



Study of the Impact of Copper on Soil Organisms and Tomato Quality

Ameur ABDELLAOUI¹, Benkhedda BELHAOUARI¹, Walid REZGUI², Younes BOURMITA¹

10.18805/ajdr.DRF-456

ABSTRACT

Background: The aim of our work is to assess the impact of copper-contaminated soil on tomato fruit and soil organisms. Excessive use of copper-based pesticides has many consequences for soil biology and food quality.

Methods: Our study was carried out in a section of a tomato plot in the Mostaganem region of northern Algeria. The plot was contaminated with copper, at different doses D1 (10 mg Cu Kg⁻¹), D2 (100 mg Cu Kg⁻¹), D3 (200 mg Cu Kg⁻¹) and D4 (300 mg Cu Kg⁻¹) in separate blocks. The concentrations of copper and carbohydrates and the homogeneity of the wells were assessed in order to determine the quality of the tomatoes in relation to the levels of soil contamination. Furthermore, the respiratory activity of the microorganisms and the feeding activity of the soil fauna were assessed.

Result: The highest copper concentrations were 1.5±0.17 mg Cu kg⁻¹ and 2.05±0.3 mg Cu kg⁻¹ in the sites contaminated by the highest doses D3 and D4 and the highest carbohydrate concentrations were 53.03±1.38 g kg⁻¹ and 61.15±0.65 g kg⁻¹ in these two sites. Microbial respiration values were lowest in D3, with 8.3.10⁻⁴ ± 3.6.10⁻⁴ mg CO₂ g⁻¹ h⁻¹ and in D4, with 1.5.10⁻³ ± 1.4.10⁻⁴ mg CO₂ g⁻¹ h⁻¹. In addition, wildlife feeding activity was low at both sites, with values of 27.56±17.77% for the D3 site and 37.5±17.48% for the D4 site. Our study has shown that copper contamination of soils affects the biological activities of soil organisms.

Key words: Bait lamina, Copper, Microbial respiration, Pesticide, Tomato.

INTRODUCTION

Tomato production often faces challenges related to pests and diseases, necessitating the use of pesticides to protect crops (Nechadi *et al.*, 2002; Nishant and Upadhyay, 2016; Son *et al.*, 2018). Among these pesticides copper is widely used due to its antimicrobial and fungicidal properties (Harkat *et al.*, 2021).

Copper has been used extensively as a fungicide for over a century (Karimi *et al.*, 2021). However, prolonged exposure to copper can lead to an accumulation of this metal in the fruit, posing toxicity risks for consumers, as plants are capable of absorbing copper and accumulating it in their tissues (Sbartai *et al.*, 2012). Furthermore, excessive accumulation of copper in the soil can alter its biological quality, as copper accumulates in the first layers of the soil (10 cm), which are home to a wide range of organisms (earthworms, fungi, bacteria, etc.) (Crowther *et al.*, 2019; Jiang *et al.*, 2007). Although copper can be effective in protecting tomatoes, it is essential to understand its effect on the soil and the fruit in order to minimise undesirable impacts on the environment and human health. The study of the impact of pollutants on the biological quality of the environment must provide information on the state of organisms living in the soil, hence the need to use bioindicators (Belhaouari *et al.*, 2014; Kadri *et al.*, 2023; Traiche *et al.*, 2018). Furthermore, the study of the impact of pollutants on foodstuffs must provide information on both their nutritional quality and the health risks of bioaccumulation (Faure and Reymier, 2021; Mohanapriya *et al.*, 2024). Our work has two objectives: (i) to assess tomato quality by evaluating copper bioaccumulation, carbohydrate concentration and tomato homogeneity after the application of copper in

¹Biotechnology Laboratory Applied to Agriculture and Environmental Preservation, Higher School of Agronomy "Mohamed El Amjed Ben Abdel Malek", Mostaganem 27000. Algeria.

²Scientific and Technical Research Center for Physico-chemical Analyses, Ex-Pasana Headquarters, Industrial Zone Bou-Ismaïl, CP 42004 Tipaza, Algeria.

Corresponding Author: Ameur ABDELLAOUI, Biotechnology Laboratory Applied to Agriculture and Environmental Preservation, Higher School of Agronomy "Mohamed El Amjed Ben Abdel Malek", Mostaganem 27000. Algeria. Email: a.abdellaoui@esa-mosta.dz

How to cite this article: ABDELLAOUI, A., BELHAOUARI, B., REZGUI, W. and BOURMITA, Y. (2026). Study of the Impact of Copper on Soil Organisms and Tomato Quality. *Asian Journal of Dairy and Food Research*. **45**(5): 813-819. doi: 10.18805/ajdr.DRF-456.

Submitted: 29-08-2024 **Accepted:** 03-12-2024 **Online:** 25-12-2024

pesticide form in an experimental field located in the region of Mostaganem in Algeria; (ii) to assess the impact of copper on soil biology using two bioindicators, the feeding activity of soil-dwelling organisms using the Bait-lamina test and the respiration of soil microorganisms via their production of CO₂.

MATERIALS AND METHODS

Study site

The study was carried out in a section of a tomato plot in the Mostaganem region (Algeria). The soil section of the tomato plot studied was contaminated with copper, with different doses applied in three separate blocks (Fig 1). The randomization of replication was conducted in 3 blocks. Each block was subjected to 4 doses of copper and a control

(Control T: 0 mg Cu kg⁻¹, D1: 10 mg Cu Kg⁻¹, D2: 100 mg Cu kg⁻¹, D3: 200 mg Cu kg⁻¹ and D4: 300 mg Cu kg⁻¹) (Kadri *et al.*, 2023). The soil used was characterized (Table 1). Our study consisted of two complementary parts: analysis of tomato quality and soil biology.

Tomato quality was studied using three parameters: phenotypic criteria, carbohydrate analysis in tomato fruit and copper analysis in tomato fruit. Soil quality was studied using two bioindicators, the activity of microbial respiration and the feeding activity of the soil mesofauna.

The laboratory analyses were carried out in the Biotechnology Laboratory Applied to Agriculture and Environmental Preservation, Higher School of Agronomy in Mostaganem, during the period 2023 and 2024.

Tomato quality

Phenotypic criteria

According to the International Standards for Fruits and Vegetables guidelines (OECD, 2019), an assessment of the homogeneity of tomatoes was conducted for samples harvested from different soils with varying degrees of contamination. This evaluation is based on standardized criteria that ensure the fruits are comparable in terms of physical characteristics and quality, thereby allowing for the analysis of the impact of contamination on their development.

Total sugars analysis of tomato fruit

The total sugars in tomato fruit were analyzed using the protocol described by (Nielsen, 2017). The operation began with the extraction of carbohydrates. The colour complex was then formed and after the calibration curve had been prepared, the absorbance of the samples was read using a spectrophotometer at a wavelength of 490 nm.

Analysis of copper in tomato fruit

In order to determine the level of copper bioaccumulation in tomato fruit, we mineralised the fruit using the method of (Jones and Benton, 2017). A test sample of 1 g of plant material was dried at 70°C for 48 h, crushed and calcined in a muffle furnace at 450°C for 4 hours. The ash was mineralised with aqua regia (25% HNO₃ and 75% HCl) in a hot plate at 90°C for 75 minutes. The copper content of the fruit was then determined by atomic absorption spectrometry (240FS AA, SpectreAA).

Biological quality of the soil

Respiratory activity of microorganisms

Microbial respiration of the soil was measured using the method (ISO 16072:2002). 20 grams of soil was incubated in a centrifuge tube suspended in a flask into which 20 ml of sodium hydroxide solution had been pipetted. The flask was sealed and incubated for 24 h in a temperature-controlled room (22±1°C). The CO₂ produced was absorbed into the sodium hydroxide solution. After titration of the solution not consumed, the quantity of CO₂ produced by the microorganisms was calculated.

Feeding activity of fauna

The feeding activity of soil fauna was measured using the Bait lamina method (ISO 18311:2016). PVC bars measuring 12 cm with 16 holes each spaced 5 mm apart were used. The cavities were filled with a paste specially designed to assess biological activity (Cellulose, Agar-Agar, dry plant debris). A total of 216 Bait lamina were placed in the site (12 Bait lamina × 3 replicates × 3 blocks). The interpretation of the results is based on the total average consumption of

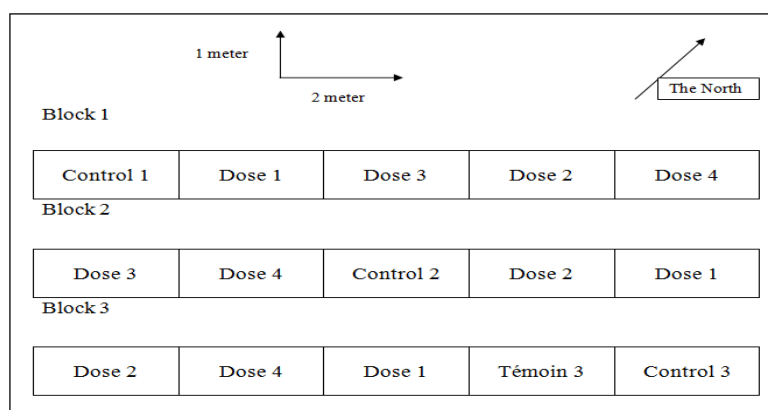


Fig 1: Field experimental plan.

Table 1: Physico-chemical characteristics of the soil.

Soil caractéristiques	pH	redox potential (mV)	Total carbon (%)	Water retention (%)	Sand (%)	Clay (%)	Silt (%) capacity (meq 100 g ⁻¹)	Cation exchange (%)	total limestone	Copper (mg Cu kg ⁻¹)
	8.33±0.12	-79±7.0	18.60±0.32	23.23±2.45	94.4±1.5	2.8±0.7	2.8±0.9	14.89±3.34	59±2	13.18±1.69

the paste in the bait lamina strips in the sites studied after one month's exposure.

Statistical analysis

As part of this study, we carried out in-depth statistical analyses to assess the relationship between the different variables. These analyses were carried out using Origin Pro 2019b software, a scientific data analysis tool renowned for its accuracy and versatility. The software's advanced features enabled the use of Duncan's test for detailed comparisons among groups, while facilitating the visualization and interpretation of complex data essential to this research (OriginLab Corporation, 2019).

RESULTS AND DISCUSSION

Tomato quality

Phenotypic criteria

After harvesting the tomato fruit from the three blocks on our site, the results of the assessment of the homogeneity of the tomato fruit were recorded. A homogeneity of colour was observed in fruits from both contaminated and in control soils. The homogeneity classes ranged from Extra to Class I (Table 2).

Tomato fruits from the control soil exhibit similar shapes and colors to those harvested from contaminated soils (D1, D2, D3 and D4).

Concentration of total sugars in tomato fruit

The fruits analysed showed significant variations in terms of total sugar content. The fruit with the highest carbohydrate concentration was at D4 (the most contaminated soil), with $61.15 \pm 0.65 \text{ g kg}^{-1}$. In contrast, the lowest concentration was $48.74 \pm 0.49 \text{ g kg}^{-1}$ in fruit from the control soil T.

In contaminated soils, an increase in the total sugars concentration of tomato fruits is observed in relation to the level of copper contamination (Fig 2).

Copper levels in tomato fruit

According to the histogram (Fig 3), the fruit analysed showed a gradient of copper contamination, with the highest copper

Table 2: Tomato fruit homogeneity table (OECD, 2019).

Class	Homogeneity of the fruit
Extra	The 5% tolerance covers all defects in shape and colour
Class I	The 10% tolerance covers all defects in shape and colour
Class II	The 10% tolerance covers all malformations and serious skin and colour defects.

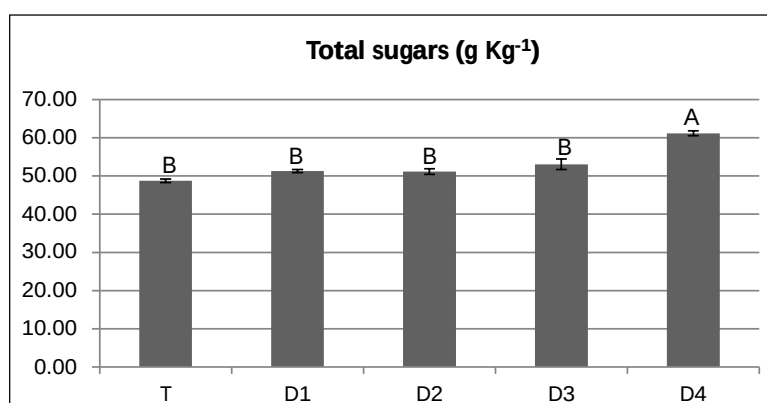


Fig 2: Concentrations of total sugars in tomato fruit. For each site, different letters indicate significant differences (Duncan's test, $p < 0.05$).

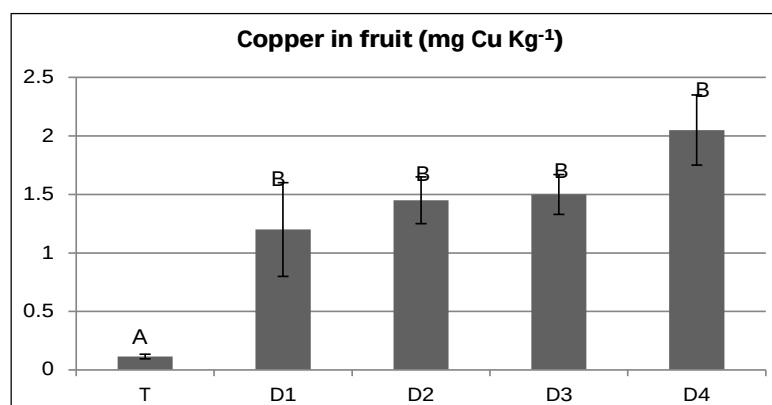


Fig 3: Copper dose in tomato fruit. For each site, different letters indicate significant differences (Duncan's test, $p < 0.05$).

concentration being $2.05 \pm 0.3 \text{ mg Cu kg}^{-1}$ in the fruit from soil D4 (the most contaminated soil). The lowest copper concentration was $0.115 \pm 0.02 \text{ mg Cu kg}^{-1}$ in fruit from the control soil T. Copper levels in tomato fruits increase in parallel with the increasing degree of soil contamination with copper.

Biological quality of soil

Microbial respiration

Our results show that the value of microbial respiration in the contaminated soils is lower than in the control soil T, with the difference becoming significant at soils D3 and D4 (Fig 4). Microbial respiration reached its highest level in the control soil T, which was not treated with copper, with a measured rate of $5.1 \cdot 10^{-3} \pm 3.6 \cdot 10^{-3} \text{ mg CO}_2 \text{ g}^{-1} \text{ h}^{-1}$. The lowest respiration $8.31 \cdot 10^{-4} \pm 3.6 \cdot 10^{-4} \text{ mg CO}_2 \text{ g}^{-1} \text{ h}^{-1}$, is recorded in the most highly polluted soil D4.

Feeding activity of fauna

Our results show that the feeding activity of fauna is lower in contaminated soils compared to the control soil, with

the difference becoming significant at sites D2, D3 and D4 (Fig 5). The highest feeding activity, at $64 \pm 15.88\%$, was observed in the control soil T, a minimally contaminated soil left untreated with copper. The biological activity of microorganisms decreases with increasing copper levels in the soil.

Impact of copper on tomatoes

The results of our research show that tomato fruit from plants grown in contaminated soils have phenotypic characteristics similar to those of fruit from control soils (Table 3). Other authors have shown that copper treatments have no effect on fruit colour, fruit shape and stalk tip colour (Namdev *et al.*, 2017). Copper is an essential element for tomatoes, playing an important biological role in protein production and is involved in plant respiration (in the krebs cycle). It is also linked to chlorophyll performance (Stevens *et al.*, 2018). Tomato tolerance to copper can be attributed to its metal complexing ability. The intracellular presence of organic ligands within tomatoes ensures complexation

Table 3: Results of phenotypic criteria for tomato fruits.

Repetition	T	D1	D2	D3	D4
Homogeneity of tomato fruit	Extra	Extra	Class I	Extra	Class I

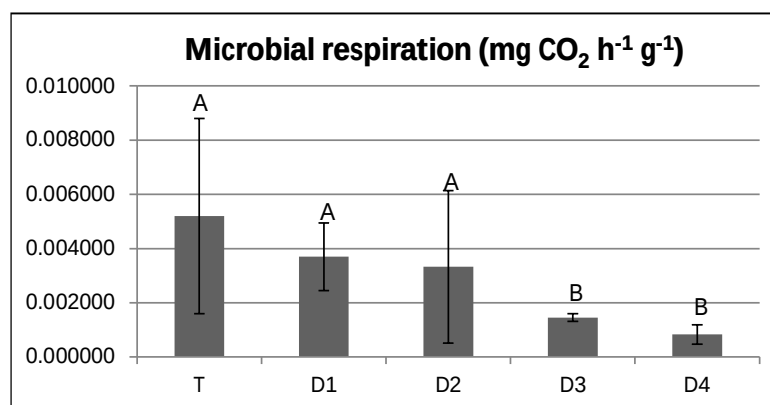


Fig 4: Microbial respiration at the site. For each site, different letters indicate significant differences (Duncan's test, $p < 0.05$).

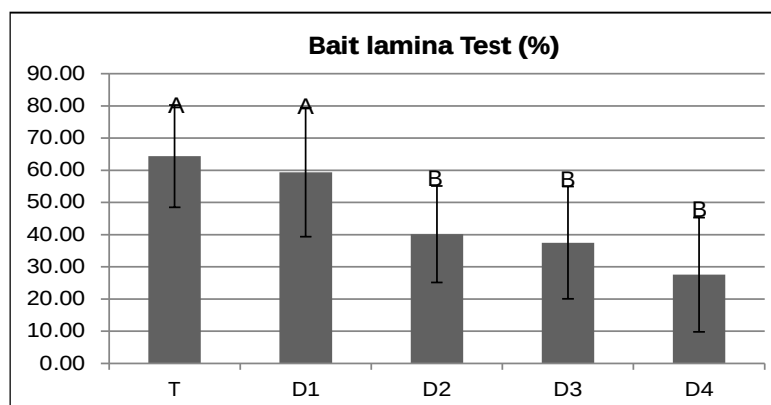


Fig 5: Feeding activity of soil fauna (Bait Lamina). For each site, different letters indicate significant differences (Duncan's test, $p < 0.05$).

and therefore detoxification of many metal ions (Tremel-Schaub and Feix, 2005). We observed an increase in the concentration of total sugars in the fruit as the copper concentration increased. This positive correlation suggests that copper-induced stress influences carbohydrate metabolism in the plant. Previous studies, such as López-Vargas *et al.* (2018), have shown that the application of Cu nanoparticles leads to the transformation of organic acids into simple sugars in tomatoes. In addition, excess copper affects enzymes involved in carbohydrate metabolic cycles (Singh *et al.*, 2007), leading to carbohydrate accumulation in fruit (Benguennouna *et al.*, 2023). Oxidative stress caused by high doses of copper pesticide can activate certain metabolic pathways in plant cells. In response to this stress, plants increase the production of antioxidant compounds, including carbohydrates that act as antioxidant molecules, neutralising free radicals and thus contributing to protection against oxidation (Liao *et al.*, 2015; Mengome *et al.*, 2014; Kang *et al.*, 2015).

The concentration of copper in the fruit from the four soils differed significantly from the control soil. According to our results, copper concentrations in tomatoes do not exceed the acceptable daily intake (ADI) of 0.15 kg kg^{-1} (Anses, 2018), equivalent to a daily intake of 9 mg Cu kg^{-1} ($0.15 \times 60 \text{ kg}$ average weight). They increase as soil contamination increases, with high copper concentrations in fruit reaching $2.05 \pm 0.3 \text{ mg Cu kg}^{-1}$ in the most contaminated soil (D4).

Tomatoes can accumulate copper in various organs, such as leaves and stems (Tremel-Schaub and Feix, 2005). They also accumulate metals in the roots (Mazhoudi *et al.*, 1997). In fact, metals are absorbed by the roots and transported to the various organs and fruits *via* the elaborated sap. Several factors can increase the uptake of metals by the roots, in particular those linked to the soil (natural concentration, pH, Eh, CEC), climate (temperature, humidity) and the plant (influence of the roots on the soil, influence of micro-organisms), can increase the uptake of metals by the roots (Tremel-Schaub and Feix, 2005).

Some authors have pointed out that there is no correlation between the concentration of total copper in the soil and the concentration of the metal in tomato fruit, stems or leaves (Badilla-Ohlbaum *et al.*, 2001).

Impact of copper on soil biology

Biological indicators are used to analyse the relationship between copper accumulation in the soil and the biological quality of the contaminated soil (Bispo *et al.*, 2009; Sheramati and Varma, 2015).

Our study showed a clear decrease in microbial respiration in soils heavily contaminated with copper, particularly in sections D3 and D4. In site D4, where the copper concentration applied to the soil reached $300 \text{ mg Cu Kg}^{-1}$, microbial respiration was $8 \cdot 10^{-4} \pm 3 \cdot 10^{-4} \text{ mg CO}_2 \text{ g}^{-1} \text{ h}^{-1}$, a reduction of 84.31% compared with the control soil, which showed respiration of $5.1 \cdot 10^{-3} \pm 3.6 \cdot 10^{-3} \text{ mg CO}_2 \text{ g}^{-1} \text{ h}^{-1}$. Microbial respiration decreased by up to 58% for copper

accumulations exceeding $300 \text{ mg Cu kg}^{-1}$ (Soler-Rovira *et al.*, 2013). Microbial respiration, which is sensitive to metal contamination, is considered to be an indicator of anthropogenic disturbance (Schloter *et al.*, 2003). High soil respiration may reflect good soil quality (Criquet, 2013).

Other researchers have indicated that soil micro-organisms, such as bacteria and fungi, may be sensitive to high concentrations of copper, which may influence their respiration activity. In wine-growing soils, a 40% reduction in microbial respiration was observed for copper levels ranging from between 50 mg Cu kg^{-1} and $100 \text{ mg Cu kg}^{-1}$ (Karimi *et al.*, 2021). Furthermore, heavy metal pollution leads to widespread “metallization” of the environment, negatively impacting soil (Vinogradov and Zubkova, 2022). Our study reveals a negative correlation between copper accumulation in the soil and microbial respiration. These results are in line with several studies showing the impact of metal pollution on soil microbial activity (Austruy *et al.*, 2016; Bahn *et al.*, 2016). Many researchers have established that certain metals, such as Cu, Al, Ag, Cd, Sn and Hg, are toxic to microorganisms (Desaunay, 2011).

With regard to the bioindicator Bait Lamina, we have observed a decrease in the feeding activity of soil organisms at several contaminated sites. Other authors have observed a decrease in the feeding activity of soil organisms in response to metal pollution (André *et al.*, 2009; Filzek *et al.*, 2004).

On sites polluted by metals, the abundance of detritus feeders is greatly reduced due to the high toxicity of the soil. Consequently, there is a large difference between controlled and polluted sites (Vorobeichik *et al.*, 2021).

Other studies have reported that copper has a negative impact on earthworms. Abundance is greatly reduced on the polluted site, but they have not completely disappeared (Vorobeichik *et al.*, 2021).

Our results indicate a negative correlation between the Bait lamina test and copper concentration in the soil, as also observed by Pesce *et al.* (2020). Several studies have demonstrated the negative impact of copper on protozoa (Ekelund *et al.*, 2003), enchytrata (Ruyters *et al.*, 2013) and springtails (Amorim *et al.*, 2005).

Collembola and enchytrata reproduction decreased by 50% after the application of 400 and $1895 \text{ kg Cu ha}^{-1} \text{ yr}^{-1}$, respectively, equivalent to 100 and $473.75 \text{ mg Cu kg}^{-1} \text{ yr}^{-1}$. Earthworm biomass was reduced by 15% following the application of $200 \text{ kg Cu ha}^{-1} \text{ yr}^{-1}$, equivalent to 50 mg Cu kg^{-1} (Karimi *et al.*, 2021).

Although copper is an essential element for many soil organisms, at high concentrations it can become toxic, like many other chemical elements (Sheramati and Varma, 2015). This toxicity can lead to a reduction in the feeding activity of soil organisms.

CONCLUSION

The aim of our study was to assess the impact of copper-induced soil contamination on the quality of tomato fruit

grown in contaminated soils and on soil organisms. The results of our work showed that the high use of copper in tomato cultivation does not have a negative effect on fruit quality. However, our results showed that excessive use of copper does have adverse effects on soil organisms. Our study contributes to a better understanding of the effects of copper-based pesticides on soil biology and tomato quality. A healthy agrosystem must ensure both good quality crops and good soil biology. Our work paves the way for further research to determine the concentrations of copper that can be used in tomato cultivation without damaging soil biology.

Conflict of interest

All authors declare that they have no conflict of interest.

REFERENCES

- Amorim, M.J. de, B., Römbke, J., Schallnaß, H. and Soares, A.M. V.M. (2005). Effect of soil properties and aging on the toxicity of copper to *Enchytraeus*. *Environmental Toxicology and Chemistry*. **24(8)**: 1875-1881.
- André, A., Antunes, S.C., Gonçalves, F. and Pereira, R. (2009). Bait-lamina assay as a tool to evaluate the effects of metal contamination on the feeding activity of soil invertebrates in a uranium mining area. *Environmental Pollution*. **157(8-9)**: 2368-2377.
- ANSES. (2018). Phytopharmacovigilance: Summary of monitoring data - Copper. French Agency for Food, Environmental and Occupational Health and Safety.
- Austruy, A., Laplanche, C., Mombo, S., Dumat, C., Deola, F. and Gers, C. (2016). Ecological changes in historically polluted soils: Bioaccumulation of metal (loid)s in microarthropods and their impact on community structure. *Geoderma*. **271**: 181-190.
- Badilla-Ohlbaum, R., Ginocchio, R., Rodríguez, P.H., et al. (2001). Relationship between soil copper content and copper levels in selected crop plants in central Chile. *Environmental Toxicology and Chemistry: An International Journal*. **20(12)**: 2749-2757.
- Bahn, M., Rodeghiero, M., Anderson-Dunn, M., Dore, S., Gimeno, C., Drösler, M., Williams, M., Ammann, C., Bérard, A., Capowiez, L., Mombo, S., Schreck, E., Dumat, C., Deola, F. and Capowiez, Y. (2016). Soil Microbial Respiration and PICT Responses to Industrial and Historical Lead Pollution: A Field Study. *Environmental Science and Pollution Research*. **23(5)**: 4271-4281.
- Belhaouari, B., Belguermi, A., Tayeb, A., Bendaha, M., Deham, F. and Mokhtari, Y. (2014). Organic pollution assessment and biological quality of the river oued rhiou (Algeria). *International Journal of Science and Basic Applied Research*. **18(1)**: 33-44.
- Benguenouna, N., Benabdelmoumene, D., Dahmouni, S., Bengharbi, Z., Foudil Mustapha, K. and Bouzouina, M. (2023). Assessing the impact of treated wastewater irrigation on citrus fruit quality: Nutritional, heavy metal and phytochemical analyses. *Tobacco Regulatory Science (TRS)*. pp. 1466-1474.
- Bispo, A., Grand, C. and Galsomies, L. (2009). The ADEME Program 'Soil Quality Bioindicators. *Étude Gest Sols*. **16**: 145-158.
- Criquet, S. (2013). Bioindicators: Biological Tools for Sustainable Soils -Oxitop Respirometry Tool Sheet. Institut Méditerranéen de Biodiversité et d'Écologie Marine et Continentale (IMBE). 4 pages.
- Crowther, T.W., van den Hoogen, J., Wan, J., Mayes, M.A., Keiser, A.D., Mo, L., et al. (2019). The global soil community and its influence on biogeochemistry. *Science*. **365(6455)**: eaav0550.
- Desaunay, A. (2011). Study and modeling of metal biosorption by bacteria: Application to the transfer of cadmium and zinc, individually or in mixture, by *Escherichia coli* and *Cupriavidus metallidurans* in Hostun sand columns. Earth Sciences. University of Grenoble.
- Ekelund, F., Olsson, S. and Johansen, A. (2003). Changes in Succession and Diversity of Protozoan and Microbial Populations in Soil Spiked with Various Copper Concentrations. *Soil Biology and Biochemistry*. **35(11)**: 1507-1516.
- Faure, A. and Reymermier, N. (2021). Évaluation des expositions des populations aux polluants environnementaux présents dans l'alimentation: Etude de faisabilité en population générale. Sciences pharmaceutiques. <https://ffdumas-03923033>.
- Filzek, P.D.B., Spurgeon, D.J., Broll, G., Svendsen, C., Hankard, P.K., Parekh, N., Stubberud, H.E. and Weeks, J.M. (2004). Metal effects on soil invertebrate feeding: Measurements using the bait lamina method. *Ecotoxicology*. **13(8)**: 807-816.
- Harkat, Y., Ziad, A. and Arabi, A. (2021). Copper Tolerance in Rhizosphere Isolates of *Pseudomonas fluorescens*.
- ISO 16072:2002. Soil Quality - Laboratory Methods for the Determination of Soil Microbial Respiration. International Organization for Standardization, Geneva, Switzerland.
- ISO 18311:2016. Soil Quality - Test Methods for the Effects of Soil Contaminants on the Feeding Activity of Soil Organisms - Bait lamina test. International Organization for Standardization, Geneva, Switzerland.
- Jiang, D., Li, Q., Liu, F., Jiang, Y. and Liang, W. (2007). Vertical Distribution of Soil Nematodes in an Age Sequence of *Caragana microphylla* Plantations in the Horqin Sandy Land, Northeast China. *Ecological Research*. **22**: 49-56.
- Jones, Jr., J. Benton. (2017). Plant Analysis Handbook III. 3rd ed. Athens, GA: Micro-Macro Publishing, Inc.
- Kadri, A., Haddad, A., Laarid, M. and Belhaouari, B. (2023). Impact of reduced tillage on soil chemistry and microbial communities used as a fertility indicator in a semi-arid region. *Current Trends in Natural Sciences*. **12(23)**: 107-117.
- Kang, M.C., Kim, S.Y., Kim, E.A., Lee, J.H., Kim, Y.S., Yu, S.K., Chae, J.B., Choe, I.H., Cho, J.H. and Jeon, Y.J. (2015). Antioxidant activity of polysaccharide purified from *Acanthopanax koreanum* nakai stems *in vitro* and *in vivo* zebrafish model. *Carbohydrate Polymers*. **127**: 38-46.
- Karimi, B., Masson, V., Guiland, C., Leroy, E., Pellegrinelli, S., Giboulot, E. and Ranjard, L. (2021). Is soil biodiversity affected by copper input or accumulation in vineyards? A synthesis of scientific knowledge. *Étude et Gestion des Sols*. **28(1)**: 71-92.

- Liao, N., Zhong, J., Ye, X., Lu, S., Wang, W., Zhang, R., Xu, J., Chen, S. and Liu, D. (2015). Ultrasonic-Assisted Enzymatic Extraction of Polysaccharides from *Corbicula fluminea*: Characterization and Antioxidant Activity. *Journal of Food Science and Technology*. **60**(2): 1113-1121.
- López-Vargas, M.D., Martínez-Sánchez, J.C., Gómez-Cruz, D. and Hernández-Hernández, M. (2018). The application of copper nanoparticles converts organic acids into simple sugars in tomatoes. *Journal of Nanoscience and Nanotechnology*. **18**(4): 2345-2352.
- Mazhoudi, S., Chaoui, A., Ghorbal, M.H. et al. (1997). Response of antioxidant enzymes to excess copper in tomato (*Lycopersicon esculentum* Mill.). *Plant Science*. **127**(2): 129-137.
- Mengome, L.E., Voxeur, A., Akue, J.P. and Lerouge, P. (2014). Evaluation of antioxidant activities in polysaccharide extracts from endemic plants in Gabon. *Journal of Bioactive Carbohydrates and Dietary Fibre*. **3**(2): 77-88.
- Mohanapriya, R., Kalpana, R. and Aravinth, K.V. (2024). Quality enhancement of fruits and vegetables through organic cultivation: A review. *Agricultural Reviews*. **45**(2). doi: 10.18805/ag.R-2351.
- Namdev, S.K., Ahirwar, K., Singh, H. and Bareliya, P.K. (2017). Title of the article. *International Journal of Agriculture Innovations*, Volume (Issue), pages. Retrieved from <https://agriinventonjournal.com/journals/index.php/IJAI/article/view/475>.
- Nechadi, S., Benddine, F., Moumen, A. and Kheddami, M. (2002). Current status of viral diseases in tomatoes and control strategies in Algeria. *EPPO Bulletin*. **32**(1): 21-24.
- Nielsen, S.S. (2017). *Food Analysis* (5e éd.). Springer, Cham. doi: 10.1007/978-3-319-45776-5.
- Nishant, N., Upadhyay, R. (2016). Presence of pesticide residue in vegetable crops: A review. *Agricultural Reviews*. **37**(3): 173-185. doi: 10.18805/ag.v37i3.3533.
- Organisation for Economic Co-operation and Development. (2019). *International standards for fruits and vegetables*. Paris: OECD. Retrieved from <http://doi.org/10.1787/941fdd50-en-fr>.
- OriginLab Corporation. (2019). *OriginPro (2019b) documentation*. Retrieved from <https://www.originlab.com/>.
- Pesce, S., Campiche, S., Casado-Martínez, C., Mahamoud Ahmed, A., Bonnineau, C., Dabrin, A., Lyautey, E. and Ferrari, B.J.D. (2020). Developing simple tools to assess the functional effects of contaminants on natural microbial and invertebrate sediment communities. *Environmental Science and Pollution Research*. **27**: 6680-6689.
- Ruyters, S., Salaets, P., Oorts, K. and Smolders, E. (2013). Copper toxicity in soils under established vineyards in Europe: A survey. *Science of the Total Environment*. **443**: 470-477.
- Sbartai, H., Djebbar, M.R., Sbartai, I. and Berrabbah, H. (2012). Bioaccumulation of Cd and Zn in tomato plants (*Lycopersicon esculentum* L.). *Comptes Rendus Biologies*. **335**(9): 585-593.
- Schlöter, M., Dilly, O. and Munch, J.C. (2003). Indicators for evaluating soil quality. *Agriculture, Ecosystems and Environment*. **98**(1): 255-262.
- Sherameti, I. and Varma, A. (Eds.). (2015). *Heavy Metal Contamination of Soils: Monitoring and Remediation*. Springer-Verlag, Germany.
- Singh, S., Sharma, R.K. and Singh, M. (2007). Effects of excess copper on carbohydrate metabolic enzymes. *Journal of Plant Nutrition and Soil Science*. **170**(2): 250-257. <https://doi.org/10.1002/jpln.200700042>.
- Soler-Rovira, P., Fernández-Calviño, D., Arias-Estévez, M., et al. (2013). Respiration parameters determined by the ISO-17155 method as potential indicators of copper pollution in vineyard soils after long-term fungicide treatment. *Science of the Total Environment*. **447**: 25-31.
- Son, D., Somda, I., Legreve, A. and Schiffers, B. (2018). Effect of plant diversification on pest abundance and tomato yields in two cropping systems in Burkina Faso: farmer practices and integrated pest management. *International Journal of Biological and Chemical Sciences*. **12**(1): 101-119.
- Stevens, G., Motavalli, P., Scharf, P., et al. (2018). Crop nutrient deficiencies and toxicities.
- Traiche, A., Belhaouari, B. and Rouen-Hacen, O. (2018). Study of macroalgae biodiversity in the western Algerian coast, Ténès. *Current Botany*. **9**: 28-32.
- Tremel-Schaub, A. and Feix, I. (2005). Soil contamination: Transfers from soil to plants. EDP Sciences, 17 Avenue du Hoggar, PA de Courtaboeuf, 91944 Les Ulis Cedex A; ADEME Éditions, 2 Square Lafayette, 49004 Angers Cedex. ISBN 2-86883-793-X.
- Vinogradov, D.V. and Zubkova, T.V. (2022). Accumulation of Heavy Metals by Soil and Agricultural Plants in the Zone of Technogenic Impact. *Indian Journal of Agricultural Research*. **56**(2): 201-207. doi: 10.18805/IJARE.A-651.
- Vorobeichik, E.L. and Bergman, I.E. (2021). Bait-lamina test for assessment of polluted soils: Rough vs. precise scales. *Ecological Indicators*. **122**: 107-277.