ISSN Versión impresa: 1992-2159; ISSN Versión electrónica: 2519-6412

Biotempo, 2024, 21(1), jan-jun.: 45-52.

doi:10.31381/biotempo.v21i1.6409

Biotempo (Lima)

https://revistas.urp.edu.pe/index.php/Biotempo

ORIGINAL ARTICLE / ARTÍCULO ORIGINAL

EFFECT OF STRATOSPHERIC CONDITIONS ON GERMINATION AND SEEDLINGS OF *SOLANUM LYCOPERSICUM* "TOMATO PRINCE BORGHESE" AND *BETA VULGARIS* "BEET"

EFECTO DE LAS CONDICIONES ESTRATOSFÉRICAS EN LA GERMINACIÓN Y PLÁNTULAS DE *SOLANUM LYCOPERSICUM* "TOMATE PRINCIPE BORGHESE" Y *BETA VULGARIS* "BETARRAGA"

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ABSTRACT

The stratosphere is a layer of the Earth's atmosphere, located above the anthroposphere and below the mesosphere. The stratosphere has particular meteorological conditions, such as high UV-A radiation, slow atmospheric pressure, and temperature variations. Currently, several studies have shown that organisms such as plants can be positively affected by exposure to stratospheric conditions, especially UV-A radiation. However, studies on the viability of seeds have been little developed. For this reason, this study aimed to evaluate the viability of *Solanum lycopersicum* Lam, 1794 "Tomato Prince Borghese" and *Beta vulgaris* Linneo, 1753 "Beet" seeds under stratospheric conditions. The seeds were taken to the stratosphere by the stratospheric balloon of the "Asociación Peruana de Astrobiología", which is also equipped with meteorological instruments to measure the altitude, temperature, atmospheric pressure, and UV-A radiation present from launch to the return of the sample. Seed viability has been determined based on a comparative analysis of germination and early stem and root elongation of seeds exposed to stratospheric and unexposed conditions. The main results show that stratospheric conditions increase significantly stem elongation in *S. lycopersicum* and total weight in both species. This research presents interesting results for the study of techniques for the rapid germination and development of crops.

Keywords: *Beta vulgaris* – germination – seedlings – *Solanum lycopersicum* – stratosphere – UV-A

RESUMEN

La estratosfera es una capa de la atmósfera terrestre, situada por encima de la antroposfera y por debajo de la mesosfera. La estratosfera presenta condiciones meteorológicas particulares, como una elevada radiación UV-A, y variaciones lentas de la presión atmosférica y la temperatura. En la actualidad, varios estudios han demostrado que organismos como las plantas pueden verse afectados positivamente por la exposición a las condiciones estratosféricas, especialmente a la radiación UV-A. Sin embargo, los estudios sobre la viabilidad de las semillas han sido poco desarrollados. Por esta razón, el objetivo de este estudio fue evaluar la viabilidad de las semillas de *Solanum lycopersicum* Lam, 1794 "Tomate Príncipe Borghese" y *Beta vulgaris* Linneo, 1753 "Remolacha" en condiciones estratosféricas. Las semillas fueron llevadas a la estratósfera por el globo estratosférico de la "Asociación Peruana de Astrobiología", que además está equipado con instrumentos meteorológicos para medir la altitud, temperatura, presión atmosférica y radiación UV-A presentes desde el lanzamiento hasta el retorno de la muestra. La viabilidad de las semillas se ha determinado a partir del análisis comparativo de la germinación y el alargamiento temprano de tallos y raíces de semillas expuestas a condiciones estratosféricas y no expuestas. Los resultados principales de esta investigación demuestran que las condiciones estratosféricas aumentan significativamente la elongación del tallo en *S. lycopersicum* y el peso en ambas especies. Esta investigación presenta resultados interesantes para el estudio de técnicas de germinación rápida y desarrollo de cultivos.

Palabras clave: *Beta vulgaris* – estratosfera – germinación – plántulas – *Solanum lycopersicum* – UV-A

INTRODUCTION

Agriculture is one of the oldest and most necessary human activities for civilization, since it provides fresh food with high content of vitamins and minerals that are useful for the organism (Flannery, 1973; Merrill, 1983). Over time, cultivation techniques have been perfected until the inclusion of new variables that can favor and increase the production of plants and fruits (Tudi *et al.*, 2021; Liu *et al.*, 2022).

Nowadays, seed germination is a biological process that has been widely studied since it will determine the adaptation of the species to environmental conditions (Klupczyńska & Pawłowski, 2021). Several authors have studied the different factors affecting germination and growth of crop plants (Kim & Kim, 2019; Al-Quraan *et al.*, 2020; Altuner, 2020; He *et al.*, 2020). Also, pretreatments using UV-A radiation have been demonstrated to increase the germination rate, foliar area, dry mass, root and stem of plants (Hamid & Jawaid, 2011; Mariz-Ponte *et al.*, 2018).

Beet and tomato are food products that present a wide range of vitamins and minerals that complement the human diet (Ordóñez-Santos *et al.,* 2011; Clifford *et al.*, 2015). In addition, they are vegetables that can be cultivated worldwide, so studying techniques for the increase and improvement of their production is very important (Ceclu & Nistor, 2020; Collins *et al.*, 2022).

In this study, we have sent two species of seeds, *Solanum lycopersicum* Lam, 1794 "Tomato Prince Borghese" and *Beta vulgaris* Linneo, 1753 "Beet", to the stratosphere, exposing them to extreme environmental conditions such as increased UV-A radiation, temperature and atmospheric pressure variations; these variables are important for the viability of the future plant. The experiment was carried out using a meteorological balloon and the viability indicators to determine were germination success and early growth of the stem and roots.

MATERIALS AND METHODS

Seed obtaining

The seeds were acquired from the company ANASAC, which is a Chilean company dedicated to the agriculture field (Anasac, 2024). Seed packs indicate that they have a purity of 99.90%.

Seed exposition to Stratosphere

The exposition of seeds to stratospheric conditions was carried out by the meteorological balloon launched by the "Asociación Peruana de Astrobiología" on February 12, 2022 in Yauca, province of Ica, Peru. The balloon reached about an altitude of 30 000 km above sea level. Once reached that altitude, the balloon exploded and dropped the seed sample

and the climatological measurement equipment with a parachute to slow the speed of impact with the ground. The meteorological measurements were made using the Strato4 instrument, which recorded temperature, altitude, humidity and UV-A radiation throughout the flight. Strato4 is a weather measurement system manufactured by the Stratoflights company in Germany (Stratoflights, 2024).

Seed cultivation

Once the sample was returned, the tomato and beet seeds were placed in a plastic multi-well seedbed at the same time as the control seeds, totaling 72 seeds. The sample size per group was 18, which was close to reported by Noble (2002).

The seeds were grown using cotton as an absorbent substrate. The use of cotton is justified in this experiment due to its liquid retaining capacity and also to its moldable structure that allows us to monitor the development of the seeds. Irrigation per sample was 5 mL of water per 24 hours. This quantity of water was chosen because it maintained a humid environment for the samples, which is favorable for seed germination (Kauth & Biber, 2015, Jung *et al*., 2020).

Germination and stem and root development

The germination time of each seed was recorded using days as the unit of measurement. Once the post-germination cycle started, the stems and roots were recorded every 3 days using centimeters as the unit of measurement.

On day 20, all evaluated individuals were transported to the Botany Laboratory of the Biological Sciences Faculty – Universidad Ricardo Palma, Lima, Perú for transplanting to a sandy substrate. Before transplanting, the weight, stem length and main root length of each individual were recorded.

Statistics and generation of graphs

Boxplots and confidence intervals were determined using R Studio software. Statistical analysis was performed by using unpaired t-tests to determine similarities or differences in the radiation-exposed and control groups. T tests were calculated by species for each of the variables.

ETHIC ASPECTS

This study has been carried out with the strictest respect for ethical principles, with the aim of making a responsible contribution to scientific knowledge and to the welfare of society.

RESULTS

Meteorological conditions

The StratoTrack4 weather measurement system shows that the maximum altitude obtained in this experiment was 28 224.5 km above sea level. In addition, it indicates that during the experiment there were temperature changes that ranged from -66.00°C to 31.90°C, giving an average of -25.02°C. Regarding humidity, extreme data of 0.10% and 99.26% were obtained, with 39.68% as arithmetic mean. The UV-A radiation has presented abrupt changes throughout the experiment, with an index between 0.32 (low) and 9.09 (very high), being 3.39 (moderate) the mean (Figure 1).

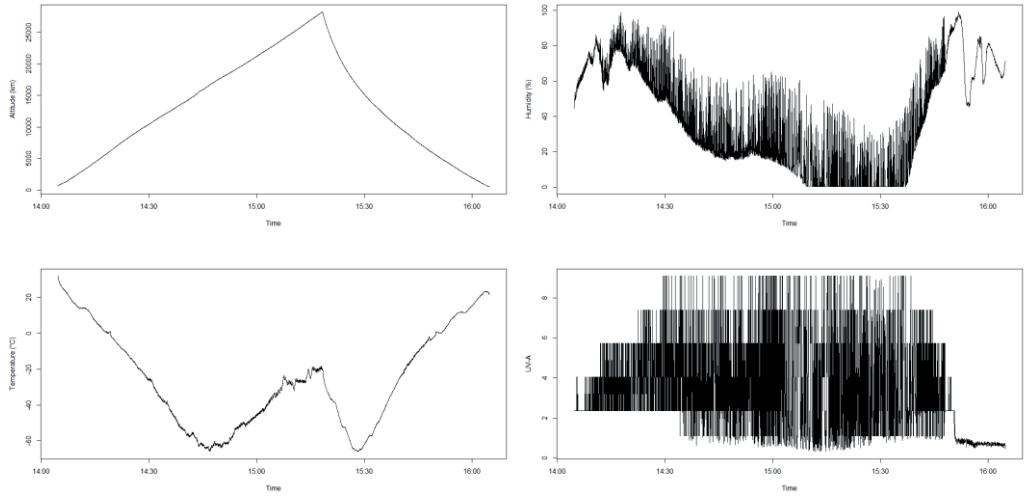

Figure 1. Meteorological conditions from the launch to the return of the sample.

Germination

For the *S. lycopersicum* group exposed to the stratosphere, germination began on day 3, with 15 germinations (83.33%) until day 5 and all of them on day 7. In the control group, germination began on day 3, with 16 seeds germinating (88.89%) by day 5 and all on day 6. T student value was 0.6014 and the *p*-value was 0.5516, therefore this result is not statistically significant.

For the group of *B. vulgaris* exposed to the stratosphere, the germination of the group started on the second day, having 15 germinations (83.33%) until day 5 and 17 seeds germinated until day 8. In the control group, germination started on the second day, having 15 (83.33%) germinations up to day 5 and 17 germinations until day 11.

It is interesting to note that both groups did not show germination in one of their individuals. (Figure 2). T student value was 0.0 and the *p*-value was 1, therefore this result is not statistically significant.

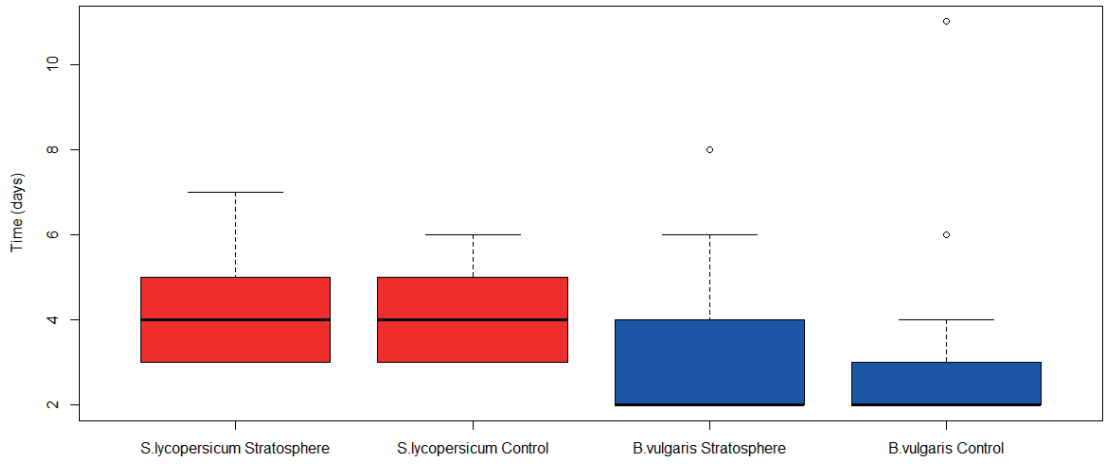

Figure 2. Seed germination of tomato and beet samples.

Total weight

For the group of *S. lycopersicum* exposed to the stratosphere, the total weight of the shoots ranges from 0.01 g to 0.15 g, obtaining a mean of 0.078. For the control group, the total weight of the shoots ranges from 0.02 g to 0.2 g, having a mean of 0.11 g (Figure 3). T student value was 2.2081 and the *p*-value was 0.0341, therefore this result is considered to be statistically significant.

The group of *B. vulgaris* exposed to stratospheric conditions presents a weight between 0.00 gr and 0.17 g, with a mean of 0.08 g. For the control group, the minimum and maximum weights obtained were 0.02 g and 0.25 g, with a mean of 0.13 g (Figure 3). T student value was 2.8018 and the *p*-value was 0.0086, therefore this result is considered to be statistically significant.

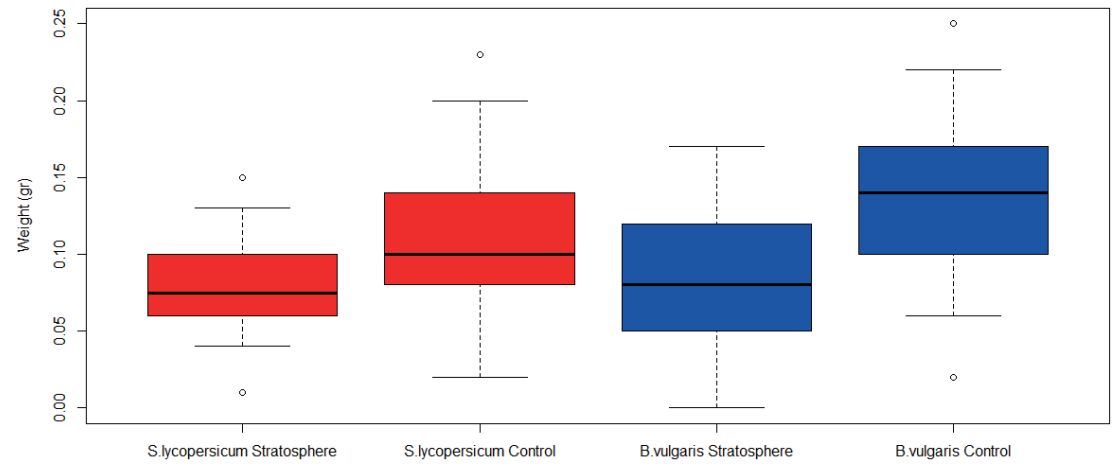

Figure 3. Total weight of tomato and beet samples.

Stem elongation

For the Tomato Prince Borghese seeds exposed to stratospheric conditions, elongations between 2 cm and 4.2 cm were recorded, with 3.38 cm as the mean. For the control group, elongations between 1.3 cm and 3.6 cm were obtained, the mean being 2.67 cm. T student value was 3.4168 and the *p*-value was 0.0017, therefore this result is statistically significant.

The beets developed two stems for each seed, therefore an average of stems was taken, obtaining an average per individual. The group that had been exposed to stratospheric conditions obtained elongations ranging from 0.7 cm to 4.4 cm, with 2.29 cm as the mean. The control group obtained elongations between 1.1 cm and 2.4 cm, being 1.875 cm the mean (Figure 4). T student value was 1.7746 and the *p*-value was 0.0855, therefore this result is considered to be not quite statistically significant.

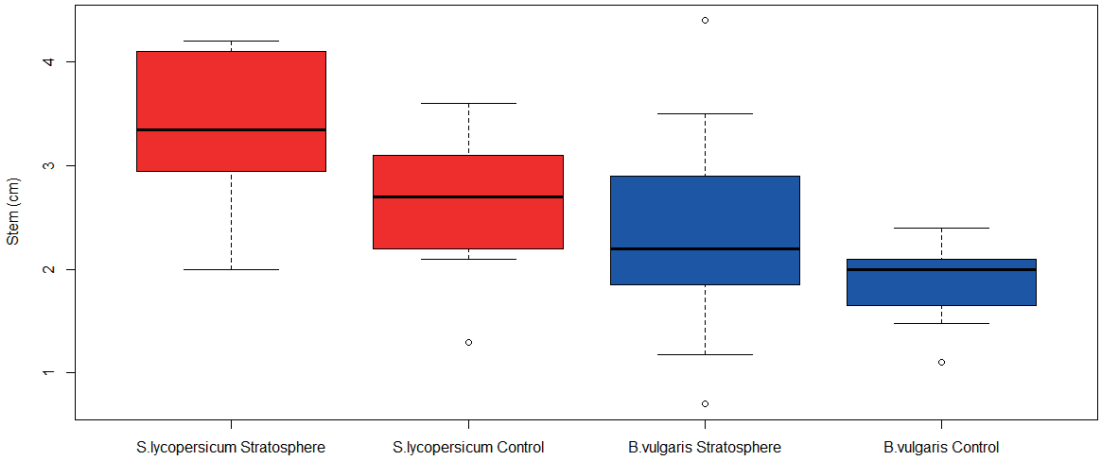

Figure 4: Stem elongation of tomato and beet samples.

Main root elongation

For *S. lycopersicum*, the group exposed to the stratosphere obtained main root elongations between 0.6 cm and 12.5 cm, with 5.85 cm as the mean. The control group obtained results between 2.3 cm and 16.1 cm, with 7.37 cm as the mean. T student value was 1.1309 and the *p*-value was 0.2660, so this result is considered to be not statistically significant.

Beta vulgaris generated two principal roots for each seed, therefore, an average of the number of that was recorded, obtaining only one data per individual. Beet seeds exposed to stratospheric conditions showed an elongation between 0.95 cm and 11.3 cm, being 3.39 the mean. The control seeds showed an elongation between 0.7 cm and 4.4 cm, being 1.99 cm the mean (Figure 5). T student value was 0.5580 and the *p*-value was 0.5807, so this result is considered to be not statistically significant.

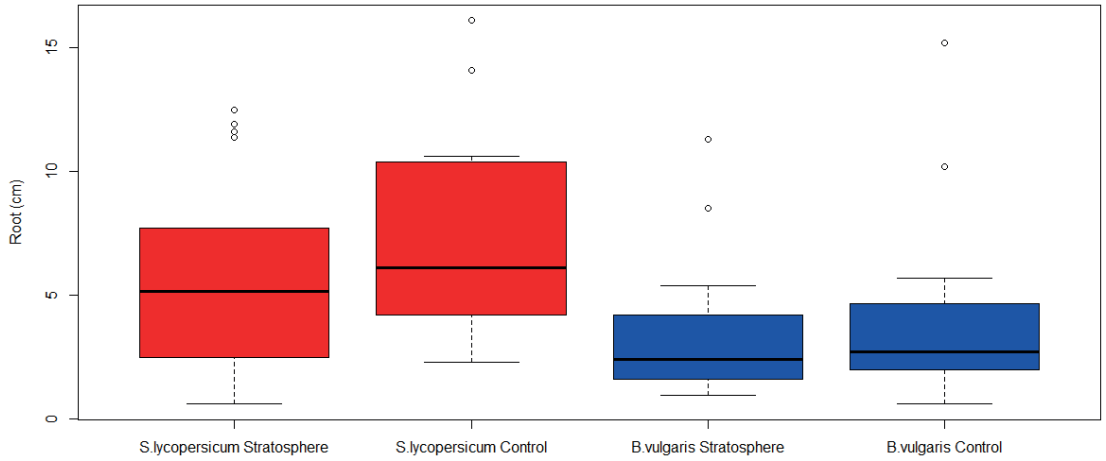

Figure 5. Principal root elongation of tomato and beet samples.

DISCUSSION

This study shows that the germination and elongation of stem and main root of *S. lycopersicum* and *B. vulgaris* didn't show significant changes when exposed to stratospheric conditions during a meteorological balloon flight. However, stem elongation in *S. lycopersicum* and total weight in both species showed significant differences. In the study by Fong *et al.* (2015), three types of seeds were exposed to stratospheric radiation using a meteorological balloon; demonstrating a negative effect on germination success but slight improvement in seedling growth of bean seeds and increased germination success as well as varied responses in seedling development of radish and maize seeds. The difference in responses to stratospheric conditions may be due to the facility of the species to adapt to unusual environmental conditions.

Several studies show that plants modify their metabolism in response to environmental conditions, optimizing their vital performance depending on them, which could accelerate or delay biomass production (Bernal *et al.*, 2015; Verdaguer *et al.*, 2017). UV-A radiation is a factor that favors plant development due to the high charge of its photons, which facilitates accelerated photosynthesis and greater energy production. However, prolonged exposure to radiation negatively interferes with the development of the other stages of the plant since it reduces root size and the amount of biomass (Noble, 2002). Studies show that treatments of 8 and 16 hours of UV-A exposure stimulate 29% and 33% plant biomass production, increasing plant length and photosynthetic response (Kang *et al.*, 2018). Additionally, exposure to UV-A radiation for 1 hour per day in 30 days' increases fruit production in plants (Mariz-Ponte *et al.*, 2019).

In this research, differences in stem elongation show that the Tomato Prince Borghese plants (stratosphere group) had a larger size compared to those in the control group. This may be due to the difference in the amount of radiation absorbed by UV-A exposure. In addition, this study shows that plants exposed to stratospheric conditions have a lower total weight compared to those in the control group. One of the responses to the difference in shoot weight is the presence of necrosis and dehydration in the roots, which avoids the accumulation of water in the plant and its optimal development. This suggests that exposure to stratospheric conditions generates visible changes in plant morphology that are counterproductive in the long term.

We concluded that there were no significant differences in the morphology of *S. lycopersicum* and *B. vulgaris* exposed to stratospheric conditions during the trajectory of a weather balloon. However, slight differences in total weight and stem elongation could demonstrate the effect of radiation on plant development. Further studies are needed to determine anomalies in the developmental stages of seeds exposed to stratospheric conditions.

ACKNOWLEDGEMENTS

The authors wish to thank Veronica Patricia Parapar Loayza for her helpful support in the life of the corresponding author. Do not let cancer win you, be strong.

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BIBLIOGRAPHIC REFERENCES

Al-Quraan, N. A., Al-Akhras, M. A. H., & Talafha, D. Z. (2020). The influence of laser beam and high light intensity on lentil (*Lens culinaris*) and wheat (*Triticum aestivum*) seedlings growth and metabolism. *Plant Biosystems*, *156*, 95-115.

Altuner, F. (2020). Determination of the effect of salt (NaCl) stress on germination of oat (*Avena sativa* L.) seeds pretreated with gibberellic acid. *Fresenius Environmental Bulletin*, *29*, 11111–11118.

Anasac (2024). ANASAC. Impulsando un futuro mejor. *Anasac.* https://anasac.com/es/seeds/

Bernal, M., Verdaguer, D., Badosa, J., Abadía, A., Llusià, J., Peñuelas, J., Nuñez-Olivera, E., & Llorens, L. (2015). Effects of enhanced UV radiation and water availability on performance, biomass production and photoprotective mechanisms of *Laurus nobilis* seedlings. *Environmental and Experimental Botany*, *109*, 264-275.

Ceclu, L., & Nistor, O. V. (2020). Red beetroot: Composition and health effects—A review. *Journal of Nutritional Medicine and Diet Care, 6*, 1-9.

Clifford, T., Howatson, G., West, D. J., & Stevenson, E. J. (2015). The potential benefits of red beetroot supplementation in health and disease. *Nutrients*, *7*, 2801-2822.

Collins, E. J., Bowyer, C., Tsouza, A., & Chopra, M. (2022). Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*, *11*, 239.

Flannery, K. V. (1973). The origins of agriculture. *Annual review of Anthropology*, 2(1), 271-310.

Fong, B. N., Newhouse, K. V., Huss, M. J., Roberts, E., Kennon, J. T., & Ali, H. (2015). Investigating the Effect of Stratospheric Radiation on Seed Germination and Growth. *Journal of the Arkansas Academy of Science*, *69*, 36-40.

Hamid, N., & Jawaid, F. (2011). Influence of seed pre-treatment by UV-A and UV-C radiation on germination and growth of Mung beans. *Pakistan Journal of Chemistry, 1*, 164-167.

He, Y. Q., Zhao, J., Feng, D. F., Huang, Z. B., Liang, J. M., Zheng, Y. F., Cheng, J., Jifeng, Y., & Zhoufei, W. (2020). RNA-Seq study reveals AP2-Domain-Containing signalling regulators involved in initial imbibition of seed germination in rice. *Rice Science*, *27*, 302–314.

Jung, E. S., Sivakumar, S., Hong, S. C., Yi, P. I., Jang, S. H., & Suh, J. M. (2020). Influence of relative humidity on germination and metal accumulation in *Vigna radiata* exposed to metal-based nanoparticles. *Sustainability*, *12*, 1347.

Kauth, P., & Biber, P. (2015). Moisture content, temperature, and relative humidity influence seed storage and subsequent survival and germination of *Vallisneria americana* seeds. *Aquatic Botany*, *120*, 297-303.

Kang, S., Zhang, Y., Zhang, Y., Zou, J., Yang, Q., & Li, T. (2018). Ultraviolet-A radiation stimulates growth of indoor cultivated tomato (*Solanum lycopersicum*) seedlings. *HortScience*, *53*, 1429-1433.

Kim, H. S., & Kim, Y. H. (2019). Influence of abiotic treatments on isoflavone accumulation in soybean seeds during germination. *Korean Journal of Crop Science*, *64*, 18–24.

Klupczyńska, E. A., & Pawłowski, T. A. (2021). Regulation of seed dormancy and germination mechanisms in a changing environment. *International journal of molecular sciences*, *22*, 1357.

Liu, S., Wang, W., Lu, H., Shu, Q., Zhang, Y., & Chen, Q. (2022). New perspectives on physiological, biochemical and bioactive components during germination of edible seeds: A review. *Trends in Food Science & Technology*, *123*, 187-197.

Merrill, M. (1983). Eco-agriculture: a review of its history and philosophy. *Biological Agriculture & Horticulture*, *1*, 181-210.

Mariz-Ponte, N., Mendes, R. J., Sario, S., Melo, P., & Santos, C. (2018). Moderate UV-A supplementation benefits tomato seed and seedling invigoration: a contribution to the use of UV in seed technology. *Scientia Horticulturae*, *235*, 357-366.

Mariz-Ponte, N., Martins, S., Gonçalves, A., Correia, C. M., Ribeiro, C., Dias, M. C., & Santos, C.

(2019). The potential use of the UV-A and UV-B to improve tomato quality and preference for consumers. *Scientia Horticulturae*, *246*, 777–784.

Noble, R. E. (2002). Effects of UV-irradiation on seed germination. *Science of the Total Environment*, *299*, 173-176.

Ordóñez-Santos, L. E., Vázquez-Odériz, M. L., & Romero-Rodríguez, M. A. (2011). Micronutrient contents in organic and conventional tomatoes (*Solanum lycopersicum* L.). *International Journal of Food Science & Technology*, *46*, 1561-1568.

Stratoflights. (2024). *Registrador de datos STRATO4. Stratoflights*. https://www.stratoflights.com/es/shop/registrador-datos/

Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., Chu, C. & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International journal of environmental research and public health, 18*, 1112.

Verdaguer, D., Jansen, M. A. K., Llorens, L., Morales, L. O., & Neugart, S. (2017). UV-A radiation effects on higher plants: Exploring the known unknown. *Plant Science, 255*, 72–81.

Received January 8, 2024.

Accepted February 29, 2024.