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Sustainable Acoustic Material Investigation Using Fruit Seeds

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ABSTRACT

In order to reduce the carbon footprint due to currently applied sound absorptive materials in the building construction industry, alternative sustainable systems are investigated in this research. By re-using the waste fruit seeds that are abundant in the Central Anatolia region of Turkey, a composite panel system is developed to be applied in buildings as a fine finish surface, like a wall or ceiling panel. The raw material is composed of various fruit seeds including cherry, watermelon, olive, etc. As a natural adhesive, the wood resin is combined with wood fire ash. The efficacy of the adhesive property is the subject of natural adhesive research Wood glue is utilized as an alternative to other adhesive materials; it is regarded to be more efficient in material production due to its practicality and accessibility. The varied combinations of seeds, tree resin and tree glue has been tested through impedance tube measurements and sound absorption coefficient data are acquired. The results indicate that the panels out of seeds joined with proper adhesives have a potential to be applied as sound absorptive decorative systems in interior spaces. The study is ongoing to alternative porous adhesives.

Keywords: Sound absorption, impedance tube, sustainable materials, acoustic panel, fruit seeds

1. INTRODUCTION

Through the use of ecologically harmful materials in the modern world, the limit of sustainability has been exceeded, and as a result, the world has been propelled into an unavoidable catastrophe. Consequently, each year the demand for green technologies has expanded considerably. To comprehend the sustainability of a substance, its effects on the environment, human health, and social justice must be evaluated. In addition, in order to ensure the sustainability of the resources, the production process should create the least amount of trash feasible, or waste products should be able to find a second life. In this aspect, renewable energy is favored over nonrenewable resources [1]. Therefore, it is essential to utilize eco-friendly and biodegradable products wherever feasible. The most prevalent materials for sound absorption include perforated wood panels, perforated gypsum board, wood wool, and melamine foam. Traditional acoustic sound-absorbing materials for architectural uses are often backed up (perforated panels or fabric-finished panels) with mineral or glass wool. As these materials are breathable and emit tiny particles, even in small amounts, they may pose future health risks to the workers in this industry. In addition, their high manufacturing costs result in significant carbon footprints and severe environmental implications [2,3].Exposure to dust is estimated to provide an average health risk [4] based on an evaluation of the situation as a whole.

Different research groups have investigated organic materials such as coconut husks and palm oil flower spikes based on their sound absorption and reflection characteristics. In these cases, after testing the materials' qualities, researchers found that organic materials have promising potential to be used in acoustical applications [5,6]. On the other hand, the recovery of bioactive substances from fruit seeds is a research movement that attempts to minimize trash production and satisfy the public's high demand for organic matter, which is believed to offer health-promoting and disease-preventive properties against chronic conditions [7]. Due to this, we believe that sound-absorbing panels produced from eco-friendly fruit seeds are less hazardous to human health. On the other hand, fruit consumption rises with global population growth. As a result, more waste fruit seeds have accumulated. Some previous work has investigated the production of sound-absorbing materials of varying thicknesses from collected fruit seeds (cherry, olive, apricot, and peach). According to these studies, the distinct shapes and sizes of fruit stones result in different sound absorption properties [8,9]. Peach-like stones with a rougher and more porous surface absorb significantly more sound. The

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behavior of tiny seeds, notably cherry seed samples, results in greater sound absorption coefficients [9].

Various species of fruit are cultivated in Turkey, which has vastly varying ecological circumstances and geographical features. A substantial percentage of Turkey's fruit production comprises stone fruits, the majority of which are waste stone fruits. This study is motivated by the widespread cultivation of cherries in the Turkish province of Konya, in the Central Anatolian area, and the dumping of cherry seeds from this region as waste. Seeds are employed as raw materials in this study of acoustic materials, and wood glue and resin are used to bind the seeds together. Various combinations of seed types with varying sizes are evaluated in an impedance tube to determine the sound absorption coefficient. As basic criteria for the selection of seeds, it is considered that they should belong to fruit species that are abundant in Turkey and that their sizes are appropriate for the sound-absorbing panel production that is intended to be produced. First, two examples are produced by combining cherry seeds from distinct batches with resin and wood glue. In addition to cherry seeds, olive and watermelon seeds are subsequently employed to broaden the variety of available materials. Since acoustic panels are intended for indoor application, the degree to which the seeds are resistant to fire is also a focus of study. Some material samples are coated with fire-resistant nano-composite paint-based coatings [10] to examine their influence on the acoustic performance of the material samples. Cherry seeds, which are the focus of this research, are colored in order to enhance fire resistance since the paint includes numerous compounds and is projected to promote fire resistance. This study intends to expand material combinations by mixing diverse seeds and to contribute to the literature in this regard by studying the influence of seed diversity on the sound absorption performance of different material compositions. The objective is to expand the possible use of local waste fruit seeds in architectural applications in order to improve acoustic comfort in interior spaces and contribute to the reuse of natural resources. The following sections introduce the methodology and results of this study.

2. METHODOLOGY

2.1 Sample Preparation

In order to gain maximal sustainability and recyclability from the sound-absorbing materials proposed for production, the collection of fruit seeds is one of the most important procedures in this study. Seasonal availability aided the gathering of cherry, olive, and watermelon seeds to be formed into sound absorbing panel samples. The waste seeds after collection are exposed to the sun for one month to totally dehydrate and dry. Fig. 1 depicts fruit seeds, which will be the raw material for the sound-absorbing panel to be formed.

a b c d

Figure 1 –Raw materials: a) Cherry seeds b) Large olive seeds c) Small olive seeds d) Watermelon seeds

To identify the most optimal variant, nine sorts of samples are prepared. As the impedance tube is a cylinder (in two different diameters), circular-shaped samples having a diameter of 100 mm and 28 mm are prepared for each of the nine samples with a thickness of 20 mm. These nine samples have different compositions in terms of ingredients (Table 1). Tree resin and wood glue are employed in the research as binding materials. First, wood resin -an organic binder (sweet gum resin, Fig. 2a, 2b)- is heated to a moderate temperature, and then wood ash is added to improve the resin's stickiness and density. Next, the mixture of resin and wood ash is combined with cherry seeds to produce the first material sample (A). Wood glue (Fig. 2c), another substance employed as a binder in the research, is later on favored owing to its practical use, and is used in the next eight samples.

a b c

Figure 2 –Adhesive materials: a) Sweet gum resin b) Heated tree resin c) Wood glue

The production phases of Material I are illustrated in Fig. 3. As seen in Figure 2c, wood glue is white in liquid form and becomes transparent upon drying. In the last material sample (I), cherry seeds coated with red spray paint and wood glue are combined, and the influence of the paint on the material's sound absorption coefficient is investigated.

Table 1: Contents of material samples A, B, C, D, E, F, G, H, and I

Material Sample	**Raw material**				**Adhesive material**		**Add.**
	 Cherry	 L.olive	 S.olive	 Watermelon	 Tree resin	 Tree Glue	 Dye
A	++++	-	-	-	+	-	-
B	++++	-	-	-	-	+	-
C	-	++	-	++	-	+	-
D	++	-	-	++	-	+	-
E	-	++++	-	-	-	+	-
F	-	++	++	-	-	+	-
G	+	++	-	+	-	+	-
H	+	+	+	+	-	+	-
I	++++	-	-	-	-	+	+

a b c d e

Figure 3 – Preparation steps of Material I: a) Painted cherry seeds b) Addition of tree glue c) Mixing tree glue and red cherry seeds d) The prepared mixture in the mold e) Mixture upon drying

2.2 Tube Measurements

Impedance tube measurements are performed with S.C.S. Kundt Tube. 'Kundt Tube' configuration represents the basic, standard system set up for absorption coefficient and acoustic impedance measurements (2 microphones-transfer function method), according to ISO 10534-2:1998 [11,12]. The double tube configuration for measuring sound absorption contains both small and large tubes. For measurements in the low frequency range (50 Hz to 1200 Hz), 100 mm tubes are used, whereas 28 mm tubes are used for measurements in the high frequency range (1200 Hz to 8000 Hz). All samples placed in tubes A, B, C, D, E, F, G, H, and I (Figure 4) are 20 mm thick and measured with a 30 mm air gap. C, D, E, F, G, and H are also measured without an air gap behind.

A B C D E F G H I

Figure 4 – Photographs of the material samples casted within tube ring.

Fig. 5 depicts the impedance tube setup and the placement of Sample C within the tube. To verify the accuracy of the data, each composition is tested multiple times, and the mean values of these repeated tests are utilized in the analysis, omitting any outlier.

a b c

Figure 5 – During the measurement of proposed products,
a) Tube set-up b) Sample C in the large tube c) Sample D in the small tube

3. RESULTS

In this section, sound absorption coefficient measurement results of samples A, B, C, D, E, F, G, H, and I are presented. Fig.6 depicts the samples tested with 30 mm air gap for samples A and B, which are formed by changing the binder. Accordingly, sample A, whose binder is resin, has absorption efficiency in a greater frequency range 500 to 2000 Hz in comparison to B, whose binder is wood glue. As shown on the graph, sample A's alpha value reaches its maximum (0.7) at 800 Hz. At low frequencies (below 250 Hz), the measurement findings for these two materials demonstrate a remarkably similar pattern, and low sound absorption. This can easily be related to the thickness of the air gap. If the thickness of the air gap is increased, the effective frequency range can move towards lower octave bands for both samples.

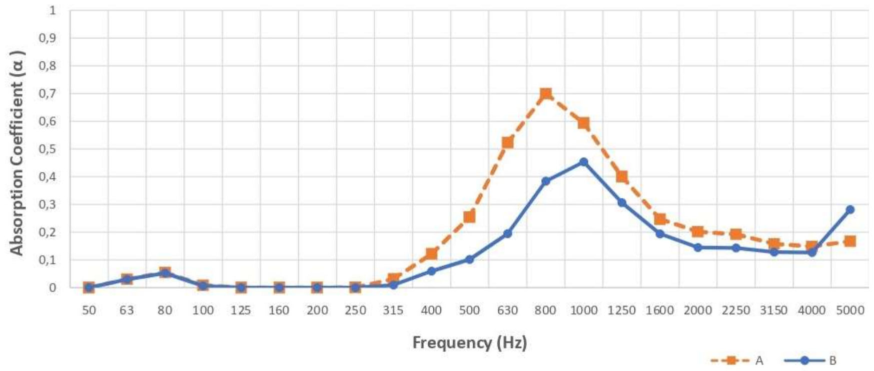

Figure 6 – Sound absorption coefficients over frequency spectrum from 50 Hz to 5000 Hz obtained for samples A and B with a 30 mm air gap backing

Fig. 7 depicts the sound absorption coefficient measurement results conducted for 20 mm thick B, C, D, E, F, G and H samples with a 30 mm air gap backing. When the results are analyzed, it is observed that all seven samples exhibit greater sound absorption between 500 Hz and 2000 Hz. The sound absorption coefficients over octave bands from 125 Hz to 4000 Hz for A, B, C, D, E, F, G, H, and I are also presented in Table 2. According to Fig. 7 and Table 2, samples H and C have the highest sound absorption performance in their effective ranges; with sound absorption coefficients reaching up to 0.70 at mid frequencies. On the other hand, samples B and I have comparatively much lower sound absorption coefficient values over the measured frequency range. While samples B and I include solely cherry seeds, sample H has cherry, large-small olive, and watermelon seeds; therefore, it can be concluded that the material's ability to absorb sound rises as the diversity of seeds (with different diameters) within the sample increases.

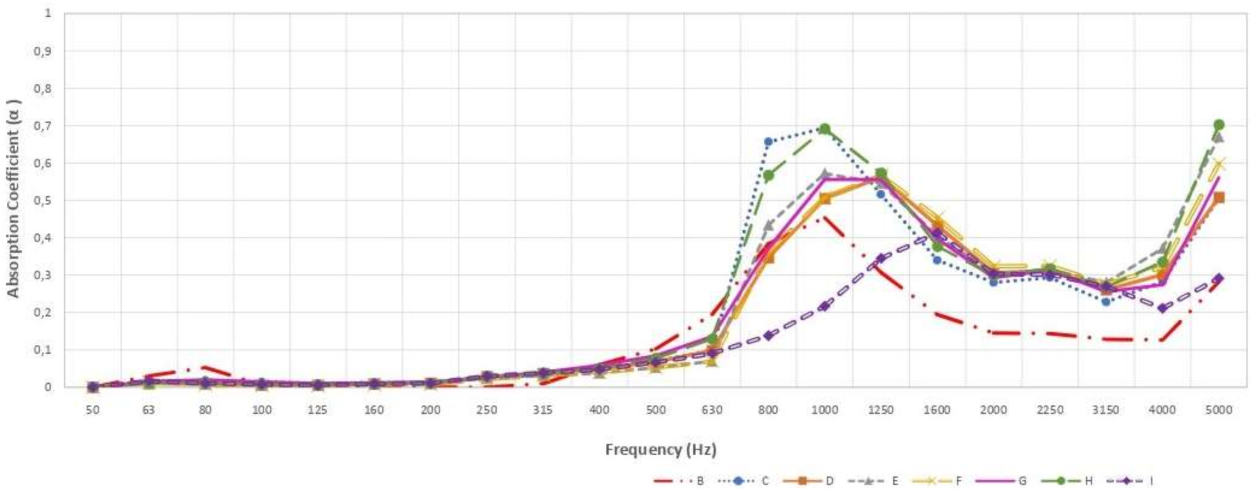

Figure 7 – Sound absorption coefficients over frequency spectrum from 50 Hz to 5000 Hz obtained for samples B, C, D, E, F, G, H and I with a 30 mm air gap behind.

Table 2: Sound absorption coefficients over 1/1 octave bands (Hz) obtained from impedance tube test for samples A, B, C, D, E, F, G, H, and I

Sample	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
A	0,00	0,00	0,25	0,59	0,20	0,15
B	0,00	0,00	0,10	0,45	0,14	0,13
C	0,01	0,02	0,07	0,69	0,28	0,28
D	0,00	0,03	0,07	0,50	0,31	0,30
E	0,00	0,02	0,05	0,57	0,30	0,37
F	0,00	0,02	0,05	0,51	0,32	0,32
G	0,01	0,03	0,08	0,56	0,29	0,27
H	0,00	0,03	0,08	0,70	0,30	0,33
I	0,00	0,03	0,06	0,22	0,30	0,21

Fig. 8 depicts the measurement results for samples C, D, E, F, G, and H with no air gap behind. The range of speech tones is 500 Hz to 2000 Hz differs within the range. Without an air gap, the effective sound absorption of the samples is in between 2000 Hz–4000 Hz, indicating high frequencies. In order to provide effective sound absorption, especially considering the intended speech frequencies for indoor custom environments, it is recommended that the panels to be applied with minimum a 30 mm air gap behind. This can be readily provided with a supporting bracket for hanging the panels on walls.

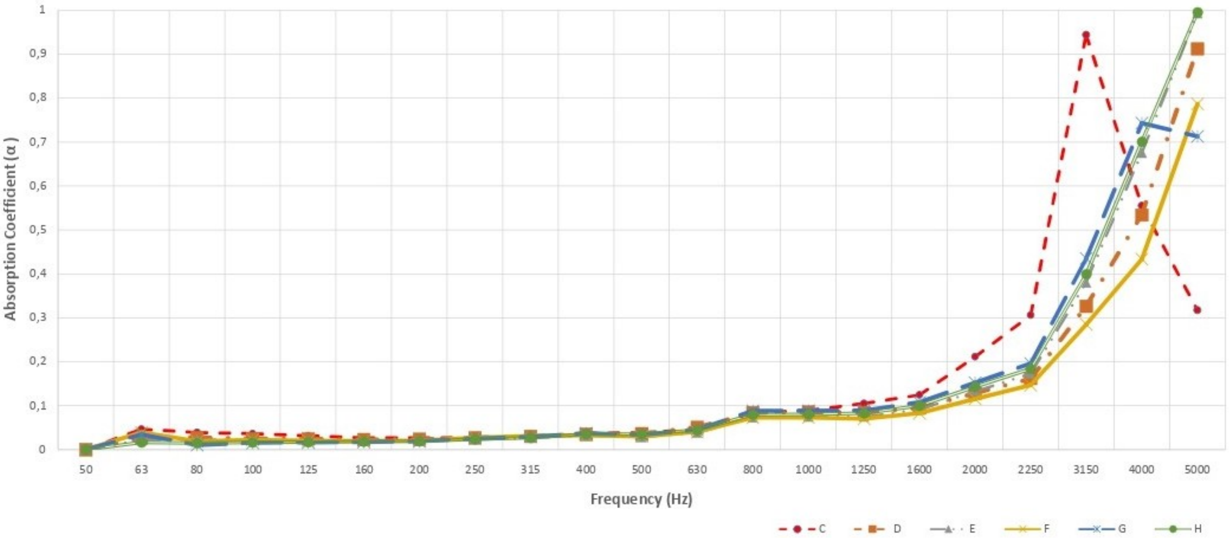

Figure 8 – Sound absorption coefficients over frequency spectrum from 50 Hz to 5000 Hz obtained for samplesC, D, E, F, G, and H without air gap behind.

By maintaining the same composition with material sample B (cherry seeds), material sample I is formed only by an additional spray-painting on to increase the fire resistance of the panel. Although the primary function of paint is to enhance fire resistance, the influence of paint on the material's sound absorption is investigated. According to Fig. 9, the paint shifted the effective frequency range from 1000 Hz to higher frequencies, 1600 Hz–5000 Hz. At 1600 Hz, the maximum sound absorption coefficient of painted sample is 0.42. Application of paint to other samples should be tested in the future to derive a better conclusion of the effective frequency range of samples that are painted for fire resistance.

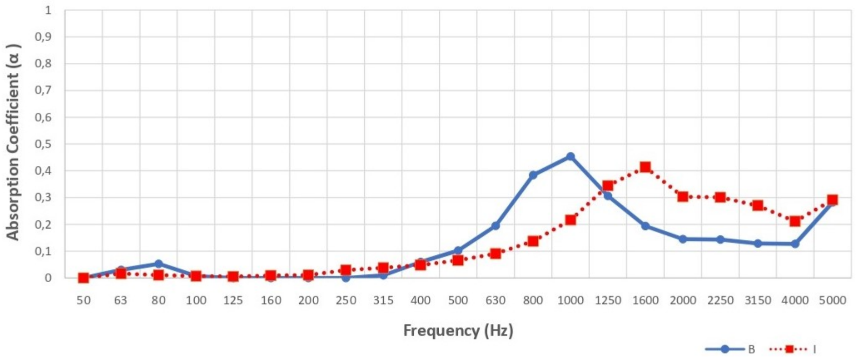

Figure 9 – Sound absorption coefficients over frequency spectrum from 50 Hz to 5000 Hz obtained for samples B and I with a 30 mm air gap behind.

4. CONCLUSIONS

The purpose of this research is to investigate reusable and biodegradable waste materials in order to provide a potential solution for sound absorptive materials to be applied in indoor spaces. This paper uses fruit seeds that are vastly trashed in the region, with a focus on cherry seeds of Central Anatolia. In the experimental set-up, nine distinct composite samples are tested to specify their sound absorption performance. The material sample containing tree resin, as a binder, is observed to be superior to that of the material sample with wood glue binder. When the numbers of seed types, thus the seed sizes, are varied the sound absorption performances of the samples are improved. The use of waste fruit seeds (cherry, olive, and watermelon) in the design and production of sound absorptive acoustic panels indicates considerable promise. Another outcome is that the spray-on paint application to increase the fire resistance of one sample panel, has shifted the effective frequency range towards higher octaves. To sum up, the developed panel systems, can find different grounds of application in indoor spaces where control of speech sound and absorption is critical, such as open-plan offices, meeting rooms, living rooms, or public places such as cafés, restaurants, etc. Further research is necessary to investigate more biodegradable binder types, as well as to observe the effects of different paints over different material samples.

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