Modelling Resilience: Tomato Plant Physiological Responses to Sound Under Stress

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Abstract

Defining what it means to ‘be alive’ is a pursuit that defies yet unifies multiple points of our understanding of resilience. To explore this concept, resilience can be viewed as a central criterion for redefining life, particularly in non-animal forms like plants, whose responses to stress reflect adaptive survival, and consequently, resilience. Emerging studies in plant bioacoustics reveal how sound frequencies influence plant height and leaf growth when stress is induced. By expanding on these findings, this research explores how sound frequencies affect tomato plant height and leaf growth as a sign of resilience. Through a controlled experiment, plants were exposed to specific sound frequencies (None, 400 Hz, 800 Hz, and 1200 Hz) inside a soundproof-box environment. Measurements of plant height and leaf growth were recorded to evaluate differences between control and experimental groups, as well as the prevalence of resilience. Collected data helped evaluate the hypothesis of “When the controlled soundproof environment is incorporated, the experiment will result in statistically significant differences in height growth in tomato plants under stress conditions and sound frequencies.” The quantitative data were then analyzed to determine how sound frequencies enhanced plant growth, which were interpreted qualitatively to consider how these biological physiological responses might inform our understanding of resilience as a defining characteristic of life. This study aims to contribute to discussions within the literature on plant-sound interactions within soundproofed environments and the resilience factor as a connecting key indicator of what it means to truly “be alive.”

Keywords: Resilience, bioacoustics, “lifeness,” physiological, boundary object, normative, descriptive, sound-plant, cultivars

INTRODUCTION

There is an issue with the methodological consistency of research exploring the influence of sound frequencies on plant growth (Chowdury, 2014). By using the sound-plant experimental results to model resilience as a measurable agent to measure “lifeness,” or the state and/or quality of having a life, resilience acts as a boundary object, a connecting element between current interdisciplinary definitions of “being alive” to one definition centered on *adaptability and survival*.

Despite emerging research on how sound frequencies influence plant life, there is a lack of comprehensive studies mediating this relationship. Previous research offers insights into the effects of music frequencies of plant physiology, but methods for recording and analyzing data are often inconsistent or underreported, leaving gaps in the reliability of findings. Additionally, sound-proofed environments are rarely used in experimental design, which presents a novel perspective for exploring this correspondence, especially through an inferred philosophical lens on the definition of "being alive." Current studies on the effects of sound frequencies in instrumentation and data collection hinder deeper understanding and reproducibility of results linking sound frequencies to plant growth. In this study, I examined the effects of sound frequencies as a projected increase of resilience in tomato plants. This was performed through sound frequency exposure on tomato plants to measure their plant height growth and leaf count growth under two varying stressed conditions: salinity and drought.

LITERATURE REVIEW

Sound has long since been associated with vitality and harmony, extending from human existence to the natural plant responses in the environment. In recent decades, studies in plant bioacoustics, or an interdisciplinary science on studying the production, reception, and transmission of sounds, have revealed that plants can perceive and respond to sound frequencies, influencing growth, gene expression, and stress resilience (Jung et al., 2018; Gagliano et.al., 2012). Yet, while these findings redefine how we view plant sensitivity to sound frequencies, philosophical concepts continue to debate what it means to "be alive," often excluding non-animal life forms from these discussions (Kushner, 1984; Fröhlich, 2022). This disjunction between empirical evidence and conceptual understanding raises an essential question: if plants demonstrate forms of adaptive and sonic responsiveness, can this be interpreted as a kind of resilience, and therefore, a redefined meaning to "being alive"?

According to the quantitative study investigating connections between sound wave frequencies to plant growth, Hassanien (2014) revealed that audible sound frequencies on plant crops enhanced several biological processes while generating sounds through plant acoustic frequency technology (PAFT). This is supported by other studies, stating that plant bioacoustics rely on the evolutionary rationale of plant perceptions of sound vibrations depending on sound pressure levels (SPL) and mechanoreceptions present. Another article by authors Atluntas and Ozkurt (2019) presented how abiotic stress influenced plant developments as an alternative to mechanical or physical force stress, which expanded the importance of sound pressure and velocity rates in seeing increased biological processes when applying the use of different types of sound frequencies. These four sources present that there is a solid link between sound frequencies in subsequently influencing plant growth, but may need more transparent descriptions of the methodological steps taken in order to produce substantial data on plant physiological responses that indicate resilience, which can be used to re-model current insights on the matter of existence.

Research on the embodiment of resilience bridges the gap in defining resilience through concepts of existential vulnerability (Binder, 2022). This enables new perspectives towards understanding the true nature of which we conceptualize defining resilience as through individual and communal manifestations of authenticity (Kaftanski & Hanson, 2022). Through research-based sound frequency trials, resilience acts as a modelled key indicator of life. This opens discussions to how such concepts could be applied in possibly modelling resilience in plants by refining our comprehension of what it means to 'be alive' through the prevalence of resilience. Malaterre and Chartier (2021) explore this topic by examining it through topic-modelling analyses that map different entities to quantify degrees of "lifeness," thus scrutinizing approaches to implementing definitions through connecting molecular and cellular compounds in living organisms to determine resilience.

Other sources relating to this connection include interdisciplinary outlooks on how resilience is operationalized throughout varying disciplines through two major criteria: structure and function (Nisioti et.al., 2023). All throughout similar studies such as those that Brand and Jax (2007) synthesized, both the descriptive and normative—factual and value-based—concepts help shape how we define resilience outside of plant physiological responses and resilience to stress. This is also presented in the underlying biological processes that allow plants to have sophisticated coping mechanisms to develop stress-tolerant cultivars or selected desired traits in which it retains when propagated (Imran et. al., 2021). These studies show that plant resilience to stress models our understanding of what it truly means to be 'alive' in terms of survival and self-continuity.

RESEARCH GAP

Amongst the developing research on the effects of sound frequencies on the growth of plants, only few studies have explored different sound frequency hertz on tomato plants (Atluntas & Ozkurt, 2019). Incorporating other stress factors aside from sound stress enabled new understanding on the impact of sound frequencies in building resilience through consistent exposure. Moreover, extensive exploration on the definite relationship between sound frequencies to the physiological effects that occur in plant species as a result of sound exposure is quite limited, which poses skepticism on the findings, given that they may be overinterpreted to provide a definite answer of whether such interactions remain a myth or not (BloomsyBox, 2024). BloomsyBox expands on these findings by stating how there is a clear lack of a nervous system in plants, which indicates possible queries on the substantiality of considering plants as suitable mediums of responding to and measuring the effectiveness of sound frequencies on non-animal life forms. Thus, to attempt to eliminate potential disruptions in acquiring accurate, reliable data, while creating grounded approaches to producing verifiable research insight, further analyses on the procedural uniformity between research studies that examine sound-plant interactions were performed.

METHODS and PROCEDURES

METHODS 1.1 *Materials and Tools*

Across the preparation and experimental process of my research, intentional choices for the materials and tools used were exercised. In arranging the plant groups, three plant pots that were nine centimeters in diameter and seven centimeters in height, a medium-sized bucket for seed germination, a gardening spade, a packet of "Jia Tai Seed OP" tomato seeds, a one kilogram bag of loose soil, and a microwave on 180°F or ≈ 82°C to sterilize the soil for 120 seconds in batches, as placed in a microwave-safe bowl were all used. Labeling the plants using a pen and small sticky notes categorized my plant pots appropriately by using "control group, salinity group, and drought group" as the titles. Additionally, in organizing the soundproof environment for my plants, a clear box was used for setup, soundproofing foam for noise cancellation, superglue for connecting the foam, and a pair of scissors to carefully cut the foam to fit according to the box. This allowed me to effectively utilize my speaker in projecting the sound frequencies through the "Sonic" app, as plant height growth was measured using a standard-length ruler. Furthermore, the use of Himalayan salt and two 500 mL beakers for the salinity group mixture, in which salt concentration levels were measured using a Vernier Electrode Amplifier, as connected to the "Vernier Graphing Analysis" app, were combined. All while maintaining safety techniques such as consistently using gardening gloves, cloths or tissue, face masks, and goggles, experimental data were collected using Excel and analyzed in the SPSSAU Website and Statistics Kingdom Website.

1.2 *Soundproof Box Environment*

Before performing the sound frequency experiment, reducing any potential noise disruptions was key to producing accurate, measurable data. The steps to prepare the soundproof box include:

1. Wipe the transparent box down to remove all debris and dust.
2. Using the ruler, measure the soundproof foam to where it fits the inner four corners of the box.
3. After cutting and fitting the foam with scissors inside to ensure no sound interferences, use the superglue to join the foam pieces together. Make the spiky parts face towards the inside of the box.
4. Make enough inner space in the middle of the box and exclude it from having any soundproofing foam. This allows the plant pots and speaker to remain steadily placed during the sound frequency trial.

1.3 *Soil and Plant Preparation*

Maintaining ethical and safe standards in the experiment was done through soil preparation and sterilization, using the 'microwave method' for the most efficient results for my research. To ensure that no harmful microorganisms or bacteria in the soil before planting, batches of soil were safely microwaved until fully sterilized. Rivera (2024) notes that this chosen method is the "most instantaneous way to sterilize soil", while effectively eliminating insects, bacteria, and diseases, which makes it more convenient compared to the other methods like soil solarization or chemical sterilization, which may have taken a longer period of time throughout my experimental process.

<u>Steps to sterilizing the soil</u>:

1. On high heat (180°F or ≈ 82°C), let the soil sterilize for about 120 seconds. It is recommended to separate the soil into batches placed in microwave-safe bowls or containers. Repeat steps until all of the soil in the bag is sterilized.
2. Allow it to cool down before pouring the soil into a medium-sized bucket.

3. After cooling down, transfer the soil into the medium-sized bucket to germinate and allow the tomato seeds to gradually grow into spores then seedlings, which took around two weeks before first experimentation.

Steps to preparing the plants:

1. Once the seedlings have grown to about five to six centimeters over a span of two weeks, carefully transfer them into three separate experimental pots, each having four seedlings in one pot.
2. Using a pen and small sticky notes, label the three plant pots accordingly: “control group, salinity group, and drought group.”

1.4 *Salinity level (Vernier)*

Organizing the stress factors, particularly salinity, needed a consistent and standardized method of preparation. According to an article by Imran et al. (2021) on abiotic stress and perception, salinity stress typically reduces growth rate, lowered root/shoot ratio maturity, as well as smaller or fewer leaves, which suggests a suitable influence to generate resilience markers of measurement. To balance salinity levels for the salinity plant group, calculations for Himalayan salt input were performed, based on the weekly watering schedule on days Monday, Thursday, and Sunday. As all plants, with the exception of the drought group, were watered three times a week with about 8.3 mL of water per day, finding the minimum amount of Himalayan salt was crucial to avoid harming the plants in the beginning stages of the experiment. The following calculations were used to determine the proportion of Himalayan salt required to one cup of water:

250 mL of water ÷ 3 days = 83.33 mL of water (1.6 teaspoons) per day

One teaspoon = 50 mL ⇨ 250 mL/50 mL= 5 mL

5 mL ÷ 3 days = ⅙ teaspoon of Himalayan salt (8.3 g of salt for in 50 mL teaspoon of water)

Thus, for every 250 mL of water used per week, 8.3 mL of Himalayan salt is added specifically for the salinity plant group. However, despite the salinity plant group receiving this standardized amount of salt per week, further consistent records of salinity levels were maintained through the use of a Vernier Electrode Amplifier that detected salt concentration in soil. By quantifying the salt concentration, we observe how much salt is needed to cause stress, given the calculated salinity levels. Steps involve:

1. Using two 500 mL beakers, separate both the soil and water into their respective beakers.

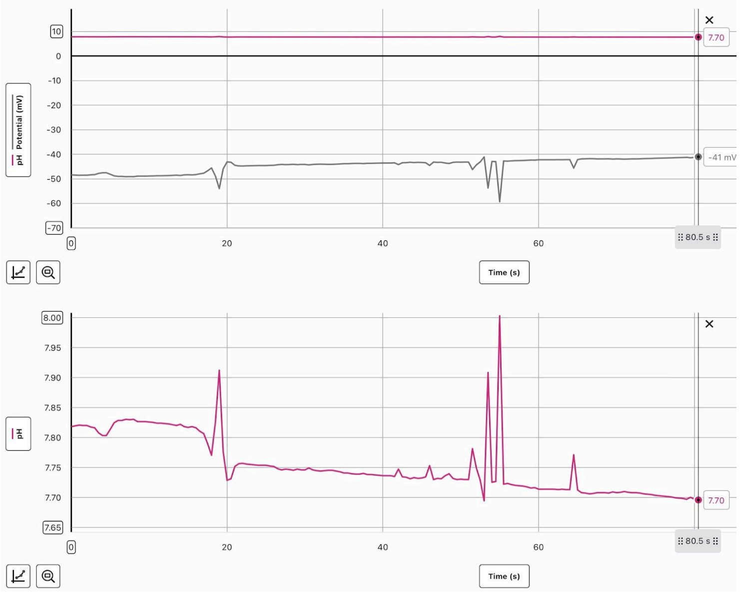
2. Taking 150 grams of soil from the salinity group, after salinity stress exposure, pour contents into the first beaker.
3. With 100 mL of water in the second beaker, now then pour it into the first beaker with the salinity soil.
4. After 10 seconds of the soil eventually reaching the bottom of the beaker as the water is poured, connect the Vernier Electrode Amplifier to any device with the “Vernier Graphing Analysis” app already opened and ready to collect data.
5. Ensure to measure the salinity levels for at least one minute. Three trials and data sets were performed for one minute and 20 seconds in duration per trial. The repeated trials throughout this process is to gather major data that would avoid inconsistencies with the results, which may often occur if too few trials are performed.

As seen in the figure below, the pH levels, across three trials in a span of a minute and 20 seconds, remained at a significantly neutral range between 7.7 to 7.8, with the highest reaching 8.40 when evaluating the three test trials performed. Such data provides informative details on plant conditions under salinity concentration levels that ensure plants within the salinity group receive sufficient amounts of salt without harming them or causing them to wilt or decay too quickly.

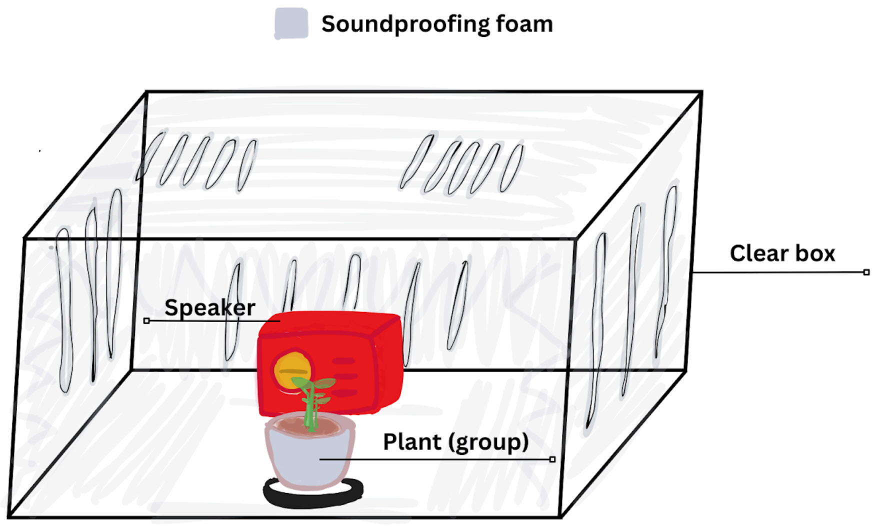
Figure 1. *Soil salinity and pH levels*

1.5 *Frequency Trials*

Conducting the sound frequency trials involved effectively setting up the environment with the least possible sound disruptions for every sound frequency range. As Råberg (n.d.) from the RISE report on soundscapes in plant cultivation states, within ecological and agronomist settings, noise pollution is a considerable factor that may impact the growth of plants and crops in plant-sound experiments. Therefore, my attempt to minimize these disturbances by creating a soundproof box environment proves a logical choice in producing that explains the real effects



of sound frequencies on tomato plants. Since each plant group contained four tomato seedlings,



which is a total of 12 sample groups across the three plant groups, measurements of height growth and leaf count were calculated in the beginning and at the end of the one-week sound frequency trial. The calculated mean values of each group were then used to measure and compare growth progression of each frequency trial. To best present the layout of my experimental process for each frequency trial, a schematic diagram was modeled to visualize all the components of the experimental setup, as performed.

Figure 2. *Schematic Diagram of Experimental Setup*

METHODS 2.1 *Summary of Data and Results*

The following collected raw data reveals small yet informative figures that show potential relations between the sound frequency ranges on the three different plant groups. By incorporating abiotic stress factors such as drought and salinity stress, signs of resilience become leading explanations for how resistance to stress would inform existing discussions on "lifeness."

Hz) Sound Frequency	*Control: initial average height*	*Control: final average height*	*Drought:initial average height*	*Drought: final average height*	*Salinity: initial average height*	*Salinity: final average height*
None	6 cm	4.04cm	6 cm	3.45cm	6 cm	5.55cm
400Hz	4.04cm	3.85cm	3.45cm	3.58cm	5.55cm	3.33cm
800Hz	4.8cm	4.9cm	4.3cm	4.5cm	3.75cm	3.78cm
1200Hz	4.9cm	4.97cm	4.38cm	4.48cm	3.9cm	3.93cm

Hz) Sound Frequency	*Control:* initial # of leaves	*Control:* final # of leaves	*Drought:* initial # of leaves	*Drought:* final # of leaves	*Salinity:* initial # of leaves	*Salinity:* final # of leaves
None	10	10	7	7	9	9
400Hz	11	11	8	8	5	5
800Hz	8	8	3	3	2	2
1200Hz	5	5	0	0	0	0

Figure 3. *The Effects of Varying Sound Frequencies on Tomato Plant Growth*

Note: Initial average height refers to the previous height of the plant before the stress environments were introduced and *before* each sound frequency trial. Final average height refers to plant condition and height measurements *after* stress and each sound frequency were introduced. In this way, effects of each sound frequency trial and range are observed based on the difference between the initial and final height measurements in between each trial to determine any notable effects the sound frequencies had on each plant group with stress exposure within a weekly interval of data collection.

Given the time constraints and the weather conditions affecting the plant growth, cutting out the sound frequency ranges 600 Hz and 1000 Hz was implemented, so the experiment fits the standards of the one-week interval between each sound trial. When evaluating the collected data, a drastic decrease in height can be observed from 0 Hz to 400 Hz within the first week of experimentation due to unanticipated cooler temperatures that reached 19° Celcius, which was colder than the normal range of 32° Celcius. This was a significant deviation from the usual experimental trial days conditions, wherein the weather normally remained at a mild temperature, neutral sun exposure, as well as stable dry atmosphere. Undeterred by the environmental interferences, the one-week interval format of my experimental process ensured that viable data are expected from each sound frequency trial through a consistent record of changes caused by each frequency.

2.2 *Data Analysis* (Processed Data)

After organizing the collected data into a clear table that presented the changes in plant height and leaf count in each plant group, further analyses were carried out to determine any noteworthy relations between each collected average height. As seen in Figure 4., differential percentages between each sound frequency trial, range, and plant group were calculated, displaying the significant measures of increase and decrease in tomato plant growth. This was performed to attempt to visualize and describe the relationships between sound frequencies for every plant group, primarily due to several other consequential factors such as weather, abiotic stress, or noise pollutants. Such effects can be identified when examining the 400 to 800Hz data, wherein an unexpected drop in height was observed, contradicting existing research on the effectiveness of higher sound frequency ranges such as exposing infected Arabidopsis plants to 1000 Hz which resulted in the up-regulation of defense signaling genes, as presented by Wu et al. (2023). However, from 800 Hz to 1200 Hz, subtle yet notable signs of growth were observed, particularly in tomato plant height, which were not seen in the leaf count growth, wherein there was a recurring zero percent of change.

(Hz) Sound Frequency	CONTROL % Change	SALINITY % Change	DROUGHT % Change
None	-33%	-8%	-43%
400Hz	-5%	-40%	4%
800Hz	2%	1%	0%
1200Hz	1%	1%	0%

(Hz) Sound Frequency	CONTROL % Change	SALINITY % Change	DROUGHT % Change
None	0%	0%	0%
400Hz	0%	0%	0%
800Hz	0%	0%	0%
1200Hz	0%	0%	0%

Figure 4. *The Differential Percentages of Plant Growth Between Each Sound Frequency Range*

2.3 *Statistical Analysis* (Two-Way ANOVA Test)

Although the processed data effectively presented the differential percentages of change amongst the sound frequency trials for every plant group, it does not provide a sufficient amount of data to explain why there had been an increase in tomato plant height from 800 Hz to 1200 Hz. Therefore, a two-way ANOVA test, also known as the Analysis of Variance test, was conducted on the Statistics Kingdom Website by using *not* the percentages of change, but the numerical differences between each sound frequency trial. Consequently, as seen in Figure 5, numerical differential values produced meaningful results that included P-values, a-values, F-statistics, and effect sizes.

(Hz) Sound Frequency	CONTROL	SALINITY	DROUGHT
None	-1.96	-0.45	-2.55
400Hz	-0.19	-2.22	0.13
800Hz	0.1	0.03	0
1200Hz	0.07	0.03	0

Figure 5. *Numerical Differential Values in Tomato Plant Height Growth*

The test revealed that “Factor-A”or the sound frequencies indicates that the data is is large enough to be statistically significant across some of the 12-sized sample differences between averages, suggesting that the null hypothesis or H_0, can be rejected due to the p-value < ɑ. The same condition has been observed in “Factor-B” or the drought and salinity stress factors, wherein the H_0 rejection presents the averages of all groups seemingly varying of data across 0 to 1200 Hz sound frequency levels from a 400 Hz difference per trial. The resulting effect size η2 of 0.51 for Factor-A, noting the difference between changes is large. Meanwhile, η2 0.0093 for Factor-B, meaning the effect size between the averages is small. These two F-statistics means that the chance of type I error (rejecting a correct H_0) is too high. A smaller p-value compared to significance value (ɑ) means that the observed results are unlikely caused by random variation, rather the effect being tested is statistically significant. Additionally, since both factors equals NaN or chance of type I error (rejecting a correct H_0 error) is high, the more support there is to H_1 or the hypothesis that confirms the relationship between the factors and effects tested. This explains how the projected tomato plant height growth remained gradually increasing between the 800 Hz and 1200 Hz in both the drought and salinity group, even though the resulting physiological responses may have been caused by compounding factors, suggesting this significance is unlikely caused due to chance.

2.4 *Hypothesis Comparison*

To model the experimental process beforehand, a null hypothesis and experimental hypothesis were formulated. The research stated the null hypothesis of “The controlled soundproof environment will *not* result in any significant differences in height and leaf growth in tomato plants under stress conditions, while incorporating exposure to sound frequencies,” and the experimental hypothesis of “When the controlled soundproof environment is incorporated, the experiment will result in statistically significant differences in height and leaf growth in tomato plants under stress conditions and sound frequencies.” The analyzed results indicate a partial support of my experimental hypothesis, as the projected data were shown to cause slight significant changes in height growth in tomato plants across varying sound frequencies, though further testing is required due to the limited sample size, environmental instability, and confounding variables present.

DISCUSSION

DISCUSSION 1.1 *Sound-plant Interactions*

In light of the previous research studies on sound-plant interactions, the data found and analyzed explores the narrow prevalence of consistent research procedures throughout the experiment. The need for specific, transparent descriptions of research methodology, experimental setup, and data analysis to the important implications is a common theme across multiple literary sources (Bhandawat & Jayaswall, 2022). Thus, these findings, alongside the descriptive process of the frequency trials conducted demonstrate the reproducible nature of my experiment, which makes an attempt to explain how plants perceive and respond to sound. Atluntas and Ozkurt (2019) discovered the improved fruit quality in tomatoes within the consumer market through controlled exposure to varying sound frequencies and sound pressure, which closely models the experimental process of my research, except that the abiotic stress factors used in my experiment were defined through drought and salinity, causing a potential accelerated decline in the tomato plant height growth and leaf count. By incorporating drought and salinity stress specifically to my tomato plants of Open Pollinated Variety, further investigations on the role of stress in sound-plant interactions occurred, providing insight on the potential to model resilience through drought and salinity resistance. Selecting these two stress factors are shown to be supportable choices, as Imran et al. say that drought is said to cause effects such as “poor germination, reduced seedling growth, reduced nutrient availability, photosynthesis, number of leaves and size of individual leaf size, and plants’ fresh and dry weight,” while salinity is said to cause “changes in leaf color and developmental aspects such as root/shoot ratio and maturity rate” (2021). The following effects listed were observed throughout the experimental trials, which supports much of the physiological responses that my plant groups had exhibited to display the interrelationship between each sound frequency and plant group.

Intriguingly, as showcased in Figure 3., the data table presented a gradual decline in not only the salinity and drought group, but also the control group, suggesting a collective environmental stressor, as caused by the sudden change in temperature, that all three plant groups experienced. Additionally, it may be considered that there may be a possibility that the soundproof box environment itself had been stressful to the plant groups, explaining greatly the gradual decline of the control group, despite not having experienced any abiotic stress factors.

DISCUSSION 1.2 *Interpreting Resilience*

Across multiple interdisciplinary perspectives and differing determinants in defining resilience, only two definitions seem to stand out in distinguishing both “being alive” and the connection between sound frequencies to plant growth: “A process to harness resources in order to sustain well-being” and “The capacity of a dynamic system to adapt successfully to disturbances that threaten the viability, function, and development of that system” (Southwick et al., 2014). These definitions inform us of how resilience is modelled through my experiment, particularly through the incorporation of stress factors that enable the potential to survive despite the external difficulties that the plants experienced. However, it is important to note that resilience as a concept is only interpreted as a boundary object, which Brand and Jax (2007) describe as having the ability to coordinate conflicting or differing groups that do not have set aims and interests about a particular concept. The physiological responses of growth among the plant groups exemplify the resilient nature of non-animal representations of life when experiencing compounding factors, recognizing the idea that plants may have a consciousness of their own. As an independent concept, even with the resulting doubt it has produced, plants as sentient beings presents a remarkable perspective on how self-sufficient organisms that are “capable of complex cognitive behavior without the presence of consciousness” could possibly exude resilience, completely for survival (Hansen, 2024).

Through the unprecedented environmental factors that hindered the optimal growth rate of each plant group as abiotic stresses were introduced, minute yet major signs of growth reveal that biological, stress-tolerant characteristics in plants allow them to symbolize what it means to have life (Imran et al., 2021). Thus, resilience as a boundary object indicates the link between the depiction of “being alive” to the sophisticated nature of a plants’ biological and physiological stress-tolerant qualities for survival. By analyzing both the physical and conceptual ideas of resilience, direct connections to our understanding of what it means to “being alive” is re-evaluated for better comprehension and definition. According to Malaterre and Chartier (2021), the significant examination of the degrees of “lifeness” surpass binary assumptions that life is determined by “more-or-less-alive” characterizations. This suggests that using the modeled resilience from my experiment would solely be utilized as inferred links to contributing to our understanding discussions about resilience as a defining characteristic of living organisms. Resilience, however, can only apply through limited interpretations as a key indicator of being alive within the perimeters of my experiment, whereas the eventual decline in my plants can be interpreted as still a form of resilience, as all groups were still able to adapt to the stressful conditions while maintaining its function on growth. This divide on the matter of existence was explained by (Kushner, 1984), wherein the two Greek terms for life *zoe* and *bios* were used to explain the matter of existence from either being alive through a consciousness or a possession of life. From the physiological responses recorded in the experiment, the tomato plant groups displayed a form of consciousness that is strictly bound by biological reactions to changes in their physical structure.

LIMITATIONS

Although my research produced viable results that solidified methodological processes that followed consistent procedures that were based on undefined aspects in the techniques that studies on sound-plant interactions had, this interrelationship between modeled resilience and sound-plant interactions is limited. For example, due to uncontrollable and unanticipated temperature changes that followed the first week of my experimentation, the sudden drop in temperature from 32° to 19° Celsius consequently caused amplified physiological stress responses in drastic plant height decline through signs of gradual wilting and stem shrinkage, displaying the disconcerting variable to my final experimental results. This greatly affects the differentiation between resilience and delayed decline of tomato plant height growth and leaf prominence, as it questions the true effectiveness of sound frequencies on causing physiological responses on tomato plants and classifies it as uncertain, especially when special adjustments to maintain the salinity concentrations of the salinity group were implemented. Additionally, the shortened range of frequencies limited the amount of data collected on the tomato plant species to a total of only 12 slots, which may not provide sufficient data that proves the effects of sound frequencies in plants. Hence, the results collected are not generalizable, given the restricted sample size and ANOVA set of results, suggesting further adjustments for future sound-plant research in the field of bioacoustics. Furthermore, the presence of gaps between the soundproof box and the soundproofing foam greatly restricted the validity of each sound frequency trial, as it may be denoted to having been influenced by surrounding noise disruptions, distorting the data in return. Alongside this, there is a high possibility that the soundproof box acted as an independent stressful environment, which could explain the accelerated height and leaf count growth decline, as the plant groups were separated from their outdoor growing environments. Lastly, the common stressful factor of noise disruption as the plants are placed outdoors after every sound frequency trial greatly contributed to these physiological stress responses. Thus, interpreting these findings into a philosophical concept of defining the state of "being alive" is confined to the resilience-based frameworks of categorization, as seen below, that were presented by authors Nisioti et al.

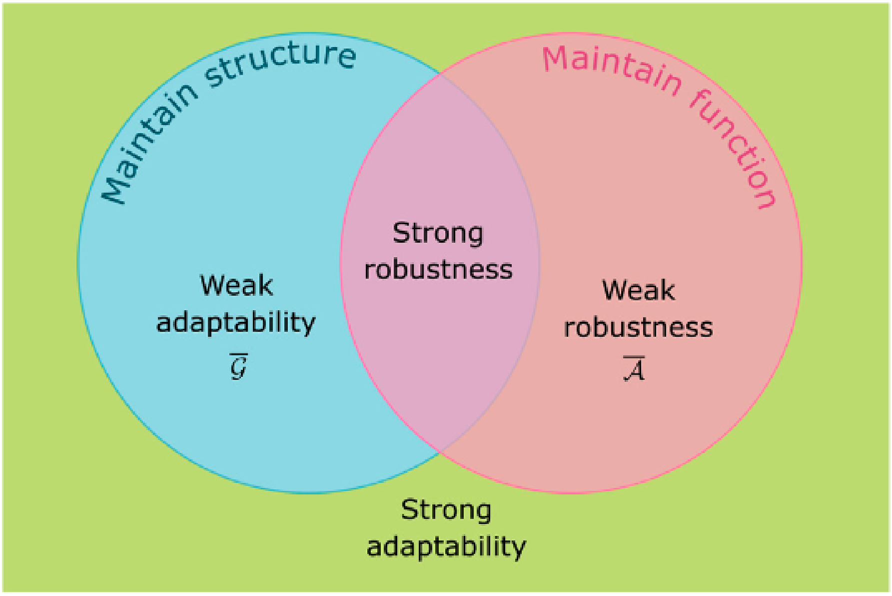


Figure 6. Nisioti, E. et al. (2023). *Resilience types. Note: Categorising approaches to resilience into four different sub-types based on whether changes on the structure or the function of the individual are allowed. Approaches in* $\overline{A}$ *do not allow change in function, approaches in* $\overline{G}$ *do not allow change in structure.* Frontier.

According to Nisioti et al., the structural, functional, adaptability, and robustness criteria in limiting the definitions to "being alive," my findings, as shown in Figure 3., reveal the potential errors in my research methods, wherein the box environment might have induced a stressful environment on its own, only enhancing the observed minute height growth despite the notable decline in plant height growth and leaf prominence, even as the tomato plant groups displayed *weak robustness ($\overline{A}$)* and *strong adaptability*—yet still indicating signs of resilience and adaptability.

IMPLICATIONS

By conducting this study, contributions to explaining the relationship between 400-1200 Hz sound frequencies and subsequent plant growth, with resilience being the core concept of the research, was made. Using resilience to define the experiment expands our own definitions and understanding of what it means to "be alive" from philosophical yet scientifically supported implications. Although it is viewed through inference, resilience modelling offers insight on just how we can redefine our current understanding on the existence of life and what it might offer to explain how sound frequencies play a role in influencing physiological changes of growth in tomato plants. On the other hand, suggestions on method choices include expanding the frequency range, plant species, soundproofing methods, and methodological transparency, used for sound-plant experiments. Through further developed descriptions of the methodological processes of conducting sound-plant interactions, future research on this interrelationship requires robust approaches in maintaining the same transparency throughout their experiment. This adaptation of the resilience value amongst individuals presents a path towards self-actuality, finding *their* own purpose in "being alive." Ultimately, this sculpts future experiments to model similar topics such as finding definitions of what it means to *have* a life and *being* alive into one promising description: "The capacity to sustain one's existence through adaptability and resilience."

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