Environment Conservation Journal 24 (3):296--304, 2023

Journal homepage: https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)

Potential effects of audible sound signals including music on plants: A new trigger

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ARTICLE INFO

Received : 27 October 2022
Revised : 26 February 2023
Accepted : 20 March 2023

Available online: 28 June 2023

Key Words:
Acoustic frequency technology
Frequency
Germination
Music
Plant growth
Sound wave

ABSTRACT

Plants are highly sensitive organisms and can indeed benefit from specific sound signals in multi-layered processes. Scientific evidences have shown the potential applications of sound wave treatment in plant biology. However, there are some limitations to sound wave treatment that must be overcome. We still do not understand how do plants initially perceive and recognize sound signals, which is very critical to maximize the effectiveness of the use of sound treatment from practical viewpoint. Proper setup of sound treatment equipment and detailed understanding and evaluation of the effects of selected frequencies and intensities along with sound exposure times are also very crucial during sound treatment. More experimental studies with different models need to be done in a multidisciplinary approach toward establishing suitable mechanism for sound treatment application in agriculture production. The aim of this paper is to provide an overview of findings associated with potential effects of audible sound waves including music on different biological, physiological and biochemical processes in plants.

Introduction

Sound wave is ubiquitous across the world. Frequency, intensity, amplitude and speed are some fundamental characteristics features of sound. Audible sound which is perceptible by human ears has frequency range of 20 Hz to 20,000 Hz. Musical sound is nothing but the regular or periodic vibrations of sound with a definite pitch combined with loudness, timbre and duration. Music is a mode of communication between human beings as well as between other living creatures. From the work of Bose (1902, 1926), an eminent biophysicist we came to know that like other living organisms plants also respond to sounds. Even the unicellular organisms are also responsive towards sound vibration (Shaobin *et al.,* 2010). Plants have well developed sensitivity towards sound wave of different ecologically significant frequencies. Buzz pollination is a strong example of it (De Luca *et al.,* 2010). Scientists have investigated the effects of pure tone audible sound and music on plants at various physiological processes like germination (Das and Ghosh, 2022), callus development (Yang *et al.,* 2004), growth (Weinberger and Measures, 1979), photosynthesis (Meng *et al.,* 2011), mechanisms of hormone production, (Zhu *et al.,* 2011) and transcription of certain genes (Jeong *et al.,* 2008). Recently plant acoustic frequency technology (PAFT) is being used to treat plants with an intermittent pulse of sound frequency with specific intensity. By applying PAFT treatment a significant increase in biological responses have been found in various fruits and vegetables (Meng *et al.,* 2012a; Hou *et al.,* 2009). The application of PAFT in greenhouses also had enhanced yields of vegetables with increased disease resistance capacity (Jiang and Huang, 2012). Increase drought tolerance (Jeong *et al.,* 2014), and decreased requirements for pesticides and chemical fertilizers were also noticed by scientists after PAFT treatment (Yu *et al.,* 2013).

Effects of pure tone audible sound waves on callus of medicinal plants

Actinidia chinensis (Kiwi) is one of the extensively used medicinal plant rich in sugar and vitamins. It

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Doi: https://doi.org/10.36953/ECJ.15592489

was found that sound stimulation accelerated the root activity in *Actinidia chinensis* including increased number of roots and total length but retarded the cell membrane permeability (Yang *et al.,* 2004). It was also reported that sound stimulation of 1 kHz with 100 dB intensity has increased the ATP content, Superoxide dismutase (SOD) and soluble protein contents in *Actinidia chinensis* but these activities decreased when sound stimulation exceeds the above mentioned frequency and intensity (Yang *et al.,* 2002; Yang *et al.,* 2003). *Dendrobium candidum* Wall. ex Lindl is a precious Chinese medicinal herbal plant used to treat eye diseases, removing toxins from human body and also have other immunomodulatory effects. The aerial parts of *Dendrobium* are mainly used for medicinal purposes (Zha *et al.,* 2009). Evidence shows increased activities of antioxidative enzymes in different parts (shoots, roots and leaves) of *Dendrobium candidum* Wall. ex Lindl under exposure to sound vibration (Li *et al.,* 2008). *Chrysanthemum* is also a worldwide used medicinal herbal plant. Studies have shown that sound stimuli could influence the growth rate of *chrysanthemum* callus by affecting the cell wall calcium (Wang *et al.,* 2002). Sound frequency of 1000 Hz with 100dB intensity had enhanced root metabolism and growth in *Chrysanthemum* including increased soluble sugar contents with higher amylase and protein activities (Jia *et al.,* 2003). Playing appropriate sound by using sound stimulation generator had enhanced levels of soluble proteins and superoxide dismutase activity along with increased rate of calcium absorption by *Chrysanthemum* callus. Sound wave exceeding 0.8 kHz and intensity of 100 dB had negative impact on the above indexes. (Liu *et al.,*2002). Sound wave stimulation accelerated the synthesis of nucleic acid and protein in *Chrysanthemum* (Wang *et al.,* 2003a). Report showed enhanced growth of *Chrysanthemum* under sound treatment with increased number of cells in the S phase and decreased number of cells in the G_0/G_1 phase (Wang *et al.,* 2003b). Indole-3-acetic acid or IAA is one of the most important auxin produced in the apical portion of shoot and younger leaves of plants and helps in plant growth and development (Cutler *et al.,* 2010; Wilkinson *et al.,* 2010). Abscisic acid or ABA is a plant stress hormone accumulated under stress condition (Zhang *et al.,* 2006; Lovelli *et al.,* 2012). Reports demonstrated that exposing *Chrysanthemum* callus to a particular sound stimulation (frequency of 1.4 kHz and intensity 95 dB) significantly increased the levels of Indole-3-acetic acid and decreased the levels of Abscisic acid when compared to control. These changes subsequently help in callus development and maturation (Wang *et al.,* 2004). Sound stimulation also had positive effects on cell membrane deformability (Wang *et al.,* 2001).

Impact of pure tone audible sound wave on different phases of plant life cycle

Sound waves with different frequencies, intensities and amplitudes affect plant growth differently in different plant species. Studies have shown that sound vibration could stimulate a seed or plant. Sound treatment with different frequencies and intensities, particularly wave of 5 kHz with 92 dB enhanced tiller growth including number of roots and plant dry weight in Rideau wheat seedlings (Weinberger and Measures, 1979). Investigating the biological effect of sound stimulation on *Oryza sativa*, scientists revealed that sound frequency of 0.4 kHz with SPL of 106 dB significantly promoted the germination index, fresh weight, shoot length, cell membrane permeability and activity of root system. Sound stimulation exceeding 4 kHz and 111 dB had negative impact on growth of *Oryza sativa* (Wang *et al.,* 2003c). Young *Zea mays* root tips showed bending pattern towards continuous sound stimuli and best response was measured between 0.2 and 0.3 kHz (Gagliano *et al.,* 2012). Scientists also revealed that sound wave with 1000 Hz and 100 dB made the germination rate faster with reduced germination time in *Echinacea angustifolia* (Chuanren *et al.,* 2004). Sound frequency of 50 Hz had positive effects on seed germination in *Oryza sativa and Cucumis sativa* (Takahashi *et al.,*1991). Germination rate of *Arabidopsis thaliana* was improved by treatment with sound frequency above 70 Hz with 0.42 mm amplitude (Uchida and Yamamoto, 2002). It has been reported that audible sound with specific range of frequencies (1000-1500 Hz, 1500-2000 Hz, and 2000-2500 Hz) and intensities (80 dB, 90 dB, and 100 dB) had different effects on mung been (*Vigna radiate*) germination and growth. Significant reduction in germination time and as enhanced plant growth were noticed after treatment with frequency around 2000 Hz and intensity around 90 dB (Cai *et al.,* 2014). Research demonstrated that *Oryza sativa* exposed to sound wave of 0.125 kHz and 0.250 kHz showed significant increase in Ald (fructose 1,6-bisphosphate aldolase) mRNA expression, in contrast treatment with 0.050 kHz has showed significant decrease in Ald mRNA expression (Jeong *et al.,*2008). Researchers also have investigated sound wave induced increased expression of TCHs genes encoding calmodulin-related proteins and xyloglucan endotransglycosylase / hydrolase in *Arabidopsis* (Johnson *et al.,* 1998). Investigating the effects of sound wave on protein structure in *tobacco*, scientists pointed out that 0.4 kHz sound frequency with 90 dB SPL influenced the secondary protein structure of the plasma membrane by increasing the α-helix and decreasing the β-turn. The rate of cell growth and phase transition temperature slowed down significantly under sound treatment (Keli *et al.,* 1999; Zhao *et al.,* 2002). Sounds of varying frequencies and intensities have changed the secondary structure of cell wall proteins by altering the amide I and II bonds in tobacco (Shen *et al.,* 1999). Sound stimulation accelerated the cell division and cell metabolism by forming increased amount of sugar and soluble protein in the cytoplasm of *Dendranthema morifolium* callus when exposed to frequency of 1 kHz with100 dB intensity (Zhao *et al.,* 2003). Sound waves also accelerated the fruit size (2.4-43.3%) and yield (8.0-15.8%) in edible mushrooms (Jiang *et al.,* 2011). It was shown that sound wave of varying frequencies influenced the impatiens and bean plants. When the wavelength of pure tone sound coincides with the average of major leaf dimensions, maximum plant growth has occurred (Collins and Foreman, 2001). Reports pointed out that polyamines play a major role in normal plant developmental processes such as cell growth, cell division, organ development, flowering, fruiting, ripening and embryogenesis (Evans and Malmberg, 1989; Pal Bais and Ravishankar, 2002). Sound wave exposure has also made plants more defensive against *Pieris rapae* caterpillar. The treated plants exhibited higher amounts of anthocyanin and glucosinolate compared to untreated control (Appel and Cocroft, 2014). Studies pointed out that sound treatment upregulated a number of genes including the mechanostimulus responsive genes, redox homeostasis genes, defence related genes, biosynthesis related genes, signalling related genes and transcription factors encoding genes in *Arabidopsis thaliana*. Sound wave stimulation with 0.5 kHz and 80 dB had showed maximum impact on phytohormones. Significant changes in the production of gibberellin (GA), indole- 3-acetic acid (IAA), jasmonic acid (JA) and salicylic acid (SA) were also noted (Ghosh *et al.,* 2016). Gibberellin and indole- 3-acetic acid are growth related hormones, whereas salicylic acid and jasmonic acid are defence related hormones in plants. Report showed that sound vibration of 1000 Hz with 100 dB enhanced the maximum disease resistance capacity both in whole plants and detached leaves of *Arabidopsis thaliana* against *Botrytis cinerea* infection. Corroboratively, during the infection period an elevated level of salicylic acid (SA) and demoted level of jasmonic acid (JA) were also noted in treated plants compared to that of control (Choi *et al.,* 2017). *Arabidopsis* exposed to sound waves either of 250 Hz or 500 Hz had enhanced expression of photosynthesis related proteins (Kwon *et al.,* 2012). *Solanum lycopersicum* (Tomato plant) is one of the most consumed and antioxidant rich vegetable source. Plants exposed to1600 Hz and 90 dB showed best results in tomato fruit with increased contents of vitamin C, lycopene, total sugar, total phenol and total acid. Sound wave accelerated the accumulation of metabolites in tomato giving rise to improved fruit quality (Altuntas and Ozkurt, 2019). Sound wave stimulation with 1 kHz delayed the ripening processes in tomato and made them firm by negatively regulating the following genes - ACS2, ACS4, ACO1, E4, E8, IN, TAGL1, HB-1, NOR, and CNR. Sound treatment also affected some transcription factors facilitating the fruit ripening processes (Kim *et al.,* 2015, 2016). Audible sound also enhanced the growth and biomass production in cells of *Picochlorum oklahomensis* (Cai *et al.,* 2016). Sound stimulation influenced plant tolerance to abiotic stresses as well. For example, one hour sound exposure of 800-15000 Hz enhanced drought tolerance in rice including higher water contents and increased conductance of stomata (Jeong *et al.,* 2014). Sound of bee buzzing facilitated the pollination of flowers by inducing pollen release from anthers (De Luca and Vallejo-Marin, 2013). Therefore bee buzzing served as beneficial signals to plants.

Influence of Plant Acoustic Frequency Technology (PAFT) on field crops and vegetables

Plant Acoustic Frequency Technology or PAFT is used to treat plants with an intermittent pulse of sound frequency with specific intensity. By applying PAFT treatment a significant increase in biological responses have been found in cotton plants including seedling height, leaf width, single boll weight, boll numbers, number of boll bearing branches and yields. All these effects were very much frequency, intensity, distance and direction of sound dependent (Hou *et al.,* 2010a). The yield of paddy and wheat were increased qualitatively and quantitavely when exposed to PAFT generator. A significant increase in protein content of rice; and protein, fat and starch contents of wheat were observed. This technology also made plants more insect pest and disease resistance by strengthening the immune systems. A 50% reduction in rice sheath blight disease was also noticed. In addition, three years experimental results revealed that PAFT could reduce the use of fertilizer by an amount of about 25% when applied in rice field (Hou *et al.,* 2010b; Yu *et al.,* 2013). Investigating the effects of PAFT on vegetables, scientists revealed an improved production of endogenous hormones including ZR, GA and IAA in eggplant, muskmelon, cowpea, tomato, and cucumber (Zhu *et al.,* 2011; Meng *et al.,* 2012a; Huang and Jiang, 2011). Scientists also have investigated the effect of PAFT on cucumbers, strawberries, and tomatoes and observed increased number of flowers and fruits along with enhanced biological changes in chlorophyll content, photosynthetic activity, non-photochemical quenching and PS II photochemical efficiency in greenhouses (Fan *et al.,* 2010; Zhou *et al.,* 2010; Meng *et al.,* 2011; Meng *et al.,* 2012b). The PAFT treated strawberries were grown stronger with greener leaves. The blossoming, fruiting and rate of photosynthesis were also accelerated significantly with an enhanced insect pests resistance and disease resistance capacity (Qi *et al.,* 2009). The application of PAFT in greenhouses also enhanced the yield of cucumber, tomato and sweet pepper with increased disease resistance capacity. It was noticed that viral and late blight diseases decreased in greenhouse tomatoes along with reduced aphids, mites and gray mold attacks (Hou *et al.,* 2009; Jiang and Huang, 2012).

Agri- wave technology which is nothing but applying PAFT technology with spraying of microelement fertilizer also has been applied on plants for enhancing the yield both qualitatively and quantitavely. This technology significantly enhanced the growth of tomatoes, promoted the ripening process and also increased the yield qualitatively and quantitavely (Hou *et al.,* 1999a). Spinach and lettuce showed similar results of enhancement in growth rate and yield when treated with Agri- wave technology. An increased amount of vitamins A, B, C and sugar contents were also found in treated plant species. Further, the agri-wave technology has increased the disease resistant properties in spinach (Hou *et al.,* 1999b).

Impact of music on different plant species

Music is made up of sound waves with various frequencies and intensities and mathematically music is ordered. Researchers have investigated the effect of music on plant growth and plants treated with certain melodies have showed better growth when compared to control (Subramanian *et al.,* 1969; Coghlan, 1994). Ponniah and Singh were two of the pioneers in this kind of work. As a source of music they played violin pieces to plants for observing plant growth (Ponniah, 1955; Singh and Ponniah, 1955). Report has pointed out that musical sound significantly accelerated the germination rate in okra and zucchini seeds when compared to untreated control and noise (Creath and Schwartz, 2004). It has been investigated that long term exposure to powerful beating of heavy metals and rock music had detrimental effects on plants. In contrast, light and soft music with gentle vibrations accelerated plant growth with increased yield and also made plants stronger (Klein and Edsall, 1965). Studies have shown that music treated plants produced thicker and greener stems and sprouted faster than control (Hicks, 1963) and music exposed vegetables exhibited improved quality and yield (Xiao, 1990). It is also reported that musical sound of different kinds had positive effects on root elongation as well as on cell metabolism (Seregin and Ivanov, 2001). Report also pointed out that classical music treated plants have shown highest growth than that of the untreated control (Retallack, 1973). Rhythmic music, one classical and another with dynamically changing lyrics increased the onion root tips elongation by enhancing mitotic cell division during germination (Ekici *et al.,* 2007). In another experiment *Rosa chinensis* plants were divided into five groups, one group was used as control group and rest were exposed to four different kinds of music including Indian Classical, Vedic chants, Rock, and Western Classical music. It was found that plants exposed to Indian Classical music and Vedic chants exhibited promoted plant growth when compared to Rock music treated group, Western Classical music treated group as well as control group (Chivukula and Ramaswamy, 2014). Rhythmic soft-melodious music promoted growth and development in eight different medicinal and ornamental plants (*Tagetes erecta, Catharanthus roseus, Trachyspermum ammi, Duranta repens, Hibiscus rosa- sinensis, Epipremnum aureum, Dendranthema grandiflorm, Ocimum sanctum*) including increased height, increased number of leaves and flowers, advanced flowering time and enhanced level of various metabolites including elevated levels of starch and chlorophyll (Sharma *et al.,* 2015). Researchers have investigated the positive impact of Indian classical raga on overall protein production in paddy, wheat, soya, horse gram and spinach plants (Reddy and Raghavan, 2013). Study has shown that light Indian music and Meditation Music could increase the height of stem and length of leaves in marigold plant along with higher number of buds and flowers whereas noise treatment had negative impacts on the above attributes. Exposure to Indian light music also showed faster sprouting and enhanced growth development in chickpea (*Cicer arietinum*) compared to untreated control plants (Chowdhury and Gupta, 2015). Classical music and rhythmic rock music had positive effects and non-rhythmic traffic noise has negative effects on number of germinated seeds, height of plants and number of leaves in *Cyamopsis Tetragonoloba* (common guar or cluster bean) as compared to control (Vanol and Vaidya, 2014). Playing rhythmic violin music and non-rhythmic traffic noise to *Phaseolus vulgaris* (common bean plant) scientists have investigated that both music and noise had positive effects on plant growth as compared to control. Rhythmic violin music treated plants showed better growth than the non-rhythmic traffic noise treated plants (Chatterjee*et al.,* 2013). Investigating the biological effects of classical music and rock music on *Triticum aestivum* (wheat) plant growth, scientists observed that plants grew well with brighter green leaves when exposed to classical music than either the control or rock music exposed plants (Rachieru *et al.,* 2017). Folk music played from wind instruments flute and pipe flute had increased average weight and yield outputs in apple tree and salad plants (Popescu *et al.,* 2013). Sanskrit sholkas (Vedic Chants) exposed *Vigna radiate* plants were much healthier and showed enhanced shoot elongation. On the contrary discouraging words had negative impact on plant growth and quality (Patel *et. al*., 2016). *Ocimum sanctum* (*Tulasi*) plants subjected to Gayatri mantra, *Solanum indicum* plants exposed to Om Rsi Kesavaaya Namah mantra and *Tylopphora indica* climbers charged with Om Anantaya Namah mantra had showed increased growth along with enhanced efficacy in curing diseases (Karnick, 1983). Playing Western pop music and Buddhist *pirith* chanting to *Codariocalyx motorius*, scientists have found discernible effects of Buddhist *pirith* chanting on plant height, number of leaves, chlorophyll content, leaflet length, leaf width and leaf area; indicating improved growth performance when compared to Western pop music and control (Munasinghe *et al.,* 2018). Study also has shown that Agnihotra which is a Vedic ritual of chanting mantras with offerings of brown rice mixed with cow ghee to the fire, produced enhanced stem length and root length in *Vigna radiate* (moong) 38% and 31% respectively than the untreated control (Abhang *et al.,* 2015). Agnihotra also contributed an accelerated germnation rate in rice seeds along with increased growth rate in rice seedlings (Swamy and Nagendra, 2004). Sindhu bhairavi classical raga exposed *Oryza sativa* (paddy), *Triticum asteivum* (wheat), *Spinacia oleracea* (palak), *Glycine max* (soya) and *Macrotyloma uniflorum* (horse gram) plants exhibited better overall plant protein productions when compared to control, Kapi and Desh ragas respectively (Reddy and Ragavan, 2013).

Conclusion

Summing up all the above scientific observations, it can be concluded that audible sound with specific frequencies and intensities facilitated different stages of plant life cycle. Investigations were also noted in this domain with music. Plants were benefited with different genre of music but that dependence were species specific. The above studies indicate that there is a strong relationship between audible sound waves and plant growth and development but the detail mechanisms still remain obscure. The positive effect of audible sound stimuli including music on seed germination; plant growth; productivity; along with reduce requirements for chemicals fertilizers, pesticides; enhanced fitness and resistance against biotic as well as abiotic factors can benefit the sustainability of agricultural sector in a green way.

Conflict of interest

The author declare that they have no conflict of interest.

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