation in grains. The values obtained for BAC and TF are shown in the tables.



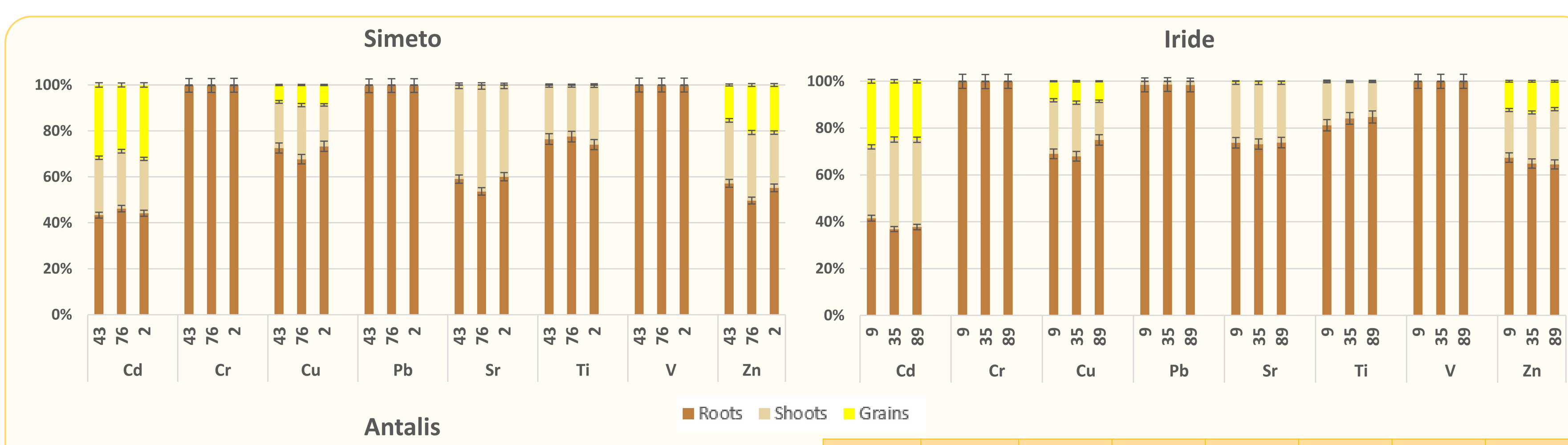


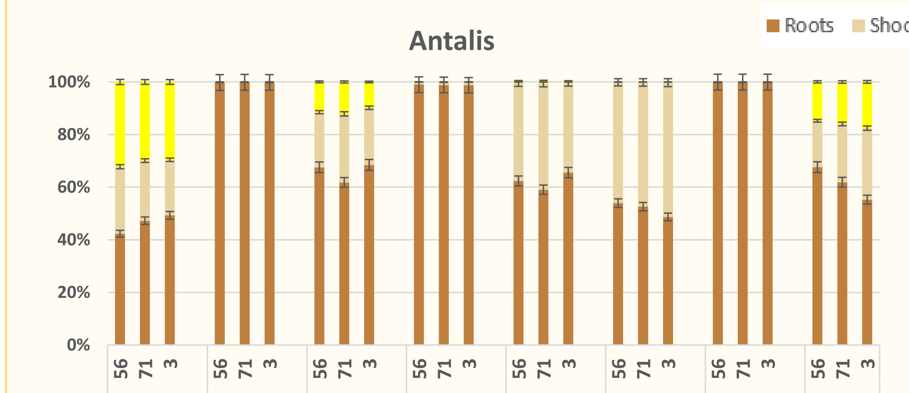
TF Grains	Cd	Cr	Cu	Sr	Ti	V	Zn
Simeto	0,0341	0,0013	0,7	0,04	0,0009	0,0002	3,0
Iride	0,0005	0,0008	0,8	0,04	0,0008	0,0002	1,1
Antalis	0,0004	0,0012	0,9	0,06	0,0011	0,0002	1,1

TF Shoots	Cd	Cr	Cu	Sr	Ti	V	Zn
Simeto	0,97	0,24	0,34	0,38	0,12	0,36	0,43
Iride	0,78	0,15	0,35	0,34	0,08	0,33	0,19
Antalis	0,71	0,48	0,47	0,52	0,32	0,43	0,22

BAC	Cd	Cr	Cu	Mn	Ni	Ti	V	Zn
Simeto	0,21	0,02	0,18	0,04	0,06	0,03	0,05	0,16
Iride	0,23	0,05	0,2	0,05	0,07	0,05	0,05	0,4
Antalis	0,22	0,03	0,15	0,04	0,05	0,03	0,04	0,42

Figure 3 (a) *Distribution of the elements in the different plant parts (Roots, Shoots and Grains) of the "Inviolatella" experimental field. In tables the values obtained for the BAC and the TF.*





TF Grains	Cd	Cr	Cu	Sr	Ti	V	Zn
Simeto	0,79	0,0014	0,12	0,007	0,004	0,0003	0,35
Iride	0,66	0,0006	0,12	0,008	0,001	0,0001	0,19
Antalis	0,62	0,0014	0,17	0,009	0,004	0,0004	0,26

TF Shoots	Cd	Cu	Sr	Ti	Zn
Simeto	0,55	0,29	0,66	0,35	0,50
Iride	0,92	0,30	0,43	0,20	0,33
Antalis	0,49	0,34	0,59	0,92	0,36

BAC	Cd	Cr	Cu	Pb	Sr	Ti	V	Zn
Simeto	0,20	0,10	0,19	0,12	0,15	0,007	0,12	0,20
Iride	0,11	0,12	0,20	0,15	0,17	0,010	0,14	0,34
Antalis	0,12	0,07	0,14	0,07	0,13	0,005	0,07	0,27

Figure 3 (b) *Distribution of the elements in the different plant parts (Roots, Shoots and Grains) of the "La castellaccia" experimental field. In tables the values obtained for the BAC and the TF.*

Although the different cultivars have therefore similar behaviour in both fields the use of PCA as an exploratory technique has shown two distinct groupings one for the "Inviolatella" field and one for the "La Castellaccia" field for the Roots (Figure 4 a) and for the Grains (Figure 4 b), but not for the shoots (Figure 4 c) (as probably for most elements it serves only as a transport channel) to mean that the different soil affects the different total content of the elements in the plant.

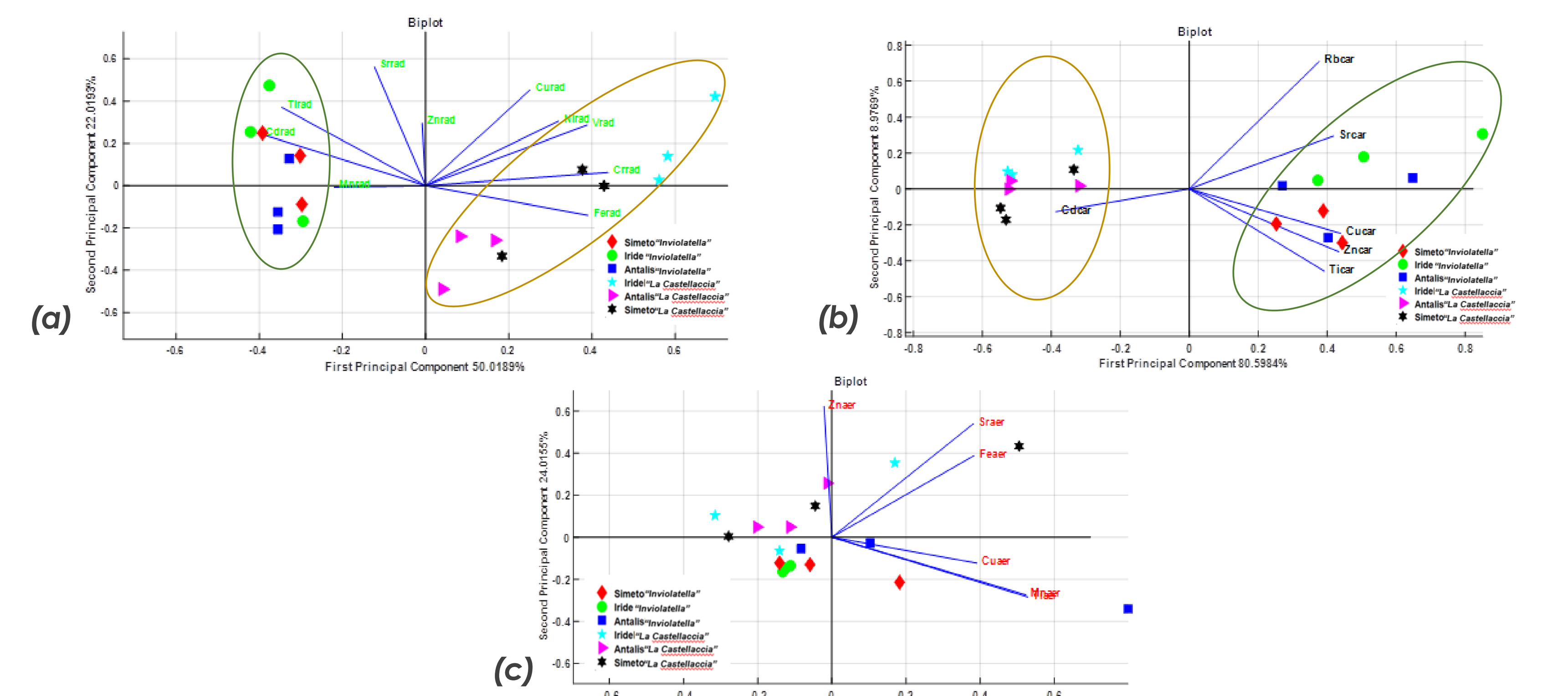


Figure 4 *Correlations of variables (levels of various elements in the Roots (a), in the Grains (b) and in the Shoots (c) of the two test fields) for each statistical unit (cultivar) with respect to the main components PC1 and PC2*

Conclusions

In conclusion, both the type of soil and the cultivar can affect the absorption and distribution of the elements in durum wheat plants. If the edible part is specifically considered, further studies on the mobility of the elements in the soil, the soil-plant interaction and the different cultivars may have important agronomic implications. Prior assessment of these interactions could be useful in order to select and cultivate certain cultivars, such as those characterised by less uptake and translocation of a certain element, to prevent food safety and food security problems.

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