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Development of a Bio-Based Acoustic Barrier for Commercial Purpose

Ayyappadasan Ganesan[1], Rubavathi Subbaiyan[2*]
[1,2]*Assistant Professor, Department of Biotechnology, K. S. Rangasamy College of Technology, Tiruchengode, India*

***Abstract*: Pollution is a common factor that affects people health adversely when exposed to a larger level. Noise pollution is becoming a threat to the populations living in urban cities. The present study focuses on identifying ecological material which can reduce the sound intensity in noisy environments. They chose ten plants for analysis. Among those, four plants had significant sound absorption capacity. These four plants were studied for their germination rate at different environmental conditions. *Azadirachta indica* L. and *Vigna unguiculata* L. were taken to analyse their sound absorption capacity when coated with perforated and smooth plywood. Based on chlorophyll content, α value at different frequencies, NRC, the germination rate of plants, the optimum plant that can absorb maximum sound waves were identified as *Azadirachta indica* L. *Azadirachta indica* L. had the leading sound absorption coefficient of 0.923 at 2000 Hz. Its NRC value was found to be 0.854. In contrast, *Vigna unguiculata* L. had a relatively lower α value at different frequencies and hence a low NRC value compared to *Azadirachta indica.* So, this plant can be used for controlling noise pollution in noisy environmental conditions.**

***Keywords*: Acoustics, Germination, Impedance tube, Lab view, NRC, Sound absorption.**

1. Introduction

Pollution is defined as an undesirable change in physical, chemical and biological characteristics of air, water and land that may be harmful to live organisms, living conditions and cultural assets. Pollution has become one of the major threats to the survival of biological species. Pollution types can be classified as air pollution, water pollution, soil pollution, noise pollution [1]. There is elevated use of modern

appliances in homes and constructions and industries due to population growth and urbanisation. Additionally, noise pollution has been considered as the main environmental pollution as it affects the quality of life. Isolation from external sound sources and sound absorption from interior spaces can be solutions for controlling noise pollution [2]. In India, there were very little researches on noise pollution being carried out. Surveys made in India reveal that noise pollution is being steadily increasing in India especially in urban cities, over the years. Being exposed to noise pollution daily, experts say people are affected with a psychological disorder, high blood pressure, permanent hearing loss, elevated aggression, insomnia, etc., [3]. The use of acoustic barriers between source and receptor is one of the most effective methods of reducing airborne noise from road and rail traffic. The acoustic walls have distinct sound absorption properties and act as a noise filter medium. The porous materials have the ability to absorb high and medium frequencies [4]. Airflow resistance simulated using a computational fluid dynamics model [5].

The structures and materials having sound insulation and high-value sound absorption properties have received much attention, and such materials are "acoustic material". When the sound waves passes through these materials, they reduce the energy of the sound waves passing through them by dissipation and converting some of the energy into heat. [6]. During the time of 1970's, predominantly used sound-absorbing materials are glass-fibre and synthetic fibres due to their excess availability in markets. These non-biodegradable materials indirectly contribute to global warming through a significant increase in CO_2. The search of viable and eco-friendly sound absorbers is constantly increasing. It was found that those that contain rice husk are suitable for coating acoustic barriers since it offers a good mechanical, durability, and acoustic performance. It was also found that rice husk cement-based composites can be used as thermal insulation layer [7].

Presently, bio-based materials are sustainable products which can be produced frequently without affecting the environment and people. Bio-acoustic barriers can be regarded as the ideal product for controlling noise pollution because of their eco-friendly nature, low weight and high sound absorption capacity [8]. Exposure to indoor air pollution was measured as the use of solid fuel for cooking. Linear mixed effect models were applied to examine the effect of indoor air pollution from solid fuel use on cognitive function [9].

When the sound wave is incident in an acoustic material, transmission occurs following absorption and reflection processes. The sound absorption coefficient (α) is depends on how much sound is absorbed by the fabric material. [10] The absorption coefficient (α) does not have any dimensions since it is a ratio and its value ranges from 0 to 1. If the value of α is 0, it means that the entire sound incident on the material was absorbed and vice versa. Presently three methods were used for calculating sound absorption coefficient. Namely, the Reverberation chamber, Reflection Method and Impedance tube method. Compared to other methods, impedance tube

*Corresponding author: rubavathi5@gmail.com

method is used because of its compatibility, low cost, efficiency, and it is highly suitable for small samples [11]. When Bamboo of 50 mm thickness having 90-125 µm of fibres was used, the noise reduction coefficient (NRC) increases in the middle and high frequency range [12].

This study aims to identify plants having higher sound absorption capacity and its subsequent development of a bio-based acoustical barrier. Based on the *in vitro* experiments and sound absorption coefficient of each selected plants, the bio-acoustic barrier was developed.

2. Materials and Methods

A. Collection of seeds based on sound absorption property

Sound absorption capacity varies with plants. Based on the absorption capacity of the plants, ten different plants were taken for analysis. Seeds of those ten different plants were potted ¾ inches deep inside soil and each pot was labelled. The following seeds and plants chosen for analysis have been procured from Tamil Nadu Agricultural University (TNAU), Coimbatore.

B. Analysis of the effect of sound absorption based on growth patterns in various level of sound

The selected seeds of plants were allowed to grow in different acoustic environments so as to identify the plants which have the maximum sound absorption capacity. Those different acoustic environments include high tone area (98 dB - 100 dB), low tone area (75 dB - 85 dB), traffic area (90 dB - 95 dB) and continuous heat and sound-producing area (85 dB - 95 dB). The control set was not exposed to noisy environments (70 dB – 80 dB). The plants were monitored regularly, and their growth was assessed. In this study, sound level meter, model 236 A, was used for measuring the sound intensity at different noisy environments. [4]

C. Effect of various sound levels on the plants by artificial acoustic set-up

The tube used for conducting experiments was according to the ASTM c384 standard. The tube used for construction of an artificial acoustic setup can be in the shape of a circle or rectangle in a constant dimension. The impedance tube should be nonporous, smooth and straight so as to maintain low attenuation. Cement, wood or plastic can be used as the material for constructing the impedance tube. Sealing has to be done properly to avoid loss of sound energy. Equipment was placed on a stable frame for avoiding oscillation in impedance tube. Sample and speakers should be placed on opposite sides of the tube. It consists of a square waveguide which is 4.15 m long and of 300x300 mm cross-section. One end of the waveguide is terminated with a 30 mm thick metal lid. Two loudspeakers were installed adjacently at the opposite end, and the coordinates of their centres are (50mm, 50mm) and (150mm, 150mm). A single microphone was used to avoid amplitude and phase mismatch problems. To evaluate the sound absorption capacity, they were exposed to different sound level. The sample to be tested is kept on the other side of the impedance tube. The amplitude and frequency of the input signal can be adjusted. Depending on the sampling rate, LABVIEW acquires the signals. Diameter of the sample and tube diameter should be the same for acquiring accurate results. There should not be any gap between the sample and the tube.Fig.1 represents the schematic diagram of the experimental set-up used for analysis. This the most common and simple method to calculate the sound absorption coefficient (α) of materials. Here the sound of a particular frequency is produced by means of a signal generator or android application in the mobile. [5]

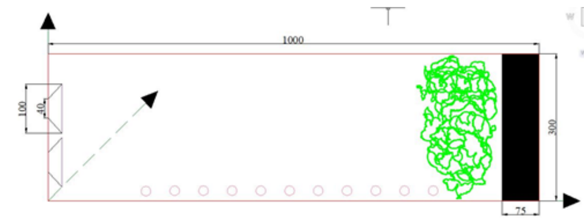

Fig. 1. A schematic illustration of the experimental setup

D. Calculation of sound absorption coefficients

The plants were kept near the metal lid. Then they were subjected to data processing and interpretation of dispersion model as well as equivalent fluid model system.

$$\alpha = \frac{I_a}{I_i}$$

where α is the Absorption coefficient
I_a is Sound intensity absorbed (w/m^2)
I_i is Incident sound intensity (w/m^2)

E. Extraction and estimation of chlorophyll [13]

The plants germinated at different noisy environmental conditions were collected. One gram of finely cut fresh plants was taken and ground with 20 of 80% acetone. It was then centrifuged at 5000 –10000rpm for 5mins. The supernatant was transferred, and the procedure was repeated till the residue became colourless. The absorbance of the solution was read at 645nm and 663nm against the solvent (acetone) blank.

The concentrations of chlorophyll a, chlorophyll b and total chlorophyll were calculated using the following equation:

Total Chlorophyll: 20.2(A645) + 8.02(A663)
Chlorophyll a: 12.7(A663) – 2.69(A645)
Chlorophyll b: 22.9(A645) – 4.68(A663)

F. Evaluation of plywood coated with paint mixture using impedance tube for evaluation of absorption capacity

Two types of plywood were used for assessing the efficient combination of powdered plant extracts with plywood. Rough plywood and smooth plywood were taken into account. Each of the plywood was coated with paint mixed with powdered plant samples in 2%, 5%, 10% and 50% concentrations. Then the sound absorption coefficient was evaluated using the impedance tube method as described in the above section.

3. Results and Discussion

A. Collection of seeds and potting

Seeds and plants of *Coriandrum sativum* L., *Vigna radiate* L., *Vigna unguiculata* L., *Tamarindus indica* L., *Azadirachta indica* L., *Erythrina variegate* L., *Trigonella foenum-greacum*

L., *Nerium oleander* L., *Caesalpinia pulcherrima* L., *Ocimum basilicum* L. were procured form Tamilnadu Agriculture University, Coimbatore. Pots were filled with soil and the seeds were potted 3/4 inches deep. All the pots were labelled and kept in different noisy environmental conditions. The plants were grown under low tone environment (75 dB - 85 dB), high tone environment (98 dB – 100 dB), normal (control) environment (70 dB – 80 dB), continuous heat with noise (85 dB – 95 dB) and traffic area (90 dB). In each area, five pots were placed. All the pots were labelled and monitored on a daily basis for assessing growth.

B. Calculation of sound absorption coefficient (α)

Initial tests were done with empty tubes. Aluminium foil with a high reflection property was kept at the other end of sample so that the absorption coefficient will be null. For the stabilisation of the impedance tube, the speaker is made to run for a certain period of time with constant temperature throughout the process. The plants placed at one end of the tube were completely covering the tube without any gap so that excess transmission of sound waves to the microphones does not occur. The sound absorption coefficients were calculated at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. Among the legumes used, the maximum absorption coefficient was obtained for *Vigna unguiculata* L. and *Vigna radiate* L. In the case of perennial plants taken into analysis, *Azadirachta indica* L. and *Tamarindus indica* L. showed higher sound absorption capacity compared to other plants.

C. Germination percentage and estimation of chlorophyll content

Based on the sound absorption coefficients obtained for plants chosen for analysis, plants having higher absorption coefficient were taken for analysis of germination percentage and estimation of chlorophyll content. *Azadirachta indica* L., *Vigna unguiculata* L., *Tamarindus indica* L., *Vigna radiata* L. were preferred for the further processes.

The germination of plants was analysed for a period of 30 days. In the case of control plants, both the legumes *Vigna unguiculata* L. and *Vigna radiata* L. germinated completely. Whereas in the case of perennial plants taken, *Tamarindus indica* L. showed the maximum germination (95%) compared to *Azadirachta indica* L. but, chlorophyll content was found to be higher in *Azadirachta indica* L. (11.08 mg/g).

In the low tone environment, *Vigna radiata* L. achieved complete germination. Yet, its chlorophyll content was very low (1.32 mg/g) compared to other plants chosen for analysis. This might be due to change in environmental conditions. Almost all the plants which were subjected to a high tone environment showed a similar germination percentage. Plants, when grown under the acceptable level of stress conditions, the level of chlorophyll increases significantly. As such, the chlorophyll content was found to be increased in all the plants. 12.89 mg/g of chlorophyll content was observed in *Azadirachta indica* L. The seed showed the highest germination rate with the least germination time when subjected to sound wave at 100dBand 1000 Hz. Music has a positive effect on seed germination due to enhanced metabolic rate of growth and development, as shown in [14].

Germination percentage of plants grown in a traffic environment was relatively lower than the germination percentage of plants grown under other environmental conditions. This can be due to air pollution caused by the automobiles passing through. In turn, this air pollution will also result in an increase in temperature in the surroundings. This combined effect of heat and pollution may have retarded the germination rate of plants. In spite of these environmental conditions, the chlorophyll content was found in significant amount in all the plants.

A very low amount of chlorophyll content was observed in plants germinated in continuous heat and noise condition. A continuous supply of heat destroys chlorophyll. Generally, Chlorophyll B will be more stable than Chlorophyll A. Results also revealed that the amount of Chlorophyll B was found to be higher than Chlorophyll A. But in the case of total chlorophyll content, this group of plants show lesser chlorophyll content.

The highest chlorophyll content (CH A + CH B) was detected for *Azadirachta indica.* L. followed by *Vigna unguiculata* L., which are grown under high tone environmental conditions. *Vigna radiata* L. showed lower chlorophyll content in spite of a higher germination rate. *Tamarindus indica* L. showed a relatively lesser amount of chlorophyll and germination percentage compared to *Azadirachta indica* L. For further analysis, *Azadirachta indica* L. and *Vigna unguiculata* L. were chosen based upon the germination rate and chlorophyll content. [4] says that chlorophyll content of *Azadirachta indica* L. was found to be higher in leaves collected from control sites compared to the chlorophyll content of leaves collected from other areas (Airport). Though there are significant differences in the amount of Chlorophyll A and Chlorophyll B present in polluted areas, total chlorophyll content was found to be in leaves collected from the control site.

D. Evaluation of the plywood coated with powdered plant samples

Perforated plywood and smooth plywood having 1/2-inch thickness were taken for evaluating the combined effect of

Table 1
Sound absorption coefficients of different plants

S. No.	Name of the plant	Frequency (Hz)				
		α_{250}	α_{500}	α_{1000}	α_{2000}	NRC
1	*Coriandrum sativum* L.	0.05	0.14	0.27	0.52	0.245
2	*Vigna radiata* L.	0.05	0.18	0.34	0.64	0.3025
3	*Vigna Unguiculata* L.	0.09	0.24	0.59	0.75	0.4175
4	*Tamarindus indica* L.	0.08	0.30	0.48	0.70	0.39
5	*Azadirachta indica* L.	0.12	0.36	0.67	0.82	0.4925
6	*Erythrina variegala* L.	0.04	0.09	0.20	0.35	0.17
7	*Trigonella foenum-greacum* L.	0.06	0.15	0.29	0.47	0.2425

Table 2
Germination percentage and chlorophyll estimation of plants at different environment

Name of the plant	NRC	% of Germination	Chlorophyll estimation (mg g^{-1})		
			CH A	CH B	Total Chlorophyll content
Control plants					
Azadirachta indica L.	0.4925	90	6.23	4.85	**11.08**
Vigna unguiculata L.	0.4175	100	2.48	1.98	4.46
Tamarindus indica L.	0.39	95	1.128	2.065	3.193
Vigna radiata L.	0.3025	100	1.03	0.46	1.49
Low tone environment					
Azadirachta indica L.	0.4925	85	5.98	4.13	10.11
Vigna Unguiculata L.	0.4175	95	2.03	1.5	3.53
Tamarindus indica L.	0.39	80	0.987	1.928	2.915
Vigna radiata L.	0.3025	100	0.94	0.38	1.32
High tone environment					
Azadirachta indica L.	0.4925	90	7.25	5.64	12.89
Vigna Unguiculata L.	0.4175	95	2.95	2.56	5.51
Tamarindus indica L.	0.39	85	1.68	2.84	4.52
Vigna radiata L.	0.3025	90	1.38	0.95	2.33
Traffic environment					
Azadirachta indica L.	0.4925	85	6.85	5.52	12.37
Vigna Unguiculata L.	0.4175	85	3.05	2.34	5.39
Tamarindus indica L.	0.39	80	1.26	2.22	3.48
Vigna radiata L.	0.3025	90	1.09	0.59	1.68
Continuous heat and noise environment					
Azadirachta indica L.	0.4925	75	3.84	4.95	8.79
Vigna Unguiculata L.	0.4175	80	1.25	2.06	3.28
Tamarindus indica L.	0.39	85	0.98	1.56	2.54
Vigna radiata L.	0.3025	80	0.23	0.75	0.98

plywood and paint mixed with on sound absorption capacity. Powdered plant extracts were prepared and mixed with the commercially available paint in different concentration of powdered plant samples (2%, 5%, 10% and 50%). They were coated on plywood and sound absorption coefficient using an impedance tube. From the results, the sound absorption coefficient has been increased to a higher level after the use of perforated plywood. Smooth plywood did not show any significant difference in the absorption of sound when combined with paint containing powdered plant samples.

The sound absorption capacity of all the plants increased gradually and considerably when combined with paint and plywood. Yet, smooth plywood coated with paint containing plant powders did not show a significant sound absorption coefficient even at 50% concentration of powdered plant samples of both the species taken for consideration. On the contrary, the sound absorption coefficient was higher in perforated plywood coated with paint containing *Azadirachta indica* L. (50 % concentration). The good absorption coefficient of *Azadirachta indica* L. increased rapidly with the use of perforated plywood. Normally, porous materials absorb sound waves more efficient than smooth materials. From the results, it can infer that perforated plywood has more sound absorption capacity than smooth plywood. The results obtained were the following [14], where they concluded that materials with open pores had higher characteristics in absorption capacity, where the materials with closed pores had lower features in absorption.

4. Conclusion

The sound absorption studies were done by the impedance tube method by considering ten plants initially. Noise reduction coefficient (NRC) was calculated based upon the sound absorption coefficients at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. Plants having remarkable sound absorption coefficients were screened for analysing germination percentage at different sound environments. They assessed the chlorophyll content of the plants experimentally. Among the four plants considered for analysing germination percentage and chlorophyll content, *Azadirachta indica* L. and *Vigna unguiculata* L. were found to have higher chlorophyll content. Then, they used these two samples for assessing sound absorption coefficient when they are coated with paint on perforated wood and smooth wood at 2%, 5%, 10%, 50% concentration of powdered plant samples. *Azadirachta indica* L. had the maximum sound absorption coefficient of 0.923 at 2000 Hz. Its NRC value was found to be 0.854. In comparison, *Vigna unguiculata* L. had a relatively lower α value at different frequencies and hence a low NRC value compared to *Azadirachta indica* L. The open pores had higher characteristics in absorption when compared to non-porous. It can be concluded that Paint with *Azadirachta indica* L. coated on perforated plywoods (1/2-inch-thick) can be used for reducing sound transmittance in noisy environments.

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