



Comparative Physiological Parameter Changes between Late Blight Infected and Herbal Foliar Spray Treated Tomato Plants (*Solanum lycopersicum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Indian agriculture faces various challenges such as small and fragmented landholdings, water scarcity, soil degradation, low productivity, market access issues, post-harvest losses, and vulnerability to climate. Late blight caused by *Phytophthora infestans* poses a significant threat to

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tomato productivity, leading to drastic reductions in plant growth and yield. Many bio-control agents, such as certain microbial species and beneficial fungi, can enhance soil health by improving nutrient cycling, suppressing soil-borne diseases, and promoting plant growth. The present study evaluates the efficacy of various aqueous plant extract formulations T1 to T5 prepared from *Carica papaya*, *Syzygium cumini*, and *Lantana camara* in mitigating the morphological and physiological impacts of the pathogen under in conditions. The diseased control exhibited severe stunting, leaf curling, and reduced reproductive traits. Among the treatments, T3 consistently demonstrated superior recovery in both vegetative and reproductive parameters. T3-treated plants recorded a shoot length of 69.4 cm, tap root length of 9.7 cm, and 99 lateral roots—values closely approximating the healthy control. Significant improvements were observed in leaf surface area (31.92 cm²), internodal length (13.3 cm), and stomatal index (13.34), indicating restored physiological function. T3 also outperformed other treatments in reproductive metrics, registering 90 flowers/plant, 17 fruits/plant, 57 seeds/fruit, and a fruit weight of 106.35 g, which is markedly higher than the diseased control (6.72 g). Additionally, near-normal leaf morphology and enhanced fruit pulp thickness (0.6 cm) confirmed visible plant recovery. While T4 and T5 also showed moderate improvements, their performance was inferior to T3 across key indicators. The results underscore the potential of specific plant-based formulations in suppressing *P. infestans* and enhancing tomato plant resilience. In conclusion, the study highlights T3 as the most effective treatment for promoting recovery from late blight, offering a promising, eco-friendly alternative to conventional fungicides in integrated disease management strategies. This study therefore provides strong evidence supporting the use of plant-based foliar sprays in integrated disease management strategies, particularly in smallholder and organic farming systems, contributing to safer crop protection and enhanced food security.

Keywords: *Physiological changes; Solanum lycopersicum; herbal foliar spray; late blight; Phytophthora infestans.*

1. INTRODUCTION

Agriculture in India is a critical sector that sustains the livelihoods of millions of people and contributes significantly to the country's economy. Importance of Agriculture: Agriculture is the primary source of livelihood for about 58% of India's population. It contributes around 17-18% of the country's GDP and is a crucial sector for poverty alleviation and rural development (Mishra, 2020). India is known for its diverse agro-climatic conditions, which support the cultivation of a wide range of crops including cereals (rice, wheat, maize), pulses (gram, lentil, pigeon pea), oil-seeds (mustard, soybean, groundnut), fruits, vegetables, and spices. India underwent a Green Revolution in the 1960s and 1970s, which significantly increased agricultural productivity through the adoption of high-yielding varieties of seeds, irrigation technologies, and agrochemicals. (Pingali, 2012). To prevent tomato crop yield loss incited by late blight, farmers use indiscriminately whatever fungicide available alone or in combination. Frequent sprays of single fungicide up to harvesting for all tomato varieties irrespective of the cropping season are also very common in response to disease symptoms on the foliage. However, the indiscriminate use of fungicides has adverse

effects on human and animal health, pollute the environment and also lead to development of resistance by the pathogen (Gudero et al., 2018; Kanwal et al., 2024).

Despite progress, Indian agriculture faces various challenges such as small and fragmented landholdings, water scarcity, soil degradation, low productivity, market access issues, post-harvest losses, and vulnerability to climate. The Indian government has implemented various policies and initiatives to support agricultural development, including subsidies, credit facilities, price support mechanisms, crop insurance, and investments in agricultural infrastructure (Gulati & Saini, 2020). There is growing emphasis on sustainable agriculture practices, technology adoption, value chain development, market reforms, and farmer empowerment to enhance agricultural productivity, income, and resilience in India. (Shah et al., 2021).

The Late Blight disease was caused by the Oomycetes fungi *Phytophthora infestans* (Mont.) de Bary and it is one of the serious diseases which cause loss in the yield of tomatoes. Tomato production worldwide is usually restrained by various infections, among them

mainly the late and early blight caused by *Phytophthora infestans* and *Alternaria solani*, respectively. Lately, there has been a growing concern over the use of synthetic fungicides on environmental and food safety, hence the need to explore other alternatives that are friendly to the user, the consumer, and the general environment (Mugao et al., 2021). Late blight earned notoriety due to its historical role in the Irish Potato Famine of the 19th century, where it caused widespread crop failures and famine. Late blight continues to pose a significant threat to global food security and agricultural economies. Additionally, ongoing research into safer, more eco-friendly fungicides and alternative disease management strategies is crucial for addressing these challenges and ensuring the long-term sustainability of agricultural systems. And bio-control would be one of the best solutions for it. Bio-control agents are typically less harmful to the environment compared to chemical fungicides. They do not leave harmful residues in soil or water bodies, reducing the risk of environmental contamination and harm to non-target organisms.

Many bio-control agents exhibit specificity towards particular pathogens, including pathogenic fungi. They can effectively target the disease-causing organisms while minimizing harm to beneficial microbes, plants, and other organisms in the environment. Pathogens are less likely to develop resistance to bio-control agents compared to chemical fungicides. This is because bio-control agents often employ multiple mechanisms of action, making it difficult for pathogens to evolve resistance. Integrating bio-control into IPM strategies offers holistic and sustainable solutions for managing pathogenic fungi and other pests. Many bio-control agents, such as certain microbial species and beneficial fungi, can enhance soil health by improving nutrient cycling, suppressing soil-borne diseases, and promoting plant growth. These beneficial effects contribute to overall soil fertility and productivity. While initial investment in bio-control may require resources for research and implementation, the long-term benefits often outweigh the costs.

In the present study, it is aimed to prepare a herbal formulation to treat Late blight diseases on some important crops like *Lycopersicon esculentum*. Additionally, the herbal extracts were made to be eco-friendly and cost-effective to meet out the farmers expectation. The present research also emphasis on the efficiency of herbal formulation against the pathogenic fungi and also its effects on improving the physiological parameters after spraying of this herbal formulation in terms of morphology, yield and productivity.

2. Materials and Methods

2.1 Selection and Collection of Plant Materials

The present work was designed to prepare a non-toxic, cost-efficient and eco-friendly herbal consortia for controlling the late blight disease in tomato plants. For that, the plants are selected which are commonly available and have high anti-fungal activity.

Based on the literature, the above-mentioned plants and their parts have been selected and used for the preparation of the anti-fungal herbal consortia to inhibit the growth of *Phytophthora infestans* which causes late blight disease in the tomato plant. From the selected plant material which is mentioned above, mature and healthy leaves have been collected.

2.2 Preparation of Herbal Consortia: (Bhupendra, 1999)

The collected plant materials (leaves) were washed with running tap water in-order to remove the dirt and the prominent mid veins in the leaves were removed using the scissors. Then the leaves are chopped into small pieces by using the knife and dropped into the mixer jar. To that chopped leaves, 30 ml of water and 2 ice cubes (to prevent from denaturing of phytochemicals or secondary metabolites) were added and finely ground using the mixer. Then the homogenate was filtered by using the 3 to 4 layers of muslin cloth. Then the aqueous extract or the filtrate was stored in a glass bottle and refrigerated at 4°C till have to be used.

Table 1. The selected plants

S.No.	Name of the Plant Used	Plant Part Used
1	<i>Carica papaya</i>	Leaves
2	<i>Lantana camara</i>	Leaves
3	<i>Syzygium cumini</i>	Leaves

2.3 Field Experimental Plot

The experiment plot for tomato has been done in 1 acre of land at Chinnappampalayam and the commercial variety of tomato "SHIVAM" was used for the present study. The spacing provided between each row of the tomato plant is 4 feet and between each plant is 2 feet. There are 12 columns in the field and each column of the plot contains 15 plants. For single formulation, 2 rows of 30 plants were selected to test and for five formulation 150 plants in 10 rows were tested. About 2 rows with 30 plants treated as control. Three times foliar herbal spray was sprayed in the interval of 10 days. The results had been noted and tabulated.

2.4 Estimation of Growth and Morphological Parameters: (Roni et al., 2016; Tejukumar et al., 2023)

The change in morphological parameters of the healthy, diseased and herbal spray treated tomato plant was observed and tabulated.

2.4.1 Shoot length

The length of the plant was measured from the base of the plant (aerial part) to the terminal tip of the plant. The total length was expressed in cm.

2.4.2 Tap root length

The length of the tap root was measured from the base of the plant from the soil surface to the terminal tip of the root and its length is expressed in cm.

2.4.3 No. of lateral roots

The total number of lateral roots in the plants were counted and tabulated and its presence denotes the efficiency of minerals and water uptake to the plant which was shown through the healthiness of the plant.

2.4.4 No. of nodes

The total number of nodal regions in the entire plant were counted and tabulated which denotes the meristematic activity of the plant.

2.4.5 Inter-nodal length

The distance between two nodes (Internode length) were measured by using the standard

measurement procedure and its length is expressed in cm.

2.4.6 Leaf surface area

Leaf surface area refers to the total outer area of a leaf, typically calculated by multiplying its length by its breadth of the leaves and its area is expressed in cm².

2.4.7 Leaf shape

The change in size and shape of the leaves from each treatment plants were noted and tabulated.

2.4.8 Petiole length

The distance between the base of the leaf to node of the stem were measured by using the standard measurement procedure and its length is expressed in cm.

2.4.9 No. of sympodia

The total number of sympodia's present in the plants from each treatments were counted and tabulated.

2.4.10 No. of inflorescence

The total number of inflorescences present in each and all branches of the plant were counted and tabulated.

2.4.11 No. of flowers/branch

The total number of flowers present in single branch of the stem were counted and tabulated.

2.4.12 No. of flowers/plant

The total number of flowers present in each and all branches of the plant were counted and tabulated.

2.4.13 Stomatal index

The total number of stomatal and epidermal cells present in the microscopic fields of leaf is counted and the stomatal index were calculated by the below formula and tabulated.

$$\text{Stomatal index} = \frac{\text{Number of Stomata}}{\text{Total Epidermal Cells}} \times 100$$

2.4.14 No. of fruits

The total number of fruits which were produced by plants at the time of harvest from different treatments were counted and tabulated.

Table 2. Ingredients and quantities used for preparation of foliar spray

Plant name	Treatments (ml/L)				
	T1	T2	T3	T4	T5
<i>Carica papaya</i>	300	150	100	200	200
<i>Lantana camara</i>	150	250	300	200	400
<i>Syzygium cumini</i>	200	300	400	200	100
Control	10% W/V of chemical fungicide (Bavistin)				

Table 3. Comparative morphological parameters of control, diseased and treated crop plant

S.No	Morphological Parameters	Control plant	Diseased plant	T1	T2	T3	T4	T5
1	Shoot length (cm)	75.4 ± 0.56	35.7 ± 0.84	42.3 ± 0.64	55.6 ± 0.43	69.4 ± 0.74	48.7 ± 0.35	62.8 ± 0.64
2	Tap root length (cm)	10.2 ± 0.74	7.8 ± 0.34	8.0 ± 0.75	8.5 ± 0.43	9.7 ± 0.53	8.2 ± 0.12	9.2 ± 0.42
3	No. of lateral roots	110 ± 0.76	65 ± 0.55	69 ± 0.63	74 ± 0.76	99 ± 0.61	73 ± 0.44	87 ± 0.69
4	No. of nodes	42 ± 0.96	19 ± 0.234	21 ± 0.83	27 ± 0.74	37 ± 0.53	24 ± 0.78	32 ± 0.23
5	Inter-nodal length (cm)	14.5 ± 0.85	4.5 ± 0.74	7.6 ± 0.76	10.4 ± 0.73	13.3 ± 0.76	9.9 ± 0.36	11.7 ± 0.63
6	Leaf surface area (cm ²)	40.85 ± 0.64	10.07 ± 0.63	11.55 ± 0.34	20.16 ± 0.53	31.92 ± 0.65	15.36 ± 0.46	25.28 ± 0.29
7	Leaf shape	Normal	Curled	Partially curled	Partially curled	Near normal	Partially curled	Near normal
8	Petiole length (cm)	10.3 ± 0.43	6.5 ± 0.74	6.9 ± 0.62	8.2 ± 0.83	9.2 ± 0.82	7.7 ± 0.25	8.7 ± 0.78
9	No. of sympodia	3 ± 0.24	2 ± 0.84	2 ± 0.04	2 ± 0.03	2 ± 0.04	2 ± 0.02	2 ± 0.01
10	No. of inflorescence	38 ± 0.74	9 ± 0.55	9 ± 0.74	14 ± 0.72	30 ± 0.65	11 ± 0.32	25 ± 0.45
11	No. of flowers/branch	12 ± 0.45	3 ± 0.27	3 ± 0.72	3 ± 0.78	9 ± 0.70	3 ± 0.52	6 ± 0.24
12	No. of flowers/plant	115 ± 0.35	25 ± 0.54	29 ± 0.26	43 ± 0.52	90 ± 0.62	35 ± 0.72	75 ± 0.52
13	Stomatal index	15.6 ± 0.32	5.17 ± 0.43	7.3 ± 0.72	8.3 ± 0.52	13.34 ± 0.62	9.29 ± 0.73	11.3 ± 0.36
14	No. of fruits	22 ± 0.63	10 ± 0.23	12 ± 0.48	13 ± 0.41	17 ± 0.39	11 ± 0.83	14 ± 0.78
15	No. of branches	9 ± 0.12	2 ± 0.43	3 ± 0.83	4 ± 0.81	7 ± 0.82	3 ± 0.56	5 ± 0.98
16	No. of seeds	78 ± 0.24	13 ± 0.63	23 ± 0.79	30 ± 0.82	57 ± 0.64	33 ± 0.72	42 ± 0.28
17	Fruit pulp thickness (cm)	0.9 ± 0.52	0.1 ± 0.43	0.2 ± 0.62	0.5 ± 0.43	0.6 ± 0.62	0.3 ± 0.43	0.4 ± 0.55
18	Weight of a fruit (g)	128.9 ± 0.53	6.715 ± 0.76	12.9 ± 0.32	50.9 ± 0.21	106.35 ± 0.43	32.60 ± 0.87	59.5 ± 0.76

2.4.15 No. of branches

The total number of branches in each plant from different treatments were counted and tabulated.

2.4.16 No. of seeds

The total number of seeds present in single fruit from different treatments were counted and tabulated.

2.4.17 Fruit pulp thickness

The fruit was cut vertically into two halves and thickness of the fruit pulp is measured by using the standard measurement procedure and its length is expressed in cm.

2.4.18 Weight of a fruit

The weight of the fruit was measured from different treatments and it is expressed in grams (g).

3. RESULTS AND DISCUSSION

Herbal-based foliar sprays are formulations derived from plant extracts, which possess inherent anti-fungal properties. These natural compounds can act against a broad spectrum of fungal pathogens while being biodegradable and safe for non-target organisms. Moreover, herbal foliar sprays are often cost-effective and can be easily prepared and applied by farmers. Research has shown that various plant extracts exhibit potent anti-fungal activities due to the presence of bioactive compounds such as alkaloids, phenolics, flavonoids, and terpenoids. These compounds can disrupt fungal cell membranes, inhibit enzyme activity, or interfere with essential metabolic processes, ultimately leading to the inhibition of fungal growth and proliferation. Furthermore, herbal foliar sprays have been reported to induce systemic resistance in plants, enhancing their natural defence mechanisms against fungal pathogens. This systemic acquired resistance (SAR) can provide long-term protection, reducing the need for frequent application of fungicides. Agricultural crops are mainly affected by many factors, including many abiotic and biotic factors. The abiotic factors such as extreme climate, soil conditions, may affect the crop physiology and productivity. The abiotic factor, which undesirable or unseasonal climatic conditions also affect the crop physiology and productivity by inducing many organisms to become more virulent. Hence

abiotic factors play a major role directly on both crop physiology and productivity. The works made (Davidson & Naidu, 2000) by some plant extracts and essential oils showed activity against a wide range of plant pathogenic fungi which biotic stress on the plants may also cause many abnormal changes.

The fungal pathogens are easily affecting the crops by various it may spread via air, water and soil. So, the fungal pathogens will become pandemic very easily and affects the entire crop fields. The fungal pathogens engulf the plant body through its extensive hyphae and forms a mycelial mat over the tissues of main crop. Mainly the parasitic nature of the fungi causes many undesirable changes in the plants like change in the morphology, physiology and productivity. To overcome the above problem there are many chemical fungicides available in the market. The chemical fungicides cause many residual side effects to the humans and animals. The crop for the present study was *Solanum lycopersicum*, which is commercially cultivated crop in the subtropical country like India. The plant cultivated for its fruit and used it in daily basis. The study plant crop was often affected by the fungal disease caused by the causal organism *Phytophthora infestans* and the chemical control was also available but the residual effects are more dangerous to humans. To overcome the problem the present study was carried out to formulate the five different formulations randomly made of plant extract having high anti-fungal activity and tested over the crop. The following plants were taken for the present study to prepare a novel formulation viz., leaf extracts of *Carica papaya*, *Lantana camara*, an exotic weed and *Syzygium cumini*.

The herbal formulation was made randomly with freshly prepared water extracts made from the above plants. The formulations and its compositions was mixed at definite ratio and showed in Table 2. The five different formulation was prepared freshly and stored in a suitable container. The formulation was prepared freshly every time and applied on the crop. The prepared formulation was applied aerially in definite time intervals at 15 days and morphological variation was observed, recorded and tabulated. The morphology of the plant showed drastically change over the diseased and control (non-infected) plant. The shoot length is one of the important physiological character which was reduced from 75.4 to 35.7 cm and root length also from 10.2 to 7.8. The no. of roots

which directly deals with the plants health was reduced from 9 to 4. The inter-nodal length and shoot length was positively correlated both of them gets reduced between control and diseased plant. The leaf shape was also changed its orientation, texture and regular shape. The petiole length is another important parameter which gets was also reduced to 6.5 from 10.3cms. Similarly all the parameters which included no. of inflorescence, no. of flowers/plant, stomatal index, no. of fruits, no. of branches, no. of seeds and fruit pulp thickness and weight of the fruit also mainly affected on the diseased plant. Similar results have been reported in many crops, the change in growth physiology is due to the phytohormone, zeatin (cytokinin) which promotes cell division and enhances the growth of lateral buds (Sosnowski et al., 2023). The foliar spray of Moringa leaf and seed extracts accelerated the growth of several plants such as sunflower (Iqbal, 2014), maize (Maswada et. al., 2018)

The diseased plant at various stages was applied with herbal formulation (Table 2) Out of the various formulations used the T5 and T3 formulations performed well in majority of the morphological parameters. About 18 parameters, including shoot length, to weight of the fruits were tested and tabulated (Table 3). The table shows the T3 and T5 formulations showed high recovery rate, comparatively and it matches to that of the control plants. The shoot length and which recorded as 75.4 cm a physiological parameter reduced to 35.7 cm but after application of the formulation, the crop recovered considerably to 69.4 cm and 62.8 cm. Next important parameter root length 10.2cm is recorded in healthy plants. The infected plant showed 7.8 cm and regains its length up to 9.7 which is more or less equal to healthy plant found in the crop, individuals treated with T3 formulation. The T5 formulation was also exhibited considerably to 9.2 cm (Table 3). The leaf parameter, which is actually deals directly with towards physiological productivity and photosynthetic apparatus. It is necessary to change in shape, size, leaf surface area and petiole length was also remarkably recovered from the disease affected crop. The T5 formulation and T3 formulation showed that 25.28cm and 8.7 cm; 31.91 and 8.2 cm respectively while the infected plant showed 10.07cm and 6.5 cm (Table 3) There are many studies have reported with a wide range of beneficial effects of applications of seaweed extract on plants, such as improved early seed

germination and establishment, improved crop performance and yield, and elevated resistance to biotic and abiotic stresses (Beckett and Van Staden, 1989, Hankins and Hockey, 1990).

The reproductive nature of the plant mainly deals with the no. of inflorescence, no. Of flowers, no. of fruits, no. of seeds. The no. of inflorescences was increased to 25 in T5 whereas 9 in diseased plant individual. The flowers are also increased to 75 and 90 in T3 and T5 while 25 diseased plants. The no. of fruits is also increased while application of the formulation (Table 3) Similarly, all the morphological, physiological and reproductive parameters were considerably recovered from the diseased crop. The evaluation of prepared formulation results showed that positively acts on the diseased plant crop and recovers the plant crop and makes them normal which regaining its healthy nature of the plant. The formulations have worked well on all possible parameters. The above formulation is completely plant based one it is completely eco-friendly which will not make any harm to the diversity. All the formulations are highly target-oriented which affects the pathogen alone and also it recovers the plant as a healthy plant.

4. CONCLUSION

The present study demonstrates the significant potential of herbal foliar sprays in mitigating the detrimental effects of late blight caused by *Phytophthora infestans* on tomato plants (*Solanum lycopersicum* L.). Among the five aqueous herbal formulations tested, T3, comprising optimal ratios of *Carica papaya*, *Lantana camara*, and *Syzygium cumini* leaf extracts, emerged as the most effective treatment in restoring both morphological and physiological parameters of infected tomato plants. The observed recovery in T3-treated plants across critical parameters such as shoot length, root development, leaf surface area, internodal length, and stomatal index closely approximated those of healthy controls. Notably, T3 also resulted in a marked improvement in reproductive traits, including flower and fruit count, seed number, and fruit pulp thickness, with fruit weights significantly higher than the diseased control group. This underscores not only the disease suppression capacity of the formulation but also its role in promoting plant vigor and productivity. The recovery of leaf morphology and petiole length further supports the restorative influence of the herbal treatments on photosynthetic efficiency and nutrient

translocation. While formulations T4 and T5 also showed promising improvements, their efficacy remained secondary to T3. The comprehensive performance of T3 indicates a synergistic effect of the selected plant extracts, likely due to their antifungal phytochemicals such as alkaloids, phenolics and flavonoids, which not only inhibited the pathogen but also triggered systemic resistance and physiological repair mechanisms within the plant. Hence eco-friendly and non-toxic nature of these herbal consortia makes them ideal for integration into sustainable agricultural practices, offering a viable alternative to conventional fungicides. This study therefore provides strong evidence supporting the use of plant-based foliar sprays in integrated disease management strategies, particularly in smallholder and organic farming systems, contributing to safer crop protection and enhanced food security.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Beckett, R. P., & Van Staden, J. (1989). The effect of seaweed concentrate on the growth and yield of potassium stressed wheat. *Plant and soil*, 116, 29-36.
- Bhupendra, K., Rana, V., Taneja, & Singh, U. P. (1999). Antifungal activity of an aqueous extract of leaves of garlic creeper (*Adenocorymbium alliaceum* Miers.). *Pharmaceutical Biology*, 37(1), 13–16.
- Davidson, P. M., & Naidu, A. S. (2000). Natural food antimicrobial systems. In A. S. Naidu (Ed.), *Natural food antimicrobial systems* (pp. 265–294). CRC Press.
- Gudero, G., Hussien, T., Dejene, M., & Biazin, B. (2018). Integrated management of tomato late blight [*Phytophthora infestans* (Mont.) de Bary] through host plant resistance and reduced frequency of fungicide in Arbaminch Areas, Southern, Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 8(9), 94–109.
- Gulati, A., & Saini, S. (2020). Agricultural reforms in India: Issues, concerns, and paths ahead. *Economic & Political Weekly*, 55(32), 21–27.
- Hankins, S. D., & Hockey, H. P. (1990). The effect of a liquid seaweed extract from *Ascophyllum nodosum* (Fucales, Phaeophyta) on the two-spotted red spider mite *Tetranychus urticae*. In *Thirteenth International Seaweed Symposium: Proceedings of the Thirteenth International Seaweed Symposium held in Vancouver, Canada, August 13–18, 1989* (pp. 555–559). Springer Netherlands.
- Iqbal, A., Iftikhar, I. I., Nawaz, H., & Nawaz, M. (2014). Role of proline to induce salinity tolerance in sunflower (*Helianthus annuus* L.). *Science, Technology and Development*, 33(2), 88–93.
- Kanwal, I., Ölmez, F., Ali, A., Tatar, M., & Dadaşoğlu, F. (2024). Evaluating the efficacy of fungicides for controlling late blight in tomatoes induced by *Phytophthora infestans*. *Journal of Agricultural Production*, 5(4), 241–247.
- Maswada, H. F., Abd El-Razek, U. A., El-Sheshtawy, A. N. A., & Elzaawely, A. A. (2018). Morpho-physiological and yield responses to exogenous moringa leaf extract and salicylic acid in maize (*Zea mays* L.) under water stress. *Archives of Agronomy and Soil Science*, 64(7), 994–1010.
- Mugao, L. G., Gichimu, B. M., Muturi, P. W., & Njoroge, E. K. (2021). Essential oils as biocontrol agents of early and late blight diseases of tomato under greenhouse conditions. *International Journal of Agronomy*, 2021(1), 5719091. <https://doi.org/10.1155/2021/5719091>
- Pingali, P. (2012). Green revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, 109(31), 12302–12308.
- Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *Proceedings of the national academy of sciences*, 109(31), 12302-12308.
- Roni, M. Z. K., Ahmad, H., Mirana, A. S., Islam, M. S., & Jamal Uddin, A. F. M. (2016). Study on morpho-physiological characteristics of five *Anthurium* varieties. *International Journal of Business, Social and Scientific Research*, 4(2), 105–113.

- Shah, A., Nazari, M., Antar, M., Msimbira, L. A., Naamala, J., Lyu, D., ... & Smith, D. L. (2021). PGPR in agriculture: A sustainable approach to increasing climate change resilience. *Frontiers in Sustainable Food Systems*, 5, 667546.
- Sosnowski, J., Truba, M., & Vasileva, V. (2023). The impact of auxin and cytokinin on the growth and development of selected crops. *Agriculture*, 13(3), 724.
- Tejukumar, B. K., Singh, P., Hiremath, V. M., Jhanji, R. K., Dubey, & Pooja, A. (2023). Influence of shade leaves on morpho-physiological characteristics of potted *Spathiphyllum*. *Indian Journal of Horticulture*, 80(2), 171–176.

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