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Acoustic Stimulation in Plants: A Narrative Review of the Effects of Audible Sound, Ultrasound, and Qur'anic Recitation

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ABSTRACT:

Review Paper

In recent decades, interdisciplinary research at the intersection of plant science and acoustics has investigated the potential effects of sound on plant growth and physiological processes. This narrative-analytical review synthesizes the available evidence on plant responses to audible and ultrasonic acoustic stimuli, with particular attention to Qur'anic recitation and its potential biological effects. Relevant studies were examined to identify reported physiological responses, proposed mechanisms, and methodological limitations. The reviewed literature suggests that both audible acoustic stimuli, including music and natural sounds, and ultrasound may influence plant growth and physiological processes under specific experimental conditions. However, the magnitude and direction of these responses vary according to the characteristics of the acoustic stimuli, plant species, developmental stage, and exposure conditions. Factors such as frequency, intensity, duration, and temporal or rhythmic structure may contribute to these variations, while the underlying mechanisms remain incompletely understood. Regarding Qur'anic recitation, some studies have reported associations with plant growth and physiological responses. However, the available evidence remains preliminary, heterogeneous, and context-dependent. In particular, existing studies do not establish whether

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the reported responses are specifically attributable to the linguistic or religious content of the recitation or primarily reflect its acoustic properties. The limited availability of standardized comparisons with acoustically matched controls, such as silence, non-Qur'anic speech, music, white noise, or other Arabic vocal stimuli, making it difficult to determine content-specific effects. Further research using controlled experimental designs, acoustically standardized exposure conditions, appropriate linguistic and acoustic controls, and independent replication is therefore needed to clarify these effects and assess their potential practical applications.

KEYWORDS: Qur'an and Botany, Acoustic stimuli, Qur'anic Recitation, Plant growth, Plant Physiology, Music and Plant Responses, Phytoacoustics, Plant Bioacoustics.

1. Introduction

As living organisms, plants are continually influenced by environmental factors that significantly affect their growth, reproduction, and resistance to biotic and abiotic stresses (Mareri et al. 2022). Among these, sound waves, encompassing both audible sounds (e.g., musical compositions) and ultrasonic frequencies (above 20 kHz), have emerged as noteworthy physical stimuli capable of influencing plant physiological processes (Mishra et al. 2016; Jung et al. 2018). These waves may influence plant physiological responses and have been associated with changes in plant structure and growth, although the underlying mechanisms of plant responses to acoustic stimulation remain insufficiently understood and may involve either stimulatory or inhibitory effects (Fernandez-Jaramillo et al. 2018).

In the early 1900s, the Indian biophysicist Jagadish Chandra Bose (1902, 1906) provided pioneering experimental observations suggesting that plants can perceive and respond to acoustic stimuli. His laboratory studies reported measurable physiological responses in plants exposed to sound and sound-induced environmental changes. These early investigations contributed to the historical development of research on plant responses to acoustic stimuli, which later evolved into what is now broadly discussed as plant bioacoustics or phytoacoustics.

Some studies have subsequently reported physiological, biochemical, and developmental responses to specific acoustic treatments (Hassanien et al. 2014). Studies in the 1950s further explored the influence of music on plant behavior and growth (Ekici et al. 2007), followed by a wide range of investigations reporting that plants can respond to various acoustic stimuli,

including music, natural sounds, and random noise. These insights have contributed to the development of plant bioacoustics as a scientific domain (Jeong et al. 2008; Chowdhury et al. 2014; Mescher & De Moraes 2015). However, the scientific status and interpretation of such findings remain the subject of ongoing debate. Earlier studies of sound-induced effects in plants were criticized for inconsistent results, inadequate standardization of acoustic stimuli, and insufficient control of experimental conditions, and the field was at times characterized as "fringe science" (Jung et al. 2018). More recent reviews have likewise emphasized that the evidence remains inconclusive, particularly regarding whether plants possess a specific capacity for airborne sound perception or acoustic communication, as distinct from responses to mechanical vibrations (Son et al. 2024). Thus, although measurable plant responses to certain acoustic or vibrational stimuli have been reported, the underlying sensory mechanisms, biological specificity, and ecological significance remain incompletely established.

In recent years, research investigating the effects of Qur'anic recitation on plants has attracted increasing attention, with studies reporting various changes in plant growth and physiological responses. Despite this growing interest, a comprehensive review that systematically examines the findings of these studies and evaluates them in comparison with plant responses to other acoustic stimuli, such as music, natural sounds, and ultrasound, remains lacking. In particular, the extent to which the reported effects of Qur'anic recitation overlap with or differ from those associated with other acoustic exposures has not been adequately explored. Addressing this gap is important for understanding the broader biological effects of acoustic stimulation and for assessing whether the reported responses to Qur'anic recitation can be distinguished from general acoustic effects. Therefore, the present review brings together and critically evaluates existing evidence on plant responses to Qur'anic recitation as well as other acoustic stimuli, providing a comparative perspective on their reported effects, proposed mechanisms, and limitations of the existing research.

2. Methodology

This research is designed as a narrative-analytical review, aiming to synthesize and critically analyze published scientific literature on the effects of audible and ultrasonic waves on plants with particular attention to Qur'anic recitation as a specific form of audible acoustic stimulation. Based on principles of biophysics and plant physiology, the study categorizes acoustic stimuli into two major types: audible waves (including classical

music, environmental sounds, and Qur'anic recitation) and ultrasonic waves (with frequencies above 20 kHz). Relevant studies were identified through literature searches in Scopus, PubMed, ScienceDirect, Google Scholar, IranDoc, SID, and MagIran using predefined search terms related to acoustic stimulation and plant responses. The search strategy involved the use of predefined keywords, including "Ultrasound on plants," "Audible sound plant growth," "Qur'anic recitation and plants," "Effect of sound frequency on plants," "Music and plants," "Ultrasound and plant growth," and "Effect of Qur'an recitation on plants."

Studies published between 2000 and 2026 that provided empirical observations or relevant quantitative or qualitative findings on plant responses to audible sound or ultrasound were considered for inclusion in the narrative synthesis. Studies were included when they directly investigated plant responses to an identifiable acoustic stimulus and provided sufficient information on the acoustic treatment and/or plant response for qualitative interpretation. Studies were excluded when they lacked empirical or directly relevant evidence on plant responses to acoustic stimulation, did not provide sufficient information to interpret the acoustic exposure or plant response, or were unrelated to the scope of the review.

As this review was designed as a narrative-analytical synthesis rather than a formal systematic review, no standardized numerical quality score was assigned to the included studies. Instead, the methodological quality and evidentiary strength of the identified studies were qualitatively appraised based on study design, the presence and appropriateness of control groups, characterization of acoustic exposure (including intensity, frequency, duration, and exposure conditions), sample or replication information, measured outcomes, and the extent to which the experimental design allowed acoustic effects to be distinguished from potential stimulus-specific effects. Publication type and methodological limitations were also considered when interpreting the strength of the evidence.

Potential sources of bias were also considered qualitatively during the interpretation of the evidence. Particular attention was given to the adequacy of control or comparison groups, consistency of acoustic exposure, completeness of outcome reporting, and limitations that could affect the interpretation of reported effects. Additional consideration was given to potential confounding factors, including differences in plant species or cultivars, developmental stage, environmental conditions, and combined treatments.

Because the literature specifically addressing the effects of Qur'anic recitation on plants is relatively limited and heterogeneous in terms of study

design and publication type, the relevant evidence was separately examined and characterized (table 1). The identified studies included experimental investigations published as journal articles, conference papers, and academic theses. The available literature was not restricted by publication type, because limiting the evidence base to journal articles would have excluded a substantial proportion of the directly relevant studies currently available in this emerging field. However, publication type and methodological heterogeneity were considered when interpreting the findings.

As this study was designed as a narrative-analytical review rather than a systematic review or meta-analysis, the PRISMA framework was not applied as a formal study-selection protocol. Nevertheless, methodological transparency was strengthened by explicitly reporting the databases searched, predefined search terms, publication period, inclusion and exclusion criteria, qualitative methodological appraisal, consideration of potential sources of bias, and the characteristics and limitations of the identified studies. This approach was adopted to provide a transparent account of the evidence identification and interpretation process while retaining the narrative and exploratory scope of the review.

3. Effects of Acoustic Stimuli on Plants

Plants are highly organized and dynamic biological systems in which interactions among different levels of organization, from cellular components to tissues and organs, generate coordinated physiological responses. The concept of self-organization describes the ability of biological systems to develop functional patterns through interactions among their internal components and their continuous exchange with the environment. In plants, this integrated organization contributes to adaptive responses by allowing multiple physiological processes to operate in a coordinated manner (Lüttge 2021).

Acoustic stimuli have increasingly been investigated as environmental signals that may influence plant growth and physiological processes. Previous studies have reported that plants can respond to sound-related stimuli; however, the magnitude and nature of these responses depend on acoustic characteristics, experimental conditions, and the type of stimulus applied. Moreover, sound waves, including both audible and ultrasonic frequencies, have attracted increasing attention as potential environmentally compatible tools in modern agriculture. As non-chemical approaches, acoustic treatments may influence crop performance and plant responses to

environmental stresses under appropriate experimental conditions (Heidari et al. 2020). Current evidence also suggests potential applications in seed treatment, crop production, and sustainable agricultural systems, although reported effects vary depending on plant species, acoustic characteristics, and treatment conditions (Li & Ramaswamy 2005).

3.1. Audible Sound Waves

Experimental evidence suggests that audible sound waves (20 Hz to 20 kHz) can influence various aspects of plant growth and physiological performance. For example, Salvia officinalis exposed to classical music showed improvements in growth-related traits and photosynthetic performance under experimental conditions (Singh et al. 2019).

Audible sound waves have also been investigated for their potential applications in crop production, particularly in improving seed germination and plant growth under controlled conditions. For example, Creath & Schwartz (2004) reported enhanced germination of Abelmoschus esculentus (okra) and Cucurbita pepo (zucchini) following exposure to musical stimuli compared with untreated controls. Jeong et al. (2008) also reported changes in rice responses following exposure to selected sound frequencies (125 and 250 Hz). Similarly, Chowdhury et al. (2014) observed improved germination and vegetative growth following exposure to soothing music. In Rosa chinensis, different musical genres produced variable responses, with Vedic chants and Indian classical music showing positive effects on several growth traits (Chivukula & Ramaswamy 2014).

In contrast, not all acoustic stimuli produce beneficial effects. Rachieru et al. (2017) found that Triticum aestivum L. (wheat) plants exposed to rock music exhibited weaker growth compared with control specimens. Similarly, adverse effects of dissonant sounds, such as traffic noise on Salvia splendens and railway noise on Centaurea hyalolepis Boiss., and Silybum marianum L., have been documented by researchers (HaghighiKafash et al. 2021). These findings suggest that reported plant responses to audible sound vary with acoustic characteristics and experimental conditions, while the consistency and practical applicability of such effects in agricultural settings require further controlled investigation.

3.1.1. Music

Music has emerged as an important experimental stimulus in the study of plant responses to sound, although it remains a relatively nascent research

field. Various genres of music, characterized by distinct frequency ranges and rhythmic patterns, have been reported to be associated with either positive or negative effects on plant growth, photosynthesis, and stress responses (Lai & Wu 2020). Additionally, some studies have suggested that plants may respond to acoustic vibrations in ways that could contribute to plant-to-plant signaling under certain environmental conditions (Mishra et al. 2016). This section categorizes different types of music based on their reported effects on plants and examines the conditions under which positive or potentially adverse responses have been observed.

3.1.1.1. Plant-Compatible Music

Music that has been reported to be associated with positive effects on plant growth and physiological processes often includes gentle frequencies, harmonic tones, and relatively regular rhythmic structures. These sound patterns have been associated with changes in seed germination and seedling development, including under some environmental stress conditions (Lai & Wu 2020).

Classical music, noted for its relatively lower frequencies and smooth tempos, is among the most widely studied genres and has frequently been associated with changes in root elongation, germination percentage, shoot height, and leaf area in various plant species (Vanol & Vaidya 2014). For example, a study involving Cicer arietinum (chickpea) reported that exposure to Indian classical music was associated with enhanced seedling development, while white noise exposure was associated with changes in germination processes (Chowdhury & Gupta 2015).

Another study reported that raagas, the melodic frameworks of Indian classical music, were associated with changes in protein content in plants such as Glycine max (soybean), Spinacia oleracea (spinach), and Triticum aestivum (wheat) (Reddy et al. 2013). Natural sounds, sometimes referred to as "green music," such as rainfall, ocean waves, and birdsong, have also been investigated in relation to plant development. However, the extent to which such effects are attributable to specific acoustic characteristics, such as frequency or harmonic structure, remains unclear. Studies have reported changes in seed germination following exposure to natural acoustic stimuli, including bird calls, insect vibrations, and water flow (Creath & Schwartz 2004). Moreover, instrumental music featuring stringed instruments such as the violin (Petrescu et al. 2020) and the pan flute (Popescu & Mocanu 2013) has also been associated with positive plant responses, further illustrating the range of auditory stimuli investigated in plant research.

3.1.1.2. Plant-Incompatible Music

Music and sounds characterized by high frequencies and rapid rhythms have been reported to be associated with changes in plant physiological processes. Such acoustic patterns have been associated with stress-related responses and, under certain experimental conditions, with inhibited growth and changes in plant performance (Alavijeh et al. 2016).

Among the frequently studied stress-inducing genres is rock music. In a study conducted by Hemamali et al. (2021), Capsicum annuum (bell pepper) plants exposed to rock music exhibited stunted growth and shortened branches compared with those in the control group. The authors suggested that the acoustic characteristics of rock music may contribute to stress-related responses; however, the specific mechanisms underlying these effects remain uncertain. Supporting this observation, Chivukula and Ramaswamy (2014) reported that plants exposed to rock music displayed bending away from the sound source, accompanied by smaller leaves and reduced development. These findings suggest that certain loud or fast-paced acoustic treatments may be associated with changes in plant growth and physiological responses; however, their effects on photosynthesis, hormonal regulation, and cellular processes require further direct investigation.

In addition to music, discordant environmental sounds, such as automobile traffic, industrial machinery, and urban noise, have also been associated with negative plant responses (Akay & Önder 2022). Some studies have reported changes in cellular, biochemical, and molecular parameters following exposure to environmental noise. For instance, Kafash et al. (2022) observed changes in the levels of phytohormones, including zeatin, salicylic acid, indole-3-acetic acid (IAA), and gibberellic acid, following traffic noise exposure. These findings indicate that environmental noise may be associated with alterations in hormonal and physiological responses; however, whether such responses reflect direct acoustic effects, generalized stress responses, or specific molecular mechanisms remains to be established. Overall, the available evidence suggests that plant responses to music and environmental noise are context-dependent and may vary according to acoustic characteristics, exposure conditions, and plant species.

3.1.2. Qur'anic Recitation

In musicological terms, *maqāmāt* (modal systems) and melodic structures can be described using measurable acoustic features, including patterns of pitch, rhythm, and vocal modulation. Qur'anic recitation

involves variations in rhythm, pitch, vocal modulation, and phonetic articulation, which can be characterized in terms of measurable acoustic properties. Accordingly, Qur'anic recitation can be examined scientifically in terms of its acoustic characteristics.

3.1.2.1. Rhetorical and Musical Characteristics

Historical discussions, including those attributed to Ibn Sīnā (Avicenna) (2014), describe the emotional influence of different melodic modes. Nelson (1985) reviewed historical scholarly perspectives on melodic Qur'anic recitation and documented its longstanding tradition within Islamic culture. Sarboland (2018) described the role of Arabic *maqāmāt* in shaping the melodic structure of Qur'anic recitation, emphasizing their characteristic modal patterns and vocal modulation. Similarly, Meshkinfam and khaleghian (2007) examined the melodic features of Qur'anic recitation from a musicological perspective. Soltanpanah et al. (2023) further analyzed the application of different *maqāmāt* in Qur'anic recitation and their relationship to the semantic organization of the verses.

Linguistic and stylistic analyses have described Qur'anic surahs as exhibiting recurring patterns of phonetic repetition, rhythm, sound distribution, and rhetorical organization. For example, Motaghizadeh et al. (2017), in their study of the aesthetic features of the surahs al-Nāziʿāt and al-Takwīr, reported that the repetition of parallel intervals, together with nasalized and fluid sounds, contributes to what they described as a cohesive sonic structure. They also showed relationships between phonetic patterns and the semantic organization of the verses.

Taken together, these rhetorical, phonetic, and musical characteristics provide two complementary perspectives for investigating the potential effects of Qur'anic recitation on plants. First, the acoustic and musical features of recitation can be examined in relation to the linguistic and semantic content of the verses, considering how phonetic patterns, rhythm, and melodic structure interact with meaning. Second, the effects of recitation can be investigated independently of semantic content, focusing on its acoustic and musical properties, particularly the different recitation styles, melodic modes (*maqāmāt*), and patterns of vocal modulation. This distinction provides a conceptual basis for exploring whether plant responses are associated with the general acoustic characteristics of Qur'anic recitation, its relationship with semantic content, or specific features of its melodic and recitational structure.

3.1.2.2. Effects of Qur'anic Recitation on Plants

Available experimental evidence includes studies that directly compared Qur'anic recitation with no-sound controls and/or other acoustic stimuli. One of the earlier studies was conducted by Dahliana (2018) as an academic thesis, comparing Qur'anic recitation with classical music in Brassica juncea. According to the reported results, Qur'anic recitation increased germination by 10%, plant height by 23.34%, leaf number by 14.81%, leaf width by 27.29%, leaf length by 39.33%, and fresh weight by 35.71%, with higher reported values for the measured growth parameters than those observed under classical music. However, the study did not include a silent control or an acoustically matched control stimulus, limiting the extent to which the observed differences can be attributed specifically to Qur'anic recitation or its content.

Zaidan et al. (2021) investigated two cucumber cultivars (Asil and Gazer) exposed to two sound levels of Qur'anic recitation throughout the growth cycle. The responses differed between cultivars and exposure levels. In Asil, loud recitation was associated with higher reported fruit yield, leaf length, and plant height, whereas low-volume recitation in Gazer was associated with reductions in several growth parameters. RAPD-PCR analysis also revealed treatment-associated differences in the reported DNA banding patterns. These findings indicate that responses may depend on genotype and acoustic exposure conditions.

Abdullah et al. (2019), in a peer-reviewed journal study, compared five acoustic treatments in Vigna radiata: soprano voice, classical music, nature sounds, rock music, and Qur'anic recitation, together with a no-acoustic-exposure condition. All acoustic treatments were reported at approximately 60 ± 10 dB. The authors reported that soprano voice had a significant effect on stem length, whereas Qur'anic recitation promoted leaf production. The study is relevant because it included multiple acoustic comparison groups and a no-exposure condition. The findings therefore support the existence of treatment-specific plant responses but do not establish a unique biological effect of Qur'anic recitation.

Wiratmoko et al. (2024) reported that Qur'anic recitation combined with biofertilizer application was associated with increased plant height and leaf number in Amaranthus tricolor. Because the study examined Qur'anic recitation in combination with biofertilizer treatments, the reported response cannot be interpreted independently as an effect of Qur'anic recitation alone.

Resti et al. (2018), published in a peer-reviewed journal, evaluated four

treatments in Alternanthera amoena: control, classical music, hard-rock music, and Qur'anic recitation. ANOVA indicated that sound exposure significantly affected plant growth. Qur'anic recitation produced the highest reported values for plant height (35.70 cm), leaf area (43.40 cm^2), root length (9.40 cm), stomatal pore length (23.00 µm), fresh weight (15.59 g), and dry weight (11.25 g), whereas hard-rock music produced the highest chlorophyll content (34.52 SPAD).

Hakim (2019), an academic thesis, compared untreated seedlings, classical music, a treatment described by the authors as "noise," and Qur'anic recitation (Surah Yasin) in Elaeis guineensis. The study reported higher values for several growth and stomatal parameters under Qur'anic recitation. This study is methodologically relevant because it included both a no-treatment condition and other acoustic treatments.

Chaidir et al. (2019), published in the Journal of Physics: Conference Series, examined Chrysanthemum sp. exposed to Surah Al-Fatihah at an average reported frequency of 1237.8 Hz for 2 h per day and compared the treatment with a no-recitation control. The study reported effects on plantlet height, leaf number, root number, and stomatal opening. However, the study did not include classical music, white noise, ordinary Arabic speech, or Arabic poetry as comparison stimuli. Its findings therefore provide preliminary evidence of a response to the tested acoustic treatment but do not distinguish the effects of Qur'anic content from those of its acoustic characteristics.

Monika (2021), an academic thesis, compared classical Mozart music, Qur'anic recitation, and a control during germination of Swietenia mahagoni. Classical music produced higher mean values for several germination-related parameters and the highest reported fresh and dry weights, whereas Qur'anic recitation produced the highest mean leaf number. The unequal sound-intensity ranges reported for the classical music and Qur'anic recitation treatments further limit interpretation of potential content-specific effects. The study therefore contributes to the evidence of variable plant responses to acoustic treatments but does not establish a consistent advantage of Qur'anic recitation.

Yuwono et al. (2022), published in a peer-reviewed agricultural journal, compared classical music, Qur'anic recitation, and no sound in hydroponically grown Ipomoea aquatica. Although descriptive differences were reported for leaf length and fresh weight, the ANOVA results showed no statistically significant differences among the three treatments for these parameters. This finding is particularly relevant because it demonstrates that reported descriptive changes should not automatically be interpreted as

statistically established treatment effects.

Jasmi et al. (2022) compared no sound, classical music, rock music, and Qur'anic recitation in Zea mays across different exposure durations. The highest reported values for several measured parameters occurred under Qur'anic recitation exposure, whereas exposure duration within the tested range did not significantly affect several of the measured outcomes. Nevertheless, the experimental design did not permit the acoustic characteristics of the treatments to be fully separated from their linguistic content.

Arifin (2022), in an academic thesis, compared a control condition, classical music, Qur'anic recitation, and hardcore music in Ipomoea reptans. The study reported a significant effect of sound type on plant growth, with hardcore music producing the most favorable overall response for several parameters. This result, together with studies reporting different responses to Qur'anic recitation or classical music, further demonstrates the heterogeneity of plant responses to acoustic treatments and argues against attributing a generalized growth-promoting effect to any single sound category.

Jasmi & Zuraidah (2024) investigated red chili seed viability using no music, classical music, rock music, and Qur'anic recitation with different exposure durations. The interaction between Qur'anic recitation and a 3-h exposure period was associated with changes in germination percentage, growth synchrony, and growth rate. These findings suggest that both sound type and exposure duration may contribute to the observed response.

Hartanto (2025), in his academic thesis and also reported in a conference publication, evaluated classical music, metal music, Qur'anic recitation, and gamelan music in tomato plants using Sonic Bloom technology. The study reported that different acoustic treatments were associated with different growth, stomatal, root, and yield-related responses. Classical music was associated with higher tomato yield, whereas gamelan was associated with several stomatal and root-related responses. These findings further demonstrate that plant responses were not consistently aligned with Qur'anic recitation or any single acoustic category.

The most recent experimental study in this set, by Munar et al. (2026), compared a control condition, Qur'anic recitation, and classical music in Brassica juncea and Brassica rapa. Acoustic exposure was reported at 90 dB over a frequency range of 20–14,500 Hz for 2h per day. According to the reported results, classical music significantly enhanced early growth, with plant-height increases reaching 102.08% in green mustard and 91.16% in

pak choi during 6–12 days after planting, while leaf area increased by up to 208.74%. Qur'anic recitation showed stronger effects at later developmental stages, including a reported dry-root weight of 0.34 g in green mustard. However, chlorophyll content was not significantly affected by the treatments. These results indicate that plant responses to the tested acoustic treatments varied with developmental stage, plant species, and measured trait.

Overall, the directly relevant literature indicates that plant responses following exposure to Qur'anic recitation have been reported in several experimental systems. However, the evidence base remains preliminary, heterogeneous, and context-dependent, and the methodological quality and publication type of the available studies vary considerably. Greater evidentiary weight can generally be assigned to peer-reviewed studies with stronger experimental designs and appropriate control conditions than to theses and conference proceedings; however, even the more controlled studies generally do not employ acoustic designs capable of fully separating measurable acoustic characteristics from linguistic or semantic content.

Direct comparisons with silent controls and several forms of music have been reported, and at least one study has included a treatment described as "noise." However, standardized comparisons involving white noise, ordinary Arabic speech, and Arabic poetry have not yet been adequately demonstrated in the identified literature. Likewise, no identified study provides a sufficiently controlled design in which sound intensity, spectral characteristics, temporal structure, timbre, and linguistic content are systematically separated. Consequently, the current evidence supports the conclusion that plants may respond differently to particular acoustic treatments, but it does not provide a sufficiently controlled basis for attributing such differences specifically to Qur'anic content.

Future studies should therefore employ carefully matched acoustic and linguistic controls, independent replication, and standardized reporting of acoustic parameters to determine whether any observed responses are attributable primarily to general acoustic stimulation or to stimulus-specific characteristics of Qur'anic recitation. Table 1 summarizes the key characteristics and findings of studies investigating the effects of Qur'anic recitation on plants, including the authors and year of publication, plant species, experimental design, acoustic treatment and exposure conditions, control or comparison groups, main reported findings, and key methodological limitations.

Table 1. Characteristics and main findings of studies investigating plant responses to Qur'anic recitation

Authors /Year	Publication Type	Plant Species	Acoustic Treatment & Exposure	Main Reported Findings	Key Methodological Limitations
1. Dahliana 2018	Academic thesis	*Brassica juncea L.*	Classical music, Qur'anic recitation; 50–78 dB	Qur'anic recitation was reported to increase germination, height, leaf number, leaf dimensions, and fresh weight.	No silent/untreated acoustic control; no matched acoustic or linguistic control.
2. Resti et al. 2018	Peer-reviewed article	*Alternanthera amoena Voss*	No treatment, Classical music, hard rock music, Qur'anic recitation	Qur'anic recitation produced the highest values for several growth traits, whereas hard rock produced the highest chlorophyll value.	No rigorous SPL or spectral matching; content-specific effects cannot be isolated.
3. Hakim 2019	Academic thesis	*Elaeis guineensis Tenera*	No treatment, Classical music, Noise, Qur'anic recitation	Qur'anic recitation was reported to improve several growth and stomatal /chlorophyll parameters.	Noise was not sufficiently characterized to establish it as white noise; no matched acoustic/linguistic control.
4. Chaidir et al. 2019	Conference article	*Chrysanthemum sp.*	No treatment, Qur'anic recitation; mean frequency 1237.8 Hz	Differences were reported in early shoot growth, plant height, leaf number, and stomatal opening.	No music, white-noise, ordinary Arabic speech, or poetry control.
5. Abdullah et al. 2019	Peer-reviewed article	*Vigna radiata*	No treatment, Soprano voice, Classical music, Nature sounds, Rock music, Qur'anic recitation	Soprano voice significantly affected stem length, whereas Qur'anic recitation was associated with increased leaf production.	Acoustic stimuli were not designed to isolate linguistic or content-specific effects.
6. Zaidan et al. 2021	Peer-reviewed article	*Two cucumber cultivars, Asil & Gazer*	Qur'anic recitation at two sound levels	Responses differed by cultivar and exposure level; reported effects included differences in fruit yield, leaf length, and plant height. RAPD-PCR showed treatment-associated differences in DNA banding patterns.	RAPD-PCR differences do not establish genetic or epigenetic mechanisms; genotype × acoustic-condition effects require further controlled validation.
7. Monika 2021	Academic thesis	*Swietenia mahagoni*	No treatment, Classical music, Qur'anic recitation	Classical music produced higher values for several parameters, while Qur'anic recitation produced the highest mean leaf number.	Acoustic intensity was not matched; no linguistic or spectral control.

Authors /Year	Publication Type	Plant Species	Acoustic Treatment & Exposure	Main Reported Findings	Key Methodological Limitations
8. Yuwono et al. 2022	Peer-reviewed article	*Ipomoea aquatica*	No treatment, Classical music, Qur'anic recitation; 65.8–73.9 dB	ANOVA showed no significant differences among treatments for leaf length and fresh weight.	No white-noise, Arabic-speech, or poetry control; acoustic matching remained incomplete.
9. Jasmi et al. 2022	Peer-reviewed article	*Zea mays*	No treatment, Classical music, Rock music, Qur'anic recitation; 70–75 dB	Recitation was reported to produce the highest values for several germination and growth traits; exposure duration was not significant for several outcomes.	dB matching does not establish spectral equivalence; no linguistic control.
10. Arifin 2022	Academic thesis	*Ipomoea reptans*	No treatment, Classical music, Hardcore music, Qur'anic recitation	Music type significantly affected growth; hardcore music was reported as the best overall treatment.	Limited acoustic characterization; no speech/poetry or matched acoustic control.
11. Jasmi & Zuraidah 2024	Peer-reviewed article	*Red chili seed*	No treatment, Classical music, Rock music, Qur'anic recitation	Qur'anic recitation × 3 h was associated with responses in germination, growth synchrony, and growth rate.	No white-noise, Arabic-speech, poetry, or matched acoustic controls.
12.Wiratmoko et al. 2024	Peer-reviewed article	*Amaranthus tricolor*	Qur'anic recitation + biofertilizer	Combined Qur'anic recitation and biofertilizer treatment was associated with increased plant height and leaf number.	The independent effect of Qur'anic recitation cannot be separated from the biofertilizer treatment.
13. Hartanto 2025	Academic thesis	*Lycopersicon esculentum*	No treatment, Classical music, Metal music, Qur'anic recitation, Gamelan	Sound type affected several growth/yield variables; classical music improved several yield traits, whereas Qur'anic recitation was higher for some vegetative biomass traits.	Responses were trait-specific; Qur'anic content was not isolated from acoustic characteristics.
14. Munar et al. 2026	Peer-reviewed article	*Brassica juncea & Brassica rapa*	No treatment, Classical music, Qur'anic recitation; 90 dB	Classical music enhanced early growth, whereas Qur'anic recitation showed stronger responses at some later stages; chlorophyll was not significantly affected.	Full spectral matching was not established; no white-noise, Arabic-speech, or poetry control.

3.1. Ultrasound Waves

Ultrasound waves are mechanical waves with frequencies above 20 kHz that have been widely used in industrial and medical applications. Increasing evidence suggests that ultrasound may affect plant growth and physiological responses, although reported responses may vary depending on treatment parameters, including frequency, intensity, and exposure duration. Experimental studies have reported that ultrasound treatments may be associated with changes in various aspects of plant performance, including germination, growth, photosynthetic activity, and nutrient uptake. For example, in Zea mays (maize), ultrasound exposure was associated with changes in photosynthesis-related enzymatic activity and nutrient uptake capacity (Singh et al. 2019). Beyond its established industrial and medical uses, ultrasound has been investigated for seed treatment, crop production, and post-harvest processing (Leong et al. 2018). It has also been applied in the extraction of bioactive compounds from medicinal plants, providing an efficient alternative to conventional extraction methods (Fallahpour Sichani & Abbasi 2025).

Several studies have demonstrated the potential of ultrasound to improve seed performance and crop establishment. Li & Ramaswamy (2005) reported enhanced seed longevity and germination following ultrasonic treatment. Similarly, Faryabi et al. (2008) identified optimal treatment durations for improving germination in Capsicum annuum and Raphanus sativus. Yaldagard et al. (2008) evaluated the effects of 20 kHz ultrasound on barley seeds and reported improved germination performance. The authors suggested that ultrasound has potential applications in agriculture and horticulture for seed priming, drying, storage, and non-chemical seed disinfection.

Furthermore, ultrasound has shown potential for improving crop performance under adverse environmental conditions. Studies have reported beneficial effects on seed performance and stress tolerance under appropriate treatment conditions (Saleminanasab et al. 2017). For example, Sharafi (2020) demonstrated that ultrasonic treatment improved seed vigor and root development in Medicago scutellata under salinity and drought stress, suggesting its potential application as a non-chemical approach for improving crop establishment under stress conditions.

4. Molecular Mechanisms and Cellular Memory in Plants

Modern plant biology has documented that plants can retain molecular

and physiological traces of previous environmental exposures, contributing to stress memory and altered responses to subsequent stimuli. Epigenetic regulation, together with changes in gene expression, has been implicated as an important component of these memory-associated processes. DNA methylation and histone modifications are among the major epigenetic mechanisms involved in regulating stress-responsive genes and modulating plant responses to environmental stress (Lämke & Bäurle 2017; Crisp et al. 2016).

Experimental studies have reported molecular and physiological responses following exposure to sound vibrations in plants. In Arabidopsis thaliana, Ghosh et al. (2016) reported transcriptomic, proteomic, and hormonal changes following sound-vibration exposure. Ghosh et al. (2017) further identified differential expression of sound-responsive genes, including genes encoding mechanosensitive ion channels, following exposure to 500 Hz at 80 dB. Similarly, Choi et al. (2017) reported increased expression of defense- and salicylic-acid-responsive genes and elevated salicylic acid levels following exposure to 1000 Hz at 100 dB in Arabidopsis thaliana challenged with Botrytis cinerea. However, these studies demonstrate short-term molecular and physiological responses to sound vibration rather than epigenetic reprogramming or cellular memory. Whether such sound-induced responses can produce persistent epigenetic changes or contribute to long-term cellular memory therefore remains unresolved and requires direct experimental validation.

Current experimental evidence indicates that acoustic stimulation may be associated with changes in gene expression, hormone levels, and stress- or defense-related signaling in plants. However, direct evidence demonstrating sound-induced changes in DNA methylation, histone modification, or chromatin remodeling remains limited.

Plant signaling networks integrate information from multiple cellular processes and coordinate responses related to growth, defense, and photosynthetic regulation. These interconnected networks contribute to plant adaptation through dynamic interactions among hormonal, metabolic, and molecular signaling pathways (Lüttge 2021). Experimental studies have reported changes in specific signaling- and stress-related responses following acoustic stimulation in plants; however, how these acoustic effects are integrated within broader signaling networks remains insufficiently understood. In particular, the extent to which acoustic signaling interacts with epigenetic regulation or contributes to persistent cellular responses has not been experimentally established.

5. Mechanisms of Sound Wave Effects on Plants

Although the mechanisms underlying plant responses to audible sound and ultrasound remain incompletely understood, accumulating evidence suggests that these acoustic stimuli may be associated with changes in a range of cellular and physiological processes. Proposed mechanisms include mechanical stimulation of plant tissues, activation of cellular signaling pathways, changes in enzyme activity and phytohormone regulation, and alterations in gene expression. However, the relative contribution of these proposed mechanisms remains to be determined through controlled experimental studies, and direct evidence supporting specific causal pathways is still limited.

5.1. Audible Sound Waves

Audible sound waves may influence plant physiology through the conversion of acoustic energy into mechanical stimuli experienced by plant tissues. These mechanical vibrations may induce changes in cellular structures, including alterations in cell wall and membrane properties, cytoplasmic streaming, and intracellular signaling processes (Hassanien et al. 2014). Mechanical resonance between external acoustic frequencies and plant tissues has been proposed as a potential mechanism contributing to sound perception; however, direct experimental validation of this phenomenon remains limited (Gagliano 2013; Cai et al. 2014).

At the biochemical level, sound stimulation has been associated with changes in antioxidant defense systems, including alterations in the activity of enzymes involved in oxidative stress regulation, which may contribute to plant responses under adverse environmental conditions (Wang et al. 2003). Furthermore, acoustic stimulation has been proposed to interact with physiological processes such as stomatal regulation, photosynthetic activity, and cellular metabolism.

At the molecular level, acoustic stimulation may influence phytohormonal balance and gene expression. Proposed molecular mechanisms include the modulation of phytohormonal signaling, calcium-dependent pathways, cellular energy metabolism, and gene expression. In addition, acoustic vibration has been investigated as a non-chemical elicitor in tissue culture systems, where it has been reported to promote organogenesis and plant regeneration (Teixeira da Silva & Dobránszki 2014).

Collectively, these findings suggest that audible sound may be associated

with changes in mechanical, biochemical, and molecular processes in plants. However, the extent to which these responses are causally linked through specific signaling pathways, as well as their biological significance, remains to be determined through further controlled experimental investigation.

5.2. Ultrasound Waves

One proposed mechanism through which ultrasound may influence plant structure and function is cavitation, a phenomenon that can occur when ultrasonic waves interact with aqueous environments. During cavitation, microscopic bubbles may be generated and subsequently collapse or oscillate, producing mechanical forces that can affect biological structures. Such effects have been proposed to alter membrane permeability and potentially influence water and ion transport and cellular activity (Mason & Lorimer 2002). These proposed effects are specific to ultrasound exposure and should not be extrapolated to other acoustic stimuli without direct experimental evidence.

In addition to mechanical effects, ultrasound exposure has also been associated with changes in stress-responsive molecular processes, including growth- and defense-related signaling (Király et al. 2025). Several experimental studies have also reported changes in the activity or expression of antioxidant enzymes, including catalase and superoxide dismutase, following ultrasound treatment (Safari et al. 2013; Wei et al. 2012). These findings indicate that ultrasound exposure may be associated with changes in antioxidant and stress-related responses, but they do not by themselves establish a specific causal molecular pathway.

Collectively, the available evidence suggests that plant responses to ultrasound may involve mechanical and molecular processes. However, the relative contributions of cavitation, signaling processes, and downstream physiological responses remain insufficiently resolved and require further investigation under controlled experimental conditions.

6. Discussion

The findings discussed in this review highlight the complexity of plant responses to acoustic stimulation and suggest that these responses may vary depending on both the type of acoustic stimulus and the conditions under which exposure occurs. The following sections compare plant responses to different acoustic stimuli and examine the factors that may account for the variability observed across studies.

6.1. Comparative Analysis of Plant Responses to Acoustic Stimuli

Numerous studies have investigated the effects of different acoustic stimuli on plant physiological processes and growth-related traits. Available evidence suggests that certain acoustic stimuli, including classical music, natural sounds, and Qur'anic recitation, may be associated with changes in plant growth and physiological responses under specific experimental conditions. Reported responses have included changes in physiological processes, enzymatic activity, and photosynthetic performance; however, the extent to which these responses are directly attributable to specific acoustic characteristics remains unclear.

Existing studies suggest that plant responses reported following Qur'anic recitation may overlap with responses reported for other acoustic stimuli; however, the limited number of standardized direct comparisons prevents firm conclusions regarding their relative biological effects. Accordingly, comparisons among acoustic treatments should primarily be interpreted in terms of measurable sound characteristics rather than as evidence of definitive content-dependent biological effects. Some experimental studies have proposed that acoustic stimulation may be associated with changes in cellular organization, nutrient allocation, and growth-related gene expression; however, the extent to which these processes contribute to observed plant responses remains insufficiently established.

Although preliminary findings have been reported, the physiological effects attributed to Qur'anic recitation require further validation under controlled and reproducible experimental conditions. Future studies should incorporate appropriate acoustic and linguistic controls to determine whether observed responses primarily reflect general acoustic properties or stimulus-specific characteristics and to clarify the biological significance and reproducibility of responses to Qur'anic recitation in plants.

6.2. Factors Underlying Variable Plant Responses

The available literature does not support a uniform physiological response of plants to acoustic stimulation. Reported effects range from stimulation of growth, photosynthetic activity, and defense-related processes to negligible or inhibitory responses. Such variability indicates that reported plant responses to acoustic stimulation are strongly context-dependent and that acoustic–plant interactions are influenced by multiple factors.

The magnitude and direction of plant responses may emerge from interactions among acoustic characteristics, plant biological attributes, and environmental conditions. Acoustic frequency, sound-pressure level, exposure duration, temporal pattern, and spectral composition determine the characteristics of the applied stimulus, whereas species or genotype, developmental stage, tissue sensitivity, and physiological status may influence how plants perceive and respond to it. Environmental factors, including light, temperature, humidity, nutritional status, and pre-existing stress, may further modify these responses. Consequently, similar acoustic treatments may produce different physiological outcomes across plant species or experimental conditions.

An additional limitation is the difficulty of determining whether apparently contrasting findings reflect genuine biological differences or methodological differences among studies. Variations in acoustic exposure protocols, distance between the sound source and the plant, background acoustic conditions, experimental duration, and outcome measurements can substantially limit direct comparisons. Therefore, positive, neutral, or inhibitory responses observed under specific experimental conditions should not be generalized as universal effects of acoustic stimulation.

From this perspective, the apparent inconsistency in the literature represents not only a limitation but also an important research opportunity. Future studies should move beyond asking whether sound affects plants and instead determine which acoustic characteristics, at what exposure levels, for how long, and under which biological and environmental conditions, produce reproducible responses. Standardized acoustic characterization, calibrated exposure protocols, appropriate controls, and harmonized physiological and molecular measurements will be essential for distinguishing general acoustic effects from stimulus-specific responses and for developing a more mechanistic understanding of plant responses to acoustic stimulation.

7. Conclusion

The available evidence indicates that plant responses to acoustic stimulation have been reported under specific experimental conditions. Studies involving audible sounds, including music and natural sounds, as well as ultrasound, have reported changes in plant growth and physiological processes. However, these responses vary considerably according to acoustic parameters, plant species, developmental stage, exposure conditions, and environmental context. The available findings do not yet

establish consistent effects across different experimental settings, and the underlying mechanisms remain incompletely understood. Reported physiological, biochemical, and molecular responses do not, by themselves, establish specific causal mechanisms. Accordingly, proposed mechanisms involving cellular signaling, phytohormonal regulation, gene expression, or epigenetic processes should be regarded as hypotheses requiring direct experimental validation rather than as established pathways.

Qur'anic recitation has also been investigated as a form of audible acoustic exposure, with some studies reporting changes in plant responses following such exposure. Nevertheless, the current evidence remains preliminary, limited, and heterogeneous, and does not establish that these responses are specific to Qur'anic recitation. In particular, the effects of measurable acoustic characteristics, including frequency, intensity, temporal pattern, and exposure duration, cannot yet be clearly distinguished from potential effects associated with linguistic features or the specific content of the stimulus. The methodological heterogeneity of the available literature, particularly the lack of adequately matched acoustic and linguistic controls, further limits the strength of causal inferences and the generalizability of the reported findings. As a narrative review, the present study is also subject to limitations arising from the heterogeneity of the included literature and the absence of a quantitative synthesis of effect sizes.

Future research should employ more rigorous comparative designs to distinguish the potential effects of Qur'anic and broader religious content from those of general linguistic and acoustic stimulation. In particular, Qur'anic recitation should be compared with other vocal stimuli, such as ordinary Arabic speech with Qur'anic, religious, or non-religious content, and Arabic poetry under carefully controlled and matched acoustic conditions. Such comparisons should seek to determine whether the observed plant responses are primarily attributable to general acoustic properties, melodic patterns, linguistic characteristics, or specific features associated with Qur'anic content. Future experiments should also carefully control and report sound pressure levels, frequency spectra, source-to-plant distance, and exposure duration, while incorporating appropriate control groups, adequate sample sizes, and independent replication. Potential agricultural applications of acoustic stimulation also require controlled greenhouse and field validation before practical benefits can be inferred from laboratory findings. Overall, the current evidence supports continued investigation of acoustic stimulation in plant research, while the biological significance and stimulus-specific effects of Qur'anic recitation remain unresolved.

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