Natural Built Social Environment Health **1**(5) 2025: 107-124 DOI: 10.63095/NBSEH.25.513288

Natural Built Social Environment Health

ISSN 3085-461X

www.nbseh.org

Impact of irrigation water sources on growth and physiological traits in tomato (*Solanum lycopersicum*)

Lamiaa Belasri [1a] ✉, Ayoub Mardi [1b], Nihad Chakri [2c], Mehdi El Mellouki [1d], Mourad Arabi [3e], Fouad Amraoui [2f], Btissam El Amrani [2g], Samah Ait Benichou [1h]

[1] Health and Environment Laboratory, Department of Biology, Ain Chock Science Faculty, Hassan II University of Casablanca (https://ror.org/001q4kn48), Morocco.

[2] Association for Action-Research for Sustainable Development, Faculty of Sciences, Aïn Chock Hassan II University of Casablanca (https://ror.org/001q4kn48), Morocco

[3] Laboratory for Improvement of Agricultural Production, Biotechnology and Environment (LAPABE)/ Water, Environment and Health Team, Faculty of Science, Mohamed I University (https://ror.org/01ejxf797), PB 717 60000, BV M6, Oujda, Morocco

[a] ***ORCID***: *0009-0005-0988-6869*, ***Email***: *lamiaabelasri@gmail.com*

[b] ***ORCID***: *0009-0004-0366-7270*, ***Email***: *mardiayoub19991@gmail.com*

[c] ***ORCID:*** *0000-0002-1510-0253*, ***Email***: *n.chakri2009@gmail.com*

[d] ***ORCID:*** *0009-0002-3328-7354*, ***Email***: *mehdielmellouki7@gmail.com*

[e] ***ORCID:*** *0000-0002-2179-663X*, ***Email***: *m.arabi@ump.ac.ma*

[f] ***ORCID:*** *0000-0001-6012-0694*, ***Email***: *amraoui_f@hotmail.com*

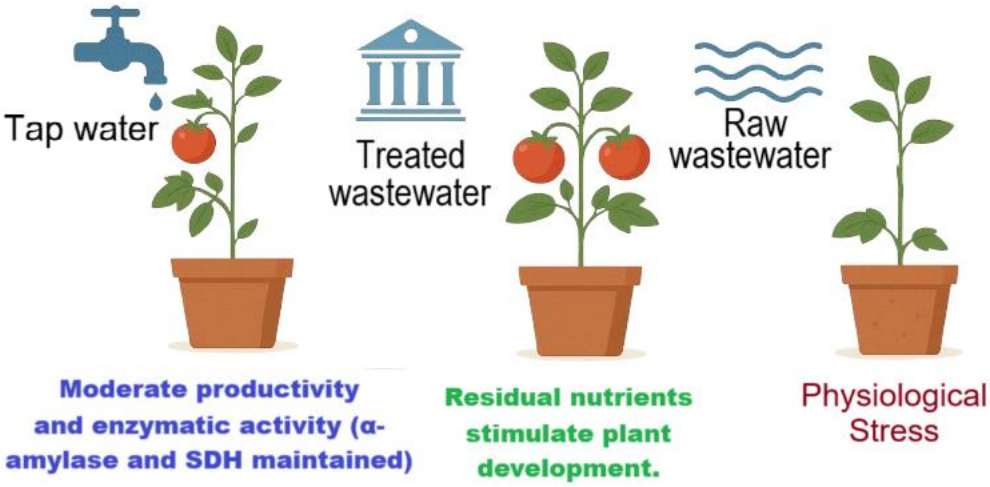
[g] ***ORCID:*** *0000-0002-2940-3503*, ***Email***: *elamrani.btissam@gmail.com*

[h] ***ORCID:*** *0000-0003-4423-2893*, ***Email***: *aitbenichous@gmail.com*

✉ **Corresponding author:** *Lamiaa Belasri;* ***Email address***: *lamiaabelasri@gmail.com*

Graphical Abstract

This study shows the effects of three irrigation water sources; tap water, treated wastewater, and raw wastewater; on the physiological and metabolic responses of tomato plants. The image points to improved growth and enzymatic activity, especially α-amylase and succinate dehydrogenase (SDH), in plants irrigated with treated wastewater. Raw wastewater causes stress, with visible declines in plant health. The visual reflects two aims: encouraging the safe reuse of treated effluents for sustainable farming, and showing the harm linked to untreated wastewater;



DOI: 10.63095/NBSEH.25.513288

Available online 08 August 2025

Citation: Belasri L., Mardi A., Chakri N., El Mellouki M., Arabi M., Amraoui F., El Amrani B., Ait Benichou S., 2025, Impact of irrigation water sources on growth and physiological traits in tomato (Solanum lycopersicum), *Natural Built Social Environment Health* **1**(5), 107-124. DOI: 10.63095/NBSEH.25.513288

Abstract: This study examined the effects of tap water (TW), treated wastewater (TWW), and raw wastewater (RWW) on *Solanum lycopersicum*. Raw wastewater showed high nitrite (42.57 ± 1.78 mg·L^{-1}) and BOD_5 (170 ± 12 mg·L^{-1}) levels. These values were lower in TWW (12.41 ± 0.56 mg·L^{-1} and 20 ± 4.5 mg·L^{-1}), which met Moroccan irrigation standards. Germination tests revealed higher α-amylase activity and germination index in RWW. This may reflect nutrient enrichment**.** After 90 days, plants irrigated with TWW showed the strongest vegetative growth, with taller stems (57.5 cm) and larger leaves. Microbiological analysis of tomato fruits showed minimal contamination across treatments. Succinate dehydrogenase activity was highest in TW-irrigated plants. This indicated optimal mitochondrial function**.** TWW produced moderate reductions in activity**.** RWW caused marked declines in both leaves and fruits**,** suggesting metabolic inhibition under stress. These findings show that TWW provides a useful balance between nutrient supply and plant health**,** supporting its suitability for sustainable irrigation.

Keywords: *Solanum lycopersicum*, Wastewater, Metabolic stress, Irrigation.

Introduction

The increasing global demand for freshwater, driven by population growth, urban expansion and climate change, has made water scarcity more severe in many parts of the world [1]. Agriculture, which uses nearly 70% of global freshwater, is especially exposed to these pressures [2]. In the Mediterranean region, several countries struggle to meet rising food needs. This is worse in areas with arid or semi-arid climates [3]. Morocco, once defined by a Mediterranean climate, now faces faster semi-aridification in key zones such as Casablanca-Settat, which is home to about 6.86 million people [4]. Agriculture remains central to Morocco's economy and society. It must now increase food production and manage water demand, as farming consumes nearly 80% of the country's freshwater [5].

In response to growing water scarcity, the reuse of treated wastewater is an alternative to standard irrigation sources. It conserves water and delivers essential nutrients, such as nitrogen and phosphorus. This practice supports circular economy aims by cutting reliance on synthetic fertilizers [6]. Concerns remain about the possible transfer of pathogens, heavy metals, and phytotoxic compounds to soil and crops [7]. In this context, the present study assesses the agronomic value of treated wastewater produced by a pilot decentralized treatment unit at the Faculty of Sciences Ain Chock (FSAC) in Casablanca, Morocco. This system uses an MBBR process followed by sand filtration to improve effluent quality [8]. The study analyses the physicochemical properties of the treated wastewater and examines its impact on seed germination, enzymatic activity, plant growth, and the microbiological safety of irrigated crops under controlled conditions.

Tomato (*Solanum lycopersicum* L.) was chosen as the test species for its agronomic, economic, and physiological importance. It is a strategic crop in Morocco, used both for local consumption and for export. Tomato is highly sensitive to water quality. It has high water needs and tends to accumulate salt and heavy metals. These traits make it a reliable bioindicator for assessing the suitability of reclaimed water for irrigation [9]. By comparing the effects of tap water, raw wastewater, and treated wastewater, this study aims to support the development of sustainable irrigation in water-limited regions such as Morocco.

Materials and methods

Site description and physicochemical assessment of wastewater

The treated wastewater used in this study came from a pilot decentralized treatment unit at the Faculty of Sciences Ain Chock (FSAC) in Casablanca, Morocco. This unit, developed by

Chakri *et al.* [8], was set up to offer sustainable wastewater treatment**.** The system combines a Moving Bed Biofilm Reactor (MBBR) with vertical sand filtration**,** which achieves high removal of organic and inorganic pollutants**.** Earlier studies confirmed the system's effectiveness and the suitability of the treated effluent for agriculture**.** Physicochemical analysis of the treated wastewater followed standard procedures [10,11]. The parameters tested included sulphates (SO_4^{2-}) using NF T 90-009, nitrites (NO_2^-) using NF T 90-013, and nitrates (NO_3^-) using NF ISO 7890-3/1988. Ammonium (NH_4^+) was tested by NF T 90-015. Orthophosphates (PO_4^{3-}) were analysed by NF T 90-023. Biological oxygen demand over five days (BOD_5) and chemical oxygen demand (COD) were measured using standard instrumental and dichromate reflux methods**,** based on NF T 90-101. pH, electrical conductivity (EC), suspended solids (SS), and turbidity were assessed using calibrated multiparameter probes, gravimetric filtration, and nephelometry. All measurements were carried out in triplicate, with blanks and standards included for quality control. The results showed that the treated wastewater met the required criteria for irrigation reuse. It provided a consistent source for tomato cultivation trials.

Plant material

Tomato (*Solanum lycopersicum*), part of the Solanaceae family, was selected as the model species for its dual role. It is a staple in Moroccan diets, eaten both raw and cooked. It also has high nutritional value, being rich in phosphorus and in vitamins A and C [12]. *S. lycopersicum* has high water needs throughout its growth, which makes it a relevant choice for studies on alternative irrigation [13].

Germination test

Germination tests were carried out using a modified version of the Zucconi [14] phytotoxicity assay, in line with OPPTS 850.4200 [15]. Seeds of *Solanum lycopersicum* L. were commercially sourced and selected for uniform size and intact shape, with no pre-treatment. Twenty seeds were placed evenly on Whatman No. 1 filter paper in sterile Petri dishes. Raw or treated wastewater was used to moisten the seeds in the test groups. Tap water was used in the control group under identical conditions. All Petri dishes were sealed and kept in the dark at 20–25 °C. After 72 hours, germinated seeds were counted, and radicle length was measured. Each treatment was tested in triplicate to ensure statistical consistency**.**

α-Amylase activity was analysed to assess metabolic response during germination**.** The extraction followed a modified protocol based on Berbezy [16]. Germinated seeds were homogenized in 50 mM Tris-HCl buffer (pH 7.5). The homogenate was centrifuged, and the supernatant was used as the crude enzyme extract.

Enzymatic activity was quantified by incubating 500 µL of extract in a mixture containing 100 mM potassium phosphate buffer (pH 6.5), 1% soluble starch, and 1% NaCl. The reaction was stopped by adding 2 N NaOH and 3,5-dinitrosalicylic acid. Absorbance was measured at 520 nm using a spectrophotometer. Total protein in the extract was measured using the Bradford method [17], with bovine serum albumin as the standard.

Greenhouse cultivation conditions and experimental design

The soil used in this experiment was the same as in our previous study. It had known physicochemical properties and proved suitable for agriculture [18]. The experiment took place in a greenhouse, using cylindrical polyethylene pots (27 cm diameter × 40 cm height). A base layer of fine gravel was added to improve drainage, reduce the risk of oxygen shortage, and limit fungal growth in the root zone. The pots were then filled with the prepared soil. *Solanum lycopersicum* seeds were sown directly, three per pot.

This trial tested the effects of irrigation using treated and untreated wastewater from the FSAC decentralized treatment unit on tomato growth. Twelve pots were randomly assigned to three groups. The control group (C) received tap water. The treated wastewater group (TW) was irrigated with effluent from the FSAC system. The untreated wastewater group (UW) received raw influent from the same source. All treatments were applied in equal volume and frequency to keep soil moisture uniform across the trial.

At the end of the growth period, several morphometric traits were measured to assess treatment effects. Plant height was measured from the base to the apical meristem. Fruit length and width were also recorded to evaluate how water quality affected reproductive growth and biomass use.

Mitochondrial extraction and succinate dehydrogenase activity assay

Mitochondria were isolated using a modified protocol based on the Romani method [19]. Fresh tomato tissues were homogenized in extraction buffer containing 0.25 M sucrose, 50 mM potassium phosphate buffer (pH 7.2), 6 mM EDTA, 10 mM β-mercaptoethanol, 0.5% polyvinylpolypyrrolidone, and 1 $mg \cdot mL^{-1}$ bovine serum albumin. The homogenate was filtered to remove debris, then centrifuged in steps to isolate the mitochondrial fraction.

Succinate dehydrogenase (SDH) activity was measured using a modified version of the Frenkel and Patterson method [20]. The reaction mixture contained 100 mM potassium phosphate buffer (pH 7.2), 10 mM potassium cyanide, 6 mM phenazine methosulphate, 20 mM sodium succinate, and 0.2 mM dichlorophenol indophenol (DCIP). Mitochondrial extract was added to the mixture, and SDH activity was tracked by measuring the reduction of DCIP at 600 nm with a spectrophotometer.

SDH specific activity was calculated as enzymatic rate per milligram of total protein. Protein content was measured using the Bradford assay, with bovine serum albumin as the standard.

Bacteriological analysis

Microbiological analysis of *Solanum lycopersicum* fruits examined contamination by total coliforms, faecal coliforms, *Clostridium* spp., and *Salmonella* spp. [21]. Total and faecal coliforms were counted using the multiple-tube fermentation method [22]. Detection of *Salmonella* spp. used the Most Probable Number technique [23]. Clostridium spores were quantified following protocols from APAT-IRSA C.N.R. and APHA [24,25].

Statistical analysis

Statistical analysis was carried out using GraphPad Prism. Results are shown as means ± standard error of the mean (SEM). Two-way ANOVA was used to assess differences in morphological, physiological, and biochemical traits of *Solanum lycopersicum* under different irrigation treatments (tap water, untreated wastewater, and treated wastewater). Differences were considered significant at $p < 0.05$.

Results and Discussion

Quality characteristics of water samples used for irrigation

Table 1 shows the physicochemical values of the three irrigation waters. Nitrite (NO_2^-) rose from 0.06 ± 0.02 mg.L^{-1} in tap water to 42.57 ± 1.78 mg.L^{-1} in raw wastewater. After treatment, levels dropped to 12.41 ± 0.56 mg.L^{-1}. This remains well above the usual threshold for urban wastewater (<1 mg.L^{-1}) but stays within the Moroccan limit for irrigation water (30 mg.L^{-1}). This reduction shows partial treatment efficiency and incomplete nitrification. Nitrate (NO_3^-) levels stayed low in all samples, from 0.01 ± 0.02 mg.L^{-1} in tap water to 1.93 ± 0.72 mg.L^{-1} in raw wastewater. After treatment, levels dropped to 0.58 ± 0.14 mg.L^{-1}. These values are below typical urban wastewater concentrations and do not pose a risk for irrigation reuse.

Ammonium (NH_4^+) increased from 0.11 ± 0.02 mg.L^{-1} in tap water to 35.15 ± 2.75 mg.L^{-1} in raw wastewater, then fell to 15.68 ± 0.93 mg.L^{-1} after treatment. Sulphate (SO_4^{2-}) levels also rose, reaching 188 ± 5.16 mg.L^{-1} in raw wastewater. Treated water showed a reduction to 100 ± 23 mg.L^{-1}, below the 250 mg.L^{-1} irrigation limit.

Table 1: Physicochemical characteristics of the water samples

Physicochemical parameters	Unit	Tap water	Treated wastewater	Raw wastewater	Usual range of urban wastewater*,**	ILV**
NO_2^-	$mg.L^{-1}$	0.06±0.02	12.41±0.56	42.57±1.78	<1*	30
NO_3^-		0.01±0.02	0.58±0.14	1.93±0.72	<1*	-
NH_4^+		0.11±0.02	15.68±0.93	35.15±2.75	20-80*	-
PO_4^{3-}		0.88±0.07	1.14±0.21	4.33±0.63	2**	-
SO_4^{2-}		88±5.16	100±23	350±15	-	250
BOD_5		0	20±4.5	170±12	200-400	40*

* Limit values according to the guidelines for treated water intended for irrigation [26]
** ILV: Irrigation Limit Value [27]

Biochemical oxygen demand over five days (BOD_5) increased from 0 $mg.L^{-1}$ in tap water to 170 ± 12 $mg.L^{-1}$ in raw wastewater, and dropped to 20 ± 4.5 $mg.L^{-1}$ after treatment. This indicates a major drop in biodegradable organic matter.

In summary, while some values remain higher than usual for urban wastewater, the treated water meets Moroccan thresholds for irrigation reuse in terms of nitrites, sulphates, and BOD_5.

Influence of raw and treated wastewater on seed germination

Germination tests showed clear differences in seed response under the three irrigation treatments (Figure 1). Seeds irrigated with raw wastewater had the highest germination index. Those given treated wastewater showed slightly lower values. Seed weight also increased under raw wastewater, followed by treated wastewater, compared to the control.

Raw wastewater probably provided extra nutrients and organic matter, which boosted seed metabolism during germination. A similar result was reported in a previous study. Rice seeds treated with municipal wastewater had a higher germination index than those irrigated with treated water [28]. The effect was linked to higher levels of dissolved nutrients and minerals in raw wastewater, which may act as natural biostimulants during early seed growth. Our findings differ from Ravindran *et al.* [29], who found a higher germination index in tomato seeds irrigated with treated wastewater than with raw effluent. This contrast may reflect variation in wastewater composition, source, or treatment method, showing the need to consider the physicochemical profile of the water used.

El Kafz *et al.* [30] showed that olive mill wastewater at high concentration was phytotoxic to tomato seeds. Dilution was needed to reduce toxicity. When treated properly, the same wastewater improved seed germination. This agrees with our results: moderate use of treated wastewater supported germination, although less effectively than raw wastewater in this case. In summary, raw wastewater enhanced early seed development under controlled conditions, though it may carry risks. Treated wastewater was safer but had a milder effect.

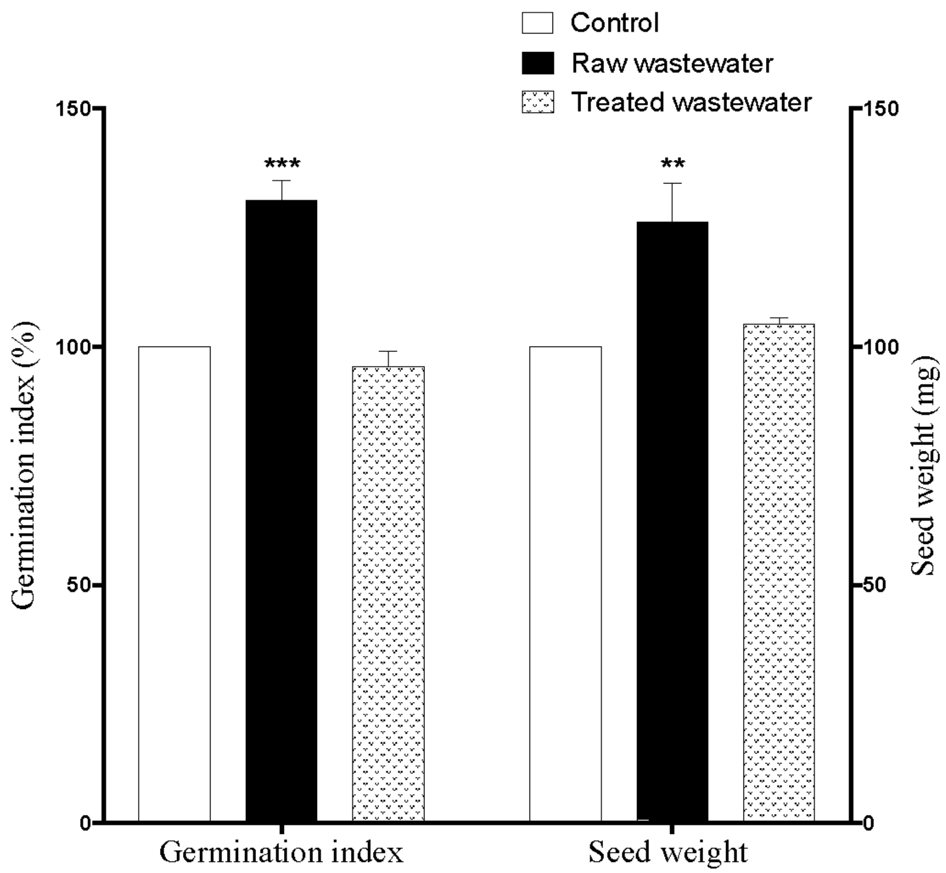


Figure 1. Effect of different irrigation types on seed germination index and seed weight. **Control**: Tap water; **Raw wastewater**: untreated effluent; **Treated wastewater**: effluent after treatment. Data are expressed as mean ± SD. **$p < 0.01$: very significant (**)**; $p < 0.001$: highly significant (***)

Variation of α-amylase activity in tomato seeds

To clarify the effect of irrigation on seed germination, α-amylase activity was measured in germinated tomato seeds [31]. This enzyme breaks down starch during germination.

Figure 2 shows that α-amylase activity differed across treatments. Seeds irrigated with raw wastewater showed the highest activity. Activity was lower with tap water and treated wastewater. This increase aligns with the higher germination index seen under raw wastewater. Raw wastewater appears to stimulate reserve mobilization in tomato seeds, possibly through bioavailable nutrients or mild stress signals that activate the enzyme [32].

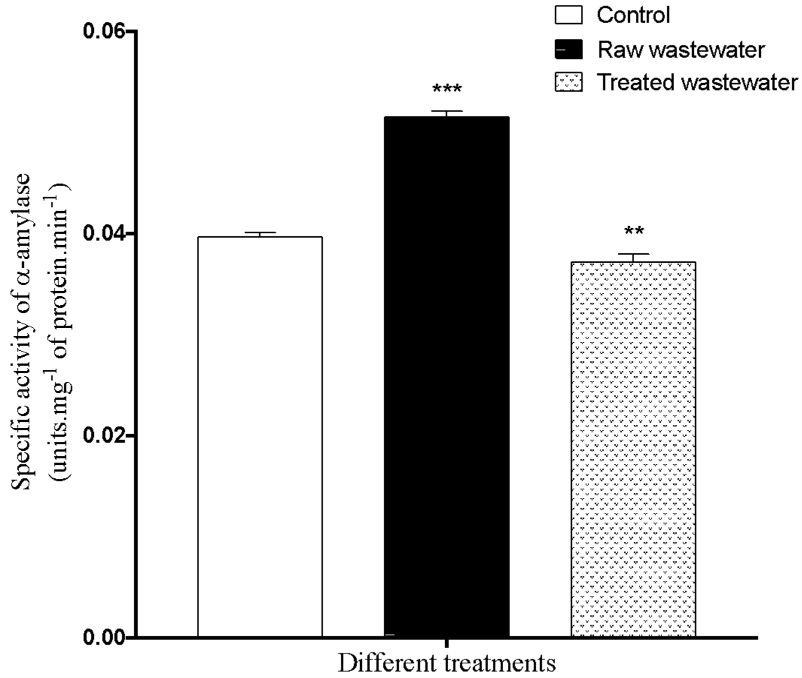


Figure 2. Effect of irrigation type on the specific activity of α-amylase (units mg^{-1} protein min^{-1}). Data are expressed as mean ± SD. **$p < 0.01$: very significant (**)**; $p < 0.001$: highly significant (***)

These results agree with Abdennbi *et al.* [32], who found increased α-amylase activity in seeds exposed to olive mill wastewater. Their study showed that wastewater can stimulate enzyme activity during early growth. Belasri *et al.* [16] also found a clear link between germination and α-amylase activity in *Medicago sativa* seeds treated with different leachate concentrations. Enzyme activity followed the same pattern as germination. In our study, the match between germination index and α-amylase activity supports the link between reserve mobilization and irrigation water quality.

Effects of raw and treated wastewater on the plant growth

Figures 3 and 4 show that irrigation with different water sources affected tomato plant morphology. Stem height and leaf size both changed. Over 90 days, stem height increased in all treatments. Plants irrigated with treated wastewater grew the tallest, reaching 57.5 cm by day 90.

wastewater (37 cm), which showed the least growth. This agrees with Muscarella *et al.* [33], who found that treated wastewater increases tomato height. The effect was linked to higher nutrient levels, especially nitrogen and phosphorus, which support vegetative growth.

Leaf length and width were also greatest in plants irrigated with treated wastewater, in line with stem growth. Ammonium (NH_4^+) and phosphate (PO_4^{3-}) in the treated water may have promoted cell division and expansion, leading to larger leaves.

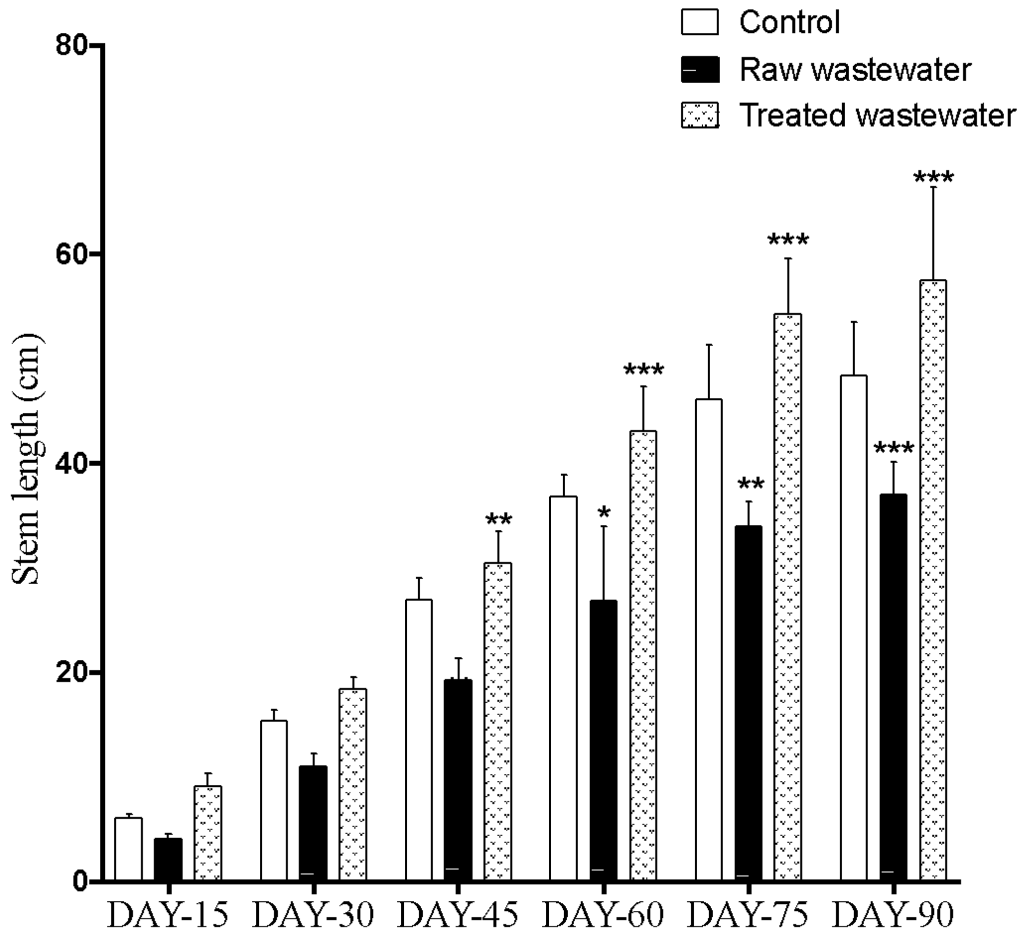


Figure 3. Temporal evolution of stem length in *Solanum lycopersicum* plants irrigated with tap water, control), treated wastewater, and raw wastewater. Values represent means ± SD (n = 10). * $p < 0.05$ (significant). ** $p < 0.01$ (very significant); ***$p < 0.001$ (highly significant).

These plants were significantly taller than those irrigated with tap water (48.35 cm) and raw Plants irrigated with raw wastewater had the smallest leaves, suggesting phytotoxic effects from untreated effluent. High nitrite (NO_2^-) and BOD_5 levels likely caused stress, reducing metabolic efficiency and limiting photosynthesis, which restricted foliar development [34].

Tap water produced intermediate growth, with moderate leaf size and stem height. The absence of both pollutants and extra nutrients explains this pattern. Tap water is safe, but lacks the fertilizing potential of treated wastewater, which may increase biomass when combined with fertilizer [35].

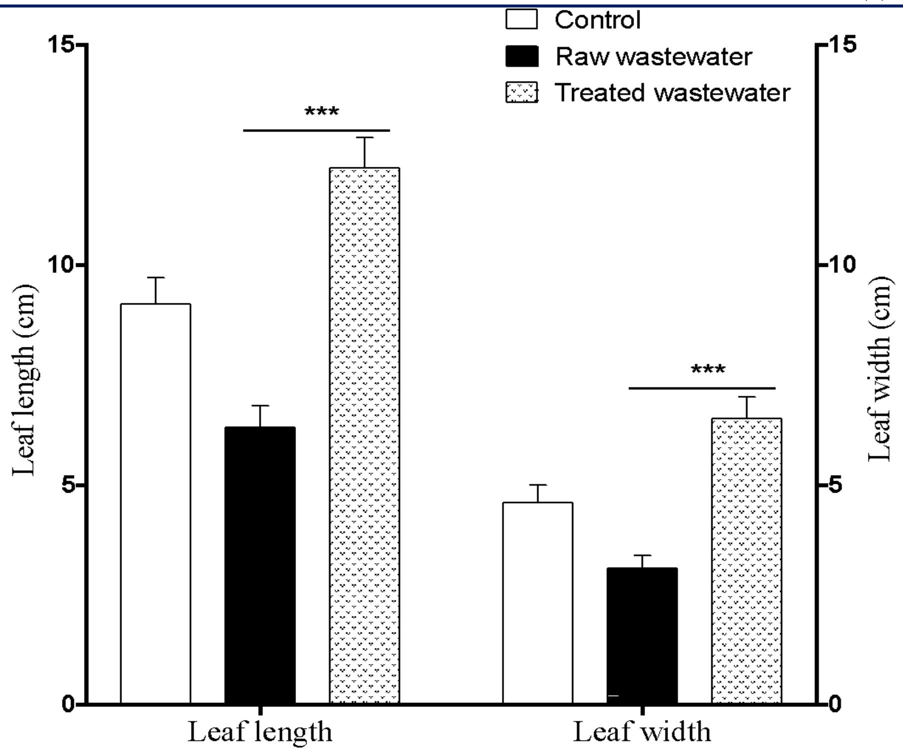


Figure 4. Final measurements of leaf length and leaf width in *Solanum lycopersicum* plants irrigated with tap water, treated wastewater, and raw wastewater. ***$p < 0.001$ (highly significant).

Microbiological characterization of harvested tomatoes

Bacteriological analysis was done to assess the sanitary quality of tomato fruits irrigated with different water sources. Tests were performed by an accredited agri-food laboratory in Casablanca, Morocco. The analysis covered tomatoes irrigated with tap water, treated wastewater, and raw wastewater.

Bacteriological analysis of tomato fruits irrigated with tap water, treated wastewater, and raw wastewater showed low microbial counts across all treatments (Table 2). Clostridium, faecal coliforms, and total coliforms were below 10 CFU/g in both control and treated wastewater fruits. Raw wastewater fruits had a slightly higher total coliform count (<4.10^1 CFU/g), but were still low. Salmonella was not detected in any sample.

Table 2. Bacteriological parameters in tomato fruits samples irrigated with tap water (control), treated wastewater, and raw wastewater.

Parameters	Units	Control	Treated wastewater	Raw wastewater
Clostridium [24, 25]	ufc/g	<10	<10	<10
Faecal Coliform [22]		<10	<10	<10
Total Coliform [22]		<10	<10	<4.10^1
Salmonella [23]	*spp/25g*	Absent	Absent	Absent

These findings agree with Ouansafi *et al.* [34], who reported no pathogenic bacteria in tomatoes irrigated with treated wastewater. Orlofsky *et al.* [36] also found low faecal indicators and no major pathogens in similar conditions. These studies show that with proper treatment and careful practices, treated wastewater carries low contamination risk. Raw wastewater raised coliform levels slightly, but counts stayed within safety limits for fresh produce. No Salmonella was found [37]. Under the study conditions, microbial loads remained low and did not present a food safety risk.

Enzymatic activity of succinate dehydrogenase in leaves and fruits

SDH activity in *Solanum lycopersicum* leaves and fruits varied with tissue type and irrigation source (Figure 5).

SDH is a mitochondrial enzyme in the tricarboxylic acid cycle and electron transport chain. It indicates mitochondrial function and metabolic state [38]. Activity was higher in leaves than in fruits across all treatments. Leaf tissues support photosynthesis and growth, requiring sustained energy. Fruits prioritize storage over respiration, so enzyme activity was lower. This matches previous findings in tomato and other solanaceous plants, where photosynthetic organs had higher SDH activity than reproductive tissues [39]. Plants irrigated with tap water had the highest SDH activity, especially in leaves. This points to healthy mitochondrial function under non-stress conditions.

Treated wastewater caused a moderate drop in SDH, mainly in leaves. This may reflect mild stress from residual elements, such as trace metals, despite the nutrients in reclaimed water [40]. In fruits, SDH activity remained higher than in the raw wastewater group, suggesting partial stress mitigation. Leaf SDH activity dropped by more than 60% under raw wastewater. Fruit activity was very low (0.0024 ± 0.0018 IU·mg^{-1} protein·min^{-1}). This sharp decline reflects toxic effects from high salinity (SO_4^{2-}) and nitrogen compounds (NO_2^-).

These disrupt mitochondrial enzymes and redox stability [41]. Earlier studies also showed that raw wastewater reduced mitochondrial function and respiration enzyme activity [18,34]. Standard deviation fell under raw wastewater, especially in fruits, suggesting a uniform stress response. This supports SDH activity as a sensitive marker of stress in response to irrigation water quality.

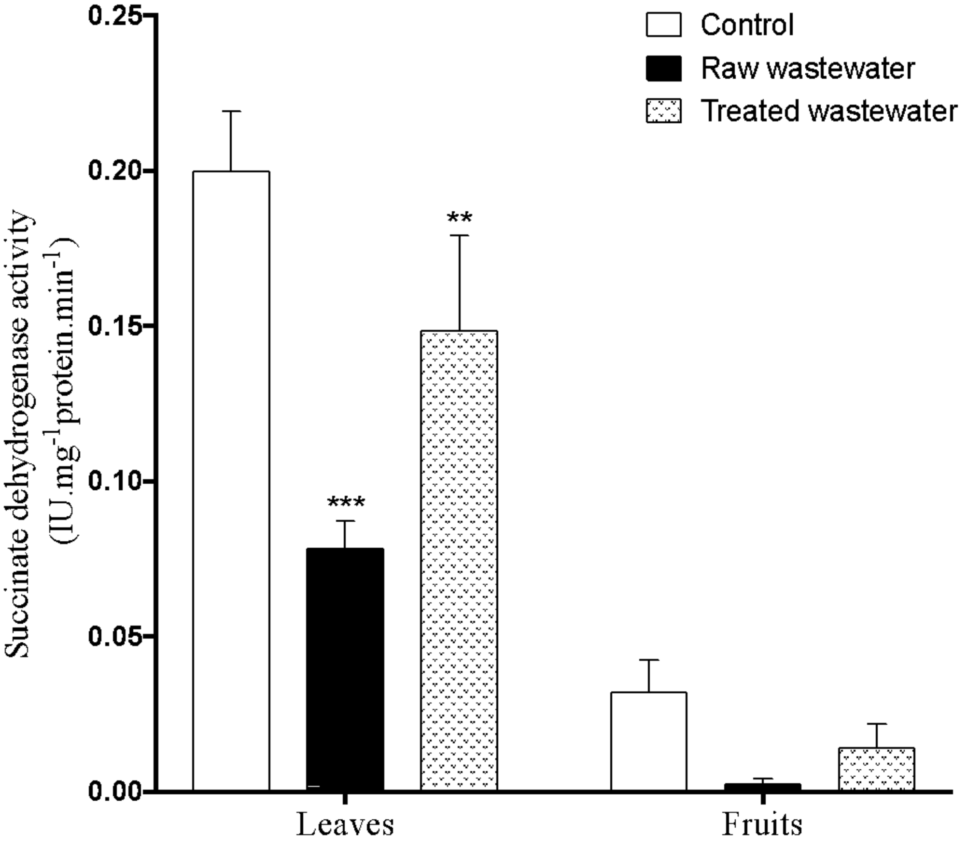


Figure 5. The enzymatic activity of SDH in leaves and fruits of tomato plants. ** $p < 0.01$ (very significant); ***$p < 0.001$ (highly significant).

Conclusion

This study assessed the agronomic value of treated wastewater from a pilot decentralized system at the Faculty of Sciences Ain Chock (FSAC), Casablanca**.** In water-scarce regions such as Morocco, reusing treated effluent can conserve freshwater and improve soil fertility**.** Physicochemical analysis showed that treatment reduced nitrites, ammonium, and organic matter to levels within national irrigation standards**.** Nitrite levels remained higher than in tap water but stayed within safe limits**,** demonstrating effective treatment. Microbiological results showed that raw wastewater boosted germination and enzyme activity but carried greater risks of phytotoxicity and contamination. Treated wastewater was safer and supported healthy early growth**.** Tomatoes irrigated with treated wastewater grew taller and had larger leaves than those irrigated with tap water or raw wastewater. Nutrients in the treated water improved development and yield**.** Microbiological testing confirmed the safety of fruit from treated wastewater plots**.** Fruits irrigated with raw wastewater showed signs of contamination risk**.** This underlines the need for proper treatment to ensure both crop productivity and food safety**.** Treated wastewater from the FSAC unit provides a sustainable option for irrigation in dry regions. It supports resource recovery, environmental protection, and plant growth. Regular water quality checks remain essential. More research is needed to test other crops and field conditions before scaling up use in agriculture.

Acknowledgements

The authors express their gratitude to the Faculty of Sciences of Casablanca (FSAC) for providing the infrastructure and to the Association for Action-Research for Sustainable Development, Faculty of Sciences, Aïn Chock Hassan II University of Casablanca for their valuable collaboration and support throughout this study.

Author Contributions

All authors contributed to the study's conception, design, data collection, and analysis. The first draft of the manuscript was written by Lamiaa Belasri, with all authors providing feedback on previous versions. All authors read and approved the final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability

All data generated in this study are included in the submitted manuscript.

Consent for publication

All authors have approved and consented to publish this paper.

Competing interests

The authors declare no competing interests.

References

[1] He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A., 2021, Future global urban water scarcity and potential solutions. *Nature Communications* **12**(1), 4667. https://doi.org/10.1038/s41467-021-25026-3

[2] FAO. 2017. *The future of food and agriculture – Trends and challenges*. Rome: Food and Agriculture Organization of the United Nations (Rome: FAO). Available at:

https://openknowledge.fao.org/server/api/core/bitstreams/2e90c833-8e84-46f2-a675-ea2d7afa4e24/content

[3] Claro, A., Fonseca, A., Fraga, H., & Santos, J., 2024, Future Agricultural Water Availability in Mediterranean Countries under Climate Change: A Systematic Review. *Water* **16**(17), 2484. https://doi.org/10.3390/w16172484

[4] Casablanca-Settat Regional Investment Center (RIC), 2018, Socioeconomic data of the Casablanca-Settat Region. https://www.hcp.ma/Les-comptes-regionaux-de-l-annee-2018_a2585.html

[5] Et-Touile, H., 2023, Water Scarcity Impacts On Food Production in Morocco. *International Journal of Strategic Management and Economic Studies* **2**(5), 1640–1653. https://doi.org/10.5281/zenodo.8355193

[6] Ungureanu, N., Vlăduț, V., & Voicu, G., 2020, Water scarcity and wastewater reuse in crop irrigation. *Sustainability* **12**(21), 9055. https://doi.org/10.3390/su12219055

[7] Yadav P., Singh R.P., Gupta R.K., Pradhan T., Raj A., Singh S.K., Kaushalendra, Pandey K.D., Kumar A., 2023, Contamination of soil and food chain through wastewater application,
In: Luiz Fernando Romanholo Ferreira, Ajay Kumar, Muhammad Bilal (Eds) *Advances in Chemical Pollution, Environmental Management and Protection*, Volume 9, 2023, pp. 109–132 (Amsterdam: Elsevier). DOI: https://doi.org/10.1016/bs.apmp.2022.11.001

[8] Chakri, N., Amrani, B. E., & Berrada, F., 2021, Modeling and optimization of wastewater treatment, from the Ain Chock faculty in Morocco, using the vertical flow filter filled with pozzolana. *Desalination and Water Treatment* **234**, 376–385. https://doi.org/10.5004/dwt.2021.27598

[9] Peco, J., Pérez–López, D., Centeno, A., Moreno, M., Villena, J., & Moratiel, R., 2023, Comparison of physiological and biochemical responses of local and commercial tomato varieties under water stress and rehydration. *Agricultural Water Management* **289**, 108529. https://doi.org/10.1016/j.agwat.2023.108529

[10] Association française de normalisation (AFNOR), 1999, *Recueils des normes AFNOR. Collection of AFNOR Standards*, Tomes 1 à 4 (Paris : AFNOR).

[11] Rodier, J., Legube, B., & Merlet, N., 2009, *L'Analyse de l'eau*, 9ème édition, entièrement mise à jour (Paris: Dunod).

[12] Yang, Z., Li, W., Li, D., & Chan, A., 2023, Evaluation of Nutritional Compositions, Bioactive Components, and Antioxidant Activity of Three Cherry Tomato Varieties. *Agronomy* **13**(3). https://doi.org/10.3390/agronomy13030637

[13] Júnior, A., De Souza Vilela, M., Carmona, R., Peixoto, J., Da Silva, N., Clara, J., Saba, E., & De Jesus Da Silva Neto, A., 2024, Nutritional quality of tomato in response to different fertilization

doses and conduction systems. *Contribuciones A Las Ciencias Sociales*. https://doi.org/10.55905/revconv.17n.7-347

[14] Zucconi, F., Pera, A., Forte, M., & DeBertolli, M., 1981, Evaluating Toxicity of Immature Compost. *Biocycle* **22**, 54–57. https://archive.org/details/sim_biocycle_1981_22_index/mode/2up

[15] US Environmental Protection Agency (USEPA), 1996, *Ecological effects test guidelines (OPPTS 850.4200): Seed germination/root elongation toxicity test*. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100RF5I.txt

[16] Belasri, L., Hmimid, F., Cherki, M., & Ait Benichou, S., 2024, Seasonal comparison of the effect of landfill leachate from Mediouna (Casablanca, Morocco) on germination and α-amylase activity in *Lens culinaris* and *Medicago sativa*. *Euro-Mediterranean Journal for Environmental Integration* **9**, 1301–1309. https://doi.org/10.1007/s41207-024-00511-5

[17] Bradford, M. M., 1976, A rapid and sensitive method for quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry* **72**, 248–254. https://doi.org/10.1016/0003-2697(76)90527-3

[18] Belasri, L., Guenaou, I., Hmimid, F., & Ait Benichou, S., 2024, Assessing the impact of leachate irrigation on *Medicago sativa* (alfalfa) growth, enzymatic responses, and heavy metal accumulation. *Environmental Science and Pollution Research* **31**, 61033–61048. https://doi.org/10.1007/s11356-024-35307-1

[19] Romani, R. J., Yu, I. K., & Fisher, L., 1969, Isolation of tightly coupled mitochondria from acidic plant tissues. *Plant Physiology* **44**, 311–312. https://doi.org/10.1104/pp.44.2.311

[20] Frenkel, C., & Patterson, M., 1973, Effect of carbon dioxide on activity of succinic dehydrogenase in ‘Bartlett’ pears during cold storage. *Horticultural Science* **8**, 395–396. Available online: https://eurekamag.com/research/000/068/000068615.php

[21] Tallon, P., Magajna, B., Lofranco, C., & Leung, K. T., 2005, Microbial Indicators of Faecal Contamination in Water: A Current Perspective. *Water Air and Soil Pollution* **166**, 139–166. https://doi.org/10.1007/s11270-005-7905-4

[22] Rice E.W., Baird R.B., Eaton A.D., Clesceri L.S. (Eds.), 2012, *Standard Methods for the Examination of Water and Wastewater*, 22nd edition (Washington, DC: American Public Health Association, American Water Works Association, Water Environment Federation)

[23] El-Lathy, A. M., El-Taweel, G. E., El-Sonosy, M. W., Samhan, F. A., & Moussa, T. A., 2009, Determination of pathogenic bacteria in wastewater using conventional and PCR techniques. *Environmental Biotechnology* **5**(2), 73–80. https://bibliotekanauki.pl/articles/363166.pdf

[24] APAT-IRSA, C.N.R., 2003, *Metodi analitici per le acque. Manuali e linee guida 29/2003*. APHA, AWWA, WEF, 1995. *Standard Methods for the Examination of Water and Wastewater*. 19th ed., (Washington, DC: APHA), https://www.irsa.cnr.it/wp/?page_id=5435

[25] American Public Health Association, American Water Works Association, Water Pollution Control Federation, & Water Environment Federation (APHA, AWWA, WEF), 1998, *Standard Methods for the Examination of Water and Wastewater* (Vol. 3). 20th ed., (Washington, DC: APHA), https://www.abpsoil.com/images/Books/Standard-Methods-for-the-Examination-of-Water-and-Wastewater-20.pdf

[26] UNEP/MAP/MED POL/WHO, 2004, *Municipal Wastewater Treatment Plants in Mediterranean Coastal Cities (II)*, MAP Technical Report Series No. 157 (Athens: United Nations Environment Programme / Mediterranean Action Plan), 1810-6218. https://digitallibrary.un.org/record/530303/files/mts157eng.pdf?ln=en

[27] Government of Morocco, 2002, Joint decree of the Minister of Equipment and the Minister in charge of Land Use Planning, Environment, Urban Planning, and Housing No. 1276-01 of October 17, 2002, establishing the quality standards for water intended for irrigation. *Official Bulletin* No. 1276-01, 1–5. https://www.susana.org/downloads?documentID=3175

[28] Gassama, U. M., Puteh, A. B., & Bangura, R. S., 2021, Impact of different concentrations of municipal wastewater on rice seed germination and seedling performance. *Zenodo* **7**(11). https://doi.org/10.5281/zenodo.5759603

[29] Ravindran, B., Kumari, S., Stenström, T., & Bux, F., 2016, Evaluation of phytotoxicity effect on selected crops using treated and untreated wastewater from different configurative domestic wastewater plants. *Environmental Technology* **37**, 1782–1799. https://doi.org/10.1080/09593330.2015.1132776

[30] El Kafz, G., Cherkaoui, E., Benradi, F., Khamar, M., Nounah, A., & Azzouzi, S., 2023, Study of the Phytotoxicity of Olive Mill Wastewater on Germination and Vegetative Growth – Case of Tomato (*Solanum lycopersicum* L). *Ecological Engineering & Environmental Technology* **24**(5), 265–274. https://doi.org/10.12912/27197050/165817

[31] Guzmán-Ortiz, F. A., Castro-Rosas, J., Gómez-Aldapa, C. A., Mora-Escobedo, R., Rojas-León, A., Rodríguez-Marín, M. L., Falfán-Cortés, R. N., & Román-Gutiérrez, A. D., 2018, Enzyme activity during germination of different cereals: A review. *Food Reviews International* **35**(3), 177–200. https://doi.org/10.1080/87559129.2018.1514623

[32] Abdennbi, S., Trabelsi, L., Ahmed, G. B., Ayadi, M., Maktouf, S., Gargouri, K., Chaieb, M., & Mekki, A., 2024, Assessment of the germination power and α-amylase activity in the soil rhizospheric compartment amended with olive mill waste waters. *Environmental Monitoring and Assessment* **196**(12). https://doi.org/10.1007/s10661-024-13380-w

[33] Muscarella, S., Alduina, R., Badalucco, L., Capri, F., Di Leto, Y., Gallo, G., Laudicina, V., Paliaga, S., & Mannina, G., 2024, Water reuse of treated domestic wastewater in agriculture: Effects on tomato plants, soil nutrient availability and microbial community structure. *Science of the Total Environment* **922**, 172259. https://doi.org/10.1016/j.scitotenv.2024.172259

[34] Ouansafi, S., Bellali, F., Maaghloud, H., & Kabine, M., 2022, Treated wastewater irrigation of tomato: Effects on crop production, and on physico-chemical properties, SDH activity and microbiological characteristics of fruits. *Environmental Challenges* **8**, 100556. https://doi.org/10.1016/j.envc.2022.100556

[35] Marcińczyk, M., Ok, Y., & Oleszczuk, P., 2022, From waste to fertilizer: Nutrient recovery from wastewater by pristine and engineered biochars. *Chemosphere* **311**, 135310. https://doi.org/10.1016/j.chemosphere.2022.135310

[36] Orlofsky, E., Bernstein, N., Sacks, M., Vonshak, A., Benami, M., Kundu, A., Maki, M., Smith, W., Wuertz, S., Shapiro, K., & Gillor, O., 2016, Comparable levels of microbial contamination in soil and on tomato crops after drip irrigation with treated wastewater or potable water. *Agriculture Ecosystems & Environment* **215**, 140–150. https://doi.org/10.1016/j.agee.2015.08.008

[37] Committee on the Review of the Use of Scientific Criteria & Performance Standards for Safe Food, 2003, Scientific criteria to ensure safe food. *Grove/Atlantic Inc* (Washington, D.C.: The National Academies Press). https://doi.org/10.17226/10690

[38] Huang, S., Braun, H., Gawryluk, R., & Millar, A., 2019, Mitochondrial complex II of plants: Subunit composition, assembly, and function in respiration and signaling. *The Plant Journal* **98**(3), 405–417. https://doi.org/10.1111/tpj.14227

[39] Kolekar, S., Sankapal, P., Khare, K., & Chinnasamy, P., 2023, Assessment of recycled treated wastewater for sustainable tomato crop production: A comprehensive review. *Environmental Challenges* **13**, 100791. https://doi.org/10.1016/j.envc.2023.100791

[40] Belasri, L., Arabi, M., Sabri, S., Hmimid, F., & Benichou, S. A., 2024, Transfer of metals from the soil to *Medicago sativa* irrigated with municipal landfill leachate. *Journal of Ecological Engineering* **25**(8), 336–346. https://doi.org/10.12911/22998993/190349

[41] Che-Othman, M. H., Millar, A. H., & Taylor, N. L., 2017, Connecting salt stress signalling pathways with salinity-induced changes in mitochondrial metabolic processes in C3 plants. *Plant Cell & Environment* **40**(12), 2875–2905. https://doi.org/10.1111/pce.13034