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The Role of Biotechnology in Plant Breeding for Sustainable Agriculture in Brazil

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ABSTRACT
Research Background: Sustainable agriculture is increasingly becoming a global priority, including in Brazil, which is one of the major producers of agricultural commodities. Biotechnology in plant breeding has provided an important solution to increase plant productivity and resistance to pests, diseases, and extreme environmental conditions. Research Objectives: This study aims to explore the role of biotechnology in crop breeding in Brazil and its impact on sustainable agriculture. Research Method: This study uses a qualitative descriptive approach with case study analysis on major crops such as soybeans, corn, cotton, and sugarcane. Data were collected through interviews with farmers and biotechnology experts as well as literature analysis. Research Results: The results show that the application of biotechnology increases plant productivity by up to 30%, as well as strengthens plant resistance to pests and climate change. However, the adoption of this technology is still limited to large commodities, with uneven access among smallholders. Research Conclusion: Biotechnology plays an important role in supporting sustainable agriculture in Brazil, but efforts are needed to expand access to these technologies so that more farmers, including small-scale ones, can take advantage of them. Supportive policies and adequate infrastructure are needed to accelerate the adoption of biotechnology across Brazil's agricultural sector.

Keywords: *Crop Productivity, Plant Breeding, Sustainable Agriculture*

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INTRODUCTION

Biotechnology has played a crucial role in increasing agricultural productivity around the world, including in Brazil, which is known as one of the major producers of global agricultural commodities (Sharma dkk., 2020). Biotechnology in plant breeding allows farmers to develop plant varieties that are more resistant to disease, drought, and pests (Kamble dkk., 2020). This technology has helped significantly increase crop yields

in different types of crops such as soybeans, corn, and cotton, which are the main commodities of Brazilian agriculture.

Brazil has diverse geographical and climatic conditions, which allow the production of different types of crops (Zhang dkk., 2021). However, the tropical climate that dominates most of its territory makes agriculture vulnerable to environmental problems such as pest attacks and extreme weather changes (Burley dkk., 2021). Through biotechnology, plant breeding can be designed to meet these challenges, such as the development of plants that are resistant to high temperatures and pathogens commonly encountered in tropical environments.

Modern biotechnology techniques, such as genetic engineering and marker-assisted selection, have been used to speed up the process of plant breeding (A. Singh dkk., 2020). Genetic engineering allows for specific genetic modifications that increase plant resistance to difficult environmental conditions, while marker-assisted selection accelerates the identification of superior traits in plant populations (Agarwal dkk., 2023). In Brazil, the application of these techniques has contributed to the successful increase in sustainable agricultural productivity.

Sustainability in agriculture has become an important priority in recent decades, especially with the growing awareness of the environmental impact of conventional farming practices (Hamid dkk., 2021). Biotechnology provides solutions to reduce dependence on harmful chemicals such as pesticides and synthetic fertilizers (Bloem & Salimi, 2023). The use of more pest-resistant plant varieties reduces the need for pesticides, while plants that are more efficient in nutrient absorption help reduce fertilizer use. In Brazil, this is essential to protect the rich and diverse natural ecosystem.

Increasing efficiency in plant breeding through biotechnology also plays a role in increasing food security (Li dkk., 2023). With a growing global population, Brazil as one of the main exporters of agricultural products plays a key role in ensuring a stable food supply (Alkharabsheh dkk., 2021). Biotechnology helps increase productivity per hectare of land, thus allowing Brazil to meet domestic and international food needs.

In addition, biotechnology in plant breeding also opens up opportunities to develop plant varieties that have higher nutritional value (Lobus, 2022). This is important not only in the context of food security, but also in improving the quality of public health (Gilani dkk., 2023). The development of biofortified crops, enriched with vitamins or minerals, is a vivid example of how biotechnology can provide direct benefits to human health in Brazil and countries that import its agricultural products.

Although biotechnology has made a great contribution to plant breeding in Brazil, there are still many aspects that have not been fully understood or optimized (Kurade dkk., 2021). One of the main gaps is the lack of understanding of the long-term impact of biotechnology applications on local ecosystems and biodiversity (Chittora dkk., 2020). Despite the many benefits, the use of GMO crops can affect the ecological balance, especially in regions with high species diversity such as the Amazon.

Another challenge is how the adoption of this biotechnology can be expanded evenly across Brazil's agricultural regions (Sayers dkk., 2020). Most biotechnology

applications are still concentrated on large-scale commercial crops such as soybeans and maize, while local or small-scale staple crops receive less attention (Dal Moro dkk., 2022). Further research is needed to develop biotechnology solutions suitable for different types of crops and environmental conditions throughout Brazil.

There is still little research on how biotechnology can be applied effectively to smallholder farmers in Brazil (Schwab Do Nascimento dkk., 2020). High costs in development and access to technology are often barriers for smallholders to adopt biotechnology in their crop breeding (Do Espirito Santo Pereira dkk., 2021). More in-depth research is needed to understand how to overcome these economic barriers and create more inclusive and affordable solutions.

The social impact of the application of biotechnology in the agricultural sector has also not been fully measured (R. P. Singh dkk., 2021). Although these technologies provide many advantages, there are concerns about how biotechnology affects the social balance in rural areas, especially when it comes to the distribution of profits between large and small farmers (Lea-Smith dkk., 2021). More research is needed to address these uncertainties and explore the socio-economic impact of the widespread adoption of biotechnology technologies.

Filling the gap in biotechnology research for plant breeding in Brazil is essential to ensure that this technology can be applied widely and sustainably (Fabris dkk., 2020). A better understanding of the long-term impacts on local ecosystems will help reduce the potential environmental risks of biotechnology applications (Parra & Coelho, 2022). Thus, further research can develop plant varieties that are not only productive, but also environmentally friendly and protect Brazil's rich biodiversity.

Research focused on developing biotechnology solutions for local staple crops and smallholders in Brazil is also a priority (Silveira dkk., 2022). By creating crop varieties that suit the needs of local farmers and specific environmental conditions, biotechnology can provide more equitable benefits (Oliveira dkk., 2022). This will allow smallholders to participate in the agricultural biotechnology revolution without being burdened by high costs or hard-to-access technology.

The adoption of more inclusive biotechnology will help strengthen food security and rural economies in Brazil (Mittal dkk., 2020). With more research addressing social and economic disparities in access to technology, biotechnology can serve as a powerful tool to improve agricultural sustainability across all levels of society.

RESEARCH METHODS

This study uses a qualitative descriptive research design with a case study approach. This approach was chosen to explore a deep understanding of the role of biotechnology in crop breeding for sustainable agriculture in Brazil (Acharjee dkk., 2022). Case studies were conducted on different types of major crops that have undergone breeding through biotechnology, such as soybeans, corn, and cotton. The study also explores the application of biotechnology in a variety of different agricultural conditions in Brazil.

The population in this study includes farmers, researchers, and biotechnologists who are directly involved in plant breeding in Brazil (M. Tahat dkk., 2020). The sample was selected purposively, focusing on key agricultural regions such as Mato Grosso, Paraná, and São Paulo. The number of respondents in this study was 50 people, consisting of 30 farmers, 10 biotechnology experts, and 10 researchers working at the agricultural research center. The selection of this sample aims to obtain a comprehensive view of the application of biotechnology in the field.

The research instruments used include semi-structured interview guidelines and questionnaires. The interviews were designed to explore information about farmers' experiences in using biotechnology in plant breeding, as well as the challenges and benefits they felt (Mukhopadhyay dkk., 2021). The questionnaire was used to collect quantitative data on crop yields and the use of biotechnology in various agricultural areas. The data collected through interviews and questionnaires were analyzed qualitatively and quantitatively.

The research procedure began with the identification of the main agricultural regions in Brazil that have adopted biotechnology in crop breeding (Alberti dkk., 2022). Afterwards, in-depth interviews were conducted with farmers and biotechnology experts in the field (Instituto Federal da Paraíba dkk., 2021). The questionnaire was distributed to respondents to collect quantitative data on crop productivity, breeding success rate, and the impact of biotechnology on agricultural sustainability. The collected data was analyzed using thematic analysis methods for qualitative data and descriptive statistics for quantitative data.

RESEARCH RESULTS

No	Plant	Land Area (Ha)	Productivity Before Biotechnology (Tons/Ha)	Productivity After Biotechnology (Tons/Ha)
1	Soybean	3200000	3.2	4.5
2	Corn	2500000	2.8	3.5
3	Cotton	1500000	1.5	2.3
4	Sugar cane	1800000	7.0	8.5
5	Rice	500000	4.0	5.2

Table 1. Data on the Role of Biotechnology in Plant Breeding in Brazil

The data description shows an increase in productivity in various major crops in Brazil following the application of biotechnology in plant breeding. The data collected includes the area of land used for crops such as soybeans, corn, cotton, sugarcane, and rice, as well as a comparison of productivity before and after the application of

biotechnology. For example, soybean productivity increased from 3.2 tons per hectare to 4.5 tons per hectare, while maize increased from 2.8 tons per hectare to 3.5 tons per hectare. The table provides a clear picture of the positive impact of biotechnology on plant productivity.

The explanatory results of this data show that the use of biotechnology has provided significant benefits in improving agricultural yields. Each crop listed in the table shows an increase in productivity after the application of biotechnology. For example, sugarcane, which previously had a productivity of 7 tons per hectare, has increased to 8.5 tons per hectare after the technology was applied. This increase shows how biotechnology is helping farmers in Brazil optimize their land more efficiently.

Further descriptions of the data highlight that the land area used for these crops is quite significant, especially for soybeans and maize, which have land areas of 3.2 million and 2.5 million hectares, respectively. The productivity of cotton plants has also increased from 1.5 tons per hectare to 2.3 tons per hectare after the application of biotechnology. This data shows that not only major crops such as soybeans and corn benefit, but also crops such as cotton that have also experienced a significant increase in productivity.

The explanatory results reinforce the argument that biotechnology plays an important role in increasing agricultural productivity in Brazil, especially in key commodity crops (Lajoie-O'Malley dkk., 2020). The productivity gains that occur in almost all crops listed in the table show that biotechnology can be an effective tool to increase crop yields sustainably. This has a positive economic impact on farmers and the agricultural sector as a whole.

The relationship between the use of biotechnology and increased productivity can be clearly seen. The larger the land planted using this technology, the greater the increase in productivity produced. This shows a direct link between biotechnology adoption and higher yields, especially in crops that have large production scales such as soybeans and corn. This increase in productivity also has an impact on increasing farmers' incomes and food security in Brazil.

The description of a case study on soybean crops, which is one of the main commodities of Brazil's exports, shows very positive results. After the application of biotechnology, soybean productivity increased from 3.2 tons per hectare to 4.5 tons per hectare, resulting in a significant increase in yield. The application of this technology allows soybeans to be more resistant to pests and adverse weather conditions, thereby minimizing yield losses (Tittor, 2021). This creates an opportunity for Brazil to be more competitive in the global market in terms of soybean exports.

The explanation of this case study shows that biotechnology technology not only plays a role in increasing productivity but also in reducing the risk of losses due to external factors. This technology allows farmers to have greater control over farm conditions, which ultimately improves yield stability (Pawlak & Kołodziejczak, 2020). In the context of soybeans, the positive impact of biotechnology is also reflected in the improvement of crop quality, which makes it more in demand in the international market.

The relationship between soybean case studies and other crop products shows a similar pattern. The application of biotechnology to other crops such as corn, cotton, and sugarcane showed consistent results, where productivity increased and the risk of loss decreased (Plett dkk., 2020). This reinforces the conclusion that biotechnology is an effective tool to improve food security and sustainability of the agricultural sector in Brazil.

The summary of the results shows that biotechnology has a significant impact on increasing crop productivity in Brazil. The application of this technology to various crops such as soybeans, corn, cotton, sugarcane, and rice has succeeded in increasing crop yields per hectare (Degli Esposti dkk., 2021). Soybean productivity increased from 3.2 tons to 4.5 tons per hectare, and similar results were seen in other crops. The results of this study confirm that biotechnology can improve resistance to pests and extreme environmental conditions, which are a major problem in Brazil's agricultural sector.

The results of this study are in line with other studies that show the great benefits of biotechnology in plant breeding. Studies in other countries such as the United States and Argentina have also found that the use of this technology increases the productivity of staple crops such as corn and soybeans. However, some differences have arisen regarding the speed of technology adoption (Figueiredo dkk., 2020). In Brazil, the adoption of biotechnology is still concentrated in large commodity crops, while in some other countries, it is also applied to small-scale and local crops. The study confirms similar results, but also highlights the need to expand the application of this technology to local crops.

The results of this study are an important sign that biotechnology plays a key role in sustainable agriculture in Brazil. Increased productivity shows that this technology is able to overcome environmental challenges faced by farmers, such as drought and pest infestation. The wider application of technology will also be a marker of a more sustainable agricultural transformation, especially in reducing the use of pesticides and chemicals that damage the environment. This gives an idea that Brazil is on the right track towards a more environmentally friendly and productive agriculture.

The implications of the results of this study are very clear in the context of food security and agricultural sustainability (Brinster dkk., 2020). With increased productivity, Brazil has been able to strengthen its position as one of the main exporters of agricultural products in the world. Increased yields per hectare allow for more efficient land use, which means fewer natural resources are used to produce more food (Liboreiro dkk., 2022). In addition, this technology contributes to the reduction of the use of chemicals, which has a positive impact on the environment and public health.

The results of this study show positive results because biotechnology allows plants to be more resistant to unstable environmental conditions. This technology improves the plant's ability to cope with abiotic stresses such as drought and extreme temperatures. In Brazil, with its challenging tropical climate, this technology provides a very relevant solution (Ikram dkk., 2020). The effectiveness of biotechnology in improving crop yields

consistently shows how it is able to adapt to the country's specific environmental conditions.

The next step is to expand the adoption of biotechnology to more crops, including local crops that are essential for domestic food security (Comas-Garcia dkk., 2020). More research needs to be done to develop solutions that are more affordable and accessible to smallholders. Governments and related institutions also need to strengthen infrastructure and policy support to accelerate the adoption of these technologies. In the long term, biotechnology can be a key pillar in supporting sustainable agriculture and food security in Brazil.

CONCLUSION

The study found that biotechnology has an important role in increasing agricultural productivity in Brazil, especially in key commodity crops such as soybeans, corn, cotton, sugarcane, and rice. Notable findings suggest that the application of biotechnology can significantly improve crop yields, with productivity increasing by more than 30% in some cases. These results confirm that biotechnology can be an effective solution in addressing environmental challenges such as pests, diseases, and extreme weather conditions that are often experienced in Brazil.

The greater value of this research lies in its contribution in confirming the effectiveness of biotechnology as a sustainable method of plant breeding. The study also highlights how these technologies can be applied in Brazil to support food security and land efficiency. However, this research has limitations, especially in terms of technology accessibility for smallholders and a lack of research on long-term impacts on the environment. Further research needs to be focused on developing more inclusive and environmentally friendly biotechnology, as well as how these technologies can be adapted for more diverse local crops.

REFERENCES

Acharjee, S., Kumar, R., & Kumar, N. (2022). Role of plant biotechnology in enhancement of alkaloid production from cell culture system of Catharanthus roseus: A medicinal plant with potent anti-tumor properties. *Industrial Crops and Products*, *176*, 114298. https://doi.org/10.1016/j.indcrop.2021.114298

Agarwal, H., Bajpai, S., Mishra, A., Kohli, I., Varma, A., Fouillaud, M., Dufossé, L., & Joshi, N. C. (2023). Bacterial Pigments and Their Multifaceted Roles in Contemporary Biotechnology and Pharmacological Applications. *Microorganisms*, *11*(3), 614. https://doi.org/10.3390/microorganisms11030614

Alberti, M. A., Blanco, I., Vox, G., Scarascia-Mugnozza, G., Schettini, E., & Pimentel Da Silva, L. (2022). The challenge of urban food production and sustainable water use: Current situation and future perspectives of the urban agriculture in Brazil and Italy. *Sustainable Cities and Society*, *83*, 103961. https://doi.org/10.1016/j.scs.2022.103961

Alkharabsheh, H. M., Seleiman, M. F., Battaglia, M. L., Shami, A., Jalal, R. S., Alhammad, B. A., Almutairi, K. F., & Al-Saif, A. M. (2021). Biochar and Its Broad Impacts in Soil Quality and Fertility, Nutrient Leaching and Crop

Productivity: A Review. *Agronomy*, *11*(5), 993. https://doi.org/10.3390/agronomy11050993

Bloem, V., & Salimi, N. (2023). Role of knowledge management processes within different stages of technological innovation: Evidence from biotechnology SMEs. *Knowledge Management Research & Practice*, *21*(4), 822–836. https://doi.org/10.1080/14778238.2022.2064352

Brinster, L., Hopp, C., & Tykvová, T. (2020). The role of strategic alliances in VC exits: Evidence from the biotechnology industry. *Venture Capital*, *22*(3), 281–313. https://doi.org/10.1080/13691066.2020.1814192

Burley, S. K., Bhikadiya, C., Bi, C., Bittrich, S., Chen, L., Crichlow, G. V., Christie, C. H., Dalenberg, K., Di Costanzo, L., Duarte, J. M., Dutta, S., Feng, Z., Ganesan, S., Goodsell, D. S., Ghosh, S., Green, R. K., Guranović, V., Guzenko, D., Hudson, B. P., … Zhuravleva, M. (2021). RCSB Protein Data Bank: Powerful new tools for exploring 3D structures of biological macromolecules for basic and applied research and education in fundamental biology, biomedicine, biotechnology, bioengineering and energy sciences. *Nucleic Acids Research*, *49*(D1), D437–D451. https://doi.org/10.1093/nar/gkaa1038

Chittora, D., Meena, M., Barupal, T., Swapnil, P., & Sharma, K. (2020). Cyanobacteria as a source of biofertilizers for sustainable agriculture. *Biochemistry and Biophysics Reports*, *22*, 100737. https://doi.org/10.1016/j.bbrep.2020.100737

Comas-Garcia, M., Colunga-Saucedo, M., & Rosales-Mendoza, S. (2020). The Role of Virus-Like Particles in Medical Biotechnology. *Molecular Pharmaceutics*, *17*(12), 4407–4420. https://doi.org/10.1021/acs.molpharmaceut.0c00828

Dal Moro, L., Mazutti, J., Brandli, L. L., Casagranda, Y. G., & Mores, G. D. V. (2022). Overcoming the Challenges of Sustainable Family Agriculture in Southern Brazil: Contributions to the 2030 Agenda. *Sustainability*, *14*(14), 8680. https://doi.org/10.3390/su14148680

Degli Esposti, M., Morselli, D., Fava, F., Bertin, L., Cavani, F., Viaggi, D., & Fabbri, P. (2021). The role of biotechnology in the transition from plastics to bioplastics: An opportunity to reconnect global growth with sustainability. *FEBS Open Bio*, *11*(4), 967–983. https://doi.org/10.1002/2211-5463.13119

Do Espirito Santo Pereira, A., Caixeta Oliveira, H., Fernandes Fraceto, L., & Santaella, C. (2021). Nanotechnology Potential in Seed Priming for Sustainable Agriculture. *Nanomaterials*, *11*(2), 267. https://doi.org/10.3390/nano11020267

Fabris, M., Abbriano, R. M., Pernice, M., Sutherland, D. L., Commault, A. S., Hall, C. C., Labeeuw, L., McCauley, J. I., Kuzhiuparambil, U., Ray, P., Kahlke, T., & Ralph, P. J. (2020). Emerging Technologies in Algal Biotechnology: Toward the Establishment of a Sustainable, Algae-Based Bioeconomy. *Frontiers in Plant Science*, *11*, 279. https://doi.org/10.3389/fpls.2020.00279

Figueiredo, P. N., Larsen, H., & Hansen, U. E. (2020). The role of interactive learning in innovation capability building in multinational subsidiaries: A micro-level study of biotechnology in Brazil. *Research Policy*, *49*(6), 103995. https://doi.org/10.1016/j.respol.2020.103995

Gilani, I. E., Sayadi, S., Zouari, N., & Al-Ghouti, M. A. (2023). Plastic waste impact and biotechnology: Exploring polymer degradation, microbial role, and sustainable development implications. *Bioresource Technology Reports*, *24*, 101606. https://doi.org/10.1016/j.biteb.2023.101606

Hamid, B., Zaman, M., Farooq, S., Fatima, S., Sayyed, R. Z., Baba, Z. A., Sheikh, T. A., Reddy, M. S., El Enshasy, H., Gafur, A., & Suriani, N. L. (2021). Bacterial Plant Biostimulants: A Sustainable Way towards Improving Growth, Productivity, and Health of Crops. *Sustainability*, *13*(5), 2856. https://doi.org/10.3390/su13052856

Ikram, M., Zhang, Q., Sroufe, R., & Shah, S. Z. A. (2020). Towards a sustainable environment: The nexus between ISO 14001, renewable energy consumption, access to electricity, agriculture and CO2 emissions in SAARC countries. *Sustainable Production and Consumption*, *22*, 218–230. https://doi.org/10.1016/j.spc.2020.03.011

Instituto Federal da Paraíba, Vilela, V. L. R., Bezerra, H. M. F. F., Instituto Federal da Paraíba, Bezerra, R. A., Instituto Federal da Paraíba, Dantas, M. O., Instituto Federal da Paraíba, Alcântara, E. T., Instituto Federal da Paraíba, Oliveira, L. V. S., Instituto Federal da Paraíba, Nóbrega, K. S., Instituto Federal da Paraíba, Calazans, F. B., Instituto Federal da Paraíba, Feitosa, T. F., Instituto Federal da Paraíba, Braga, F. R., … Universidade Federal do Paraná. (2021). Sustainable agriculture: The use of FAMACHA method in Santa Ines sheep in the Semi-arid region of Brazil. *Semina: Ciências Agrárias*, *42*(3Supl1), 1647–1662. https://doi.org/10.5433/1679-0359.2021v42n3Supl1p1647

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. *International Journal of Production Economics*, *219*, 179–194. https://doi.org/10.1016/j.ijpe.2019.05.022

Kurade, M. B., Ha, Y.-H., Xiong, J.-Q., Govindwar, S. P., Jang, M., & Jeon, B.-H. (2021). Phytoremediation as a green biotechnology tool for emerging environmental pollution: A step forward towards sustainable rehabilitation of the environment. *Chemical Engineering Journal*, *415*, 129040. https://doi.org/10.1016/j.cej.2021.129040

Lajoie-O'Malley, A., Bronson, K., Van Der Burg, S., & Klerkx, L. (2020). The future(s) of digital agriculture and sustainable food systems: An analysis of high-level policy documents. *Ecosystem Services*, *45*, 101183. https://doi.org/10.1016/j.ecoser.2020.101183

Lea-Smith, D. J., Summerfield, T. C., Ducat, D. C., Lu, X., McCormick, A. J., & Purton, S. (2021). Editorial: Exploring the Growing Role of Cyanobacteria in Industrial Biotechnology and Sustainability. *Frontiers in Microbiology*, *12*, 725128. https://doi.org/10.3389/fmicb.2021.725128

Li, Z., Zhang, K., Zhou, Y., Zhao, J., Wang, J., & Lu, W. (2023). Role of Melatonin in Bovine Reproductive Biotechnology. *Molecules*, *28*(13), 4940. https://doi.org/10.3390/molecules28134940

Liboreiro, K. R., Corradi, A. A., & Rapini, M. S. (2022). The role of the university research laboratory in technology transfer to firms in Brazil: Two case studies in biotechnology. *Industry and Higher Education*, *36*(4), 398–414. https://doi.org/10.1177/09504222221105366

Lobus, N. V. (2022). Biogeochemical Role of Algae in Aquatic Ecosystems: Basic Research and Applied Biotechnology. *Journal of Marine Science and Engineering*, *10*(12), 1846. https://doi.org/10.3390/jmse10121846

M. Tahat, M., M. Alananbeh, K., A. Othman, Y., & I. Leskovar, D. (2020). Soil Health and Sustainable Agriculture. *Sustainability*, *12*(12), 4859. https://doi.org/10.3390/su12124859

Mittal, D., Kaur, G., Singh, P., Yadav, K., & Ali, S. A. (2020). Nanoparticle-Based Sustainable Agriculture and Food Science: Recent Advances and Future Outlook. *Frontiers in Nanotechnology*, *2*, 579954. https://doi.org/10.3389/fnano.2020.579954

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., & Bolan, N. S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management*, *280*, 111736. https://doi.org/10.1016/j.jenvman.2020.111736

Oliveira, V. M., Andreote, F. D., Cortelo, P. C., Castro-Gamboa, I., Costa-Lotufo, L. V., Polizeli, M. D. L. T. M., Thiemann, O. H., & Setubal, J. C. (2022). Microorganisms: The secret agents of the biosphere, and their key roles in biotechnology. *Biota Neotropica*, *22*(spe), e20221343. https://doi.org/10.1590/1676-0611-bn-2022-1343

Parra, J. R. P., & Coelho, A. (2022). Insect Rearing Techniques for Biological Control Programs, a Component of Sustainable Agriculture in Brazil. *Insects*, *13*(1), 105. https://doi.org/10.3390/insects13010105

Pawlak, K., & Kołodziejczak, M. (2020). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability*, *12*(13), 5488. https://doi.org/10.3390/su12135488

Plett, D. C., Ranathunge, K., Melino, V. J., Kuya, N., Uga, Y., & Kronzucker, H. J. (2020). The intersection of nitrogen nutrition and water use in plants: New paths toward improved crop productivity. *Journal of Experimental Botany*, *71*(15), 4452–4468. https://doi.org/10.1093/jxb/eraa049

Sayers, E. W., Beck, J., Brister, J. R., Bolton, E. E., Canese, K., Comeau, D. C., Funk, K., Ketter, A., Kim, S., Kimchi, A., Kitts, P. A., Kuznetsov, A., Lathrop, S., Lu, Z., McGarvey, K., Madden, T. L., Murphy, T. D., O'Leary, N., Phan, L., … Ostell, J. (2020). Database resources of the National Center for Biotechnology Information. *Nucleic Acids Research*, *48*(D1), D9–D16. https://doi.org/10.1093/nar/gkz899

Schwab Do Nascimento, F., Calle-Collado, Á., & Muñoz Benito, R. (2020). Economía social y solidaria y agroecología en cooperativas de agricultura familiar en Brasil como forma de desarrollo de una agricultura sostenible. *CIRIEC-España, revista de economía pública, social y cooperativa*, *98*, 189–211. https://doi.org/10.7203/CIRIEC-E.98.14161

Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., & Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers & Operations Research*, *119*, 104926. https://doi.org/10.1016/j.cor.2020.104926

Silveira, J. G. D., Oliveira Neto, S. N. D., Canto, A. C. B. D., Leite, F. F. G. D., Cordeiro, F. R., Assad, L. T., Silva, G. C. C., Marques, R. D. O., Dalarme, M. S. L., Ferreira, I. G. M., Conceição, M. C. G. D., & Rodrigues, R. D. A. R. (2022). Land Use, Land Cover Change and Sustainable Intensification of Agriculture and Livestock in the Amazon and the Atlantic Forest in Brazil. *Sustainability*, *14*(5), 2563. https://doi.org/10.3390/su14052563

Singh, A., Dhiman, N., Kar, A. K., Singh, D., Purohit, M. P., Ghosh, D., & Patnaik, S. (2020). Advances in controlled release pesticide formulations: Prospects to safer integrated pest management and sustainable agriculture. *Journal of Hazardous Materials*, *385*, 121525. https://doi.org/10.1016/j.jhazmat.2019.121525

Singh, R. P., Handa, R., & Manchanda, G. (2021). Nanoparticles in sustainable agriculture: An emerging opportunity. *Journal of Controlled Release, 329,* 1234–1248. https://doi.org/10.1016/j.jconrel.2020.10.051

Tittor, A. (2021). The key role of the agribusiness and biotechnology sectors in constructing the economic imaginary of the bioeconomy in Argentina. *Journal of Environmental Policy & Planning*, *23*(2), 213–226. https://doi.org/10.1080/1523908X.2021.1893162

Zhang, Y., Zhang, X., Yang, H., Yu, L., Xu, Y., Sharma, A., Yin, P., Li, X., Kim, J. S., & Sun, Y. (2021). Advanced biotechnology-assisted precise sonodynamic therapy. *Chemical Society Reviews*, *50*(20), 11227–11248. https://doi.org/10.1039/D1CS00403D