**Current Trends in Natural Sciences**
Vol. 14, Issue 27, pp. 314-319, 2025
https://doi.org/10.47068/ctns.2025.v14i27.036

Current Trends in Natural Sciences (on-line)
ISSN: 2284-953X
ISSN-L: 2284-9521

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ISSN: 2284-9521
ISSN-L: 2284-9521

# DESIGN OF AN ULTRASONIC SYSTEM FOR IMPROVING PLANT NUTRITION

**Anda Cringureanu[1], Cristian Popescu[2], Dan Nitoi[1], Oana Chivu[1], Andreea Otomega[1], Teodorescu Marius[3], Alexandra Popescu[1]**

[1]National University of Science and Technology Politehnica Bucharest, Department of Quality Engineering and Industrial Technologies, Splaiul Independentei no. 313, Sect. 6, Bucharest, Romania
[2] National University of Science and Technology Politehnica Bucharest, Pitești University Centre, Pitești, Romania
[3] Academia de Politie "Alexandru Ioan Cuza", Aleea Privighetorilor, Nr. 1-3, Sector 1, Bucuresti, Romania

Current Trends in
Natural Sciences

***Abstract***
*Ultrasounds represent mechanical oscillations with frequencies between 18000....100000 Hz which have been proven in recent years to have special applications in many fields such as health, aerospace, automotive, military, engineering, consumer goods industry. For all of these, there is currently a lot of research, very well documented and substantiated. In contrast to these, one of the lesser known applications refers to the ultrasonic activation of the natural system formed by plants and the soil in which they grow and develop. By applying an ultrasonic field, in the soil in the immediate vicinity of the plant roots, there is a better homogenization of the soil, a more uniform distribution of the different types of its granulations, a better adhesion of the soil on the contact surface between it and the plant roots so that the process of nutrient absorption is made more efficient. Thus, this article presents a large part of the ensemble that takes place in this environment as well as the design of an ultrasonic system capable of influencing, when introduced into the soil, the processes that take place at the interface between the soil and plant roots.*

*Keywords: growing, plant, soil, ultrasonic, vibrations*

## 1. INTRODUCTION

Ultrasounds are sound waves with frequencies higher than 20 kHz, imperceptible to the human ear, but with significant potential in stimulating plant growth and development. Recent research highlights multiple benefits of ultrasound treatments on plants, from improving seed germination to increasing resistance to abiotic and biotic stresses. Studies have found that applying an ultrasonic vibration field has different effects like in the following (Shin et al., 2011; Teixeira da Silva and Dobranszki, 2014; Bhandawat and Jayaswall, 2022; Gong et al., 2024). On the other hand, ultrasound has found another important application, namely in remediation of soil quality, in the elimination of heavy substances and pollutants. These capabilities are not studied in this article but will constitute a separate activity for the authors' future research in this field (Effendi et al., 2019; Lei et al., 2020; Choi et al., 2021)

1. Effect of ultrasound on seed germination
1.1. Increase in germination rate
The application of ultrasound can significantly improve the germination rate of seeds, especially in the case of aged or damaged seeds. For example, the application of ultrasound with vibration


*Corresponding author, E-mail address: nitoidan@yahoo.com

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frequencies of 20–45 kHz for short periods (30–60 seconds) increased the germination rate of Arabidopsis thaliana and maize seeds. This effect is attributed to the formation of pores in the seed coat, facilitating the absorption of water and oxygen necessary for germination (Figure 1).

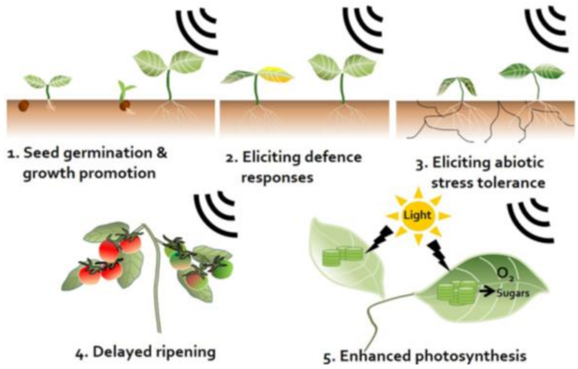


***Figure 1. General effect of ultrasound on plant development***

The application of constant frequency ultrasound helped to improve seed germination. In one study, corn seeds were exposed to an ultrasonic field with frequencies between 20-40 kHz for 40 seconds. The germination percentage increased by about 10% and the radicle length of corn seeds increased by about 230%. Ultrasound treatment also significantly increased the content of acid protease by about 96%, α-amylase by about 73% and β-amylase by about 49%. Transcriptome analysis showed that 11,475 differentially expressed genes (DEGs) were found in the ultrasound and control treatment groups. Metabolic pathways and transcription factors were significantly enriched after ultrasound treatment. This included metabolism and processing of genetic information, i.e. ribosome, proteasome and pyruvate metabolism, sesquiterpenoid, triterpenoid and phenylpropanoid biosynthesis and oxidative phosphorylation, as well as transcription factors in NAC, MYB, bHLH, WRKY, AP2, bZIP and ARF. The application of variable frequency ultrasonic field increased auxin, gibberellin and salicylic acid by 5.5%, 37.3% and 28.9%, respectively. Abscisic acid significantly decreased by 33.2%. The related DEGs were up- and down-regulated to different degrees. Seed germination under the abiotic stress conditions of salt stress (NaCl solution), drought (PEG solution) and waterlogging (water-saturated sand bed) under ultrasonic treatment was promoted, the radicle length was significantly increased by 30.2%, 30.5% and 27.3%, respectively; and the germination percentage by 14.8%, 20.1% and 21.6%, respectively. These findings provide new insights into the mechanisms by ultrasound to promote the germination of maize seeds.

1.2. Improving seed coat permeability

Ultrasound can induce the formation of pores in the seed coat, facilitating the absorption of water and oxygen necessary for germination. This effect was observed in Arabidopsis thaliana seeds, where ultrasonic treatment significantly increased the germination rate of aged seeds.

2. Stimulation of enzymatic activity and metabolism

The application of the ultrasonic field activates hydrolytic enzymes essential for the mobilization of nutrient reserves in seeds.

In this regard, laboratory experiments were conducted to determine the effect of ultrasound on the germination of chickpea, wheat, pepper and watermelon seeds. All tests were performed at a


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frequency of 40 kHz in a system consisting of a tank with ultrasonically activated water with two variables, namely the duration of ultrasound application (5, 10, 15, 30, 45 or 60 min) and the germination temperature (15 or 20 °C) and tests were performed in which the seeds were soaked in water without an ultrasonic field. The effects of ultrasound on seed germination varied between crops and were more evident on germination rate, expressed as germination rate index (GRI), rather than on germination percentage (GP). A significant increase in GRI of chickpea, wheat and watermelon was found, resulting in a maximum increase of 133% (at 45 min), 95% (30 min) and 45% (5 min), respectively, over control seeds. The beneficial effects of ultrasound on GRI of these crops were observed at both 15 and 20 °C, suggesting that the application of the ultrasonic field offers a practical priming method to overcome the slow germination that can occur at low temperatures.

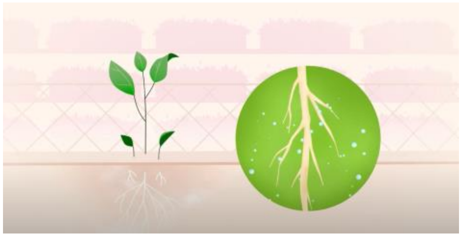

***Figure 2. The effect of ultrasound on nutrient absorption***

3. Regulation of phytohormones and gene expression
Ultrasound influences the levels of phytohormones involved in germination and growth. In ultrasonically treated corn seeds, an increase in the content of indoleacetic acid (IAA) by 5.5%, gibberellin (GA) by 37.3% and salicylic acid (SA) by 28.9% was observed, while abscisic acid (ABA) decreased by 33.2%. These hormonal changes are associated with the activation of genes responsible for germination and growth.

4. Improve tolerance to external stresses
The application of ultrasonic field can increase the tolerance of plants to abiotic stresses such as salinity, drought and flooding. In maize, ultrasound led to increases in radicle length by 30.2% and germination rate by 14.8% under saline stress. In fenugreek (Trigonella foenum-graecum), ultrasound improved seedling growth and soluble protein content under saline stress. Fenugreek is a globally important legume that is widely cultivated for its therapeutic benefits in most parts of the world. Seeds, on the other hand, have a poor germination and growth rate when exposed to salinity. During germination and early seedling stages, all tests were performed at 40 kHz in a water bath ultrasonic device with two durations (10 and 20 min) under salinity stress using different concentrations of NaCl (0, 1000, 3000 and 5000 mg/l). Application of ultrasonic field to fenugreek seeds for 10 and 20 min has a significant impact on seed germination, early seedling development and biochemical constituents under normal and stress conditions.

5. Stimulates defense against pathogens
Ultrasound can activate plant defense mechanisms against pathogens. For rice, ultrasonic treatment increased antioxidant enzyme activity and reduced disease index caused by Rhizoctonia solani, indicating improved disease resistance.


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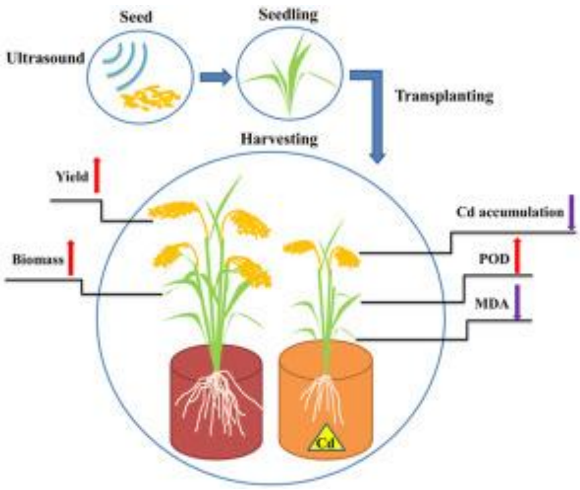


***Figure 3. Effect of ultrasound on seed growth***

6. Applicability in agriculture and horticulture
Due to its beneficial effects on germination, growth and resistance to external actions, ultrasound has considerable potential in agriculture and horticulture. It can be used to improve seed performance, reduce the use of chemicals and increase crop yields.
6.1. Stimulation of germination and early plant development
- Acceleration of germination - ultrasound facilitates the absorption of water through microcracks in the seed coat.
- uniformization of seedlings - germination becomes more synchronized, ideal for industrial agricultural production.
- reduction of germination time - useful in crops with a short vegetation period.
6.2. Enzyme activation and improvement of metabolism
- activation of α-amylase and proteases - key enzymes in the mobilization of energy reserves.
- stimulation of protein and carbohydrate synthesis: helps in the rapid development of young plants.

## 2. DESIGN OF THE ULTRASONIC TRANSDUCER USED IN BIOLOGICAL STATE IMPROVEMENT

From the studies on the improvement of the processes and phenomena that take place in plants and at the interface between them and the soil in which they appear and develop, it is found that multiple certain and undeniable advantages are exhibited. The problem that arises is that the presentation of the ultrasonic system that leads to the appearance of multiple beneficial effects is missing in most research. Next, the authors propose an ultrasonic system whose action refers precisely to its use in the proposed field. Thus, in figure 4 the design of this system is presented, which is made up of the following elements: 1- the ultrasonic concentrator that has a cylindrical, uniform shape with a length of 200 mm. This concentrator is introduced near the plants precisely to facilitate the appearance of the multiple advantages presented. The concentrator has the role of concentrating the ultrasonic energy amplified by the amplifier 2 that is placed right next to the nodal flange 3. This has the role of fixing the ultrasonic system, taking into account that exactly in this area, the amplitude of the oscillations is zero. With 4 is shown the body of the ultrasonic transducer that oscillates with the frequency and amplitude of the vibrations produced by the four piezoceramic discs 5. On their left side is built the ultrasonic reflector 6.


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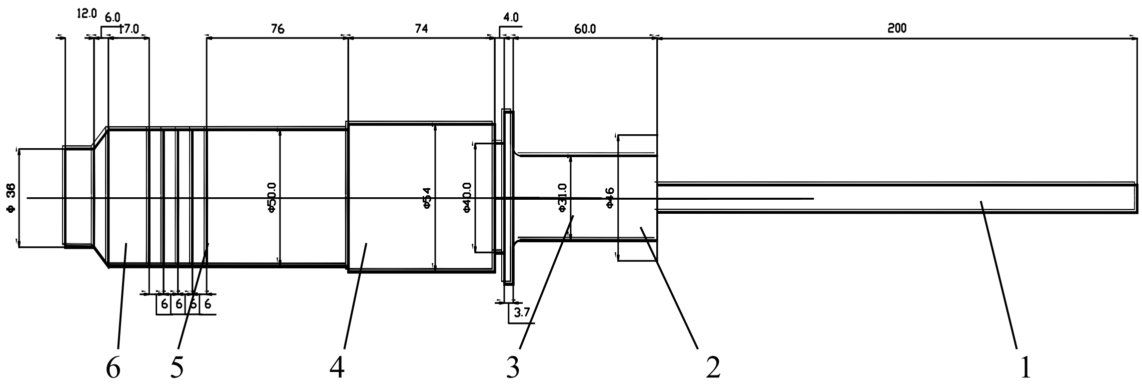


*Figure 4. Presentation of the ultrasonic system used in improving plant growth processes*

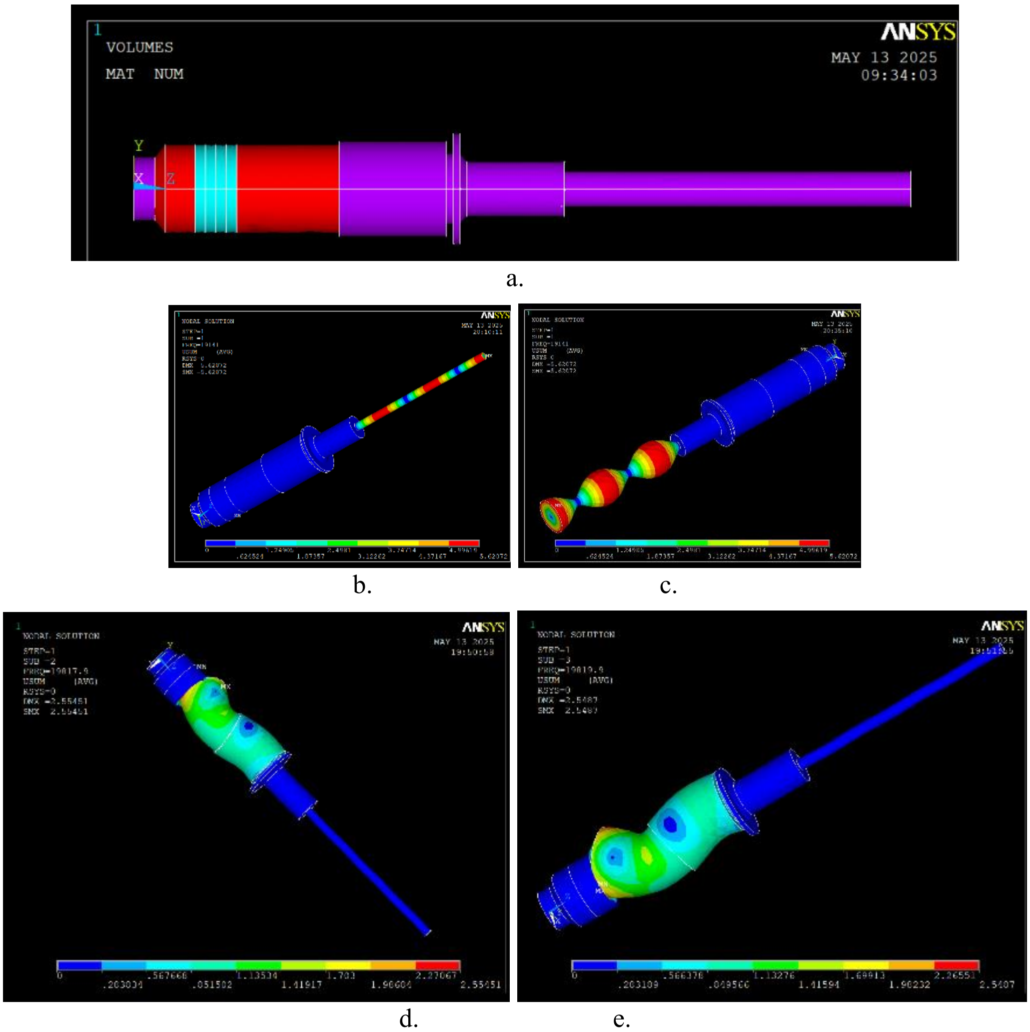


*Figure 1 Mathematical model of the ultrasonic transducer used to improve the plant development process; a. – transducer geometry, b. – real vibration mode at frequency f = 19141 Hz, c. – vibration mode with artificial magnification, d. – vibration mode at frequency f = 19019 hz, c. – vibration mode at frequency f = 19017 Hz.*


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In order to use the designed ultrasonic system, it is necessary to know its useful vibration frequencies. This frequency or frequencies are determined by creating a model and analyzing the simulation of its vibration frequencies, which determines the effectiveness of its use for the proposed purposes. Figure 5 a shows the model of the designed transducer created using the Ansys software. Figure 5b shows the vibration in real dimensions of the ultrasonic concentrator. The oscillation vents are shown in blue and the oscillation maxima in red. For an optimal understanding of the vibration mode at frequency f = 19141 Hz, an amplified image of it is shown in figure 5c. Since the purpose of a modal analysis is to immediately find the useful vibration frequencies without wasting precious time scanning all the frequencies in the useful, ultrasonic range, two other vibration frequencies are shown in figure 5 d and 5e that do not serve the proposed purpose at all and are achieved at frequencies f = 19019 Hz. and f = 19017 Hz.

## 3. CONCLUSIONS

The use of ultrasound has many advantages both from a technological, engineering and natural science and medical point of view. The presented article studies the advantages of using ultrasound in plant biology and in the second part presents the design as well as the modeling and simulation of the functioning of the ultrasonic transducer used in improving the plant development process. The design of the ultrasonic system is very important, especially since it must correspond to the desired functional role. The optimal vibration frequency at which it operates as well as the corresponding vibration mode have been determined.

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