THERMAL CONDUCTIVITY ANALYSIS OF MYCELIUM-BASED COMPOSITES DERIVED FROM *PLEUROTUS OSTREATUS* AND SUNFLOWER SEED HUSKS

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(Received 12th Mar 2025; accepted 25th Aug 2025)

Abstract. The increasing demand for environmentally friendly insulation materials has led to the exploration of mycelium-based composites as viable alternatives to insulation materials derived from petrochemicals. This study quantifies thermal conductivity (k) for mycelium composites grown on sunflower husks (unsalted roasted vs. salted roasted) colonized by *Pleurotus ostreatus*. Across 0–50 °C, k ranged from 0.045–0.058 W/m·K, with the unsalted-husk composite consistently lower than its salted counterpart. The materials are lightweight and produced from renewable feedstocks, aligning with circular-economy objectives. Results suggest competitive insulation performance relative to common commercial materials, while highlighting processing variables (salt content, temperature) that modulate k. Limitations and scale-up considerations are outlined for future work.
Keywords: *biodegradability, circular economy, heat flow meter, green building, biomaterials*

Introduction

Conventional insulation materials such as expanded polystyrene (EPS) and extruded polystyrene (XPS) raise concerns due to their petrochemical origin, limited recycling infrastructure, and potential contribution to microplastic pollution at the end of their service life (Papadopoulos, 2005; Sohn et al., 2020). Notably, the blowing agents used in the production of EPS and XPS insulation boards, for instance hydrofluorocarbons, have been reported to be compounds with high global warming potential (EEA, 2025). Considering their embedded energy values, the intensive use of fossil resources during both manufacturing and disposal of such foam materials is a major contributor to their carbon footprint (Cosentino et al., 2023).

On the other hand, mineral wool materials (e.g., glass wool, rock wool) are produced in high-temperature melting and fiber-drawing processes (Johra, 2021). These production methods require significant energy consumption and yield substantial CO_2 emissions. Moreover, if appropriate occupational safety measures are not implemented during installation or removal, mineral wool fibers may release airborne particulates that can irritate the respiratory system (Papadopoulos, 2005). Prolonged exposure to these particles poses potential health risks (EEA, 2025).

Consequently, both the dependence on fossil fuels in production and the waste management challenges associated with end-of-life disposal have strengthened the necessity of developing eco-friendly, renewable, and biodegradable alternatives to conventional insulation materials. In this context, mycelium-based composites, produced using biodegradable and renewable raw materials with a low carbon footprint, offer a significant alternative in terms of environmental sustainability (Jones et al., 2017). Insulation materials manufactured from organic feedstocks and aligned with circular economy principles are garnering increasing interest for a sustainable future (Johra, 2021).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_96039615

These environmental and health-related concerns have accelerated interest in the development of sustainable and biodegradable building materials as alternatives to conventional insulation materials (Cosentino et al., 2023; Papadopoulos, 2005). Furthermore, advancements in fungal biotechnology, including AIdriven optimization of cultivation processes and selective genetic improvements in fungal strains, have opened new avenues for enhancing the efficiency and scalability of mycelium-based materials. These innovations have the potential to further improve the mechanical and thermal properties of fungal composites, making them even more viable for industrial applications (Albayrak et al., 2024, 2025). In this regard, research on the application of fungal mycelium-based composites has intensified in recent years. Mycelium, by utilizing the high cellulose-lignin content found in agricultural and food industry residues as a nutrient source, forms a fibrous structure with low energy requirements and rapid growth potential (Jones et al., 2017). Such an approach not only enables waste reduction and valuable raw material recovery but also facilitates the production of lightweight, porous biocomposite panels characterized by low thermal conductivity (Haneef et al., 2017). The ability of such materials to reduce CO_2 emissions, enhance energy efficiency, and biodegrade at the end of their lifecycle presents a significant opportunity for the future construction sector in light of circular economy principles.

The appeal of mycelium-based composites largely stems from the bio-transformative capacity of fungal mycelium on cellulosic and lignocellulosic waste materials (Haneef et al., 2017). *Pleurotus ostreatus*, in particular, stands out due to its rapid growth rate and ability to decompose a wide range of waste substrates (Jones et al., 2017). The fibrous structure of fungal mycelium envelopes the substrate surfaces, acting as a natural binder and enabling the production of monolithic composite structures without requiring additional adhesives. As a result, these composites exhibit a porous and lightweight structure, demonstrating low thermal conductivity values suitable for insulation applications (Haneef et al., 2017). Additionally, the rapid development of *P. ostreatus* reduces production time while allowing for lower energy consumption and carbon emissions (Jones et al., 2017). The biodegradable nature of the final product also ensures a lower environmental impact compared to conventional disposal methods (Cosentino et al., 2023).

Sunflower seeds and particularly their husks, due to the husks' cellulose and lignin content, present an excellent raw material source for biocomposite production (Mohd Basri et al., 2021). Moreover, the large-scale availability of sunflower husks as agricultural waste provides substantial advantages in terms of sustainability. Compared to rice husks or wheat straw, sunflower husks exist in greater quantities, making them a promising alternative within a circular economy framework. In countries with extensive sunflower production, the seeds are primarily processed for snack consumption or oil extraction, leading to large amounts of otherwise discarded husks. By systematically collecting and processing these husks into value-added products, both environmental benefits and economic gains can be realized (Cosentino et al., 2023). Therefore, incorporating agricultural residues like sunflower husks into mycelium-based composites contributes not only to biodegradable and sustainable material development but also to optimizing waste management practices in line with circular economy goals (Jones et al., 2017).

Mycelium-based composites (MBCs) are recognized as promising alternatives in sustainable construction materials due to their lightweight, biodegradable properties, and low carbon footprint. Their thermal insulation potential is highly dependent on the material's internal structure, production methods, and substrate composition (Alaneme et al., 2023).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Several studies indicate that the thermal conductivity values of MBCs generally range between 0.03–0.07 W/m·K (Bıyık and Özgür, 2024; Sariay et al., 2023). This range is comparable to that of conventional commercial insulation materials, offering sustainability advantages. However, due to the heterogeneous nature of mycelium composites, variations in thermal conductivity are frequently observed. Particularly, the composition of the substrate and variations in the mycelium growth process directly influence the void ratio and thermal performance of the composite (Walter and Gürsoy, 2022).

Key factors affecting the thermal performance of mycelium composites include the type of substrate used, mycelium growth duration, moisture content, and any pressing (compression) methods. Studies in the literature suggest that lignocellulosic substrates such as wheat straw, sawdust, rice husks, and sunflower husks enhance mycelium bonding strength, thus improving the mechanical durability of the material (Sariay et al., 2023).

Research findings indicate:

- Hemp fiber and straw-based mycelium composites exhibit lower thermal conductivity due to their high fiber content (Alaneme et al., 2023).
- Rice husk-based mycelium composites demonstrate higher density and improved thermal performance compared to other substrates (Cosentino et al., 2023; Mohd Basri et al., 2021).
- Wheat straw and sawdust-based composites form a more homogeneous structure attributed to their fibrous nature, optimizing thermal conductivity performance (Koparan and Alkan, 2024).

To enhance the thermal performance of mycelium composites, optimization strategies such as hot pressing, bio-based additives (e.g., nano-cellulose or biopolymers), and surface hydrophobic treatments are being explored (Alaneme et al., 2023; Kutbay et al., 2022).

Overall, mycelium-based composites demonstrate strong potential as an environmentally friendly alternative to conventional insulation materials, particularly due to their low carbon footprint, biodegradability, and effective thermal insulation properties. The widespread availability and low cost of sunflower husks further support their viability for industrial adoption. Future research should focus on optimizing mechanical durability and water resistance to enhance commercial feasibility (Walter and Gürsoy, 2022). Furthermore, large-scale production assessments and cost analysis studies will be crucial in transitioning these materials into viable commercial alternatives (Kirdök et al., 2024).

Aim of the study. This work compares thermal conductivity of *P. ostreatus* based composites grown on unsalted roasted vs salted roasted sunflower seed husks at −5, 0, 10, 20, 30, 40, 50°C; standardizes units (W/m·K) and temperature reference points; and discusses limitations and scale-up considerations.

Materials and methods

In this study, the edible and cultivated basidiocarp of *Pleurotus ostreatus* (Jacq.) P. Kumm. (Turkish name is “İstiridye Mantarı”) (Sesli et al., 2020) and the seed husks of the sunflower plant (*Helianthus annuus* L.), commonly consumed as snacks (both unsalted and salted roasted), were used as substrates.

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The research was conducted at the Mycelium Production Laboratory of the Selçuk University Mushroom Application and Research Center.

For the production of mycelium using the tissue culture method, a defined piece (3-5 g) of fresh tissue from *Pleurotus ostreatus* was inoculated onto the surface of Malt Extract Agar (MEA) medium, which had been previously sterilized under aseptic conditions. The inoculated medium was then incubated at 25°C for 15-20 days (*Fig. 1*). At the end of the incubation period, pure mycelium cultures were obtained on the MEA medium surface (*Fig. 2*).

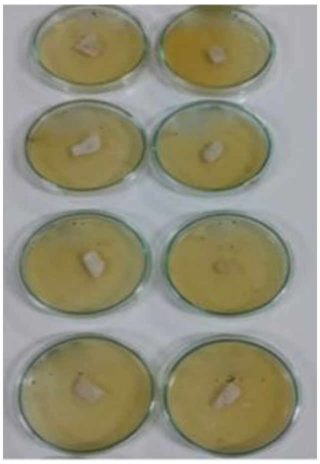

Figure 1. *P. ostreatus tissue samples inoculated onto the surface of the MEA medium*

Figure 2. *P. ostreatus culture with fully developed mycelium*

The sunflower seed husks, both salted and unsalted roasted, intended for use in the study were ground in a mill to specific particle-sizes range (3-5 mm). The ground husks were soaked in clean water for two days. After soaking, the husks were drained using a sieve, ensuring they remained slightly moist. Following the drainage, they were weighed separately, and 2% gypsum (by weight, based on the kilogram amount) was added and mixed thoroughly.

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This mixture was then transferred into 1-L glass jars, leaving a 8-10 cm of space at the top. The jars were sealed tightly to prevent air leakage. Subsequently, they were sterilized in an autoclave at 134°C for 20 min. After sterilization, the jars were removed from the autoclave and allowed to cool.

Once cooled, defined-size (20 × 20 mm) pieces of fully developed mycelium from petri dishes were aseptically transferred into the jars using a scalpel (*Fig. 3*). The inoculated jars were then sealed with pre-sterilized, perforated sponge lids that allowed airflow. Finally, the jars were placed in a mycelium incubation chamber set at 24°C with 80–85% relative humidity to allow for mycelial colonization and development for 14-21 days.

Figure 3. *Inoculation of substrates with mycelium*

The fully developed mycelium-substrate mixtures in the jars (*Fig. 4*) were broken into loose particles and transferred into pre-sterilized 60 mm molds under a biosafety cabinet. The molds were then placed in a humidity chamber set at 24°C with 80% relative humidity to allow further development.

Figure 4. *Fully developed mycelium-substrate mixtures in the jar*

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Once the biomaterials had fully developed within the molds, they were removed and subjected to a drying process in an oven at 45°C for 48 h (*Fig. 5*).

Figure 5. *Biomaterials fully developed in the mold and oven-dried*

HFM conductivity test: The thermal conductivity test was conducted following the method described by (Koru, 2017). According to this method, thermal conductivity variations resulting from different concentrations were measured using the Lasercomp HFM Fox-50 heat flow meter, which operates under the conditions specified in ASTM C518, EN 12667, and ISO 8301 standards (*Fig. 6*).

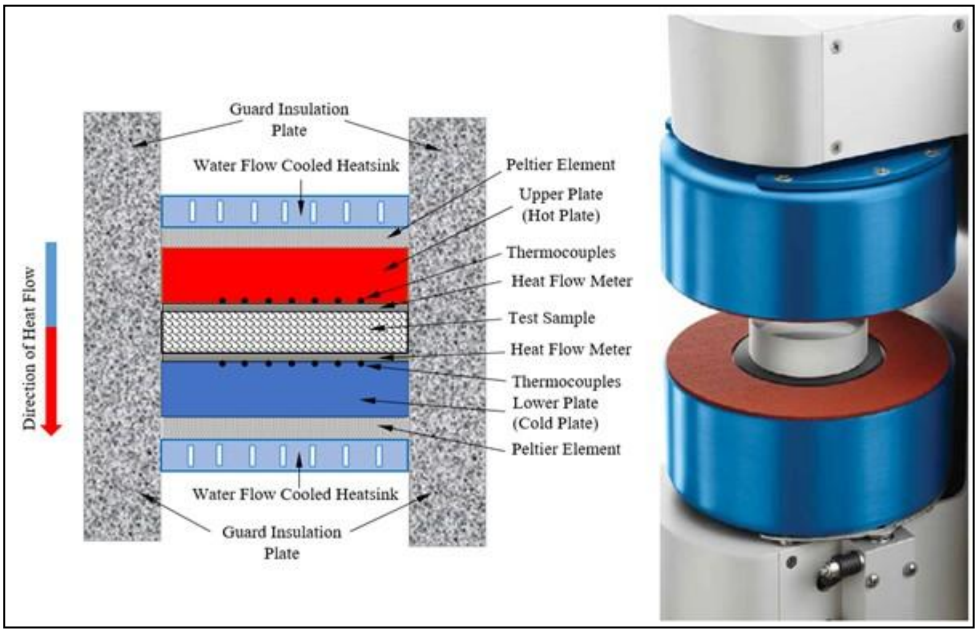

Figure 6. *HFM Fox-50 heat flow meter device and operational schematic (Koru et al., 2017)*

During testing with the HFM device, the sample is placed between two plates maintained at different temperatures. These plates are kept at a constant temperature through the Peltier effect. Meanwhile, heat flow and temperature across the sample are measured using heat flow sensors and thermocouples located on the upper and lower plates of the device.

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Thermal conductivity is determined once the HFM device reaches thermal equilibrium and establishes a steady temperature gradient. The thermal conductivity measured by the HFM device is calculated using the Fourier thermal conductivity equation (*Eq. 1*).

$$q = -kA\frac{\Delta T}{\Delta x} \qquad \text{(Eq.1)}$$

In this formula, q (W/m²) represents the heat flux, k (W/m.K) denotes thermal conductivity, A (m²) is the area, ΔT (K) indicates the temperature difference, and Δx (m) refers to the sample thickness. The HFM device operates by utilizing this equation along with calibrated software to measure, record, and output the results.

Before initiating the experiment, the device is calibrated using Pyrex-7740 and Pyrex calibration files with known thermal conductivity values at various temperatures.

In this study, the thermal conductivity coefficients of the obtained biomaterials were measured using the HFM method at seven different temperature values (-5, 0, 10, 20, 30, 40, 50°C).

A schematic representation of the procedural steps performed in this study is provided in *Figure 7*.

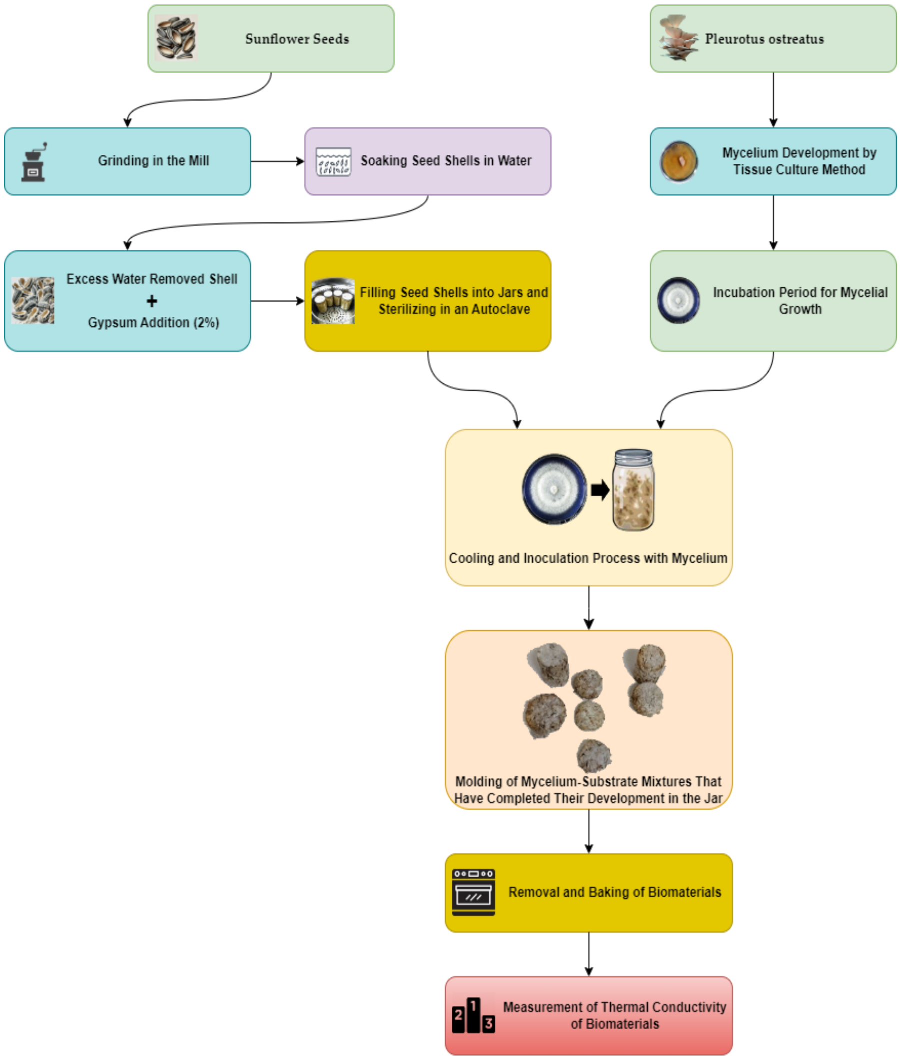

Figure 7. *Process steps*

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Results

The thermal conductivity coefficients of the biomaterial obtained from *Pleurotus ostreatus* and the seed husks of the sunflower plant (both salted and unsalted roasted) were measured using the HFM method at seven different temperature values. Results are summarized in merged table (*Table 1*) and corresponding figures (*Figs. 8–10*).

Table 1. *Thermal conductivity coefficients of the material obtained from unsalted roasted sunflower seed husks at seven different temperature values*

Temperature (°C)	-5	0	10	20	30	40	50
Unsalted roasted (W/m.K)	0.0046	0.045	0.047	0.048	0.05	0.052	0.054
Salted roasted (W/m.K)	0.0047	0.048	0.05	0.052	0.054	0.056	0.058

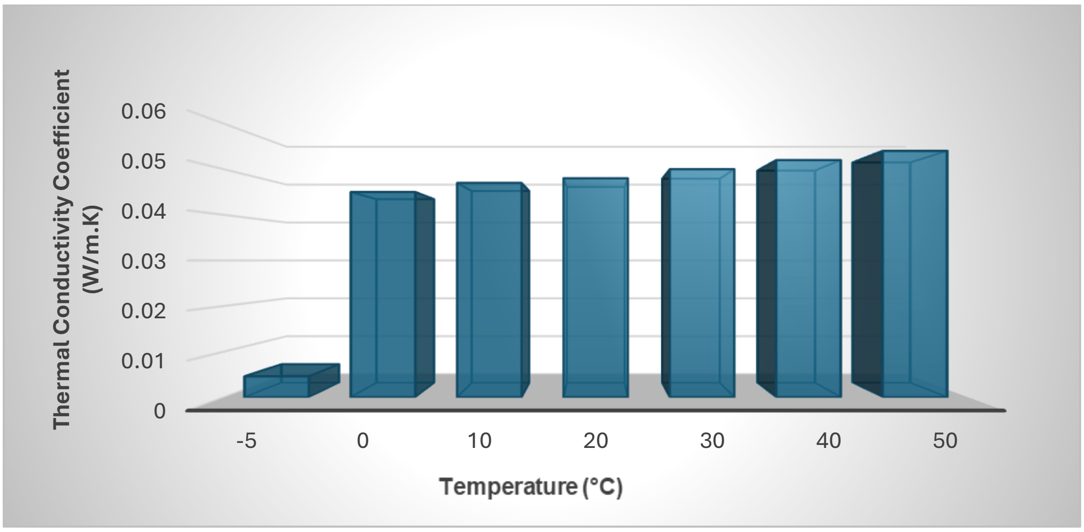

Figure 8. *Graph of thermal conductivity coefficients of the material obtained from unsalted roasted sunflower seed husks at seven different temperature values*

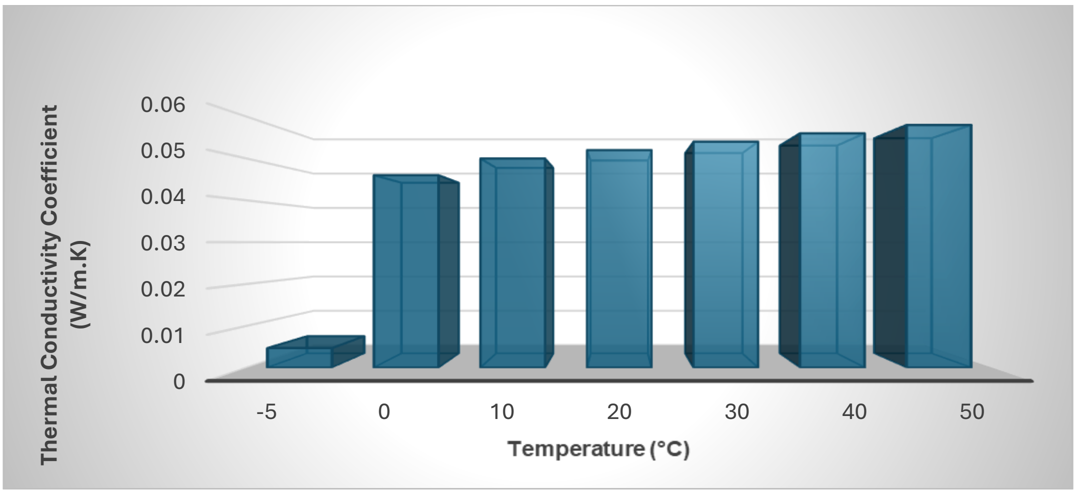

Figure 9. *Graph of thermal conductivity coefficients of the material obtained from salted roasted sunflower seed husks at seven different temperature values*

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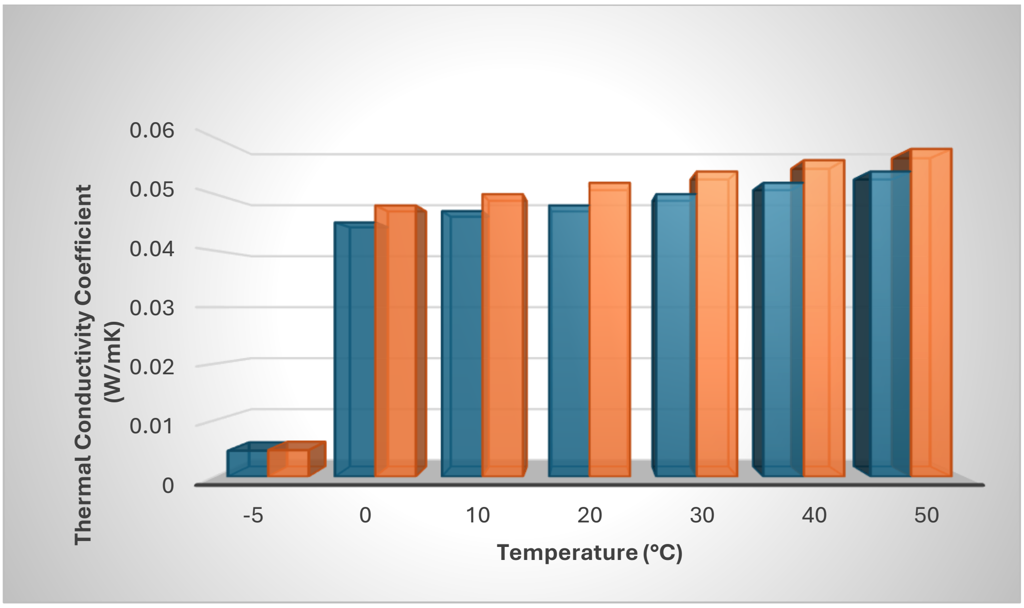

Figure 10. *The material obtained from unsalted (blue column) and salted (orange column) roasted sunflower seeds was compared in terms of thermal conductivity coefficients at seven different temperature values*

Discussion

When examining the data for the biomaterial obtained from *Pleurotus ostreatus* and unsalted roasted sunflower seed husks (*Table 1*), the thermal conductivity coefficient was measured as 0.0046 W/m.K at -5°C, 0.045 W/m.K at 0°C, 0.047 W/m.K at 10°C, 0.048 W/m.K at 20°C, 0.05 W/m.K at 30°C, 0.052 W/m.K at 40°C, and 0.054 W/m.K at 50°C.

Similarly, for the biomaterial derived from *P. ostreatus* and salted roasted sunflower seed husks (*Table 1*), the thermal conductivity coefficient was recorded as 0.0047 W/m.K at -5°C, 0.048 W/m.K at 0°C, 0.05 W/m.K at 10°C, 0.052 W/m.K at 20°C, 0.054 W/m.K at 30°C, 0.056 W/m.K at 40°C, and 0.058 W/m.K at 50°C.

When comparing the results, it is evident that at all temperature levels, the thermal conductivity coefficients of unsalted roasted husks are lower than those of salted roasted husks. This indicates that, in terms of insulation, unsalted roasted husks perform better. The observed difference can be attributed to the absorption of salt during roasting. Even though the husks were soaked in water before the mycelium inoculation process, some salt was still retained, negatively affecting mycelium development. This likely reduced the binding strength compared to the unsalted roasted husks, resulting in increased conductivity and lower insulation performance (Plausible mechanism: osmotic/ionic stress reducing mycelial network density).

Upon reviewing the existing literature, a study by Sivaprasad et al. (2021), which is similar to our research, examined the thermal conductivity of mycelium-based biomaterials produced using *Pleurotus ostreatus* and a 3:2 mixture of sawdust and coconut coir substrate. They conducted the thermal conductivity test using the HFM method and obtained a value of 0.069950 W/mK at 40°C. In our study, at the same temperature, the thermal conductivity coefficients of the biomaterials were 0.052 W/mK (unsalted) and 0.056 W/mK (salted). These values indicate that the biomaterials obtained in our study exhibit better insulation performance.

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Bıyık and Özgür (2024), determined the thermal conductivity coefficient of biomaterials obtained from *Ganoderma resinaceum* mycelium and wheat straw using a Deneysan HT-350 thermal conductivity test device. Their result of approximately 0.4 W/m.K is substantially higher than our values.

In another study, Shao et al. (2016) investigated the thermal conductivity of composite materials prepared using *Ceriporia lacerata* mycelium and soybean straw. They recorded a thermal conductivity coefficient of 0.0540 W/m.K at 25°C. Comparing this with our results at similar temperature points—0.048 W/m.K (unsalted) and 0.052 W/m.K at 20°C, and 0.05 W/m.K (unsalted) and 0.054 W/m.K at 30°C—it can be observed that at 20°C, both of our biomaterials exhibit lower thermal conductivity than *C. lacerata*-based material. Furthermore, at 30°C, our unsalted roasted seed-based material has a lower conductivity coefficient, while the salted roasted material exhibits an equal value.

Yang et al. (2017) conducted a study using *Irpex lacteus* mycelium with plant-based materials such as wheat bran and corn kernels. They measured the thermal conductivity values of the obtained biomaterials within the range of 0.05–0.07 W/m.K. Comparing their materials with ours, it is evident that their thermal conductivity values are higher, indicating lower insulation performance.

Răut et al. (2021) measured the thermal conductivity coefficients of a biopolymer composite obtained from wheat straw, bacterial spores, pellets, polypropylene (PP), and *Ganoderma lucidum* mycelium. Their results were 0.029 ± 1.04 W/m.K at 10°C, 0.034 ± 1.68 W/m.K at 25°C, and 0.035 ± 1.05 W/m.K at 40°C. Compared to our findings, similar values were observed at 10, 20, and 30°C.

Dias et al. (2021) investigated the thermal conductivity coefficient of a biomaterial composed of *Ganoderma resinaceum* mycelium and *Miscanthus x giganteus* (giant reed) following ISO 8302 standards. They measured conductivity up to 35°C, with values ranging between 0.0882 and 0.104 W/mK. Our study extended the measurements up to 50°C, obtaining results within the range of 0.0046–0.058 W/mK. These findings indicate that both of our biomaterials exhibit lower thermal conductivity than those derived from G. resinaceum, making them more effective insulators.

Xing et al. (2018) tested the thermal conductivity of materials obtained from wheat straw and rye grains combined with *Oxyporus latermarginatus* (OXY), *Ganoderma resinaceum* (GAN), and *Megasporoporia minor* (MEG) species. Their findings reported conductivity values of 0.078 W/mK for OXY, 0.079 W/mK for MEG, and 0.081 W/mK for GAN, all of which are significantly higher than the values obtained in our study.

Wimmers et al. (2019) examined the thermal conductivity of materials produced using *Fomitopsis pinicola*, *Gloeophyllum sepiarium*, *Laetiporus sulphureus*, *Phaeolus schweinitzii*, *Piptoporus betulinus*, *Pleurotus ostreatus*, *Polyporus arcularius*, *Trametes pubescens*, *T. suaveolens*, and *Trichaptum abietinum* mycelium along with birch, aspen, spruce, pine, and fir sawdust. Their findings reported thermal conductivity values ranging between 0.051 and 0.055 W/m.K. Since the study did not specify the temperature reference point, a comparison with our average conductivity values suggests that our biomaterials exhibit similar thermal performance.

The thermal conductivity coefficient of glass wool, which is commonly used as an insulation material, is 0.040 W/m.K, while polystyrene has a range of 0.031–0.037 W/m.K (Arslan and Aktaş, 2018) Comparing these materials with the biomaterials obtained in our study, it is evident that glass wool and polystyrene exhibit slightly lower thermal conductivity values. However, the differences are not significantly large.

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Another insulation material, polyvinyl chloride (PVC) foam, has a thermal conductivity coefficient of 0.057 W/m.K at 0°C (Özer and Acun Özgünler, 2019). Comparing PVC with both of our biomaterials, it is evident that our materials have lower thermal conductivity values. This confirms that our biomaterials not only offer effective insulation but also provide environmental benefits as sustainable alternatives.

Conclusions

In this study, the thermal conductivity properties of mycelium-based biocomposites produced using *Pleurotus ostreatus* mycelium and sunflower seed husks were examined in detail. The data obtained from the HFM test conducted within the scope of the study indicate that mycelium-based composites are among the promising alternative materials for thermal insulation. The thermal conductivity coefficients measured at different temperature values demonstrate that the material is comparable to commercial insulation products. In particular, the biocomposite produced with unsalted roasted sunflower husks exhibited lower thermal conductivity compared to its salted variant. This finding suggests that salt content may have a negative impact on mycelium growth and the porosity structure of the material.

The obtained results highlight that mycelium-based biocomposites, with their lightweight, biodegradable, and environmentally friendly properties, have the potential to serve as alternatives to conventional insulation materials such as EPS, XPS, and glass wool. Compared to similar studies in the literature, the biocomposite produced in this study exhibits a lower thermal conductivity coefficient, indicating superior insulation performance.

Furthermore, the large-scale availability of sunflower seed husks as agricultural waste and their low-cost nature provide an opportunity to utilize such biomaterials in accordance with circular economy principles. Sunflower seeds, widely consumed as snacks, generate significant amounts of husk waste after consumption. These husks contribute to environmental pollution in public spaces, parks, and streets, posing a major challenge in waste management. This study aims to repurpose these waste materials in the production of mycelium-based biomaterials, thereby reducing environmental pollution while transforming them into value-added products. Through this approach, the study contributes both to waste management and the development of a sustainable building material.

However, further research is required regarding factors such as the mechanical strength, moisture permeability, and long-term durability of mycelium-based composites. Future studies focusing on hydrophobic coatings, mechanical reinforcement techniques, and process optimization could enhance the commercial viability of these materials.

In conclusion, this study demonstrates that mycelium-based biocomposites, produced using renewable and sustainable raw materials, possess high potential for thermal insulation applications. Their low energy consumption, biodegradability, and environmentally friendly production processes suggest that these materials could be effectively utilized in green building technologies and ecological insulation solutions. In this regard, the widespread adoption of mycelium-based materials could represent a significant step toward reducing the environmental impact of conventional insulation materials.

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DOI: http://dx.doi.org/10.15666/aeer/2305_96039615

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