Investigation of the Sound-absorbing Performances of Pure Coffee Grounds

Chun-Won Kang,[a] Kazuharu Hashitsume,[b] and Eun-Suk Jang [a,c,d,*]

Various natural sound-absorbing materials such as rice by-products, coir fiber, date palm fiber, peanut husks, hardwood cross-sections, and forest by-products have been introduced to replace petroleum-based sound-absorbing materials in previous studies, and their sound-absorbing performance was significant. This study investigated the sound-absorbing performance of pure coffee grounds as an eco-friendly sound-absorbing material. After inserting coffee grounds into cylindrical holders with lengths of 20, 30, and 40 mm, the density of the coffee grounds was adjusted from 0.2 to 0.5 g/cm^3. Then, the sound absorption coefficients were measured by an impedance tube. As the thickness and density increased, the sound absorption coefficient at low frequencies improved. However, the sound absorption coefficient at high frequencies decreased. The optimal noise reduction coefficient (NRC) of coffee grounds investigated in this study was 0.61 at a density of 0.3 g/cm^3 and thickness of 50 mm. This result shows a sound-absorbing performance that is comparable to other natural sound-absorbing materials. This study concludes that coffee grounds have high use-value as an eco-friendly sound-absorbing material.

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Keywords: Coffee grounds; Sound absorption coefficient; Noise reduction coefficient; Eco-friendly sound-absorbing material

*Contact information: a: Department of Housing Environmental Design, College of Human Ecology, Jeonbuk National University, Jeonju 54896, South Korea; b: Graduate Schools of Education, Shimane University, Matsue 690-8504, Japan; c: Research Institute of Human Ecology, College of Human Ecology, Jeonbuk National University, Jeonju 54896, South Korea; d: Sambo Scientific Co., Ltd., R&D Center, Seoul 07258, South Korea; *Corresponding author: esjang@sambosc.com*

INTRODUCTION

Coffee is one of the most popular foods in the world (Pramudita *et al.* 2017; Saberian *et al.* 2021). About 170,000 tons of raw coffee beans were imported to Korea in 2018, which represents about 1.8% of the global production of about 9.48 million tons in 2017 to 2018. Korea is the 6th largest importer in the world after the European Union, the United States, Japan, Russia, and Canada (Song 2020).

With the increase in coffee consumption, environmental pollution issues, such as plastic cups, are becoming a significant issue (Changchenkit and Plangklang 2020). Plastics break down into microplastics and enter the soil and oceans, eventually reaching our food sources (Miranda and de Carvalho-Souza 2016). Accordingly, there are functional studies on regulating the use of plastics and their replacement (Jang and Kang 2020; Onen Cinar *et al.* 2020).

In addition to the plastic used in coffee containers, the coffee grounds also have an adverse effect on the environment. Only 0.2% of coffee beans are consumed as coffee, and the remaining 99.8% are thrown away as coffee grounds (Nam *et al.* 2017). Indiscriminately discarded coffee grounds can cause soil and air pollution during landfilling and incineration (Park *et al.* 2021).

Coffee grounds are composed of cellulose, hemicellulose, and lignin; they are rich in protein and sugar (Ballesteros *et al.* 2014). Recycled coffee grounds are actively being studied for use as compost (Ryu *et al.* 2014), bio-adsorbents (Castillo *et al.* 2020), and biodiesel (Abomohra *et al.* 2021). In addition, applications in building materials, such as bricks (Velasco *et al.* 2016) and insulation materials, are active fields of research (Lachheb *et al.* 2019).

This study focused on the use of coffee grounds as a sound-absorbing material. There have been many previous studies on sound-absorbing materials using eco-friendly natural materials. These natural sound-absorbing materials have included rice by-products (Olcay and Kocak 2021), coir fiber (Taban *et al*. 2019), date palm fiber (Mohammad *et al*. 2019), peanut husks (Jang 2022a), hardwood cross-sections (Jang and Kang 2021a,b) and forest by-products (Jang 2022b). The performance of these natural sound-absorbing materials showed the possibility of replacing the existing petroleum-based sound-absorbing materials with natural materials.

However, there have been a few studies on the use of coffee grounds as sound-absorbing materials. The surface of the coffee grounds particles is porous, and the rough surfaces have sound absorption potential (Saberian *et al.* 2021).

Gama *et al.* (2017) created polyurethane foam by liquefying coffee grounds. It has been reported that this may provide better sound absorption properties and promising improvements in mechanical and thermal properties. Ricciardi *et al.* (2017) reported that pressurized panels made from coffee grounds had excellent sound absorption and insulation properties in the mid and high frequencies. They suggested that coffee grounds could be a potential green building material.

Yun *et al*. (2020) manufactured recycled coffee ground board for sound absorption and reported that after applying the recycling coffee waste board in the café, the acoustic definition (D50) was 0.8 above 500 Hz. Additionally, the recycled coffee ground board decreased the reverberation time from 1.2 seconds (without sound-absorbing material) to 0.7 seconds, and there was a 7 dB decrease in sound pressure level. Moussa *et al*. (2022) manufactured coffee grounds composite board added potato starch binder and investigated their sound absorption coefficient. They reported that the weighted sound absorption coefficient (α_w) of the 2 cm thick board was 0.37, which showed better sound absorption than that of rock wool (0.25).

In previous studies, the coffee grounds sound absorber was mainly used mixed with other materials or manufactured in the form of panels. The primary purpose of this study is to investigate the sound absorption properties of pure coffee grounds without any processing or treatment.

In addition, this study compared the sound absorption capacity of natural sound-absorbing materials using agricultural by-products investigated in previous studies. This study could provide primary data for researchers who want to use coffee grounds as interior materials.

EXPERIMENTAL

Materials

For this study, the coffee grounds, as shown in Fig. 1, were procured from Didm cafe (Jeonju, Korea). They were residues after brewing coffee. The coffee grounds were dried in an oven at 40 °C for 24 h before the experiment.

Sample holders with a diameter of 2.9 mm and lengths of 2, 3, and 4 cm were prepared for this study. Coffee grounds were placed in each cylindrical sample holder. The holders were filled with densities ranging from 0.2 to 0.5 g/cm^3, respectively. To prevent the samples from dripping, thin nylon mesh fabrics were applied to the front of each holder. The thickness of the mesh was 0.1 mm, and the hole diameter was 0.2 mm.

Fig. 1. Sample preparation of air-dried coffee grounds

Particle Shape and Size Analysis

This study used a particle shape analyzer (model: FlowCam 8000, Yokogawa Fluid Imaging Technologies, USA) to measure coffee grounds' particle shape and size. Approximately 10 ml of samples were diluted in ultrapure water, and they were analyzed for particle shape and size as they flowed through the cell at 1.5 mL/min.

Acoustic Characterization

Figure 2 shows a schematic for the impedance tube used to measure the sound absorption coefficient in this study. The impedance tube (model: Type 4206, B&K, Nærum, Denmark) was used for measuring the sound absorption coefficient at frequencies ranging from 50 to 6,400 Hz. The impedance tube is based on the ISO 10534-2 (2001) standard and is a quick and easy method for measuring the incidence sound absorption coefficient (Jang and Kang 2021a).

When a plane wave sound is emitted from a power amplifier, some sound energy is absorbed by the sample and some is reflected. The sound absorption coefficient is calculated using the transfer function method from the sound pressure signal superimposed by the two microphones.

The sound absorption coefficient measurement through the impedance tube measured the ambient air temperature and relative humidity, and the volume of the microphone was calibrated before the measurement. In addition, the two microphones used in the impedance tube were calibrated against each other using standard switching techniques (Doutres *et al.* 2010). After the sample holder was inserted into the impedance tube, it was sealed with an O-ring to prevent leakage (Lu *et al.* 2000).

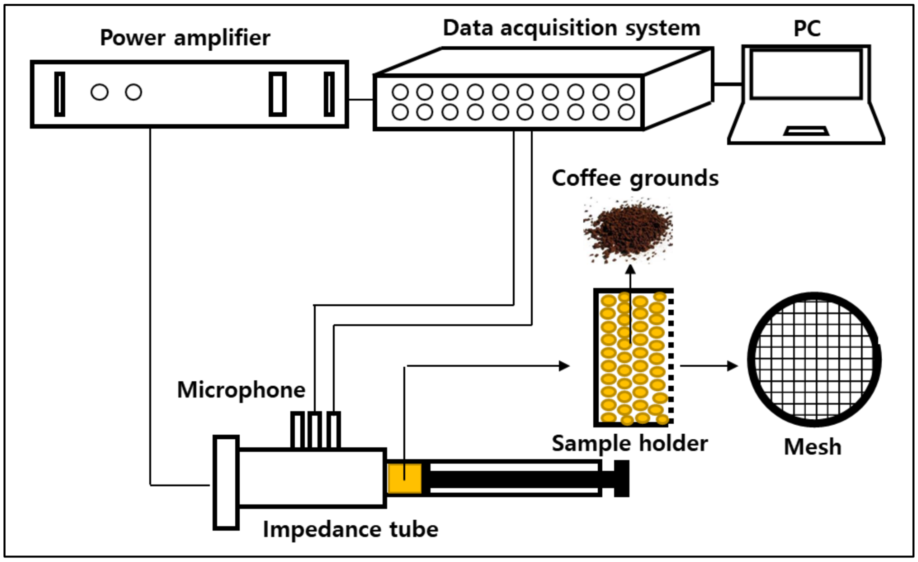


Fig. 2. Schematic for impedance tube to measure sound absorption coefficient (Kang *et al.* 2021)

From the measured reflection coefficient *r*, the sound absorption coefficient α was calculated as Eq. 1. The graph of frequency *vs.* sound absorption coefficient was drawn by software (PULSE LabShop ver 21.0.0.567, B&K, Nærum, Denmark). In addition, the noise reduction coefficient (NRC; average sound absorption coefficient at 250, 500, 1,000, and 2,000 Hz) was introduced to represent the sound absorption performance of the sound-absorbing material as an index (Jang and Kang 2021b), which was calculated as in Eq. 2:

$$\alpha = 1 - |r|^2 \quad (1)$$

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (2)$$

During sound absorption coefficient testing, the environmental variables were 21.8 °C for temperature, 55% for humidity, 344.29 m/s for sound velocity, 1.213 kg/m^3 for air density, and 417.7 Pa/(m/s) for acoustic impedance.

RESULTS AND DISCUSSION

Particle Shape and Size of Coffee Grounds

Figure 3 shows the geometry of coffee ground particles. Their mean aspect ratio was analyzed as 0.69 ± 0.13, 0.78 ± 0.11 of mean circularity, and 1.31 ± 0.25 mean compactness. In addition, their mean particle size was 42.56 ± 25.14 µm. These coffee ground particle shapes were non-uniform and were tiny particle sizes. These shapes and sizes favor sound absorption because they scatter sound energy.

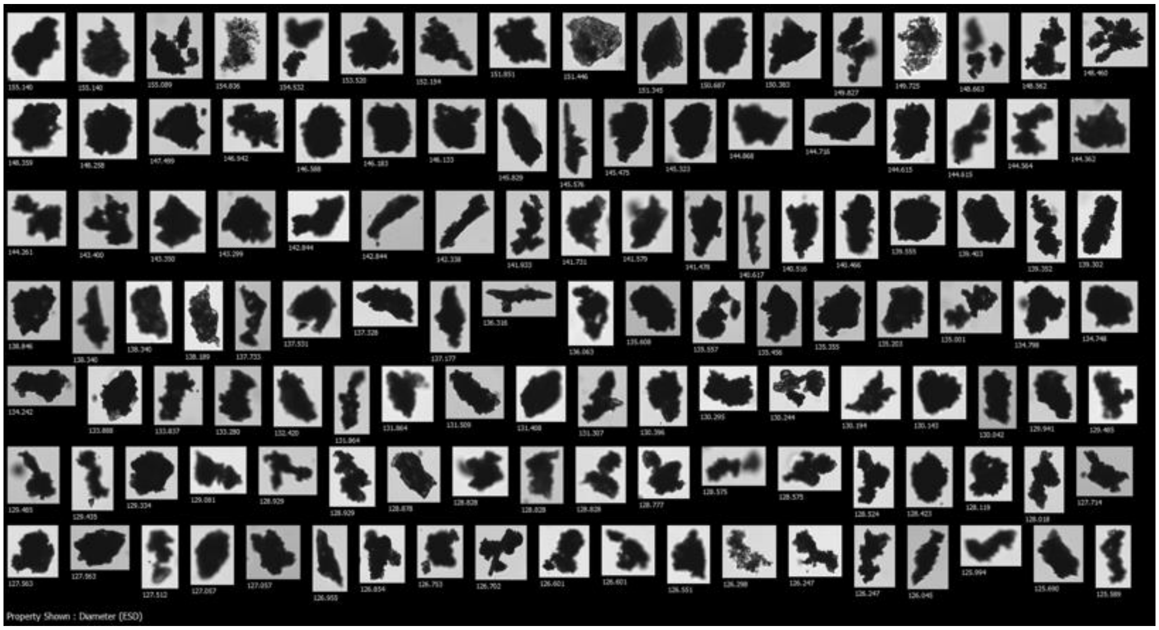


Fig. 3. The geometry of coffee ground particles

Sound Absorption Properties of Coffee Grounds

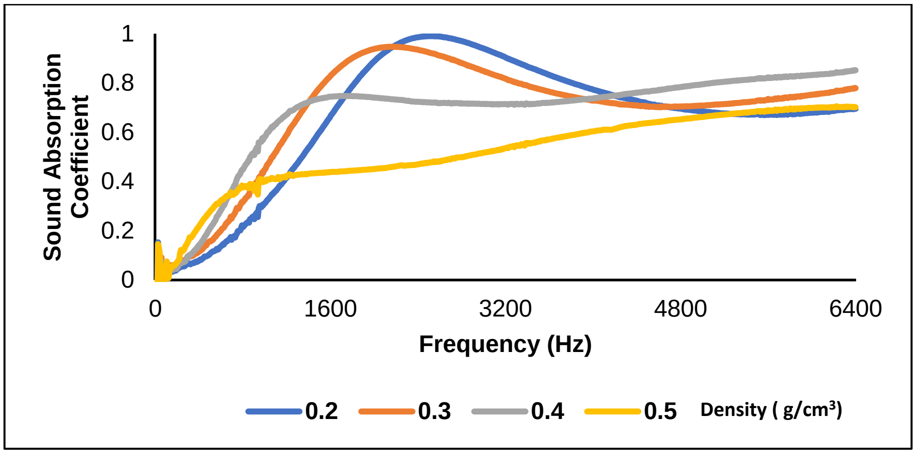
Figure 4 provides the coffee grounds' sound absorption coefficient curves depending on thickness (20, 30, and 50 mm) and density (0.2, 0.3, 0.4, and 0.5 g/cm^3). Overall, the sound absorption coefficient at low frequencies improved as the coffee grounds' thickness increased. Additionally, as the density of coffee grounds increased, the sound absorption coefficient at low frequencies was improved.

Thickness is the main parameter affecting the absorption performance of natural fibrous materials (Amares *et al.* 2017). Thicker absorbers have better sound absorption at lower frequencies. The reason is that at low frequencies the sound waves have a higher wavelength, which facilitates the absorption of sound waves in a thicker sound-absorbing material (Amares *et al.* 2017). The Johnson-Allard rigid frame model can predict this phenomenon. When the thickness of the porous sound absorbing material is increased, the absorption peak shifts to the low-frequency region, whereas the sound absorption in the high-frequency region decreases (Mamtaz *et al*. 2016).

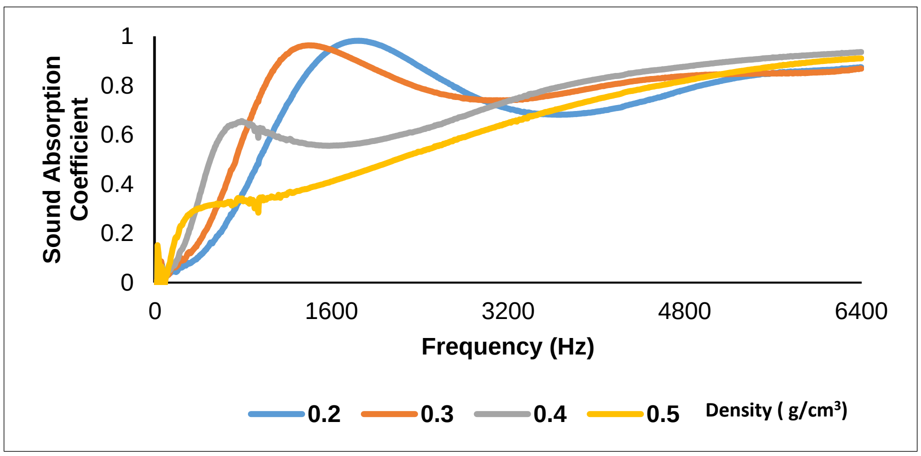
However, the absorption is not necessarily proportional to the thickness and may vary depending on the type of material and installation method (Samsudin *et al.* 2016).

As the density increases, the path of the pore (tortuosity) becomes more complex. In general, this makes it challenging to absorb sound, but for low frequencies with long wavelengths, it can be easily absorbed (Taban *et al.* 2021). However, if the density increases above a certain level, the pores may become clogged and have difficulty absorbing sound.

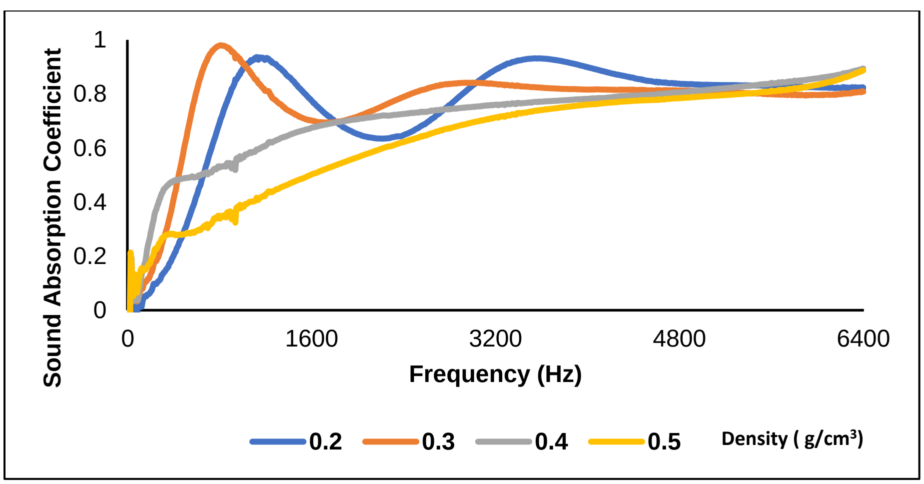
As a result, as the thickness and density of coffee grounds increased, the sound absorption characteristics at low frequencies tended to improve. However, the sound absorption at high frequencies decreased.



(a) Thickness 20 mm



(b) Thickness 30 mm



(c) Thickness 50 mm

Fig. 4. Sound absorption coefficient curve of the coffee grounds depending on thickness (a: 20, b: 30, and c: 50 mm) and density (0.2, 0.3, 0.4, and 0.5 g/cm^3)

Table 1 provides the NRCs of the coffee grounds for a range of thicknesses and densities. As the thickness increased, the NRC also increased. As for the density, the NRC increased with increasing density up to 0.3 g/cm^3, but then decreased at densities greater than 0.3 g/cm^3. This has the effect of complicating the tortuosity up to a density of 0.3 g/cm^3, which is thought to improve the sound absorption performance. Increasing the tortuosity of the void space between particles accelerates the scattering of sound waves, which can improve the sound absorption performance (Liu *et al*. 2019). However, when the density increases to 0.3 g/cm^3 or more, it is thought that the sound absorption performance is reduced because the space for sound waves to penetrate is clogged. In this study, the optimal NRC of coffee grounds was 0.61 at a density of 0.3 g/cm^3 at a thickness of 50 mm.

Table 1. Coffee Ground's NRC for a Range of Thicknesses (20, 30, and 50 mm) and Densities (0.2, 0.3, 0.4, and 0.5 g/cm^3)

	Thickness (mm)		
Density (g/cm^3)	20	30	50
0.2	0.34	0.44	0.49
0.3	0.41	0.50	0.61
0.4	0.40	0.46	0.54
0.5	0.31	0.34	0.37

Figure 5 provides a comparison between the optimal NRC of coffee grounds investigated in this study and the optimal NRC of the natural sound-absorbing materials investigated in the previous study. The natural sound-absorbing materials investigated in previous studies were reported as follows: balsa wood (10 mm thickness with 30 mm rear air-gap depth, 142 kg/m^3) (Jang and Kang 2021b), rice composite (25 mm thickness with 262 kg/m^3) (António *et al.* 2018), luffa fiber (4 layers with 100 mm real air-gap depth, 148 kg/m^3) (Thilagavathi *et al.* 2018), coir fiber (45 mm thickness with 30 mm rear air-gap depth, 130 kg/m^3) (Taban *et al.* 2019), date palm fiber (50 mm thickness) (Mohammad *et al.* 2019), and jute felt (8 layers, 144 kg/m^3) (Basu *et al.* 2021).

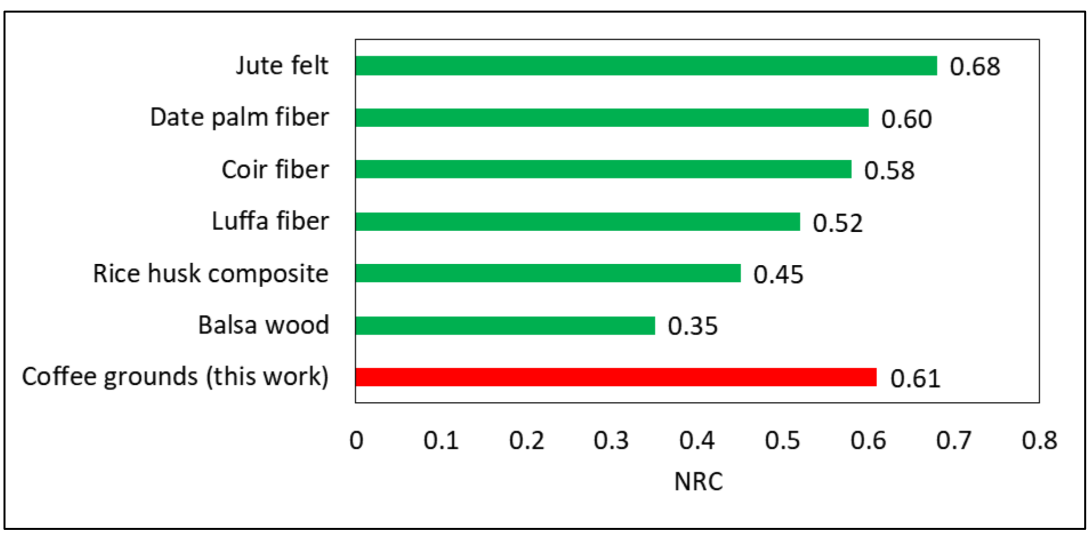


Fig. 5. NRC comparison between coffee grounds and natural sound-absorbing materials

As a result of the NRC comparison between coffee grounds and other natural sound-absorbing materials, it was found that coffee grounds had an excellent sound-absorbing performance. However, this study only evaluated the material's performance at the laboratory level. In the future, it is necessary to manufacture a large-scale coffee ground mat applicable to commercialization and to check the sound-absorbing performance of the material by the reverberation thread method.

This study proposes using coffee grounds as a natural sound-absorbing material as the primary recycling purpose. The sound-absorbing coffee ground mat can then be further recycled in the future, for example in compost, as a bio-adsorbent, or in biodiesel.

CONCLUSIONS

1. As the thickness of the sound-absorbing coffee grounds material increased, the noise reduction coefficient (NRC) increased. However, with increasing density, the NRC initially increased up to 0.3 g/cm^3, but then decreased at higher density.
2. The optimum sound absorption performance of coffee grounds was 0.61 (NRC) at a density of 0.3 g/cm^3 and a thickness of 50 mm.
3. In the NRC comparison of coffee grounds and other natural sound-absorbing materials, it was found that coffee grounds had excellent sound-absorbing properties.
4. This study proposed to use the coffee grounds as a natural sound-absorbing material for primary recycling purposes.

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Authors' Contributions

Conceptualization: CWK, Methodology: CWK, ESJ, Formal analysis: ESJ, Software: ESJ, Writing - original draft: ESJ, Writing - review & editing: CWK, KH and ESJ, Corresponding: ESJ, Supervision: CWK. All authors read and approved the final manuscript.

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