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Can Plants Talk? Unlocking the Power of Ultrasound in Plant Communication and Precise Irrigation

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Abstract. Plants in adverse conditions, such as drought, emit ultrasonic waves between 20 kHz and 150 kHz. Research indicates that plant cells have many mechanically sensitive channels that can detect sound vibrations, then cause physiological changes or gene expression responses. Because plants do not have a nervous system, we hypothesize that they utilize ultrasonic signals for inter-plant communication, particularly in regulating transpiration on their leaves. The findings are revealing: exposure to ultrasonic waves led to increased leaf surface temperatures compared to control conditions, which indicates a significant reduction in transpiration. Non-contact infrared thermal imaging was employed to monitor the leaf surface temperatures of hydrated potted plants under conditions without ultrasonic exposure and with 22 kHz and 30 kHz ultrasonic waves, proving that ultrasound directly affects leaf temperature and transpiration rates. Under 22 kHz ultrasound and 30 kHz ultrasound, leaf surface temperatures rose by an average of 1.8°C and 1.9°C, respectively, while they rose by 1.0°C in the control group. The results show that ultrasound exposure lowers the effectiveness of transpiration by about 40– 50%, which causes changes in the body that can be seen from the stomata. These results not only prove a new dimension of plant communication but also create opportunities for non- invasive plant health diagnostics and smart irrigation systems, transforming modern agriculture. This provides strong evidence that plants use ultrasonic signals to regulate transpiration; these findings have significant impact on precision farming and water conservation. Understanding the auditory language of plants is not just a research project but also a discovery that might change our interaction with the environment and propel environmentally friendly living.

Keywords: ultrasonic wave, mechanically sensitive channel, regulate transpiration.

1. Research Motivation

Long-lasting weather and climate change make it very hard for farmers worldwide to grow crops and save water. Scientists and farmers seek creative answers to maximize water use and raise plant resilience. Recent research indicates that plants release ultrasonic signals during drought stress, implying that these signals might be a means of communication controlling physiological reactions. However, the exact role of these ultrasonic emissions in plant physiology and communication remains unclear and requires further investigation.

Previous research has found that plants under adverse conditions emit ultrasound between 20 kHz and 150 kHz. For example, tomatoes and tobacco emit 35 and 11 ultrasonic signals per hour, respectively, under drought stress, and 25 and 15 per hour when cut (Hadany et al., 2019). Other experiments have shown that plant cells possess mechanically sensitive channels capable of detecting sound vibrations (Haswell et al., 2011), which trigger physiological changes (Gagliano et al., 2012; Oda et al., 2021) or gene expression responses (Ghosh et al., 2016). Since plants lack a nervous system, we aim to determine whether they use ultrasonic signals to communicate and regulate transpiration.

Since leaf temperature is closely tied to stomatal transpiration, it provides a non-invasive method for estimating transpiration efficiency. The relationship between plant transpiration and leaf temperature is approximately linear—higher transpiration leads to lower leaf temperature, while reduced transpiration results in higher leaf temperature.

To investigate this, I used non-contact infrared thermal imaging to monitor the leaf temperature of a potted Ixora plant that was not lacking water. I tested the leaf temperature without ultrasonic emission and the leaf temperature after ultrasonic emission. A comparison of the two experiments with the ambient temperature can be used to estimate whether ultrasonic waves have an effect on the transpiration of leaves, indirectly confirming whether plants use ultrasonic signals as a means of communicating information to regulate transpiration. Understanding this mechanism could lead to advancements in precision agriculture, helping farmers make informed irrigation decisions and optimize plant water efficiency in response to climate challenges.

2. Literature Review

2.1. Ultrasound Emissions: Their Significance in Plant Stress Response

Plant Ultrasound Emissions Research shows that plants under stress—that is, dehydration or physical damage—emit ultrasonic vibrations ranging from 20 kHz to 100 kHz (Khait et al., 2023). Under drought stress, tomato and tobacco plants, for example, emit 35 and 11 ultrasounds per hour respectively; under cut, respectively, 25 and 15 ultrasounds. These emissions imply a possible mechanism by which plants can transmit stress responses using airborne sound signals (Hadany et al., 2019).

2.2. Sound Vibrations Detection in Plants

Although they lack a nervous system, plants have mechanically sensitive ion channels that pick out outside vibrations. Plants are able to sense and react to outside stimuli including ultrasonic waves by these mechanosensitive channels (MSL, MCA). Channel activation can cause physiological changes including stomatal closure, lower transpiration, and alterations in gene expression (Gagliano et al., 2012; Oda et al., 2021).

2.3. Leaf Temperature Regulation and Evapotranspiration

Control of plant temperature depends much on transpiration. Water evaporates as stomata open, therefore reducing leaf temperature. Less water escapes when stomata shut, which raises leaf temperature. Research indicates that light-induced stomatal opening results in evaporative cooling (Murata et al., 2007) and that variations in leaf temperature affect transpiration efficiency rather closely (Li et al., 2018). This gives a consistent approach for tracking transpiration dynamics via thermal imaging.

2.4. Effect of Ultrasound on Transpiration and Photosynthesis

Ultrasonic irradiation (17 kHz, 30W) lowered photosynthesis and transpiration (José et al., 2021) according to research on aquatic lily plants. Leaf temperature rose with exposure and absorption of leaf chlorophyll changed dramatically. These results confirm the theory that transpiration efficiency and stomatal function are influenced by ultrasonic exposure.

3. Hypothesis

It has been confirmed that plants emit ultrasound waves when they are short of water. Some studies have also pointed out that emitting ultrasound waves at aquatic lilies will reduce photosynthesis and transpiration. Since the stomata of leaves close when plants are short of water, causing the leaf temperature to rise, other research have used infrared thermal imaging cameras to monitor the leaf temperature of crops and observe crop transpiration for to determine water shortage conditions as a basis for precise irrigation. Continuing our previous year's research, we wanted to use an infrared thermal imager to monitor leaf temperature to monitor plant transpiration, and changes in the plant stomata. We did experiments with ultrasound emitted at the plant and without (22KHZ and 30KHZ) on watered Ixora flowers in pots, monitoring changes in leaf temperature and observing whether there was a difference between the two experiments. If the change in leaf temperature in the ultrasound experiment is higher than that in the no ultrasound experiment, it is consistent with previous research on aquatic lilies, indirectly confirming that the ultrasound emitted by the stem when the plant is water-deficient provides evidence that notifies the leaves to adjust transpiration.

4. Research Methodology

4.1. Instruments and Materials

- FLIR Thermal Imager-E6: Captures thermal images of the leaves. (Fig. 1)
- Signal Generator: Provides ultrasound waves for the experimental test.
- Ultrasonic Horn (40 kHz): Emits ultrasonic waves; measures intensity 15 cm from the horn.
- Thermometer: Measures the temperature of the leaf surface and room.
- Thermohydrometer: Measures temperature and humidity in the environment.
- Illuminance Meter: Records lighting levels (lux).

Figure 1. Experimental equipment

4.2. Experimental Design Experimental Setup

- Control Test (Without Ultrasound Exposure) as shown in Fig.2
  - Potted plant (*Ixora* species)
  - Thermal imager (FLIR Thermal Imager-E6)
  - Thermohydrometer

Figure 2. Control Test (Without Ultrasound Exposure)

- Experimental Test (With Ultrasound Exposure) as shown in Fig.3
  - Signal generator
  - Ultrasonic horn
  - Potted plant (Ixora species)
  - Thermal imager (FLIR Thermal Imager-E6)
  - Thermometer

Figure 3. Experimental Test (With Ultrasound Exposure)

4.3. Experimental Procedure

1. Duration: Each test lasts 1 hour.
2. Environmental Recording:
   - I record room temperature every one minute.
   - Thermal images of the leaves are stored so that I can analyze late on.
   - Humidity and lighting (lux) levels will be recorded.
3. Temperature Measurement:
   - I will record the lowest temperature data for both the room and leaf surface in a fixed area.
   - I will use these values are used to generate a statistical curve of temperature variation.
4. Data Analysis:
   - I will use software to analyze the highest, lowest, and average temperature differences between the start and end of each experiment.

5. Experiment Results

A set of controlled tests were done to determine the effect ultrasound has on plant transpiration. Every experiment measured plant temperatures by using infrared thermal imaging before and after ultrasonic wave exposure. The tests were performed under two conditions:

Experiment # 1

- **Test Time**: 13:15–14:20
- **Ultrasound Condition**: 22 kHz for 20 minutes
- **Room Temperature**: 30.9–31.2°C
- **Humidity**: 70%
- **Temperature Change**:
  - **Maximum**: 31.4°C → 33.5°C (+2.1°C)
  - **Minimum**: 30.7°C → 33.1°C (+2.4°C)
  - **Average**: 30.9°C → 33.3°C (+2.4°C)
- **Lighting**: 1200 Lux

Results are shown in Fig.4.

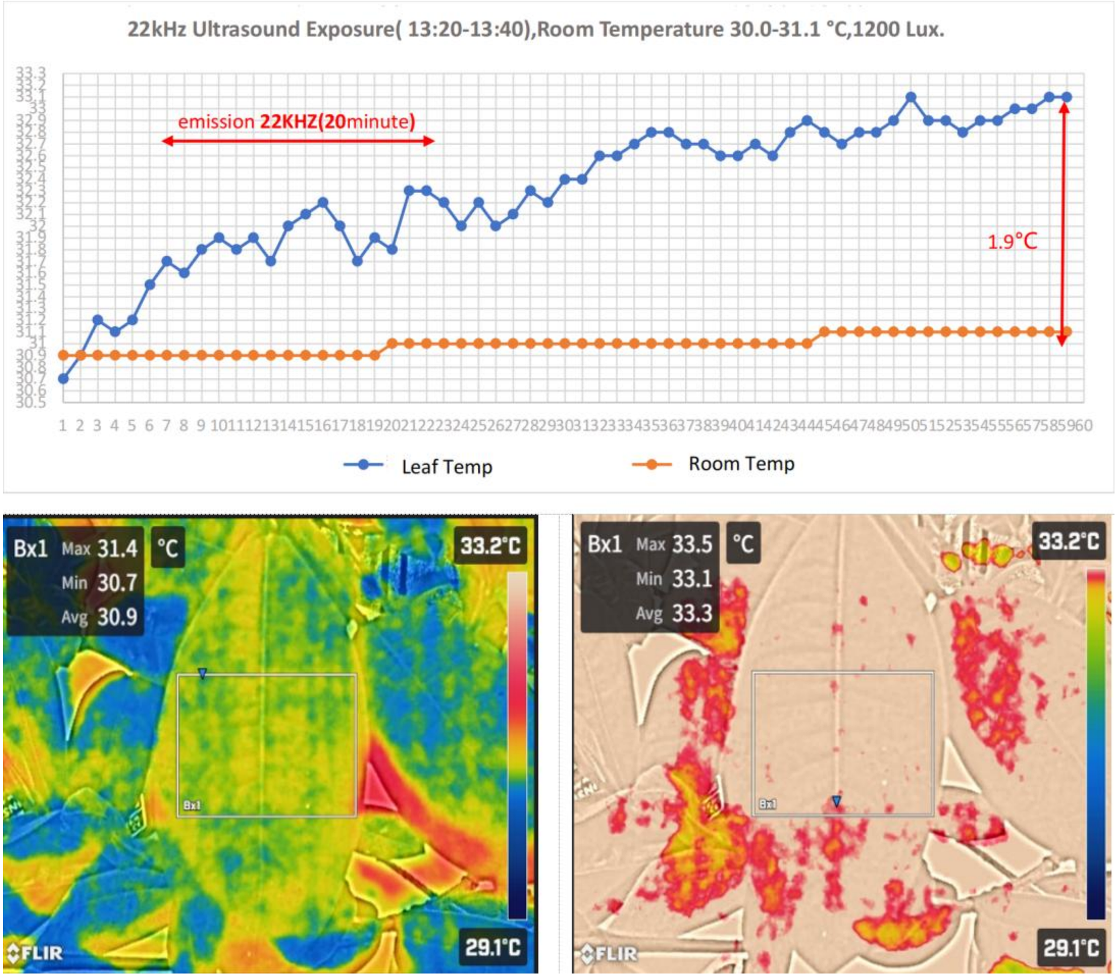

Figure 4. Results for Ultrasound Condition:22KHz, 30-31.1°C, 1200Lux

Table 1. Temperature for Experiment # 1

Leaf Surface Fixed Area Temperature	13:15 Leaf Thermal Image	14:15 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	31.4	33.5	2.1
Minimum (°C)	30.7	33.1	2.4
Average (°C)	30.9	33.3	2.4

Experiment # 2

- **Test Time**: 08:20—09:21
- **Room Temperature**: 30.9—31.4°C
- **Humidity**: 62%
- **Temperature Change**:
  - **Maximum**: 32.0°C → 33.0°C (+1.0°C)
  - **Minimum**: 31.3°C → 32.2°C (+0.9°C)
  - **Average**: 31.5°C → 32.5°C (+1.0°C)
- **Lighting**: 1200 Lux

Results are shown in Fig.5.

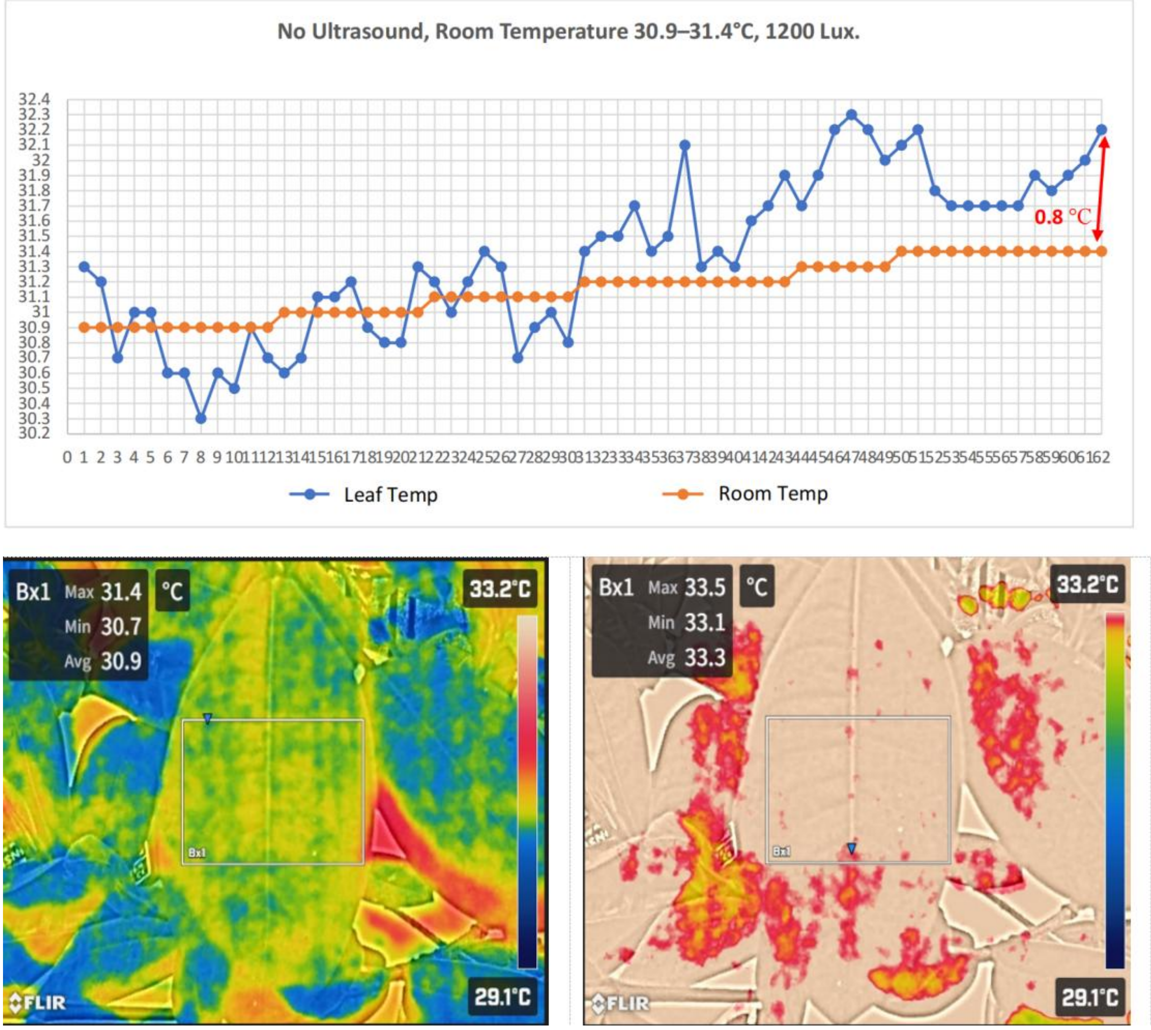

Figure 5. Results for No Ultrasound, 30.9-31.4°C, 1200Lux

Table 2. Temperature for Experiment # 2

Leaf Surface Fixed Area Temperature	08:20 Leaf Thermal Image	09:21 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	32	33	1
Minimum (°C)	31.3	32.2	0.9
Average (°C)	31.5	32.5	1

Experiment # 3

- **Test Time**: 11: 10—12:10
- **Room Temperature**: 27.1—26.8°C
- **Humidity**: 50%
- **Temperature Change**:
  - **Maximum**: 26.9°C → 28.0°C (+1.1°C)
  - **Minimum**: 26.5°C → 27.6°C (+1.1°C)
  - **Average**: 26.7°C → 27.8°C (+1.1°C)
- **Lighting**: 1000 Lux

Results are shown in Fig.6.

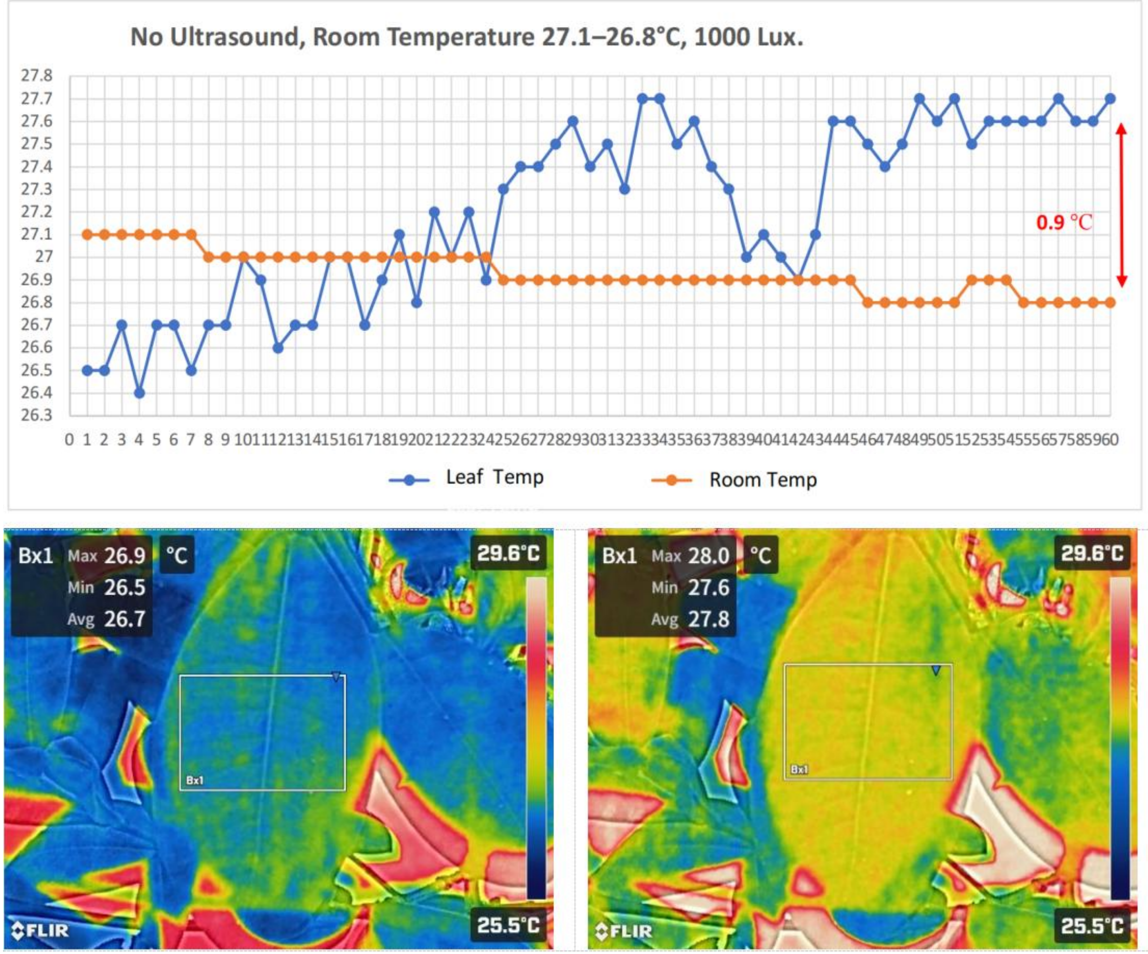

Figure 6. Results for No Ultrasound, 27.1-26.8°C,1000Lux

Table 3. Temperature for Experiment # 3

Leaf Surface Fixed Area Temperature	11:10 Leaf Thermal Image	12:10 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	26.9	28.0	1.1
Minimum (°C)	26.5	27.6	1.1
Average (°C)	26.7	27.8	1.1

Experiment # 4

- **Test Time**: 13:40—14:40
- **Ultrasound Condition**: 22 kHz
- **Room Temperature**: 28.2—29.7°C
- **Humidity**: 64%
- **Temperature Change**:
    - **Maximum**: 30.4°C → 31.9°C (+1.5°C)
    - **Minimum**: 29.3°C → 31.4°C (+2.1°C)
    - **Average**: 29.7°C → 31.7°C (+2.0°C)
- **Lighting**: 1100 Lux

Results are shown in Fig.7.

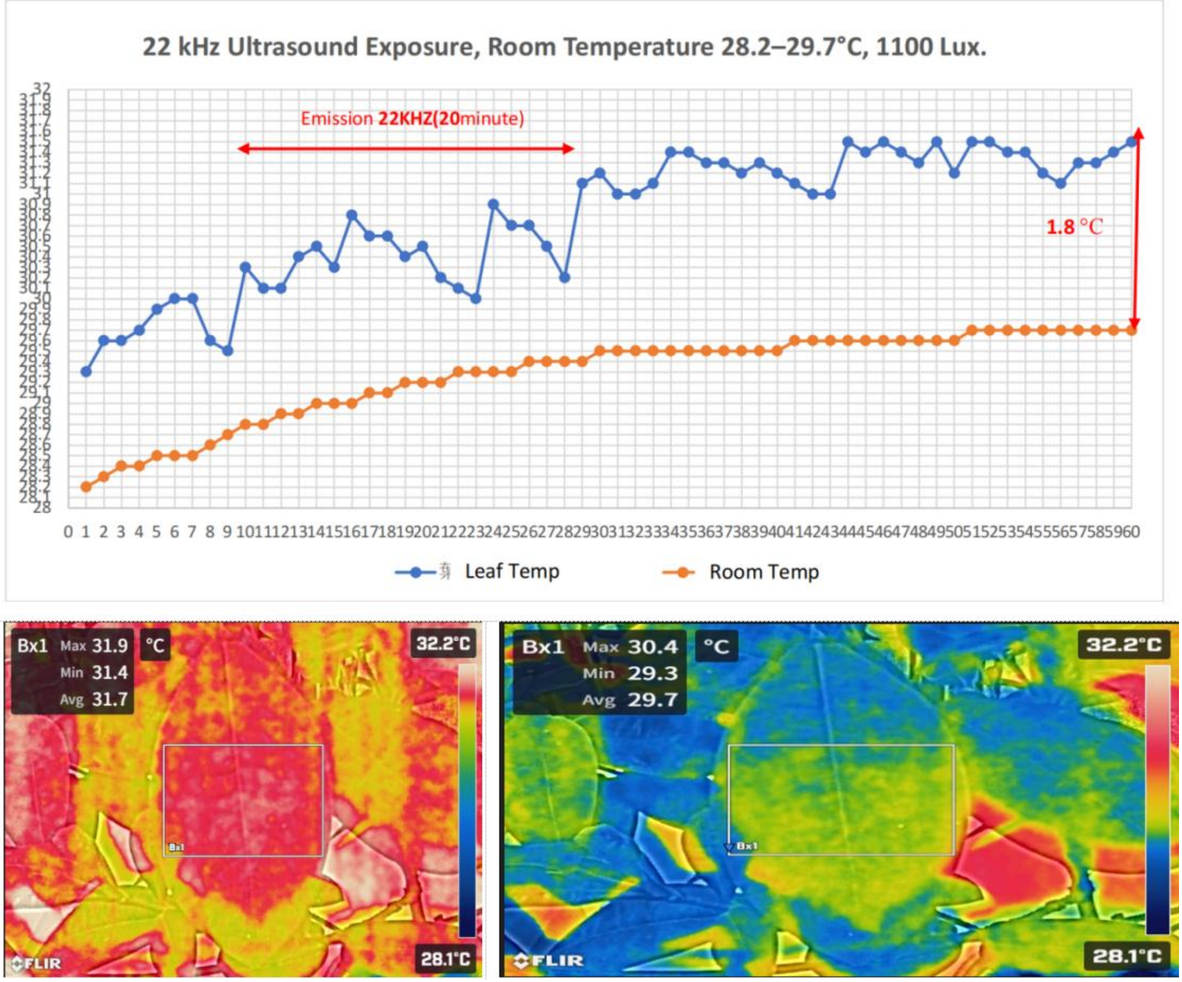

Figure 7. Results for 22kHz Ultrasound, 28.2-29.7°C, 1100Lux

Table 4. Temperature for Experiment # 4

Leaf Surface Fixed Area Temperature	13:40 Leaf Thermal Image	14:40 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	30.4	31.9	1.5
Minimum (°C)	29.3	31.4	2.1
Average (°C)	29.7	31.7	2.0

Experiment # 5

- **Test Time**: 13:05–14:05
- **Ultrasound Condition**: 30 kHz (With Watering)
- **Room Temperature**: 25.4–25.6°C
- **Humidity**: 67%
- **Temperature Change**:
  - ○ **Maximum**: 26.1°C → 27.6°C (+1.5°C)
  - ○ **Minimum**: 25.7°C → 27.1°C (+1.4°C)
  - ○ **Average**: 25.8°C → 27.3°C (+1.5°C)
- **Lighting**: 1000 Lux

Results are shown in Fig.8.

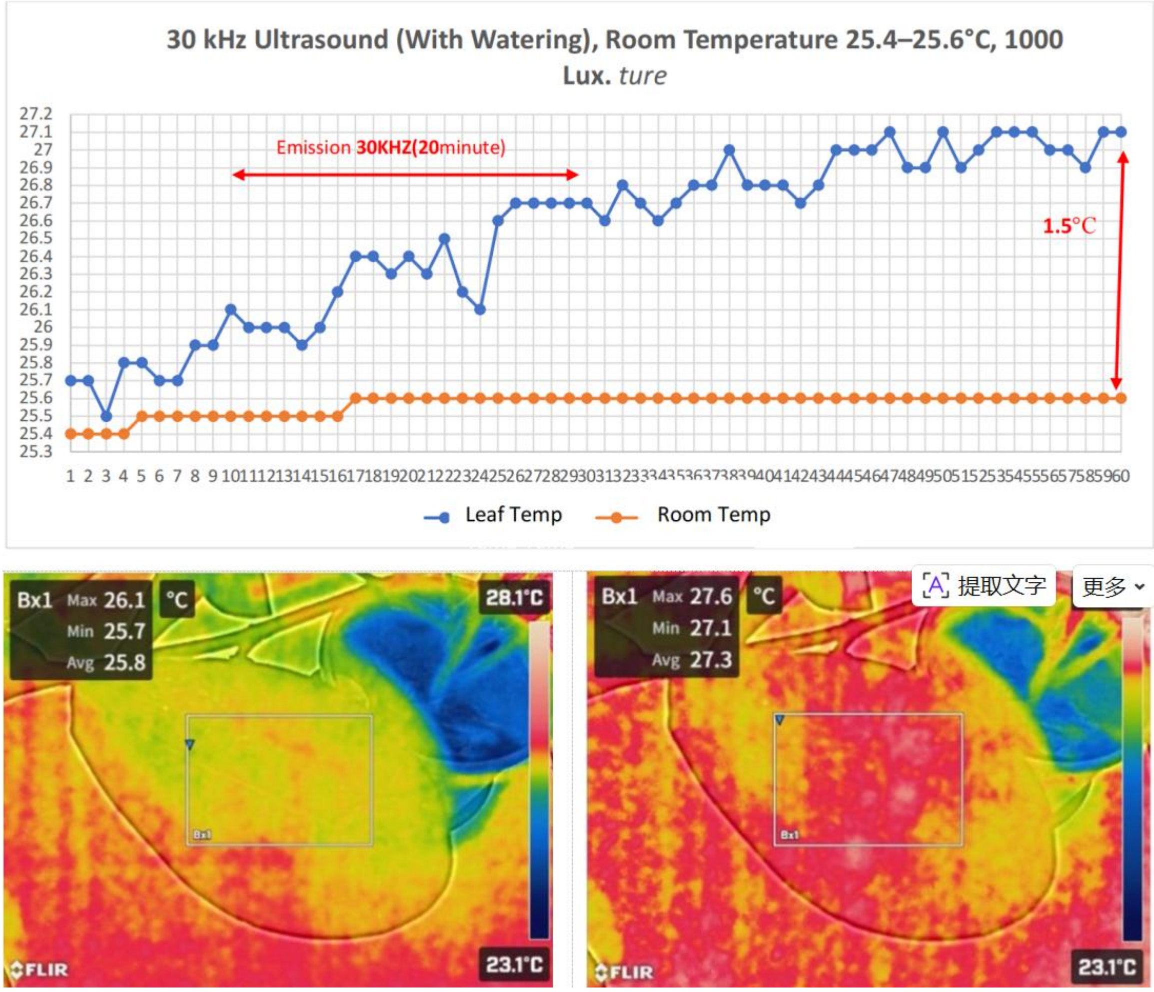

Figure 8. Results for 30kHz Ultrasound, 25.4-25.6°C,1000Lux

Table 5. Temperature for Experiment # 5

Leaf Surface Fixed Area Temperature	13:05 Leaf Thermal Image	14:05 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	26.1	27.6	1.5
Minimum (°C)	25.7	27.1	1.4
Average (°C)	25.8	27.3	1.5

Experiment # 6

- **Test Time**: 12:37—13:37
- **Ultrasound Condition**: 30 kHz
- **Room Temperature**: 24.0—24.1°C
- **Humidity**: 74%
- **Temperature Change**:
  - **Maximum**: 24.6°C → 26.4°C (+1.8°C)
  - **Minimum**: 24.0°C → 25.7°C (+1.7°C)
  - **Average**: 24.2°C → 26.0°C (+1.8°C)
- **Lighting**: 900 Lux

Results are shown in Fig.9.

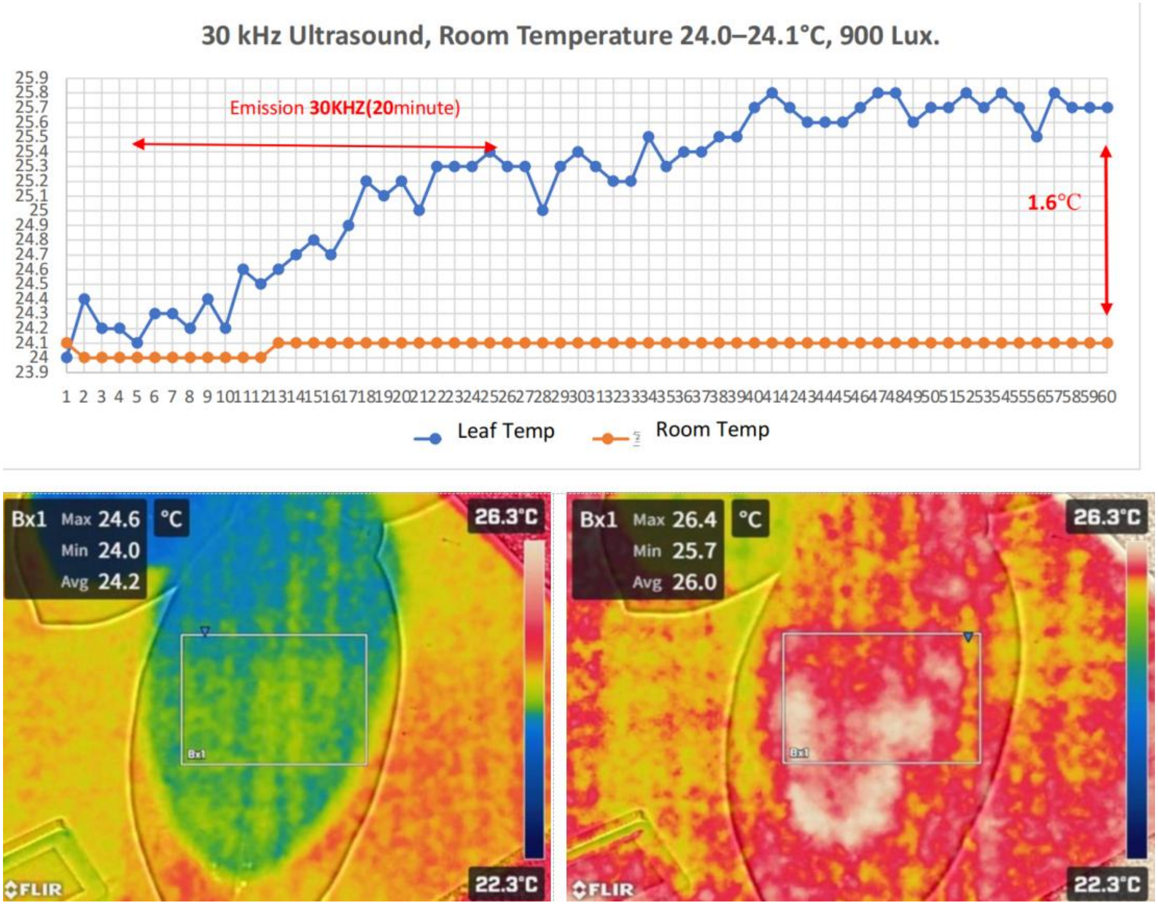

Figure 9. Results for 30kHz Ultrasound, 24.0-24.1°C,900Lux

Table 6. Temperature for Experiment # 6

Leaf Surface Fixed Area Temperature	12:37 Leaf Thermal Image	13:37 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	24.6	26.4	1.8
Minimum (°C)	24.0	25.7	1.7
Average (°C)	24.2	26.0	1.8

Experiment # 7

- **Test Time**: 08:55–09:55
- **Room Temperature**: 24.5–24.6°C
- **Humidity**: 80%
- **Temperature Change**:
  - **Maximum**: 26.0°C → 27.1°C (+1.1°C)
  - **Minimum**: 25.3°C → 26.5°C (+1.2°C)
  - **Average**: 25.5°C → 26.8°C (+1.3°C)
- **Lighting**: 900 Lux

Results are shown in Fig.10.

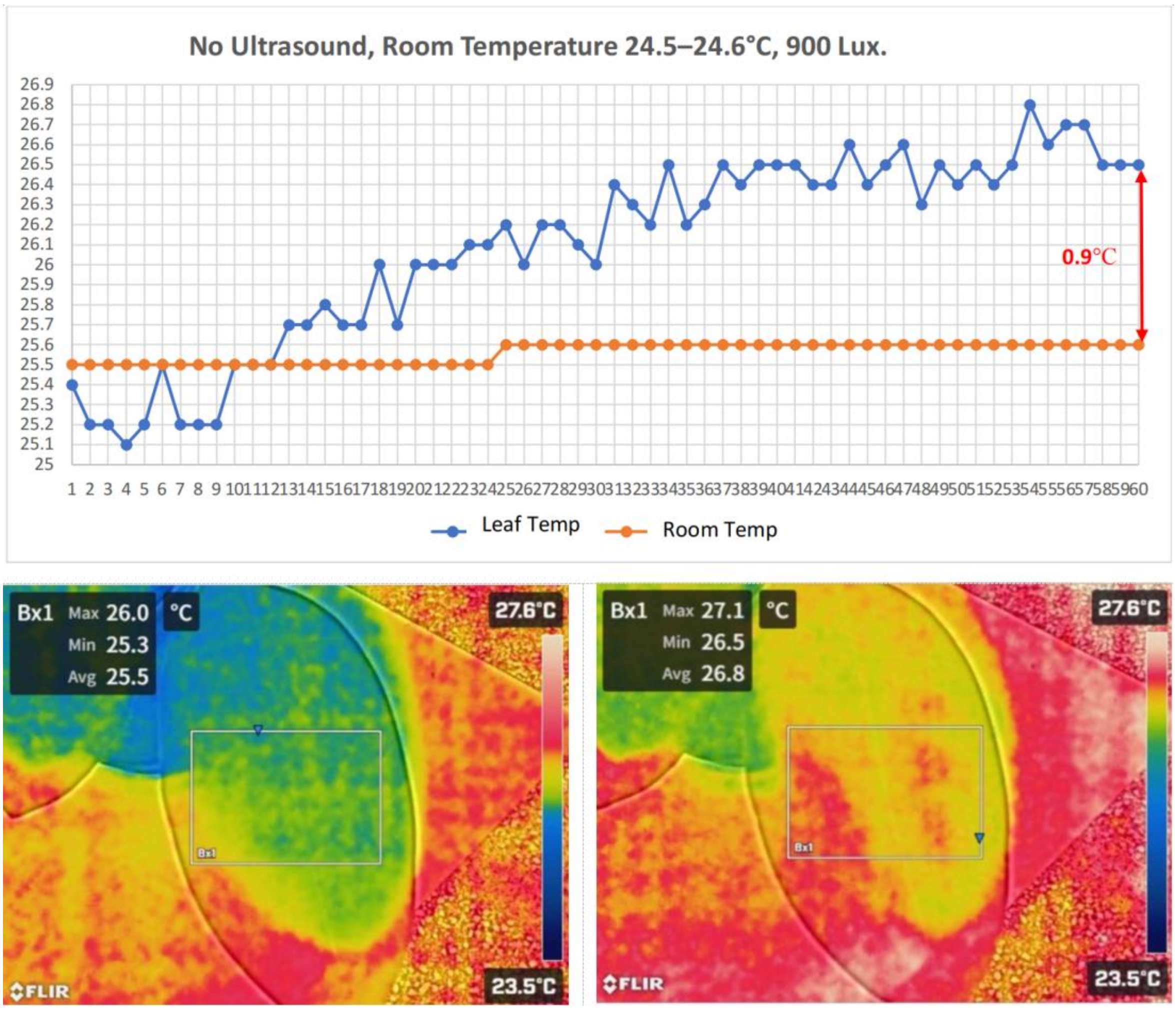

Figure 10. Results for No Ultrasound, 24.5-24.6°C,900Lux

Table 7. Temperature for Experiment # 7

Leaf Surface Fixed Area Temperature	08:55 Leaf Thermal Image	09:55 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	26.0	27.1	1.1
Minimum (°C)	25.3	26.5	1.2
Average (°C)	25.5	26.8	1.3

Experiment # 8

- **Test Time**: 14:00–15:00
- **Ultrasound Condition**: 30 kHz
- **Room Temperature**: 27.2–27.3°C
- **Humidity**: 71%
- **Temperature Change**:
    - **Maximum**: 27.8°C → 29.7°C (+1.9°C)
    - **Minimum**: 27.3°C → 29.2°C (+1.9°C)
    - **Average**: 27.6°C → 29.5°C (+1.9°C)
- **Lighting**: 1000 Lux

Results are shown in Fig.11.

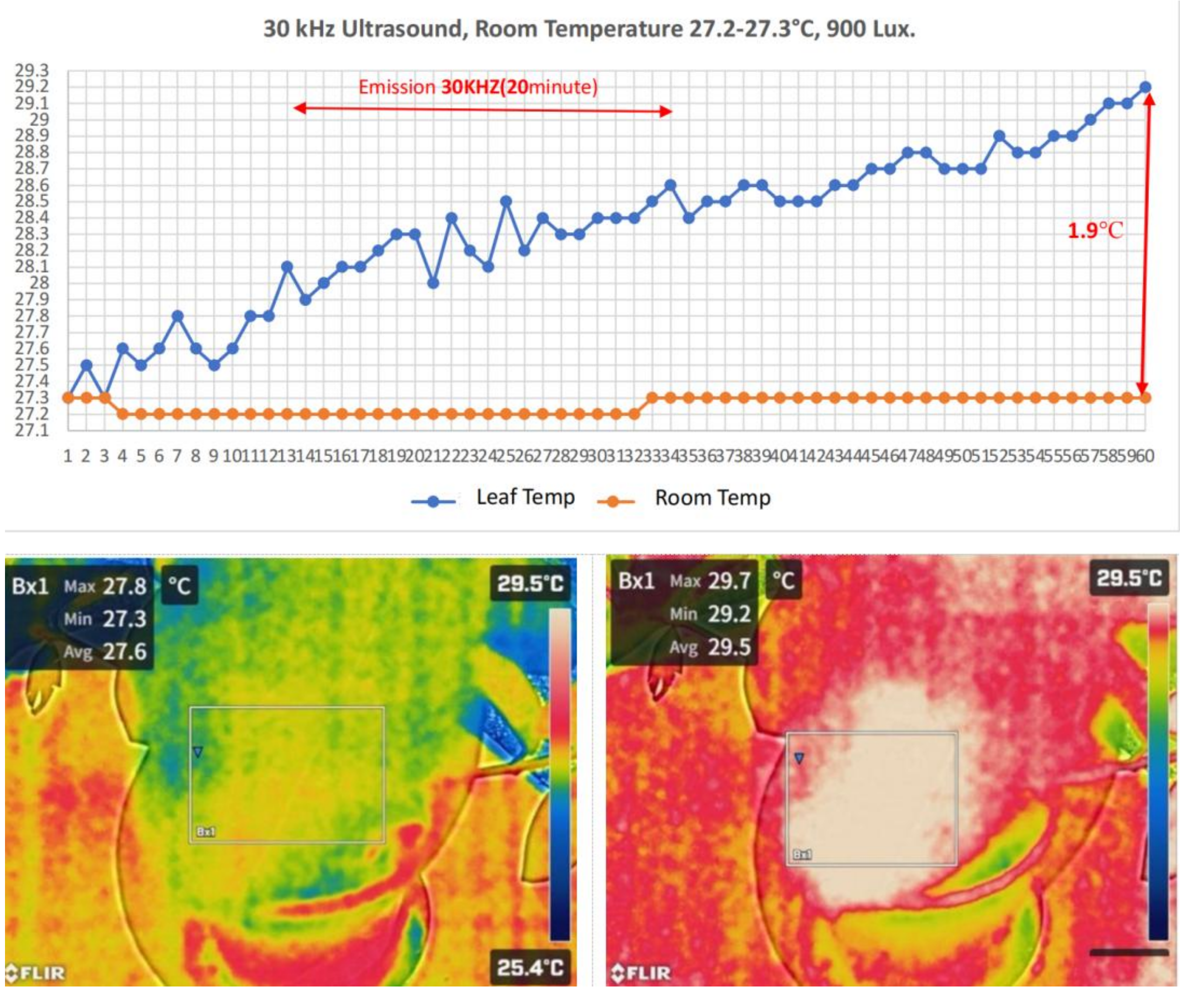

Figure 11. Results for 30kHz Ultrasound, 27.2-27.3°C,900Lux

Table 8. Temperature for Experiment # 8

Leaf Surface Fixed Area Temperature	14:00 Leaf Thermal Image	15:00 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	27.8	29.7	1.9
Minimum (°C)	27.3	29.2	1.9
Average (°C)	27.6	29.5	1.9

Experiment # 9

- **Test Time**: 12:25–13:25
- **Room Temperature**: 27.3–27.5°C
- **Humidity**: 77%
- **Temperature Change**:
  - **Maximum**: 27.9°C → 29.0°C (+1.1°C)
  - **Minimum**: 27.5°C → 28.4°C (+0.9°C)
  - **Average**: 27.7°C → 28.7°C (+1.0°C)
- **Lighting**: 900 Lux

Results are shown in Fig.12.

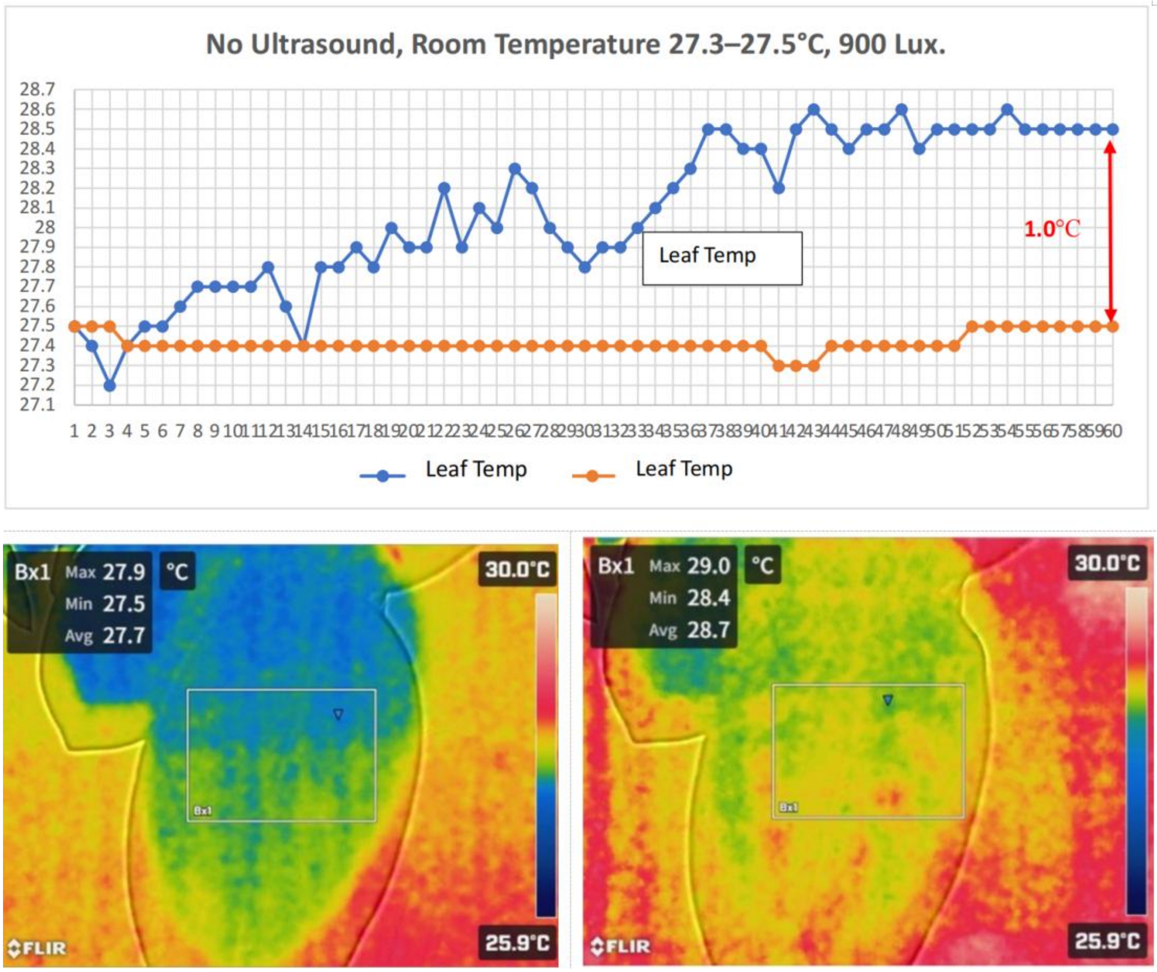

Figure 12. Results for No Ultrasound, 27.3-27.5°C,900Lux

Table 9. Temperature for Experiment # 9

Leaf Surface Fixed Area Temperature	12:25 Leaf Thermal Image	13:25 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	27.9	29.0	1.1
Minimum (°C)	27.5	28.4	0.9
Average (°C)	27.7	28.7	1.0

Experiment # 10

- **Test Time**: 12:00–13:00
- **Room Temperature**: 23.4–23.6°C
- **Humidity**: 68%
- **Temperature Change**:
  - **Maximum**: 24.6°C → 25.5°C (+0.9°C)
  - **Minimum**: 24.3°C → 24.8°C (+0.5°C)
  - **Average**: 24.5°C → 25.1°C (+0.6°C)
- **Lighting**: 850 Lux

Results are shown in Fig.13.

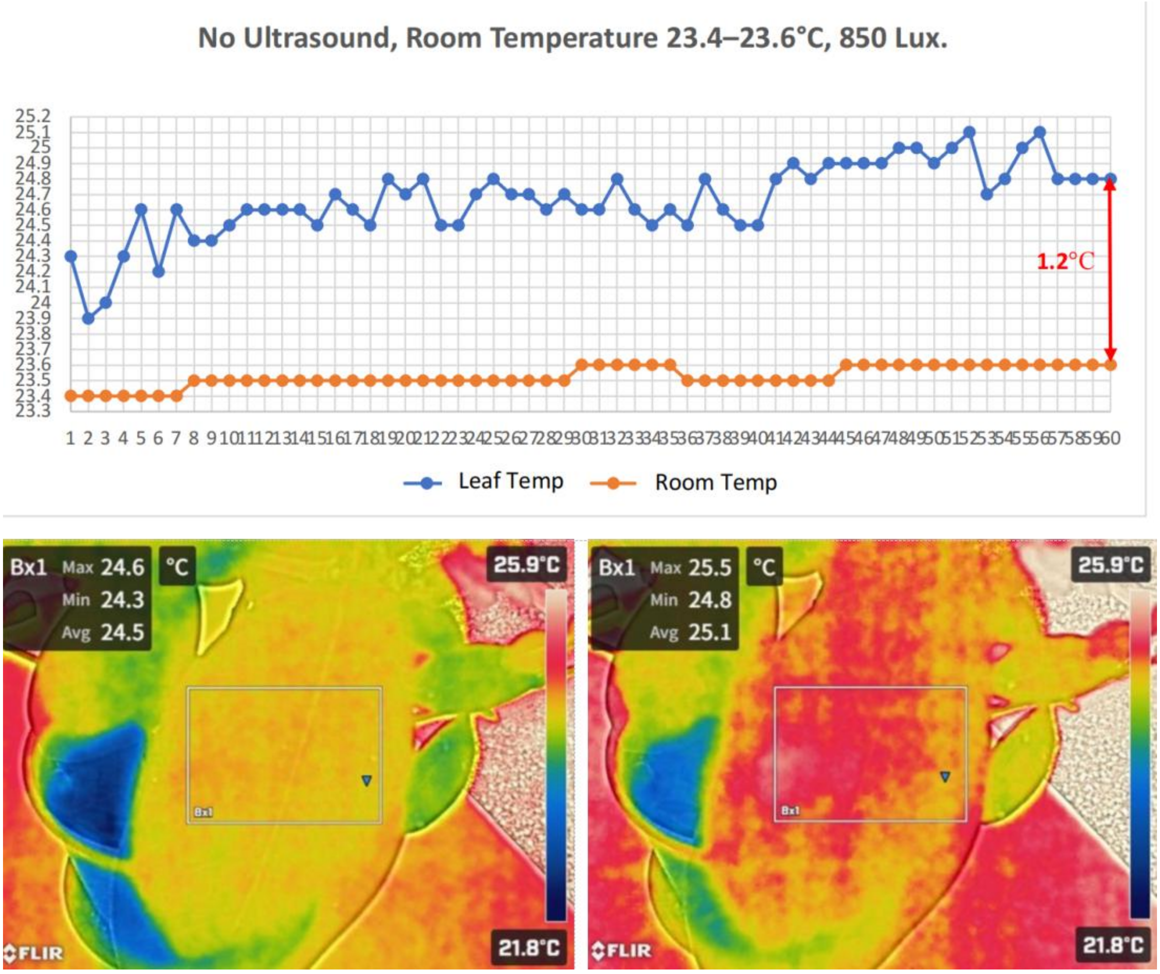

Figure 13. Results for No Ultrasound, 23.4-23.6°C,850Lux

Table 10. Temperature for Experiment # 10

Leaf Surface Fixed Area Temperature	12:00 Leaf Thermal Image	13:00 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	24.6	25.5	0.9
Minimum (°C)	24.3	24.8	0.5
Average (°C)	24.5	25.1	0.6

Experiment # 11

- **Test Time**: 09:00–10:00
- **Room Temperature**: 22.9–22.7°C
- **Humidity**: 42%
- **Temperature Change**:
    - **Maximum**: 23.3°C → 24.5°C (+1.2°C)
    - **Minimum**: 22.9°C → 23.8°C (+0.9°C)
    - **Average**: 23.1°C → 24.1°C (+1.0°C)
- **Lighting**: 800 Lux

Results are shown in Fig.14.

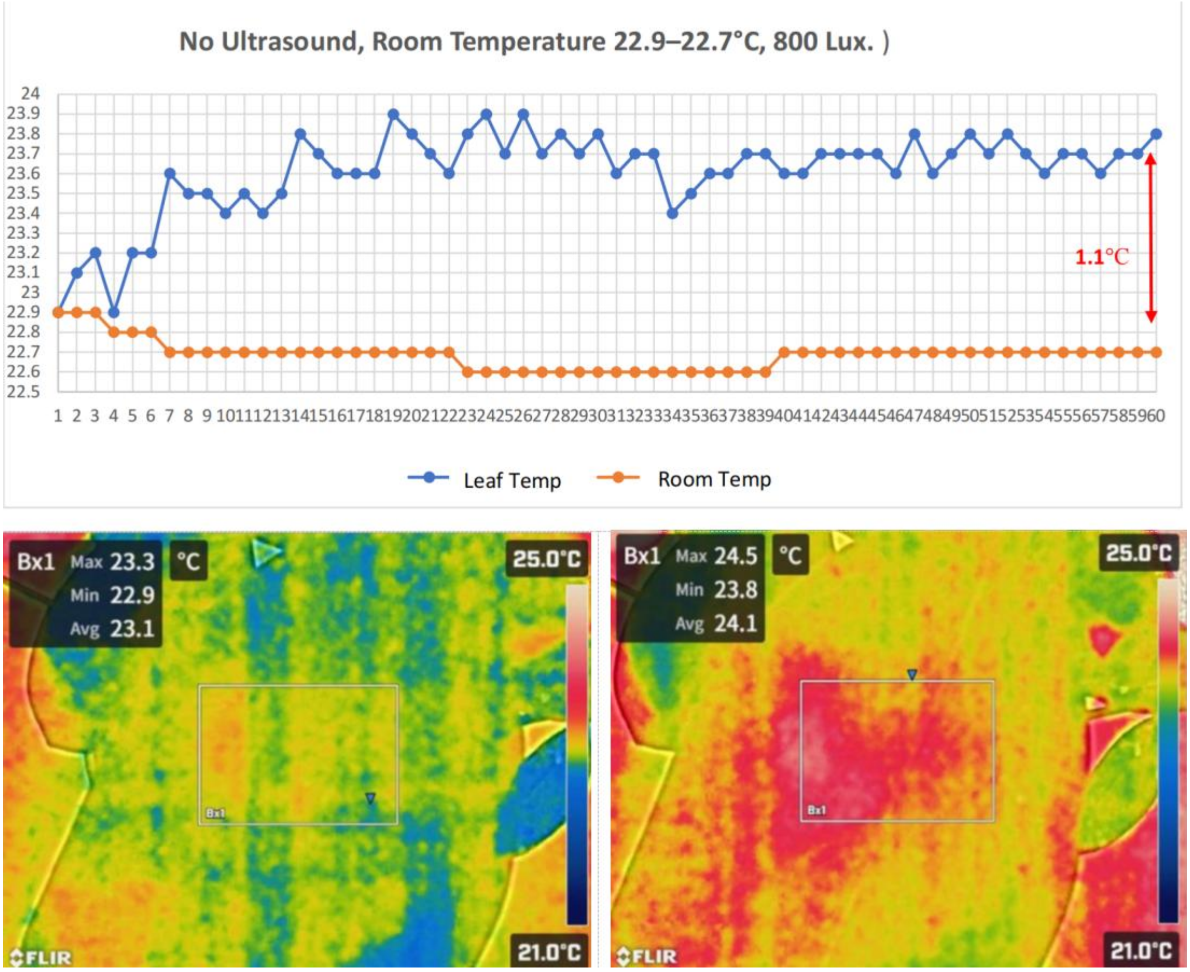

Figure 14. Results for No Ultrasound, 22.9-22.7°C,800Lux

Table 11. Temperature for Experiment # 11

Leaf Surface Fixed Area Temperature	09:00 Leaf Thermal Image	10:00 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	23.3	24.5	1.2
Minimum (°C)	22.9	23.8	0.9
Average (°C)	23.1	24.1	1.0

Experiment # 12

- **Test Time**: 13:00–14:00
- **Ultrasound Condition**: 22 kHz
- **Room Temperature**: 22.7–22.8°C
- **Humidity**: 39%
- **Temperature Change**:
  - **Maximum**: 23.2°C → 25.1°C (+1.9°C)
  - **Minimum**: 22.9°C → 24.3°C (+1.4°C)
  - **Average**: 23.0°C → 24.8°C (+1.8°C)
- **Lighting**: 800 Lux

Results are shown in Fig.15.

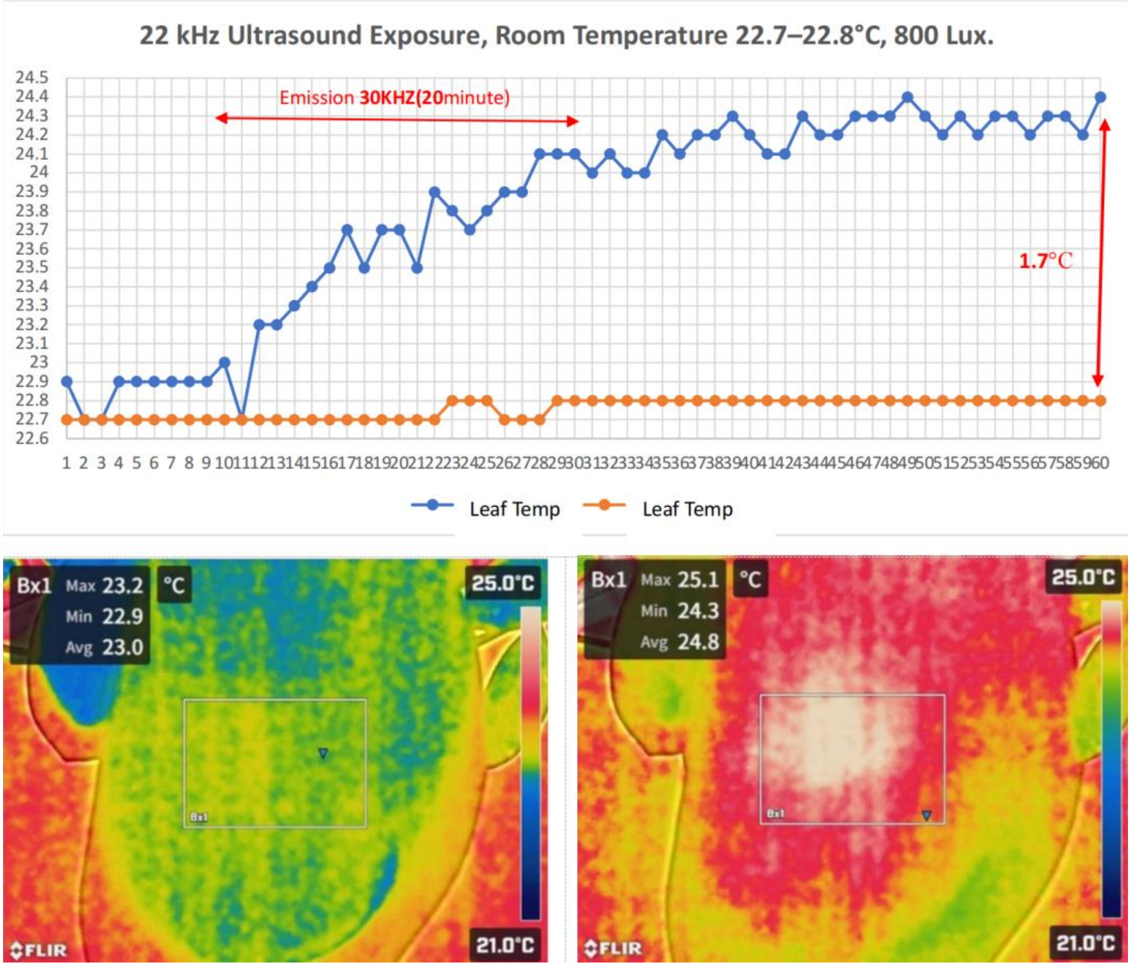

Figure 15. Results for 22kHz Ultrasound, 22.7-22.8°C,800Lux

Table 12. Temperature for Experiment # 12

Leaf Surface Fixed Area Temperature	13:00 Leaf Thermal Image	14:00 Leaf Thermal Image	Temperature Difference (°C)
Maximum (°C)	23.2	25.1	1.9
Minimum (°C)	22.9	24.3	1.4
Average (°C)	23.0	24.8	1.8

6. Results

6.1. Ultrasound Exposure Increased Leaf Temperature

- Ultrasound exposure consistently produced greater increases in leaf surface temperature across multiple tests compared to non-ultrasound conditions.

- The temperature difference in the ultrasound-exposed groups averaged 0.8–1.4°C greater. Lower Transpiration Effect

- The rise in temperature implies that ultrasonic signals induce stomatal closure, thereby lowering transpiration.

- This effect was strongest at 30 kHz ultrasound, which shows that it changes with frequency.

6.2. Possibilities for Application in Agriculture

- The discovery of ultrasound as a physiological signal by plants could improve the efficiency of precision irrigation strategies, therefore increasing water conservation.

- The development of non-invasive plant health monitoring systems could be facilitated by an understanding of these ultrasonic processes, which would allow for the early detection of water stress as shown in Table 13&14.

Table 13. Leaf Temperature Changes in Non-Ultrasound Experiment

Leaf Surface Fixed Area Temperature (1-Hour Difference)	#1 (22kHz)	#4 (22kHz)	#5 (30kHz)	#6 (30kHz)	#8 (30kHz)	#11 (22kHz)
Maximum (°C) Temperature Difference	2.1	1.5	1.5	1.8	1.9	1.9
Minimum (°C) Temperature Difference	2.4	2.1	1.4	1.7	1.9	1.4
Average (°C) Temperature Difference	2.4	2.0	1.5	1.8	1.9	1.8
Ultrasound Emission (20 min)	↑0.9	↑0.9	↑0.7	↑1.2	↑0.8	↑1.1
Room Temperature (°C)	30.9-31.2	28.2-29.7	25.4-25.6	24.0-24.1	27.2-27.3	22.7-22.8
Humidity (%)	70	64	67	74	71	63

Table 14. Leaf Temperature Changes in Ultrasound Experiment

Leaf Surface Fixed Area Temperature (1-Hour Difference)	#2	#3	#7	#9	#10	#12
Maximum (°C) Temperature Difference	1.0	1.1	1.1	1.1	0.9	1.2
Minimum (°C) Temperature Difference	0.9	1.1	1.2	0.9	0.5	0.9
Average (°C) Temperature Difference	1.0	1.1	1.3	1.0	0.6	1.0
Room Temperature (°C)	30.9-31.4	27.1-26.8	24.5-24.6	27.3-27.5	23.4-23.6	22.9-22.7
Humidity (%)	62	50	80	77	68	63

7. Discussion and Implications

7.1. Use of Ultrasound in Plant Communication

This research offers strong proof that plants control transpiration by using ultrasonic signals as a physiological signal. I verify that ultrasonic exposure affects stomatal behavior by proving that ultrasonic waves raise leaf surface temperature, hence leading to stomatal closure and lower evapotranspiration.

These results, observed consistently across multiple trials, reinforce the robustness of the findings and indicate a strong correlation between ultrasound exposure and stomatal regulation.

Most importantly, this result corresponds with earlier research on water plants, therefore strengthening the theory that ultrasonic emissions work as a plant communication tool. The average temperature increases 0.8°C or more in the plants that been exposed by ultrasound, shows the biological relevance of ultrasonic signaling.

7.2. Implications for Sustainability and Agriculture

Plant acoustic signals define future technologies, environmental protection, and agricultural research as well as their dependencies. Finding these signals sets the stage for ground-breaking innovations in precise irrigation, early drought detection, and controlling plant growth. Knowing how plants react to ultrasonic waves could lead to useful applications maximizing resource efficiency and raising crop resilience against climate change.

7.3. Water Conservation and Precision Agriculture

By allowing farmers to create real-time, flexible irrigation plans, ultrasonic monitoring and infrared thermal imaging could guarantee that crops receive just the right amount of water, therefore increase water utilization and minimize agricultural losses since climate change worsens globally droughts.

7.4. Non-Chemical Control of Plant Growth

Using ultrasonic signals in artificial simulation to affect plant behavior could result in non-chemical growth control, therefore lessening of dependency on pesticides and chemical fertilizers.

7.5. The Rise of Bioacoustics Era

The study opens new directions for sound-based plant interactions. a significant progress in the field of plant bioacoustics, Future research should:

- Investigate the role of ultrasound in a wider range of plant species.
- Explore how different ultrasound frequencies influence plant physiology.
- Evaluate whether ultrasound-based treatments can enhance agricultural productivity and sustainability.

8. Conclusion

This research provides crucial evidence that ultrasound exposure (22 kHz and 30 kHz) raises leaf temperature by approximately 0.8°C. It confirms the impact of ultrasonic exposure on transpiration regulation. These findings support the hypothesis that plants utilize ultrasonic signals to manage water loss. Moreover, it shows that plants may produce and react to ultrasonic signals directly affecting their physiological processes.

This discovery changes our perspective on agriculture and sustainable development.

Through ongoing research on plant bioacoustics, we can fully comprehend plant communication, transforming crop management, environmental sustainability, and interconnections between ecosystems. If plants can "speak" through ultrasonic waves, it is time for us to learn how to listen—**and to apply this knowledge to redefine human- plant interactions globally, maximize resource management, and improve sustainable agriculture.

References

[1] Agnieszka, W. K., Kristine, Y. C., Oula, G., & David, S. E. (2019). Leaf age and eCO2 both influence photosynthesis by increasing light harvesting in mature *Eucalyptus tereticornis* at EucFACE. *Environmental and Experimental Botany, 167*, 103859. https://doi.org/10.1016/j.envexpbot.2019.103859.

[2] Baldwin, I. T., Halitschke, R., Paschold, A., von Dahl, C. C., & Preston, C. A. (2006). Volatile signaling in plant-plant interactions: “talking trees” in the genomics era. *Science, 311*, 812 – 815. https://doi.org/10.1126/science.1118446.

[3] Chen, J. (n.d.). *4-2 Leaves and Transport Function*. Camdemy. https://www.camdemy.com/media/15562.

[4] Dutta, S., Chen, Z., Kaiser, E., Matamoros, P. M., Steeneken, P. G., & Verbiest, G. J. (2022). Ultrasound pulse emission spectroscopy method to characterize xylem conduits in plant stems. *Research*. https://spj.science.org/doi/10.34133/2022/9790438#U94684318.

[5] Ghosh, R., Mishra, R. C., Choi, B., Kwon, Y. S., Bae, D. W., Park, S. C., ... & Bae, H. (2016). Exposure to sound vibrations lead to transcriptomic, proteomic, and hormonal changes in *Arabidopsis*. *Scientific Reports, 6* (1), 33370. https://doi.org/10.1038/srep33370.

[6] Gilbert, L., & Johnson, D. (2017). Plant–plant communication through common mycorrhizal networks. In *Advances in Botanical Research* (Vol. 82, pp. 83 - 97). Academic Press.

[7] Haswell, E. S., Phillips, R., & Rees, D. C. (2011). Mechanosensitive channels: what can they do and how do they do it? *Structure, 19* (10), 1356 - 1369. https://doi.org/10.1016/j.str.2011.09.005.

[8] Heffner, H. E., & Heffner, R. S. (2007). Hearing ranges of laboratory animals. *Journal of the American Association for Laboratory Animal Science, 46* (1), 20 - 22.

[9] José, A. C., et al. (2021). Ultrasound irradiation effect on photosynthesis and transpiration of aquatic lirium plants. *International Journal of Radiation Biology, 97* (11), 1617 - 1623. https://pubmed.ncbi.nlm.nih.gov/34402394/.

[10] Khait, I., Lewin-Epstein, O., Sharon, R., Saban, K., Perelman, R., Boonman, A., ... & Hadany, L. (2018). Plants emit informative airborne sounds under stress. *Biorxiv, 507590*. https://www.sci.news/biology/plants-ultrasonic- clicks-07895.html.

[11] Khait, I., Lewin-Epstein, O., Sharon, R., Saban, K., Goldstein, R., Anikster, Y., ... & Hadany, L. (2023). Sounds emitted by plants under stress are airborne and informative. *Cell, 186* (7), 1328 - 1336.

[12] McElrone, A. J., Choat, B., Gambetta, G. A., & Brodersen, C. R. (2013). Water uptake and transport in vascular plants. *Nature Education Knowledge, 4* (5), 6. https://www.nature.com/scitable/knowledge/library/water-uptake-and-transport-in-vascular-plants - 103016037/.

[13] M. Zhang, & Willison, J. H. M. (1992). Electrical impedance analysis in plant tissues: The effect of freeze-thaw injury on the electrical properties of potato tuber and carrot root tissues. *Canadian Journal of Plant Science, 72*, 545 - 553. https://doi.org/10.4141/cjps92 - 063.

[14] Oda, S., Sakaguchi, M., Yang, X., Liu, Q., Iwasaki, K., & Nishibayashi, K. (2021). Ultrasonic treatment suppresses ethylene signaling and prolongs the freshness of spinach. *Food Chemistry: Molecular Sciences, 2*, 100026. https://doi.org/10.1016/j.fochms.2021.100026.

[15] Orzechowska, A., Trtílek, M., Tokarz, K., & Rozpądek, P. (2020). A study of light-induced stomatal response in *Arabidopsis* using thermal imaging. *Biochemical and Biophysical Research Communications, 530* (3), 603 - 609. https://doi.org/10.1016/j.bbrc.2020.09.020.

[16] Ponomarenko, A., Vincent, O., Pietriga, A., Cochard, H., Badel, É., & Marmottant, P. (2014). Ultrasonic emissions reveal individual cavitation bubbles in water-stressed wood. *Journal of the Royal Society Interface, 11* (99), 20140480. https://doi.org/10.1098/rsif.2014.0480.

[17] Ratnesh, C. M., Ritesh, G., & Hanhong, B. (2016). Plant acoustics: In the search of a sound mechanism for sound signaling in plants. *Journal of Experimental Botany, 67* (15), 4483 – 4494. https://doi.org/10.1093/jxb/erw209.

[18] Rafał, C. (2016). Trees call for water when they are thirsty. *Forest Monitor.*https://www.forest-monitor.com/en/trees-call-for-water-when-they-are-thirsty/.

[19] Taiwan Seismometer Company. (n.d.). Vegetation crop water stress index mapping dedicated unmanned aerial vehicle infrared thermal imaging system. *PDIC.* https://www.pdic.com.tw/workswell-cwsi-crop-water-stress-index-camera-wiris-agro-r.html.