



Dijlah Journal of Agricultural Sciences

Journal homepage: <https://djas.uowasit.edu.iq/index.php/djas/en>



Research article

Antioxidant glutathione enhances *Citrus aurantium* L. seedlings growth under lead stress

Asmahan Shayal AbdulKareem, Hassanain M. Gabash* & Jamal Abdul Redha AL-Rabea'a

Department of Horticulture and Landscaping, College of Agriculture, University of Basrah, Iraq

ARTICLE INFO

Keywords:

Bitter orange seedlings, glutathione, vegetative growth characteristics.

Article history:

Received: 23 Aug 2026

Accepted: 9 Sep 2026

Online: 30 Sep 2026

ABSTRACT

Heavy metals contamination in our environment is the most significant and growing problem these days due to their cumulative toxicity and non-biodegradability, leading to be stability in the ecosystem for long periods. The accumulation of pollutants in the environment has a negative aspect, affecting the various components of our ecosystem and causing numerous risky effects on plants and humans. The mitigation of perilous effect of heavy metals through ecofriendly substances is being urgent necessity. Current study provides evidence about antioxidant glutathione efficiency to ameliorate *Citrus aurantium* L. seedlings growth that grown under lead stress. Obtained result indicated that glutathione enhanced vegetative growth traits of sour orange seedlings including plants height, branches number and length, leaves number, leaf area index, weight and dry weight of leaves and biomass percentage of leaves. In short, glutathione increased *C. aurantium* seedling tolerance to the lead stress by promoting their vegetative growth and enhancing their capacity to pollutants adaptation.

1. Introduction

Sour orange, scientifically known as *Citrus aurantium* L., belongs to the Rutaceae family, characterized by the presence of aromatic oil glands in most of its plant parts, distinguishing it from other Rutaceae family species. *C. aurantium* are evergreen trees, widely cultivated in tropical and subtropical regions around the world. (Rafiq et al., 2018; Zhong and Nicolosi, 2020). Citrus trees have a distinguished position among fruit trees due to the nutritional, economic, medicinal, and aesthetic importance, as they are rich in vitamins, especially vitamin C, A, B1, and B2. They are also rich in minerals such as calcium, phosphorus, potassium, zinc, iron, manganese, chlorine, sodium, sulfur, copper, and other elements. In addition, sour orange is rich with sugars, which constitute 80-90% of the total dissolved solids and play an important role in activating the work of enzymes in the human body and providing energy. Fruits are a good source of dietary fiber, containing a small percentage of proteins and a very low-fat content (Liu et al., 2010; Al-alaf, 2017). The global production of citrus fruits ranking in the top after grapes production, Brazil is the largest

✉ *Corresponding author:
hassanain.gabash@uobasrah.edu.iq (Hassanain M. Gabash)

producer, followed by China, United States, Mexico, India, Spain, Iran, Italy, Nigeria, and Turkey.

Global fruit production in 2017 amounted to approximately 124,246,000 metric tons distributed among the world countries (FAO, 2017). In Iraq, most citrus species are widely cultivated due to their suitability for environmental conditions, especially in the central and southern regions, where the number of fruit trees amounts to 7,651,746 and the production quantity amounts to 191,333 tons (Central Organization for Statistics and Information Technology, 2021). Due to climate changes, citrus trees are exposed to various types of abiotic stresses such as heat, heavy metals, drought, and salinity, which passively effect on quantity and quality of the productivity (Gabash et al., 2023). A significant increase in lead accumulation in soil causes toxicity and thus affects the diversity and metabolic functions of the microbial community, further reducing microbial biomass and enzyme activities which are important for the soil health. As a result, decreasing in the soil fertility, which ultimately affects plant health, growth, and productivity (Lugun et al., 2022). In addition, lead toxicity also depends on pH, alkalinity, and solubility (Botte et al., 2022). Bioaccumulation and biomagnification of lead are likely to occur at every level of the food chain, exacerbating its environmental impact and threatening the health of organisms at the higher trophic level (Meena et al., 2020). Gabash and his colleagues reported that lead stress on date palm trees at a concentration of 50 mg/L led to an increase in the leaves content of hydrogen peroxide and malondialdehyde and remarkable decrease in the membrane stability index of leaf cells (Gabash et al., 2024).

Glutathione is a tripeptide amino acid composed of glycine, cysteine, and glutamic acid that acts as a defense system and coenzyme in plants (Balavandy et al., 2014). Glutathione is an antioxidant, protect plants from oxidative damage that caused by reactive oxygen species (ROS) and detoxify cells. It also acts as a chelator of toxic metals such as metalloids by transporting and sequestering them in the vacuole. It also enhances plant tolerance to various abiotic stresses, including high and low temperatures, salinity, drought, and toxic metal stress. Glutathione is found in several intracellular locations, such as the endoplasmic reticulum, cytosol, mitochondria, chloroplasts, and vacuoles (Hasanuzzaman et al., 2017). Jung et al. (2021) indicated that foliar application of glutathione on *Brassica napus* seedlings that exposed to cadmium stress completely reduced the inducible ROS levels, enhanced antioxidant defenses and redox regulation by increasing the concentrations of antioxidant molecules AsA, GSH, and NADPH in the seedlings and rebalancing stress hormones. This was positively reflected in the fresh and dry weight of the vegetative system under the influence of glutathione treatments, especially with the high concentration of 100 mg kg⁻¹. Abadi (2025) reported that glutathione mitigated the diminishing effect of heavy metals cadmium and lead on some vegetative growth traits of *Ziziphus mauritiana* Lam. plant including plant height, number of branches, stem diameter, leaf area, average fresh and dry weight of leaves, and number of leaves, as well as total chlorophyll content.

Current study aims to investigate the efficiency of antioxidant glutathione in improving *C. aurantium* tolerance to lead stress and mitigating its toxicity through promoting vegetative growth and biochemical traits of seedlings.

2. Materials and Methods

Orange seedlings were obtained from a private nursery. They were equal in the height, size, and vegetative growth, disease free, and planted in 1 kg plastic bags. After one month, seedlings transferred to 2 kg plastic bags with fresh soil. Two weeks later, acetate lead Pb(CH₃COO)₂·3H₂O

was added to the seedlings soil with irrigation water at 200 mg L⁻¹ as a contamination source. Bitter orange seedlings were watered with lead-contaminated water monthly for three times. Three days after each lead treatment, the seedlings were sprayed with glutathione at concentrations of 0, 50, 100, and 200 mg L⁻¹, and the spreading agent Tween 20 was added at a concentration of 0.1% to the prepared concentrations in order to reduce the surface tension of water and increase the adhesion of the agent to the leaves and ensure complete wetting. The spraying process was carried out during the early morning hours. Horticultural service operations were carried out for the seedlings under study including irrigation, weeding, hoeing, and N-P-K fertilization (3 g L⁻¹). The physical and chemical properties of pots soil Compound fertilizer N-P-K (20-20-15) was added to it at a concentration of. were estimated as shown in Table 1.

Table (1) Physical and chemical properties of pots soil.

No	Indicator	Values	UoM
1	pH	7.23	-
2	EC	7.38	dS m ⁻¹
3	OM	0.93	%
4	CEC	13.67	Centimol kg ⁻¹
5	Total lead	10.91	mg kg ⁻¹
Soil separators %			
1	Sand	11.81	%
2	Silt	42.76	%
3	Clay	45.43	%
4	soil texture		Silty caly

Vegetative growth traits studied:

1- Average of stem height (cm): The height of the main stem of the seedling was measured using a measuring tape from the soil surface level in the bag to its growing tip at the end of the plant, and the average was then calculated for each treatment.

2- Average of stem diameter (mm): The reading for this trait was taken by measuring the diameter of the main stem. A digital vernier caliper was used for this purpose. The readings were taken for each experimental unit, and the average was then calculated for each treatment.

3- Average of of branches number (branch seedling⁻¹): The number of lateral branches was calculated for each seedling, then the average was calculated for each treatment.

4- Average length of vegetative branches (cm): The lengths of the branches were measured from the point of connection of the branch to the main stem to the end of the branch using a metric ruler, and the average was calculated for each treatment.

5- Average of number of leaves (leaf seedling⁻¹): The total number of leaves was calculated for the orange seedlings under study at the end of the experiment in June, and the average number of leaves was then calculated for each treatment within the three replicates.

6- Average of leaf length (cm): The leaf length was measured by taking (15 leaves) from different seedlings branches for each replicate and each treatment, and the average was calculated.

7- Average of leaf width (cm): The leaf width was measured by taking (15 leaves) from different seedlings branches for each replicate and each treatment, and the average was calculated.

8- Average of leaf area (cm²): The leaf area was calculated according to described method by Dvornic, (1965). From each plant, five fully expanded leaves were taken, then 5 discs were cut from them with a disc cutter measuring 0.5 cm, and the leaves and pieces were dried in an electric oven at a temperature of 70 °C until the weight was constant, then the dry weight of the leaves and the dry weight of the pieces were recorded and calculated according to their average, then the area of one leaf was calculated according to the following equation:

Area of one leaf (cm²) = Average dry weight of the leaves of the seedling (g) × Average area of the cut part of the leaf (cm²) / Average dry weight of the cut area (g), then the leaf area of each seedling was extracted from the following equation: Leaf area of the seedling (cm²) = Average leaf area (cm²) × Average number of leaves for each seedling.

9- Average of fresh and dry weight of leaves (g): Calculated by taking 15 leaves from each seedling, each replicate, and each treatment, weighing them and recording their fresh weight. Then, leaves dried in an electric oven at 70°C for 48 hours (Al-Mosuly, 2019) until the weight stabilized. The dry weight of the leaves was then measured in (g).

10- Average of leaf dry matter percentage (%): Calculated by following equation

$$\% \text{ leaves dry matter} = \text{leaves dry weight} / \text{fresh dry weight} \times 100$$

Biochemical traits:

1-Total chlorophyll content (mg100 g⁻¹ fresh weight): Estimate of total chlorophyll in leaves based on the Holden method described by Howertiz (1975).

2-Hydrogen peroxide (H₂O₂) content: Estimate the hydrogen peroxide content of the leaves by following the method described by Sergiev *et al.* (1997).

3- Malondialdehyde (MDA) Content: The tissue content of MDA was estimated according to the method of Heath and Packer (1968).

4- Membrane Stability Index (MSI): Based on the stability index of membranes in leaves according to Lutts *et al.* (1996).

3- Results and Discussion

The data in Tables (2, 3) indicated that there was a significant difference between the treatments in the vegetative growth including the average of stem height and diameter, number and length of branches, the number of leaves, their length and width, the total leaf area, and the fresh and dry weight of leaves. The treatment with the antioxidant glutathione at a concentration of (200 mg L⁻¹) obtained the highest averages in the studied traits, reaching (122.53 cm, 5.68 mm, 8.22 branches seedling⁻¹, 39.21 cm, 52.20 leaf seedling⁻¹, 7.67 cm, 3.53 cm, 33.09 cm², 5.35 g, 1.79 g) respectively compared to the control treatment, The percentage of dry matter of leaves, increased at both concentrations (50 and 200) mg L⁻¹ recording (34.16 and 33.46) g, respectively, The results presented in Tables 2 and 3 showed that spraying bitter orange seedlings with the antioxidant glutathione had a positive effect on the studied vegetative growth characteristics. The amelioration in the vegetative growth due to glutathione

treatment could be related to its biostructure. Glutathione is a short peptide consisting of three amino acids (glutamic acid, cysteine, and glycine) which play an important role in plant reactions against aging and harmful environmental stresses due to their antioxidant properties. In addition, amino acids control the permeability of membranes and the absorption of ions which enhance plant tolerance efficiency against various stresses. Amino acids also act as osmotic substances, regulate the process of opening and closing stomata, and have positive effects in removing the toxicity of heavy metals and preventing their entry into the plant. Some plants secrete amino acids into the soil through their roots, and these amino acids are considered a food source for some microscopic organisms, such as sulfur bacteria, which react with heavy metals to form a sulfide precipitate that prevents the heavy element from entering the plant (Al-Rubaye, 2021). In addition to the critical role of glutathione in the photosynthesis, glutathione implicates in the formation of salicylic acid and plant defense signals. Salicylic acid works to preserve auxins and inhibit the enzyme IAA oxidase. It also boosts photosynthesis efficiency and gibberellins and cytokines and formation which consequently increase cell division and plant growth (Ghairb and Hegazi, 2010). Glutathione is an antioxidant that protects cells from decomposition (due to stress) and maintains their active form through its amino acids content. For example, cysteine involve in the structure of the sulfur bond and serve as a sulfur donor, which protects cells from free radicals. Obtained result exhibited increase in the dry weight and dry matter percentage of leaves which may be attributed to amino acids presence and their role in proteins synthesis (Smith, 1985). The use of the antioxidant glutathione at high concentration (200 mgL^{-1}) led to a reduction in the damage that appeared on Some Vegetative Characteristics of *Ziziphus mauritiana* Lam. resulting from heavy metal stress (Abadi *et al.*, 2025).

The data in Tables (4) indicated that there was a significant difference between the treatments in the biochemical traits including the average of Chlorophyll pigment, Hydrogen peroxide, Malondialdehyde and Membrane Stability Index. The treatment with the antioxidant glutathione at a concentration of (200 mg L^{-1}) obtained the highest averages in the Total chlorophyll content and Membrane Stability Index reaching as well as reducing the leaves hydrogen peroxide content and Malondialdehyde averages recorded reached ($0.612 \text{ mg } 100\text{g}^{-1} \text{ f.w.}$, 84.11% , $0.81 \text{ nmol. L}^{-1}$, $2.19 \text{ nmol. L}^{-1}$) respectively compared to the control treatment.

The results presented in Tables 4 showed that treatment bitter orange seedlings with the antioxidant glutathione had a positive effect on the studied biochemical characteristics, this may be attributed to glutathione being a source of thiol groups in cells. The thiol groups in glutathione bind to heavy metals, thus limiting their mobility. Glutathione plays an antioxidant role, participating in the homeostasis of reactive oxygen species and the detoxification of toxic exogenous metals by reducing the levels of oxidative stress markers (hydrogen peroxide and Malondialdehyde) in cells. Furthermore, increased glutathione concentrations contribute to enhanced plant tolerance to heavy metal-induced stress by regulating antioxidant systems (Josevzak *et al.*, 2012). The results of this study are consistent with those of numerous scientific studies, which have shown that glutathione use supports the activity of antioxidant enzymes such as SOD, APX, POD, and GR thereby improving plant tolerance to heavy metal toxicity, It therefore reduces physiological and metabolic disturbances caused by heavy metal stress by lowering levels of oxidative stress markers. (Daud *et al.* 2016: Khan *et al.*, 2016). In addition, glutathione stabilizes or balances oxidation within the stress-affected plant cell by transporting toxic metals such as metalloids after chelating and sequestering them in the vacuoles (Hasanuzzaman *et al.*, 2017). The results of the study by Chen *et al.* (2010) showed a significant decrease in accumulation levels O_2^- , H_2O_2 , and MDA

when rice seedlings exposed to cadmium were treated with exogenous glutathione, The main reason for this is the modification of the antioxidant system.

Table (2) Effect of glutathione on some vegetative growth traits of bitter orange seedlings growth under lead stress

Glutathione (mgL ⁻¹)	Average stem height (cm)	Average stem diameter (mm)	Average number of branches of branch seedling ⁻¹	Average length of vegetative branches (cm)	Average number of leaves leaf seedling ⁻¹
0	91.13	3.38	4.11	26.56	34.11
50	110.22	4.59	5.87	31.78	39.55
100	115.09	5.23	6.66	35.61	45.12
200	122.53	5.68	8.22	39.21	52.2
L.S.D	5.19	0.41	1.23	3.14	4.03

Table (3) Effect of glutathione on some vegetative growth traits of bitter orange seedlings growth under lead stress

Glutathione (mgL ⁻¹)	Average leaf length (cm)	Average leaf width (cm)	Average leaf area (cm ²)	Average (f.w.) of leaves (g)	Average (d.w.) of leaves (g)	Average leaf (d.m.) percentage (%)
0	5.92	2.81	19.74	3.32	1.02	30.72
50	6.52	3.03	25.32	4.04	1.38	34.16
100	7.21	3.21	29.61	4.76	1.43	30.04
200	7.67	3.53	33.09	5.35	1.79	33.46
L.S.D	0.31	0.19	2.65	0.53	0.31	2.82

Table (4) Effect of glutathione on some biochemical traits of bitter orange seedlings growth under lead stress

Glutathione (mg L ⁻¹)	Chlorophyll (mg 100 g ⁻¹ f.w.)	H ₂ O ₂ (μmol L ⁻¹)	MDA (nmol L ⁻¹)	MSI (%)
0	0.431	1.01	2.37	71.83
50	0.489	0.93	2.31	75.01

100	0.531	0.87	2.25	79.27
200	0.612	0.81	2.19	84.11
L.S.D	0.041	0.06	0.07	2.26

4- Conclusion

The results of current study indicated that lead oxidative stress significantly reduced the vegetative growth characteristics of orange seedlings, and negatively affected on the growth efficiency and health of plants. However, the treatments with glutathione particularly with 200 mg L⁻¹ improved the seedlings growth and boosted their tolerance to lead oxidative stress. Our study elucidated that the possibility to mitigate the impact of pollutants such as lead on other plants through utilization of antioxidants including glutathione.

References

- Abadi, Z. M. (2025). Effect of glutathione on the vegetative and fruiting growth of *Ziziphus mauritiana* Lam. Tuffahi contaminated with lead and cadmium [Master's thesis, College of Agriculture, University of Basra].
- Abadi, Z. M., Mohammed, K. H., & Abdul Wahid, A. H. (2025). Effect of glutathione treatment in reducing the stress of heavy metals and its effect on some vegetative characteristics of *Ziziphus mauritiana* Lam. apple seedlings. IOP Conference Series: Earth and Environmental Science, 1487, 012064. <https://doi.org/10.1088/1755-1315/1487/1/012064>
- Al-Alaf, A. H. I. (2017). Fruits—Your health in your hands. Dijlah Publishers and Distributors.
- Al-Mosuly, M. A. (2019). The complete book on fertilizers and fertilization: Analysis of soil, plants, and water. Dar Al-Kotob Al-Ilmiyah.
- Al-Rubaye, B. C. H. (2021). Questions and answers in the physiology of stress (1st ed.). College of Agriculture, Al-Muthanna University.
- Balavandy, S. K., Shameli, K., Biak, D. R. B. A., & Abidin, Z. Z. (2014). Stirring time effect of silver nanoparticles prepared in glutathione mediated by green method. Chemistry Central Journal, 8, 11. <https://doi.org/10.1186/1752-153X-8-11>
- Botté, A., Seguin, C., Nahrgang, J., Zaidi, M., Guery, J., & Leignel, V. (2022). Lead in the marine environment: Concentrations and effects on invertebrates. Ecotoxicology, 31(2), 194–207. <https://doi.org/10.1007/s10646-021-02504-4>
- Central Organization for Statistics and Information Technology. (2021). Citrus tree production report. Ministry of Planning and Development Cooperation, Republic of Iraq.
- Chen, F., Wang, F., Wu, F., Mao, W., Zhang, G., & Zhou, M. (2010). Modulation of exogenous glutathione in antioxidant defense system against Cd stress in the two barley genotypes differing in Cd tolerance. Plant Physiology and Biochemistry, 48(8), 663–672. <https://doi.org/10.1016/j.plaphy.2010.05.001>
- Daud, M. K., Mei, L., Azizullah, A., Dawood, M., Ali, I., Mahmood, Q., Ullah, W., Jamil, M., & Zhu, S. J. (2016). Leaf-based physiological, metabolic, and ultrastructural changes in cultivated cotton cultivars under cadmium stress mediated by glutathione. Environmental Science and Pollution Research, 23(15), 15551–15564. <https://doi.org/10.1007/s11356-016-6739-5>
- Dvornic, V. (1965). Lucrai practice deampelografic, Ed. *Dideatica sipedagogiea. Bucuresti, RSR Romaina*. (CF Awan 1986. MSC. Thesis, University of Mosul).
- Food and Agriculture Organization of the United Nations. (2017).

- Gabash, H. M., Al-Rabea'a, J. A. R., & Mohammed, K. H. (2023). Response of anatomical traits to environmental stresses in the leaves of local orange seedlings (*Citrus sinensis* L.). *Journal of Global Innovation in Agricultural Sciences*, 11(3), 439–445.
- Gabash, H. M., Resan, A. Z., Awad, K. M., Suhim, A. A., & Abdulameer, A. H. (2024). Biochemical responses of date palm (*Phoenix dactylifera* L.) to combined stress of salinity and nickel. *Basrah Journal of Agricultural Sciences*, 37(1), 236–246.
- Gharib, F. A., & Hegazi, A. Z. (2010). Salicylic acid ameliorates germination, seedling growth, phytohormones and activity in bean (*Phaseolus vulgaris* L.) under cold stress. *Journal of American Science*, 6(10), 675–683.
- Hasanuzzaman, M., Nahar, K., Anee, T. I., & Fujita, M. (2017). Glutathione in plants: Biosynthesis and physiological role in environmental stress tolerance. *Physiology and Molecular Biology of Plants*, 23(2), 249–268. <https://doi.org/10.1007/s12298-017-0422-2>
- Heath, R. L., & Packer, L. (1968). Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Archives of Biochemistry and Biophysics*, 125(1), 189–198. [https://doi.org/10.1016/0003-9861\(68\)90654-1](https://doi.org/10.1016/0003-9861(68)90654-1)
- Horwitz, W. (Ed.). (1975). Official methods of analysis of the Association of Official Analytical Chemists (12th ed.). Association of Official Analytical Chemists.
- Jozefczak, M., Remans, T., Vangronsveld, J., & Cuypers, A. (2012). Glutathione is a key player in metal-induced oxidative stress defenses. *International Journal of Molecular Sciences*, 13(3), 3145–3175. <https://doi.org/10.3390/ijms13033145>
- Jung, H.-I., Lee, T.-G., Lee, J., Chae, M.-J., Lee, E.-J., Kim, M.-S., Jung, G.-B., Emmanuel, A., Jeon, S., & Lee, B.-R. (2021). Foliar-applied glutathione mitigates cadmium-induced oxidative stress by modulating antioxidant-scavenging, redox-regulating, and hormone-balancing systems in *Brassica napus*. *Frontiers in Plant Science*, 12, 700413. <https://doi.org/10.3389/fpls.2021.700413>
- Khan, M., Daud, M. K., Basharat, A., Khan, M. J., Azizullah, A., Muhammad, N., Muhammad, N., Rehman, Z. U., & Zhu, S. J. (2016). Alleviation of lead-induced physiological, metabolic, and ultramorphological changes in leaves of upland cotton through glutathione. *Environmental Science and Pollution Research*, 23(9), 8431–8440. <https://doi.org/10.1007/s11356-015-5959-4>
- Liu, Y., Heying, E., & Tanumihardjo, S. A. (2012). History, global distribution, and nutritional importance of citrus fruits. *Comprehensive Reviews in Food Science and Food Safety*, 11(6), 530–545. <https://doi.org/10.1111/j.1541-4337.2012.00201.x>
- Lugun, O., Singh, R., Jha, S., & Pandey, A. K. (2022). Impact of heavy metals on different ecosystems. In A. Kumar (Ed.), *Environmental toxicology and ecosystem* (pp. 139–164). CRC Press.
- Lutts, S., Kinet, J. M., & Bouharmont, J. (1996). NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. *Annals of Botany*, 78(3), 389–398. <https://doi.org/10.1006/anbo.1996.0134>
- Meena, V., Dotaniya, M. L., Saha, J. K., Das, H., & Patra, A. K. (2020). Impact of lead contamination on agroecosystem and human health. In D. Gupta, S. Chatterjee, & C. Walther (Eds.), *Lead in plants and the environment* (pp. 67–82). Springer.

- Rafiq, S., Kaul, R., Sofi, S. A., Bashir, N., Nazir, F., & Nayik, G. A. (2018). Citrus peel as a source of functional ingredient: A review. *Journal of the Saudi Society of Agricultural Sciences*, 17(4), 351–358. <https://doi.org/10.1016/j.jssas.2016.07.006>
- Sergiev, I., Alexieva, V., & Karanov, E. V. (1997). Effect of spermine, atrazine and combination between them on some endogenous protective systems and stress markers in plants. *Proceedings of the Bulgarian Academy of Sciences*, 51, 121–124.
- Smith, T. A. (1985). Polyamines. *Annual Review of Plant Physiology*, 36, 117–143. <https://doi.org/10.1146/annurev.pp.36.060185.001001>
- Zhong, G., & Nicolosi, E. (2020). Citrus origin, diffusion, and economic importance. In *The citrus genome* (pp. 5–21). Springer.