

Update on the Effects of Sound Wave on Plants

Md. Emran Khan Chowdhury¹, Hyoun-Sub Lim^{2*} and Hanhong Bae¹

***Corresponding author**

Tel : +82-42-821-5766

Fax: +82-42-823-8679

E-mail : hyounlim@cnu.ac.kr

¹School of Biotechnology, Yeungnam University, Gyeongsan 712-749, Korea

²Department of Applied Biology, Chungnam National University, Daejeon 305-764, Korea

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Plant growth is considered the sum of cell proliferation and subsequent elongation of the cells. The continuous proliferation and elongation of plant cells are vital to the production of new organs, which have a significant impact on overall plant growth. Accordingly, the relationship between environmental stimuli, such as temperature, light, wind, and sound waves to plant growth is of great interest in studies of plant development. Sound waves can have negative or positive effects on plant growth. In this review paper we have summarized the relationship between sound waves and plant growth response. Sound waves with specific frequencies and intensities can have positive effects on various plant biological indices including seed germination, root elongation, plant height, callus growth, cell cycling, signaling transduction systems, enzymatic and hormonal activities, and gene expression.

Keywords : Frequency, Plant growth, Sound wave

Introduction

Plants are complex multicellular organisms that are exposed to nature under various environmental conditions. Environmental factors have a great influence on the growth and development of plants, which interact with their environment through epidermal cells. A series of biological changes occurs in living plant systems that reflects its speed of growth. Accordingly, the growth of plant cells and tissues in response to different physical stimuli is a cardinal field of study in cell biology (Braam and Davis, 1990).

Sound is an external factor that has a great impact on the biological index of plants (Bochu *et al.*, 1998, 2001; Zhao *et al.*, 2000; Liu *et al.*, 2001; Yiyao *et al.*, 2002; Yang *et al.*, 2002; Yi *et al.*, 2003a) and can either promote or suppress growth. Sound is an oscillation of waves of pressure transmitted through gases, liquids or solids. As waves propagate, they transport energy. In addition, sound disperses information about the surrounding and living organisms adhere this information /and or communicate through wave motions. The amount of the energy in the wave determines the measures of the sound wave and its travelling time. The audible sound that humans can hear falls into frequencies ranging from 20 Hz–20,000 Hz (Hertz) (Dorrell, 2005),

while sound above this range is known as ultrasound and that below this range is known as infrasound. Sound waves transported through a medium via the mechanism of particle interaction are characterized as mechanical waves (Pierce, 1989). In nature, almost all living organisms are immersed in a variety of sound waves and interact with them.

The use of sound and music to improve the health of living organisms is not a novel idea. Indeed, the beneficial and harmful effects of sound in terms of music were recognized by the ancient Greeks and Romans (Rooke, 1985). Music, which is made up of sound waves with different frequencies and intensities (Telewski, 2006), has been used for the treatment of illnesses, including neuropathy and depression (Wicke, 2002). Dr. TC Singh first studied the effects of music on plants in the 1950s (Tompkins and Bird, 1989). In 1973, D Retallack published a book titled, "The Sound of Music and Plant", which described experiments involving plants and music. In these experiments she played sounds and particular styles of music to plants and found that the best growth results were obtained when classical music was played. Moreover, stimuli such as sound fields, supersonic sound, electromagnetic fields, micro gravity, and mechanical vibrations impacted plants (Bush, 1995; Frazee, 1996). Indeed, sound vibration has also been shown to stimulate seed germination and plant growth (Braam and Davis, 1990). Moreover, various studies have investigated the effects of music and sound on paddy crops (Subramanian *et al.*, 1969), wheat (Weinberger and Measures, 1979), purple passion vine plants (Tompkins and

Bird, 1989), and *Arabidopsis* (Braam and Davis, 1990). Taken together, these studies belong to the field of acoustic biology. Overall, little research has been conducted in this field due to the lack of precise instrumentation to measure the response of plants to sound as well as a lack of confirmed scientific information in this area of study. Therefore, we are conducting research to determine the relationship between the exposure of plants to sound and subsequent plant growth. Growth response depends on the frequency and intensity of sound (Liu *et al.*, 2001). It is known that different frequencies and intensities of sound impact different plants; however, further studies are needed to clarify these variations. Here, we have summarized the impact of sound waves and music on plant response in terms of growth and development.

Role of Sound Waves on Plant Growth and Development

A key feature of living organisms is the ability to sense and respond to different physical stimuli. Light, temperature and a variety of chemical signals are common environmental physical stimuli detected by biological organisms. In addition, organisms perceive a variety of external mechanical stimuli, including those induced by pressure gradients of wind in the atmosphere as well as pressure gradients in aquatic systems created by currents or tidal flows. These types of mechanical stimuli, which are collectively known as touch or thigmostimuli, produce a number of thigmoresponses in plants including thigmomorphogenesis, thigmotropism, thigmonasty and thigmotactic response (Jaffe *et al.*, 2002; Braam, 2005). Pressure waves created by sound waves are transmitted in aerial, solid and aquatic environments. However, it is not clear if plants can respond to sound that impact them as mechanical waves transmitted through wind pressure.

The interaction between living organisms and audible sound is usually neglected in biological research. Nevertheless, sound waves with appropriate length of action time and proper intensity or frequency are known to stimulate cell growth in some plants (Bochu *et al.*, 1998; Yiyao *et al.*, 2002). Additionally, some studies have investigated the relationship between plants and sounds and scientists have reported the response of plants to sound waves and music via different aspects of plant growth and development. The effects of music to improve crop yield and quality have been reported in tomato plants, barley and other vegetables (Hou and Mooneyham, 1999; Spillane, 1991; Xiao, 1990). Weinberger and Measures (1979) reported the effects of intensity in audible sound on the growth and development of Rideau winter wheat. The authors concluded that the vegetative growth response of winter wheat to audible sound was mainly dependent upon both frequency and intensity. They reported that sonication at 5 kHz and 92 dB (decibel) led to stimulate tiller growth with an increase of plant dry weight and number of roots. Hou *et al.* (1994) reported 100 Hz fre-

quency of an external sound showed positive impact on philodendron plant growth. Qi *et al.* (2010) showed the influence of sound wave stimulation on strawberry leaf area/dimensions, the photosynthetic characteristics, and other physiological responses. The authors reported that the sound waves promoted the growth of strawberry, as well as sound waves enhanced the resistance of strawberry against diseases and insects.

Two plant species such as beans and impatiens were affected by sounds of varying frequencies. The authors reported that optimum plant growth occurred when the plant was exposed to pure tone sound in which the wavelength coincided with the average of major leaf dimensions. The plant growth was decreased when exposed to random noise (Collins and Foreman, 2001).

Seed Germination. Different metabolic activities including enzyme activation and hormonal changes occur during seed germination, and sound is known to directly affect biological systems including those involved in seed germination. Creath and Schwartz (2004) compared effects of music, noise, and healing energy using seed germination assay. Musical sound has been shown to significantly enhance the sprouting of okra and zucchini seeds than the noise effect. This effect is independent of temperature, location of the experiments, seed type, specific petri dish, and person doing the scoring. The healing energy also had significant effect like sound compared to the untreated control of seed germination. The authors concluded that sound vibrations such as music and noise as well as biofield such as bioelectro-magnetic and healing intention directly affect living biological systems (Creath and Schwartz, 2004). Seeds of *Echinacea angustifolia*, a medicinal plant, showed improved germination rate to chemical and physical factors, such as scarification, chilling period, light, applied chemicals (6-benzylaminopurine, gibberellic acid), and sound stimulation (Chuanren *et al.*, 2004). The seeds showed the highest germination rate with the least germination time when subjected to sound wave at 100 dB and 1,000 Hz. The author concluded that the germination rate was greatly enhanced and seed dormancy was completely reduced. Sound waves were also found to enhance the germination index, height of the stem, relative increase rate of fresh weight, activity of the root system, rooting ability, and the penetrability of the cell membrane of paddy rice seeds. The authors reported that 400 Hz and 106 dB showed positive effect on the growth stimulation of the paddy rice seed, but high frequency and intensity of sound wave were shown to be harmful (Bochu *et al.*, 2003). Hageseth (1974) investigated the effects of sound on the mathematical parameters that described quantitatively the barley seed germination process. The author found differential germination rate as a function of time using various frequencies of noise from 100 to 9,000 Hz.

Root elongation is related to cell metabolism, and positive relationships between root growth and different types of music have been reported (Seregin and Ivanov, 2001). Moreover,

rhythmic classical music and rhythmic music with dynamically changing lyrics positively affected root elongation and mitotic division in onion root tips during germination. The authors found the correlation between root elongation and mitotic index (MI) and further showed improved growth when compared to control (Ekici *et al.*, 2007). The contents of soluble sugar, protein, and the amylase activity in chrysanthemum increased significantly in response to sound waves with certain intensities (100 dB) and frequencies (1,000 Hz) which indicated that sound stimulation could enhance the metabolism of roots and the growth of *Chrysanthemum* (Yi, 2003b). Sound waves of certain frequencies also enhanced root development of paddy rice (Bochu *et al.*, 2003). There are many reports about the effect of mechanical vibration including frequency and amplitude on seed germination. It promotes seed germination in *Cucumis sativa* and *Oryza sativa* using 50 Hz (Takahashi *et al.*, 1991). When the authors used the fixed amplitude of vibration at 0.42 mm and vibration frequencies above 70 Hz in *Arabidopsis thaliana*, the seeds showed increased rate of germination. The increase in the germination rate was based on the acceleration calculated from the frequency and amplitude of vibration (Uchida and Yamamoto, 2002). The percent of germination and seedling growth of trees such as red pine, tamarack, and white spruce showed no significant positive effect to sonication at 1 MHz with an intensity in the range of 0.5–1.0 W/cm², but jack pine showed significant increase in number of seedlings as well as its total length (Weinberger and Burton, 1981). The authors concluded that the stimulation of jack pine seed germination and seedling growth were related to localized micro heating and nuclear effects. Enhancing the rate of corn seed germination and reduction of time needed for germination have been achieved by immersing the seeds in an aqueous solution including dissolved inert gas with sonication at a frequency between 15–30 kHz and energy density between 1–10 W/cm² (Shors *et al.*, 1999).

Biochemical and Physiological Activities. The division and growth of plant tissues are greatly affected by soluble proteins in tissues. The accumulation of soluble protein contents affects cell division, the content of enzymes and metabolization level (Yiyao *et al.*, 2002). Sound waves at different frequencies and strength have been shown to alter the secondary structure of cell wall proteins of tobacco by changing Amide I and Amide II bonds (Ziwei *et al.*, 1999). Moreover, sound at specific frequencies and intensities promoted the content of soluble proteins and sugars in the cytoplasm of *Dendranthema morifolium* callus (Zhao *et al.*, 2003). The optimum intensity and frequency of sound field stimulation enhanced soluble protein contents and the growth of chrysanthemum calli remarkably (Bochu *et al.*, 2001; Yiyao *et al.*, 2002; Yi *et al.*, 2003b). An audible sound frequency by sonication for 4 weeks at 5 kHz enhanced the amount of alanine and glycine, whereas asparagine content was lower in the sonicated endosperm tissue of Rideau wheat grains compared to untreated controls (Measures and Wein-

berger, 1973). Sound stimulation increased the cell wall and membrane fluidity, which facilitated cell division and growth (Keli *et al.*, 1999; Zhao *et al.*, 2002). Sound stimulation also increased the fluidity of the physical state of lipids in plasma-membrane and influenced the secondary structure of proteins in cell walls and plasmalemma (Yi *et al.*, 2003c). These structural changes of protein and membrane fluidity aided membrane trafficking modulation (Apodaca, 2002) and metabolic activity acceleration (Yi *et al.*, 2003c). Moreover, the polyamine content and oxygen (O₂) uptake rate in Chinese cabbage and cucumber increased in response to sound at 20,000 Hz, and “green music” which consists of a classical music with some natural sounds (Qin *et al.*, 2003). It has also been reported that polyamines are involved in plant developmental processes such as cell division, root growth, reproductive organ development, floral initiation and development, embryogenesis, tuberization, and fruit development and ripening (Evans and Malmberg, 1989; Bais and Ravishankar, 2002).

Plasma membrane H⁺-ATPase is a type of glycoprotein across membranes, which plays an important role in the growth and development of plants. Certain intensity (100 dB) and frequency (1,000 Hz) sound waves increased the activities of plasma membrane H⁺-ATPase (Wang *et al.*, 2002; Yi *et al.*, 2003a), which regulated physiological and biochemical processes such as growth, development, turgor pressure and maintenance of plasma pH (Serrano, 1989; Grouzis *et al.*, 1990; Michelet and Boutry, 1993). Plasma membrane H⁺-ATPase is sensitive to Ca²⁺ concentration. Specifically, plasma membrane H⁺-ATPase activities and the concentration of Ca²⁺ increased in response to sound wave stimulation (Wang *et al.*, 2002; Yi *et al.*, 2003a). Moreover, sound wave stimulation increased the cytosolic Ca²⁺ in chrysanthemum callus cells (Liu *et al.*, 2001). Ultrasound also stimulated the callus cells of *Aloe arborescens* to adapt the environmental stress through increased plasma membrane Ca²⁺-ATPase activity (Liu *et al.*, 2006). Certain frequencies and intensities of sound reduced the penetrability of the cell membranes of paddy rice, but high frequency and intensity was harmful and increased the cell membrane penetrability (Bochu *et al.*, 2003). Overall, these findings indicate that proper sound waves can improve cell function under a variety of unfavorable conditions by reducing the cell membrane penetrability, which facilitates plant growth and development.

Cellular Response. High frequency and intensity of sound can cause cell damage, but at a proper frequency and strength it can promote the growth of plant cells (Bochu *et al.*, 1998). Sound at specific frequencies and intensities significantly increased the callus growth of different plants such as *Dendranthema morifolium* (Zhao *et al.*, 2003) and *Oryza sativa* (Liu *et al.*, 2003). Moreover, audible sound significantly increased the colony formation of *E. coli* under normal growth conditions. The response of bacterial cells to audible sound was stimulated due to the involvement of several potential mechanisms (Shaobin *et al.*,

2010). Specifically, sound at 1,000 Hz and 100 dB increased the ATP content of *Actinidia chinensis* callus, which was favorable for vigorous growth and plant development (Xiaocheng *et al.*, 2003b). Sound waves also greatly affected the cell cycle in *Chrysanthemum* (Xiujuan *et al.*, 2003a). Specifically, the number of cells were increased in the S phase due to sound waves (1,000 Hz and 100 dB), indicating that sound waves accelerated the growth of chrysanthemum. Ultrasound effectively increased the conversion frequency of *Dendrobium officinale* protocormlike bodies (PLBs) to shoot production in micro propagation when administered at 28,000 Hz and 300 W for 5 min (Wei *et al.*, 2012). In addition, ultrasound was reported to cause the transient formation of callose in cotton seeds (Currier and Webster, 1964). Plant growth and development reflect the increase of different growth parameters including plant height, branching, flowering and fruiting, and fresh and dry weight. Moreover, 400 Hz sound waves, as well as cuckoo, cricket and mixed insect songs reportedly showed a positive effect on the height of cowpeas (*Vigna unguiculata*) during the seedling stage (Jun and Shiren, 2011).

Plant acoustic frequency technology (PAFT) is the treatment of plants with a specific sound frequency. This treatment was found to increase the yield and quality, and strengthen disease-resistance in pepper, cucumber, and tomato (Tian *et al.*, 2009). Moreover, the net photosynthetic rate, maximum fluorescence, photochemical efficiency of photosystem II and non-photochemical quenching were also markedly increased by sound in strawberry leaves (Zhou *et al.*, 2010; Meng *et al.*, 2012).

Protective Enzyme Activities. Free radicals including O_2^- , OH^\cdot and 1O_2 are generated by plant cells through various processes (Xiujuan *et al.*, 2003b; Gadjev *et al.*, 2006). These free radicals have a strong capacity to oxydate many functional molecules. Accordingly, elimination of H_2O_2 is an important consideration for maintenance of low free radical levels in plant cells because it can generate more OH^\cdot and 1O_2 free radicals. Peroxidase (POD) and catalase (CAT) primarily decompose H_2O_2 , and superoxide dismutase (SOD) eliminates O_2^- . Sound wave stimulation increased the activities of various plant protective enzymes such as SOD, POD, and CAT, which had a great influence in reducing the accumulation of active oxygen species (AOS) which may protect cells from oxidative damage. Also, different cell compartments might activate different defensive system, which directly avoids the excessive production of AOS. Sound wave stress also induces the lipid peroxidation in *Dendrobium candidum* plant by increasing the content of malondialdehyde, a decomposition product of polyunsaturated fatty acids hydroperoxides (Li *et al.*, 2008). The effect of sound wave on the synthesis of nucleic acid and protein in chrysanthemum was investigated by Xiujuan *et al.* (2003b). The authors reported that sound wave had no significant increase of DNA content, but they enhance the synthesis of RNA and soluble protein. The authors concluded that some stress-induced genes might

be switched on under sound wave stimulation resulting in increased level of transcription.

Genetic Response. Gene expression levels are known to be related to the biological function of plants. Rapid and dramatic fluctuations of gene expression occur in response to different environmental conditions and lead to physiological and developmental changes in plants. These molecular responses facilitate acclimatization of plants to different environmental conditions. The genetic response of plants to sound waves is similar to their response to touch and wind as sound is a mechanical wave vibration. However, limited research has been conducted to investigate gene expression.

Several genes are up or down-regulated in response to different external stimuli. For example, mechano stimulation induced expression of the touch (*TCH*) genes (Braam, 1992; Braam *et al.*, 1997; Sistrunk *et al.*, 1994; Braam, 2005), and frequency specific sound led to significant upregulation of the expression of genes encoding a putative fructose 1,6-bisphosphate aldolase (*ald*) and ribulose 1,5-bisphosphate carboxylase (Rubisco) small subunit (*rbcS*) in rice plants (Jeong *et al.*, 2008). The 1,506-bp *ald* promoter was also found to be a sound-responsive promoter, indicating that specific frequencies of sound can regulate the expression of any gene fused with the *ald* promoter (Jeong *et al.*, 2008). The authors concluded that gene expression was up-regulated at 250 Hz, but down regulated at 50 Hz. Moreover, sound wave stimulation accelerated the synthesis and total content of RNA (Xiujuan *et al.*, 2003c; Hongbo *et al.*, 2008), but had no influence on DNA content (Xiujuan *et al.*, 2003c). Several biotic stresses down-regulated the expression of genes involved in photosynthesis (Bilgin *et al.*, 2010). The authors concluded that the down-regulation of photosynthesis related genes and up-regulation of genes coding for the synthesis of jasmonic and salicylic acid were part of a defense response to various stress.

Conclusions

The growth, development, and genetic characteristics of plants are greatly influenced by different environmental factors. However, the mechanisms by which sound wave stimulation influences plant growth and development remain obscure. Nevertheless, physiological and developmental changes including gene expression occur in plants due to physical environmental stimuli. Several investigations of the relationship between sound wave and plant growth promotion were discussed in this review, and the results of these studies indicated that there is a strong relationship between sound waves and plant growth. Sound waves with specific frequencies and intensities have been shown to have significant effects on a variety of biological, biochemical, and physiological activities including gene expression in plants. However, sound waves with high frequency and intensity can be harmful to the proper growth and

development of plants. Further studies are needed to confirm and elucidate the relationship between sound waves and plant response.

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