Scientia Horticulturae 235 (2018) 340–348

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Effects of acoustic waves on plants: An agricultural, ecological, molecular and biochemical perspective

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ARTICLE INFO

Keywords:
Acoustic waves
Sound vibrations
Plants
Secondary metabolites
Molecular
Elicitors

ABSTRACT

Plants are sessile organisms that need to face threats presented in its surrounding; consequently, they have developed mechanisms to perceive the signals of the ambient and to process them in order to detect threats or advantageous circumstances that could increase their chances of survival.

One of the mechanisms is dedicated to detect sound vibrations (SV) or acoustic waves (AW). The SV has the ability of modifying the behavior of plant cells through Ca^{2+} and ROS cues linked to signaling process of stressed plants. These signals cause behavior changes in the cell, regulate gene expression and/or modify its biochemical activity in order to face the biotic and abiotic factors that could provoke damage in the plants. The plants face threats through the generation of compounds or substances that cause a signaling cascade and provoke a modification in its behavior. The signaling cascade caused by sound perturbations generally results in the generations of secondary metabolites that are beneficial to human health, principally, against the chronic diseases. Nowadays, reliable mechanism that could explain precisely the ability of plants to perceive, process or emit acoustic waves have not been proposed; however, there are several compounds that are generated when the plant is stressed by biotic and abiotic factors and coincide with compounds that are produced by the plants when they are under a treatment of specific SV. This allows infer that acoustic waves could serve as elicitor, sometimes, cheaper and friendlier with environment compared with the commonly used biotic or abiotic elicitors.

1. Introduction

Plants are organisms susceptible to environmental changes; therefore, they have developed defense mechanisms acquired during years of evolutions that have a role against herbivores, pest, pathogens and environmental changes. This defense mechanisms generate chemical compounds, among other signals, which are used as army that provokes, per example, changes of odor, taste, texture and color in plants (Bennett and Wallsgrove, 1994; Kim et al., 2015); these chemical compounds are known as secondary metabolites. The secondary metabolites are not involved in the growth and development process of plants but they are included in their defense process against stress; consequently, it is necessary to have plants under a biotic or abiotic stress to generate secondary metabolism that provokes the generation of these chemical compounds (secondary metabolites) (Bartwal et al., 2013). Nowadays, these stresses could be applied externally and controllably in order to improve resistance and nutritional and sensorial characteristics in plants; one of these techniques is the use of chemical elicitors (Garcia-mier et al., 2015).

The secondary metabolism generates bioactive compounds with antioxidant benefits such as carotenoids, vitamin C and phenols. These compounds are of great significance in health-protecting factors for humans and, the generation of them depends of several elements such as cultivar, maturity, growing conditions and postharvest manipulation.

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https://doi.org/10.1016/j.scienta.2018.02.060
Received 25 October 2017; Received in revised form 9 February 2018; Accepted 22 February 2018
0304-4238/

Several studies reveal an inverse relation between consumption of food rich in bioactive compounds and chronic diseases; for that reason, there is a necessity of increasing the bioactive compounds in foods.

Nowadays, farmers employ pesticides to protect plants against diseases and pest; however, these protections can cause health threats to consumers and negative effects to environment. Therefore, there is a necessity of having alternatives less harmful to environment that decrease the use of chemical pesticides and permit the generation of safer food. Nowadays, it has emerged the usage of acoustic vibrations to generate a controlled abiotic stress in plants, this kind of elicitor improves growth conditions (Collins and Foreman, 2001), energy metabolism (Xiaocheng et al., 2003), gene expression related with stress (Hongbo et al., 2008), increase secondary metabolites (Li et al., 2008) and resistance to diseases (Choi et al., 2017). The understanding of the plant mechanism to detect and transmit sounds as consequence of stress will allow giving to plants a controlled stress, causing an activation of defense against a particular disease or pest; this will permit the generation of non-environmental-damage pesticides or the generation of specific metabolic compounds, per example those of interest to human health.

In the last 20 years, important researches have been focused in unveiling the signaling mechanism of plants. For example, several studies proved how, under different types of stress, the plants emit cues for warning neighbor plants about the stress, in such way, the unstressed plants, located further away from the stressed plants, could receive the warning signaling and start a defense strategy. The unstressed plants that received the alarm also are able to transmit it to other plants (Falik et al., 2011). The hypothesis is that the plants perceive and emit this alarm through sound vibrations or acoustic waves. However, nowadays, scientific studies have not reported reliable mechanisms that explain in detail the acoustic communicative abilities of plants, most of them report how physiological process change when acoustic stimulation exists and how this can bring agricultural and biotechnological benefits leaving frequently relegated their ecological meanings. Therefore, the ecological meaning of the application of acoustic waves in plants is very important, because it permit the understanding of the sensing mechanism of acoustic waves in plants, which could help to comprehend how the plant perceive and transmit sound vibration. This knowledge could allow generating specific acoustic waves that maximize plant benefits in agriculture and biotechnology. For instance, the generation of functional food that helps to combat chronic disease such as diabetes.

Physiological and developmental variations happen in response to alterations of environmental conditions and these results correlated with changes in plant gene expression. It is not fully elucidated how plants perceive sounds; however, it is stated that sound waves induce changes at physiological and molecular levels such as changes in levels of phytohormones (Bochu et al., 2004), synthesis of RNA and protein, antioxidant enzymes and, possibly, regulation of gene expression. (Jeong et al., 2008). It is important since this strategy could increase the metabolic functions of the cells.

The present work shows a review about sound vibrations or acoustics waves applied to plants. The focus of manuscript is the ecological meanings of sound vibrations and its benefits in agriculture and biotechnology. In the same way, the manuscript mentions the physiological, molecular and biochemical changes induced in plants by acoustic waves, and at the end, a possible mechanism of sensing the vibration sound is proposed based on some signals presented in the plants under acoustic vibration treatment.

2. Ecological importance of sound vibrations in plants

In agriculture, there are several phenomena associated with physiological process of the plants; one of them is the emission of sound vibration (SV) by consequence of its physiological processes. This is a phenomenon of ecological importance because plants can use it to take advantage and face threats of the surrounding. For example, plants emit acoustic waves when they transport water from root to leaves; this phenomenon is associated with a xylem cavitation. It is suggested that a coherent bubble system of the xylem conduits operate as a force-transmitting medium that transports water in traveling waves (Laschimke et al., 2006), this opens the possibility to explain one way of the acoustic emission in plants as effect of a controlled process, instead of a problem related to a stress. Therefore, the ecological importance of this acoustic emission lies in that some kind of stress could be found by monitoring these acoustic waves; in the same way, this acoustic release could allow applying a controlled stress to plants not under a real stress in order to make them more resistant against certain biotic of abiotic factors.

Plants could emit sounds, using the activity of mechano-chemical enzymes such as myosins, which use chemical energy from the hydrolysis of adenosine triphosphate (ATP) in actin filaments to generate mechanical vibration within cells (Telewski, 2006). Other interesting hypothesis is on base of observations of nano mechanical motions of cardiomyocytes such as heart cells or auditory hair cells; this could explain how individual vibrations of plant cells produced by movement of organelles could send information related to plant cells status, affecting neighboring cells and eventually producing a collective effect in which all cells are synchronized. On the same way, this vibration signal could be amplified within the plant and also outside it (Gagliano et al., 2012a). The ecological significance is the possibility to detect the biotic stress occurred in plants caused by pathogens through monitor this type of sound emissions.

One of the most encouraging studies that might reveal and support the acoustic signaling as communication alternative pathway between plants is the study accomplished by Gagliano and Renton in 2013, the study shows how a Basil plant (*Ocimum basilicum*, Lamiaceae) stimulates the germination of chilli seeds, even when all signal pathways between plants (chemical, touch and light) were blocked. Basil plant is well known for its ability to keep the soil moisture and act such as organic living mulch (Gagliano and Renton, 2013). The results showed how the basil plant stimulated the germination rate compared with control, inferring that possibly the acoustic communication could be the alternative pathway between Basil and chili plants. On the similar way, a comparable experiment was done using a plant that exude chemicals from roots or aerial parts that inhibit growth or even kill the neighboring plants. Unfortunately, in this case, results contrast with the expectative and no statistical difference between control and treatment was observed (Gagliano et al., 2012b). The importance of these ecological SV reside on the possibility that the stimulus in germination rate of Basil is because of the SV related to some physiological process of plants, which permitted elicit to other plants.

In the nature, one of the most important ecological SV is the acoustic emission of predatory insects. Appel and Cocrof in 2014 reported an increase in the production of chemical defenses such as anthocyanin and glucosinolate in *Arabidopsys thaliana*, these compounds have benefits against human cancer. The results reveal that plants can discriminate SVs emitted by the chewing of caterpillars from those caused by wind or other insects such as pollinators (Appel and Cocroft, 2014). During this study, chewing vibrations were recorded using a laser Doppler vibrometer and piezoelectric sensors fixed under leafs, afterwards, the recorded sounds were used for reproducing caterpillar feeding vibrations near of not stressed plants. An interesting result is that leaves under threat presented an increase in chemical responses, suggesting that vibrations travel throughout the plant, stimulating other leaves. Other hypothesis is that the sound vibration in the leaves triggered volatile chemical signals that travel to others leaves not under SV treatment. Nonetheless, it is necessary experiments for detecting the warning signals emitted by plants to understand the nature of them and verify if other plants can detect these alarms. In the same way, it is imperative to prove the existence of the emission of volatile chemicals after an acoustic stimulus in plants. The ecological importance of this