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Recycling Pig Slurry Solid Fraction Compost as a Sound Absorber

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Abstract: The aim of this investigation was to determine the physical and acoustical properties of compacts made from composted pig slurry solid fraction (SF) in order to assess the potential to recycle this agricultural waste as a sound absorber. The compacts were obtained by compression. The physical parameters investigated were bulk density, durability, and particle size distribution. The acoustical features of the compacts were studied with an impedance tube device in order to verify the acoustic absorption coefficient. Two composts were prepared: pig SF compost without a bulking agent (SSFC) and pig SF compost with wood chips as a bulking agent (WCC). The study's results indicated that compost particles dimension played a key role in the physical and acoustical properties of the compacts: the smaller the particles, the higher the physical and acoustical properties of the compacts. The densification process increased the bulk density of the investigated composts up to 690 kg m^{-3} for SSFC and 660 kg m^{-3} for WWC, with, respectively, medium (77.9%) and low (66.5%) durability. The addition of woody bulking agent significantly reduced the absorption coefficient: the best results, in terms of potential use as a sound absorber, were observed for compacts made from composted pig slurry solid fraction without the addition of wood chips.

Keywords: composting process; pig manure; bulk density; durability; particle size; absorption coefficient

1. Introduction

Noise emission can be controlled by sound absorber materials able to reduce the sound reflected from surfaces [1–3]. The sound absorbers are typically highly porous synthetic materials, such as rock wool, glass wool, polyurethane, or polyester, which are expensive to produce and are generally based on petrochemicals [4]. The growing awareness towards the environmental implications and health issues associated with these materials has increased the attention being paid to natural materials [5]. In this contest, there is emphasis on the use of green, ecofriendly materials in fields like automotive and building construction. This trend is also growing in the area of acoustic and noise control [6]. A high number of potential candidate materials are available from the biomass in the form of organic fibres, either vegetable or animal in origin, to replace the non-natural materials adopted to manufacture conventional sound absorbers. There are many advantages of natural fibers like their low cost, low impact on the environment, good mechanical properties, and low production cost over the conventional noise control material [6]. Furthermore, according to Oldham et al. [2], they are inherently sustainable as they constitute part of the carbon and nitrogen natural cycles.

All these aspects increase the interest in exploring alternative resources to be exploited as noise absorption materials that are more environmentally sustainable than synthetic conventional materials [7].

Previous studies [8] investigating the characteristics of compacts made from compressed pig slurry solid fraction (SF) highlighted that it is a porous material, permeable to air and, therefore, potentially has acoustical features that can be used as a sound absorber.

Pig slurry derived from intensive livestock farms is agricultural waste produced in large quantities all over the world. China is the world's largest producer and consumer of pigs, accounting for nearly one-half of both [9]. The European Union (EU) is the second-largest pig producer (20% of the global production) and the largest net exporter of pigs, while the United State (US) are in third position, accounting for approximately 10% of global production [9]. Furthermore, we are currently witnessing a huge increase in pig breeding in other countries such as Brazil [10]. In all these countries, pig production continues to exhibit a long-term trend of an increasing concentration of large operations in specialized geographic areas such as the Yangtze River in China; Iowa, Minnesota, and North Carolina in the US; Denmark, Belgium, Spain, Germany, and Italy in the EU; and the Southern states of Brazil [9–12]. With reference to Italy, 90% of the total national assets of pigs is concentrated in the northern regions, such as Piedmont, Lombardy, Veneto, and Emilia Romagna [13]. In such contexts, an enormous amount of manure rich in nutrients, mainly nitrogen and phosphorous, is produced. Nowadays, slurry storage followed by application on agricultural soils as fertilizer is the most common disposition practice since it contributes to an increase organic matter (OM) in soil, provides nutrients to the plants, is technically simple, and exhibits reduced costs compared with other available solutions [14,15]. Nevertheless, in developed countries, mineral fertilizers are the main source of nutrients applied to crops, while manures are second in nutrient inputs to agricultural land [16].

However, agricultural land application, when inadequately adopted in a concentrated geographical area, may lead to water pollution through run-off, often culminating in fish kills, eutrophication, phosphate leaching, the accumulation of heavy metals as copper (Cu) and zinc (Zn), and high ammonia losses to the atmosphere accompanied by serious odour problems, causing a public nuisance [15,17,18].

To reduce the environmental impact and the odour nuisance of pig slurry, several techniques, as alternatives to its direct land application, have been introduced to properly manage high volumes of pig excreta. One of the most common processes is the mechanical separation of the slurry in a liquid fraction (LF) and a minor solid fraction (SF) rich in nutrients and organic matter [15,19]. This technique has been identified as one of the most potentially environmentally beneficial options in manure management [20].

One of the most penalizing SF characteristics is the low density (<500 kg m^{-3}) that increases the handling and transportation costs [8]. One possible solution to this problem is the densification of SF. Densification has been shown to increase the SF bulk density from an initial bulk density value <500 kg m^{-3} to a final one higher than 1000 kg m^{-3} [8]. Thus, the densification of SF could reduce the costs of transportation, handling, and storage [21].

However, the moisture content of SF is the most important limiting factor for densifying; according to Alemi et al. [22], the optimal moisture content for SF densification varies between 20% and 40%. Previous studies [14,23] prove that composting in turned windrows is a simple and affordable method to reduce the moisture content of SF because of the heat developed by the process. The addition of carbon rich lingo-cellulosic bulking agents, such as wood chips, to the SF optimizes the substrate properties, such as the carbon to nitrogen ratio (C/N) and air spaces, positively affecting the composting process [24].

The aim of the current study was to determine the sound absorption coefficient of compacts made from composted pig slurry solid fraction in order to recycle this agricultural waste as a sustainable sound absorber. Different techniques for producing SF-based compost, with and without bulking agent (wood chips), were explored. The study also focused on the density and durability of compacts, since these properties, according to previous studies [25,26], mostly affect the quality of compacts during handling and transportation.

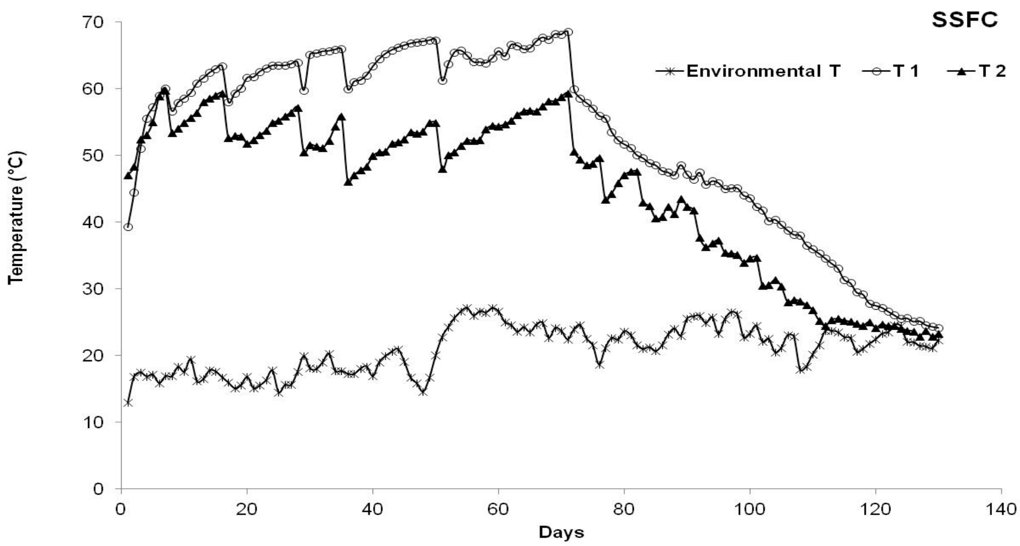
2. Materials and Methods

2.1. Composting Trial

The composting trials were carried out at the IMAMOTER facilities in Turin, Italy (N 44°57′25.0′′, E 7°33′27.8′′, 245 m above sea level).

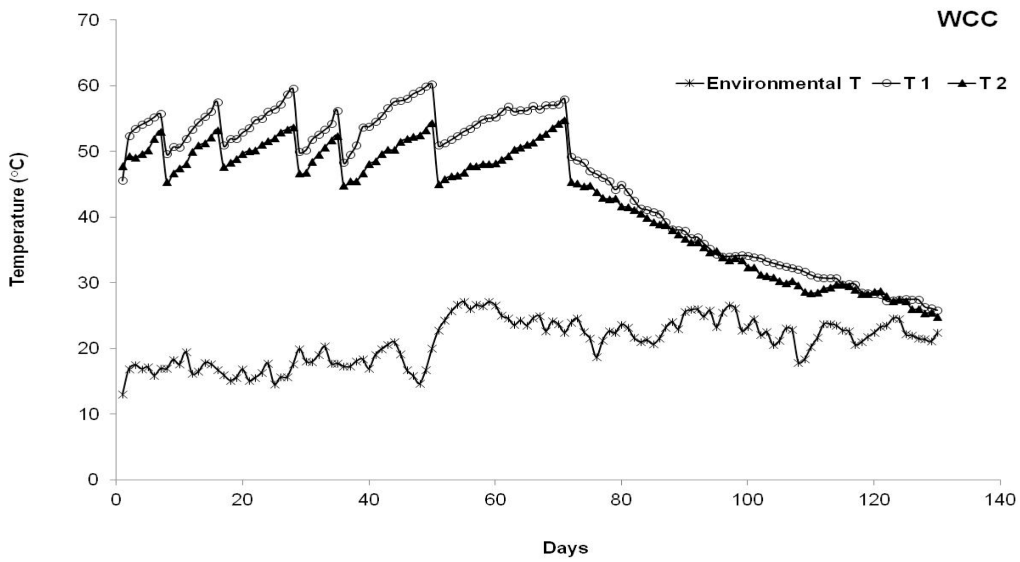
Two different composts were produced from the same SF obtained from a screw press separator. The pig slurry SF compost (SSFC) was obtained by composting 6000 kg of pig SF, while the wood chip compost (WCC) was produced after composting 8000 kg of the same pig slurry SF with 2400 kg of wood chips processed from urban garden pruning residues. Following literature recommendations [27,28], before undergoing composting, the wood chips were ground in a hammer mill with a screen size of 4 mm. During WCC windrow preparation, materials were thoroughly mixed to achieve a theoretical C/N ratio equal to 30, so as to optimise the composting performance [24]. After the set-up, windrows were placed on a concrete floor and the process was monitored for 130 days. The temperature of each SF windrow was continuously recorded with three sets of thermocouple sensors (Type K) connected to a multi-channel acquisition system (Grant, mod. SQ 1600). Each set consisted of two thermocouples placed at depths of 0.2 m (T1) and 0.6 m (T2) from the windrow surface and a third one for the ambient temperature. The temperatures were continuously monitored and recorded (Figure 1).

Windrows were composted with a turned strategy to reduce the moisture content of the organic materials, making them suitable for the following compaction process [14,23]. During the experimental period, windrows were turned six times (day 7, 16, 28, 35, 50, and 71).



(A)

Figure 1. *Cont.*



(**B**)

Figure 1. Temperature trends (°C) recorded during the composting trial (daily average). (**A**) Slurry Solid Fraction Compost -SSFC; (**B**) Wood Chips Compost—WCC.

At the end of the composting process, the moisture content of SSFC and WCC was 34.6% and 33.1%, respectively and, hence, suitable for compaction [22]. However, the moisture content of the samples (mass of 10 kg for each compost type) was reduced to 10% by drying in an oven set to 50 °C [29]. The samples were subsequently stored in plastic bags and kept in a cold room at 4 °C for a minimum of 72 h [30]. The moisture content was determined using the American Society of Agricultural and Biological Engineers (ASABE) Standard S358.2 [31], which recommends an oven drying of the samples at 103 °C for 24 h. Only one moisture level of 10% (wb) was used and this was based upon a literature review: at this moisture level, high quality compacts were produced from various straws and biomasses [32–34].

2.2. Particle Size Distribution

The particle size distribution was determined for pig slurry SF, woodchips, and final composts (SSFC and WCC) by a vibrating screen method according to the procedure by Allaire and Parent [35].

Approximately 300 g of each sample was placed on top of a set of three sieves with mesh sizes of 5.0, 2.0, and 0.5 mm, arranged from the largest to the smallest opening. Sieves were equipped with a collecting container at the bottom and a lid at the top and were sieved both vertically and horizontally until no further changes occurred in the distribution of the particles. At the end of the procedure, the various fractions remaining in the sieves and in the lower container were collected and weighed. Sieving was replicated five times.

The studied materials were then classified into four particle size ranges (<0.5 mm, 0.5–2.0 mm, 2.0–5.0 mm, >5.0 mm).

Particle size distribution was determined when the raw materials were at their original moisture content, while compost samples were sieved and classified after being dried to 10% of their wet basis moisture content and before densification.

2.3. Bulk Density

The initial density of SSFC and WCC was 150 and 250 kg m^{-3}, respectively.

Density was determined according to the ASABE Standard S269.4 [36]. This method involves pouring the bulk solid into a cylindrical container with a diameter of 380 mm and a height of 495 mm (volume of 0.05615 m^3). The material was levelled across the top of the surface of the container and weighed. Mass per unit volume gave the density of the biomass in kg m^{-3}.

Bulk density measurements were repeated five times and the mean value is reported.

2.4. Densification Equipment and Sample Preparation

The press used to obtain the compressed material has two opposite hydraulic cylinders.

The unit, fitted with an oil-hydraulic system, can deliver up to 297 kN in a time variable from 0 to 210 s.

The press can be equipped with different compressing chambers as needed. In order to obtain the samples required for the acoustic tests, two circular chambers were realized, respectively, with a 28 mm and 100 mm of diameter and 14 cm^3 and 189 cm^3 volume.

Upper and lower cylinders are fitted with load cells (model TMT–HY–C/PS, max rated load 200 kN) that give signals proportional to the compressing force. The top of the plunger is connected to a potentiometric displacement sensor (model Gefran LT-M-0500-S 500 mm full stroke), giving the exact position and volume of the compressing chamber. The oil feed line is equipped with a pressure transducer (Gems sensor 3100 series, 0–250 bar). Signals from the load cells and displacement transducer are processed by a pc-based acquisition system (DS-NET with BR8 module) with the sampling rate set at 1 ks s^{-1}.

All the collected data was recorded with properly configured software (Dewesoft 7.0) for post-processing operations.

The mass of the investigated composts used for making compacts was 10.0 ± 0.5 g and 120.0 ± 0.5 g for the 28 mm and 100 mm diameter chambers, respectively. The pressure applied on the particulate materials investigated was in the range 5.0–7.0 MPa. The range of pressure was selected according to the study conducted by Zafari and Kianmehr [37], which highlighted that, when compressing cattle manure, the best compact durability was obtained when adopting a pressure in the range of 3.5–6.0 MPa. No binder-additive was added to the materials submitted to the process.

Figure 2 shows samples of the compacts obtained by the experiment.

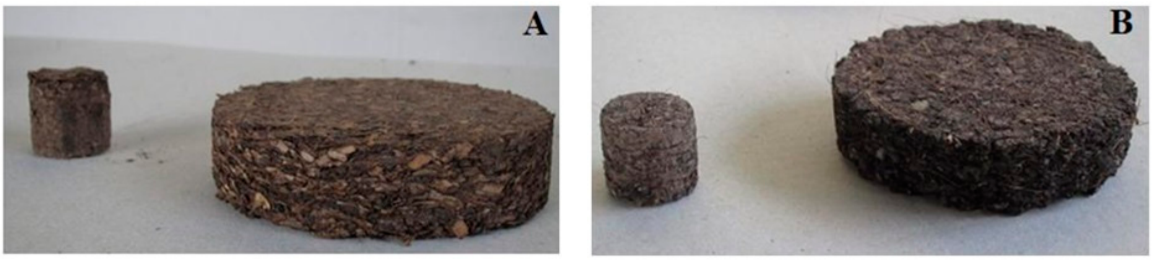


Figure 2. Densified samples of WCC—Wood Chips Compost (**A**) and SSFC—Slurry Solid Fraction Compost (**B**) obtained by applying pressures in the range of 5.0–7.0 MPa.

Compacts were ejected out of the chamber after the compression by means of the plunger. The length and the diameter of each compact was measured by a digital calliper, while a digital balance (accuracy 0.01 g) was used to measure the mass of densified material. The density of the samples was calculated from the ratio of mass to volume (obtained from length and diameter measurements).

2.5. Durability

Durability of the compacts was assessed according to the ASABE Standard S269.4 [36] requiring a rotating tumbling device with inner dimensions of 300 × 300 × 460 mm and external cover made of mash (12.5 mm). The axis of rotation is horizontal.

Durability of the investigated compacts is determined by tumbling 10 test samples for three minutes at 40 rpm. When overturned, compacts are attritioned due to impacts among themselves and against the inner sides of the container. After being overturned, compacts are sieved through a mesh of a diameter approaching 0.8 times the initial diameter of compacts. The durability is expressed as percentage determined as the ratio between the weights of the samples after and before the abovementioned operation, multiplied by 100. Durability measurements were repeated five times, reporting the average value.

2.6. Impedance Tube Device and Acoustical Test

According to ISO 10534-2 [38], sound absorption measurements were performed using the transfer function method. This method allows one to readily obtain measurements of normal incidence parameters using small samples that are easy to assemble and disassemble. Moreover, from knowing the normal incidence properties, it is also possible to apply some corrective formulas to obtain an approximate value of the random incidence absorption coefficient.

Two impedance tubes characterized by different diameters were utilized (Figure 3). The big one had an internal diameter of 100 mm, which corresponds to the low frequency range (100–1200 Hz), while the small one had an internal diameter of 28 mm, which corresponds to the high frequency range (1000–5000 Hz). Each tube had a length of 560 mm and mounted two microphones.

Figure 3. Impedance tubes device used in the experiment to evaluate the acoustic properties of SSFC and WCC in the high frequency range (1000–5000 Hz) and in the low frequency range (100–1200 Hz).

According to Berardi and Iannace [4], to reduce the possible gaps between the sample and the container, extreme care was taken to seal the border without creating any local compression between the tube and the compacts. In this way, the size of voids between the tested material and the sample holder was reduced so that the circumferential effect could be considered negligible. The effect of the irregularities in the samples, and in particular at the edges of them, was taken into consideration by repeating the tests with five different samples. For each sample, the measurements were repeated three times.

2.7. Data Analysis

Analysis of variance (ANOVA) was performed to compare variations in the density, durability, and absorption coefficient of compacts. The normality of data distribution and assumption of equal variance were checked using the Shapiro-Wilk and Levene test, respectively.

The statistical analyses were performed by SPSS software (IBM SPSS Statistics for Windows, Version 21.0., IBM Corp., Armonk, NY, USA).

3. Results

3.1. Particle Size Distribution

As shown in Figure 4A, the majority of the wood chips particles—63.3%—are included in the range 2.0–5.0 mm, while most of the SF particles—48.1%—are in the range 0.5–2.0 mm.

The particle size distribution of the composted materials (Figure 4B) resulted in a higher percentage of finer elements than in the raw materials. Thus the composting process affects the average dimension of the particles of the materials involved in the process. This is probably because of the moisture content reduction following the drying phase and the effects of biomass degradation that occur during the composting process.

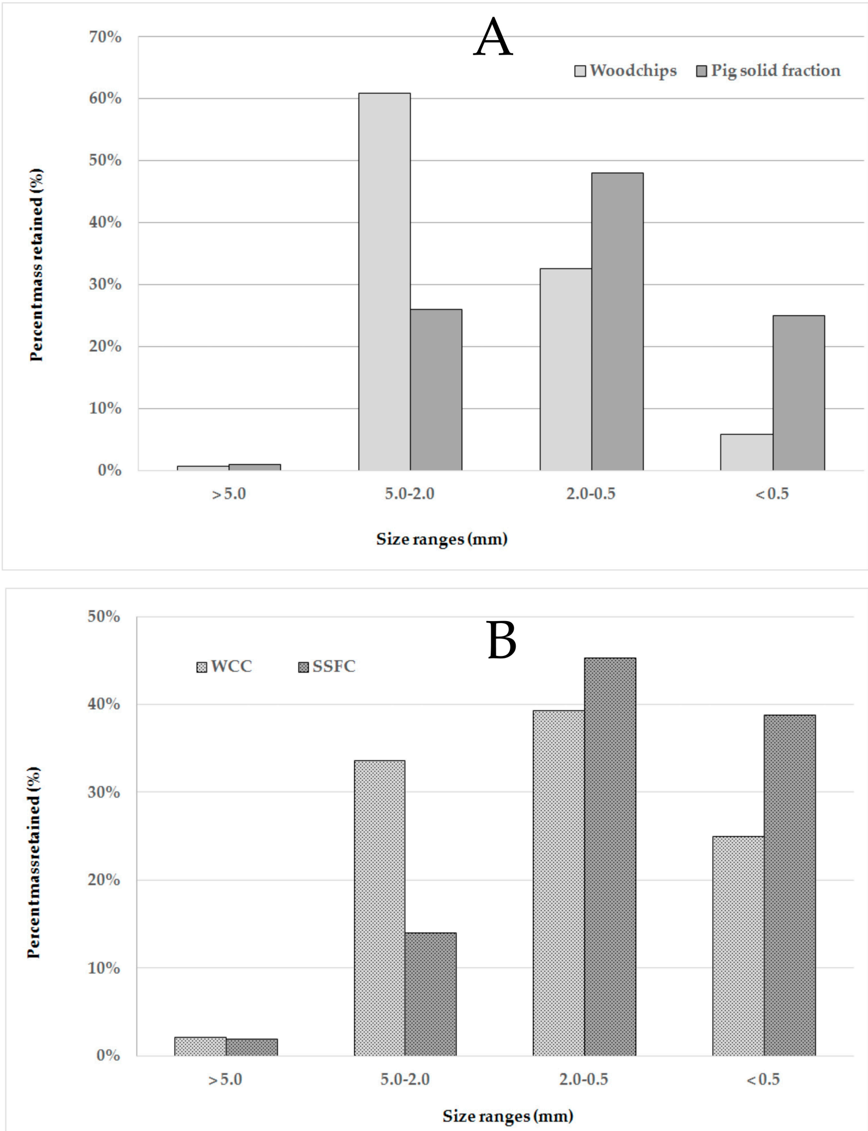


Figure 4. Particle size distribution of the raw materials—pig slurry solid fraction and wood chips—(**A**) and the final composts—SSFC and WCC—(**B**).

3.2. Compact Density

As stated by Ruiz Celma et al. [39], the bulk density of compacts should be taken into account when designing or adopting handling and storage procedures to preserve the integrity of densified materials.

No significant differences ($p > 0.05$) were found when comparing WCC and SSFC density values. The results from the experiment showed average bulk density values of 660 kg m^{-3} and 690 kg m^{-3} for WCC and SSFC, respectively (Figure 5).

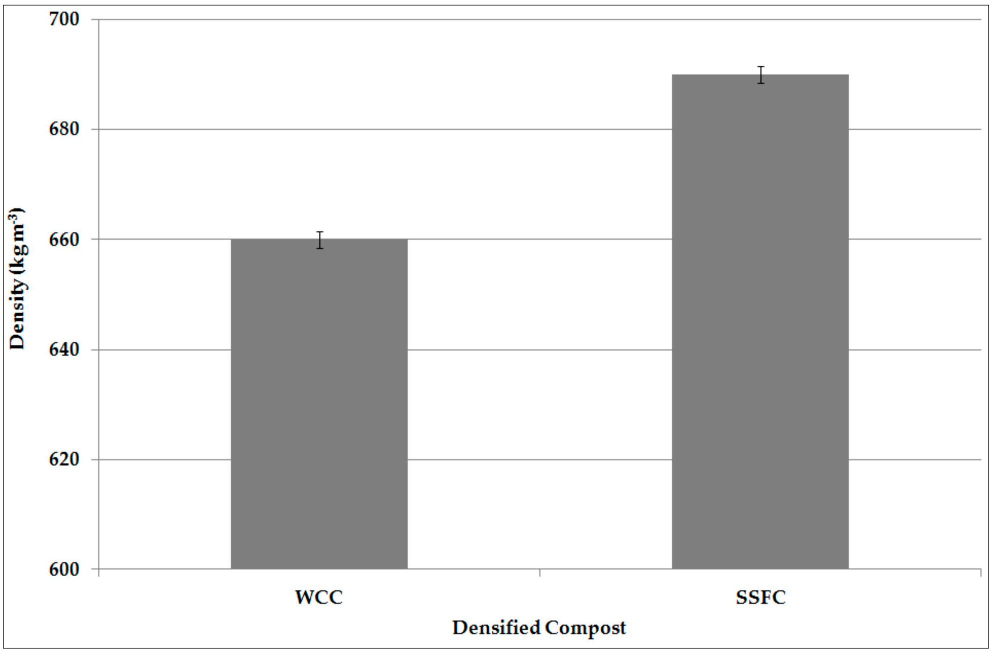


Figure 5. Average density values (kg m^{-3}) of WCC and SSFC obtained applying pressure in the range 5.0–7.0 MPa. Error bars indicate standard error (n = 5).

3.3. Durability

The durability test simulates the mechanical handling of densified materials, predicting the possible fines produced [21].

The results of the durability test performed with the manufactured compacts showed (Figure 6) that SSFC was characterized by durability values significantly ($p < 0.05$) higher than WCC. In particular, the average compact durability was 66.5% and 77.9% for WCC and SSFC, respectively.

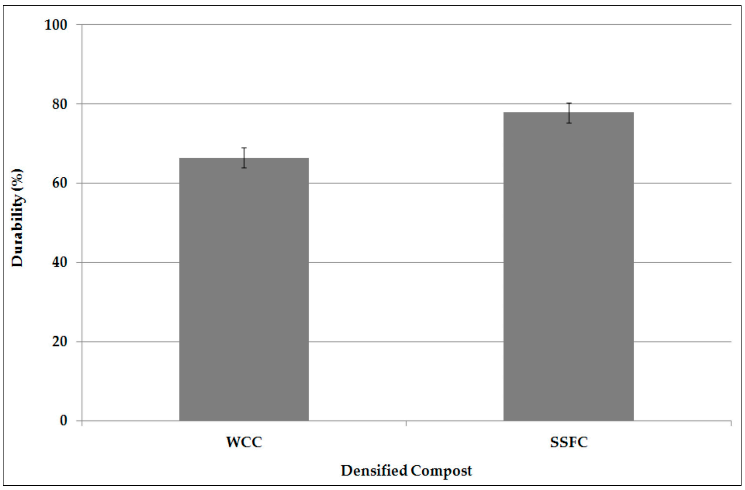


Figure 6. Average durability values (%) of WCC and SSFC obtained applying pressure in the range 5–7 MPa. Error bars indicate standard error (n = 5).

3.4. Measuring the Acoustic Absorption Coefficient

The sound absorption coefficient, α, is the ratio of the absorbed (and possibly transmitted) energy to the incident energy (possibly per unit time and surface) on any material surface. Typically, the sound absorption coefficient values range from 0 to 1: a value equal to 0 means zero absorption (total reflection), while a value equal to the unit means total absorption. The absorption coefficient is a function of frequency and was determined on 1/3 octave bands.

The two composts investigated, although being comparable as regards density, exhibited different acoustic properties in the medium range of frequencies (600–1250 Hz). In this range of frequencies, the average sound absorption coefficient value was equal to 0.42 and 0.56 for WCC and SSFC, respectively (Figure 7). This difference is probably due to the presence of wood chips, which reduced the porosity of the compacts and, consequently, the acoustic absorption. Comparing WCC and SSFC, no significant differences ($p > 0.05$) were found at low (<600 Hz) and high (>1250 Hz) frequencies.

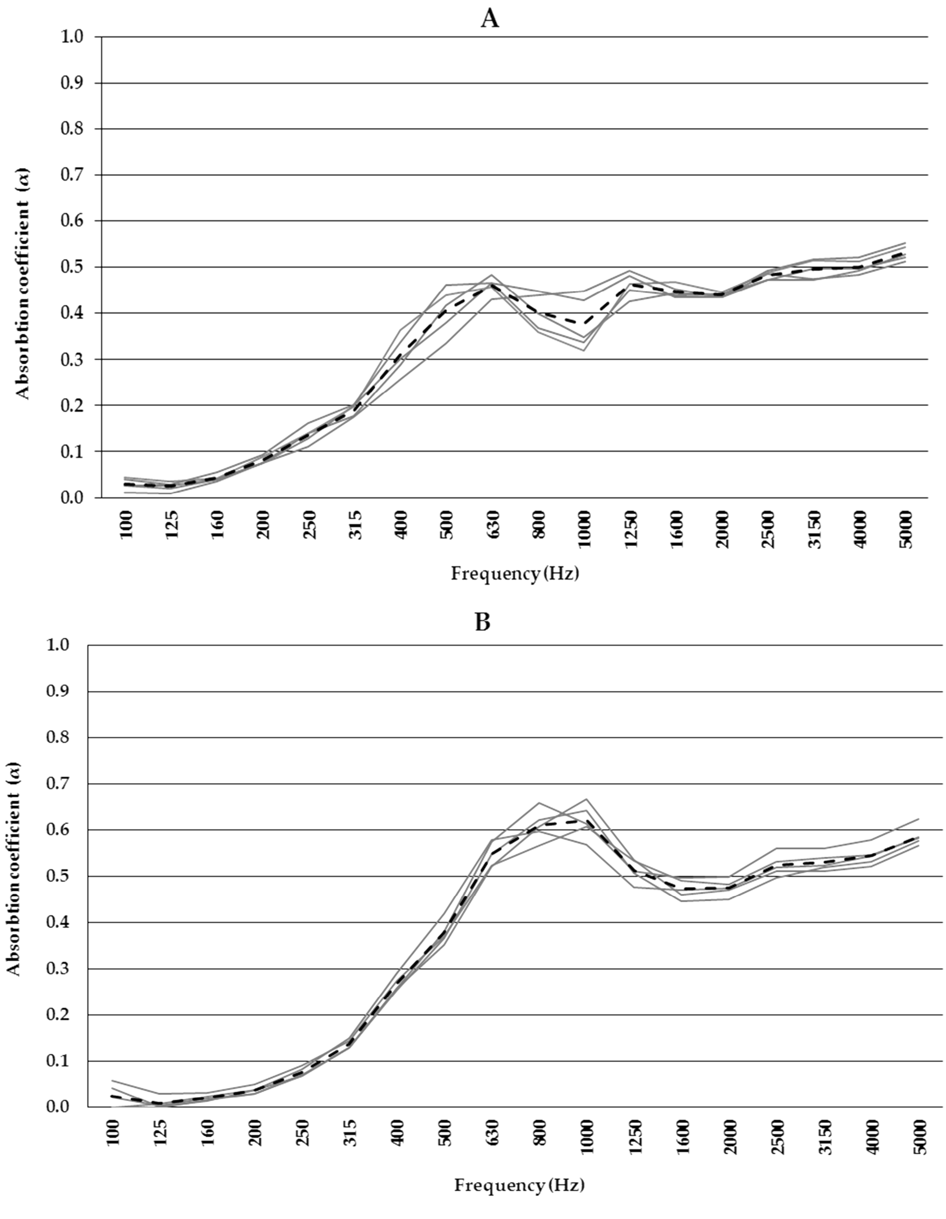


Figure 7. Absorption coefficient (α) of compacts made from WCC (**A**) and SSFC (**B**). The dashed line represents the average α values of five samples.

4. Discussion

Previous studies conducted by Kaliyan and Morey [21] highlighted that the ideal particle size distribution to produce good-quality compacts presents approximately half of the particles in the range 0.5–2.0 mm and at least 40% of the particles smaller than 0.5 mm. The studied feedstock did not fulfil these requirements, but nevertheless, in all composts investigated, particles in the 0.5–2.0 mm range were the most represented, while the percentage of particles finer than 0.5 mm ranged from 25.0% to 38.8%. The same study [21] reported that smaller particles help the densification process and the optimum quality of the compacts would generally come from a mixture of different particle sizes because the mixture of particles would create inter-particle bonding with nearly no inter-particle spaces.

Concerning the density of compacts, Berardi and Iannace [4], during the compaction of different natural fibres, reported lower values, ranging from 50 kg m^{-3} for light kenaf to 470 kg m^{-3} for cane (only wood). Such differences are probably due to the different amount of cellulose, hemicelluloses, and lignin in the basic materials.

Adapa et al. [40] established a durability scale for compacts: high when the computed value is above 80%, medium when the value is between 70% and 80%, and low when the value is below 70%. According to this scale, the SSFC compacts presented a medium-high durability, while those from WWC can be considered as being of a low durability, and thus less resistant to breakages during handling and transportation.

Many studies reported a relationship between particle size and durability [37,41]. The relationship is confirmed by this study where SSFC compacts—those with higher durability values—are characterized by a smaller particle size (Figure 4B). Smaller particles have a larger surface area of contact and make the formation of bonds/solid bridges during the densification process possible. In contrast, as confirmed by Kaliyan and Morey [21], larger particles, which characterized WCC (Figure 4B), have fissure points that cause cracks and fractures in the compacts.

The comparison between the sound absorption coefficient values obtained from natural fibres investigated by Berardi and Iannace [4] and those computed for WCC and SSFC is presented in Table 1.

Table 1. Comparison between sound absorption coefficient values of WCC and SSFC and those obtained by Berardi and Iannace [4] in their study focused on natural fibres.

Material		Thickness (m)	Frequency (Hz)				
			125	250	500	1000	2000
Kenaf	(Dense)	0.04	0.08	0.18	0.32	0.70	0.94
Wood	(Fibers)	0.06	0.20	0.40	0.50	0.65	0.91
Wood	(Mineralized)	0.03	0.05	0.10	0.10	0.20	0.40
Hemp		0.03	0.01	0.15	0.25	0.51	0.70
Coconut		0.05	0.10	0.20	0.34	0.67	0.79
Cork		0.03	0.01	0.02	0.10	0.30	0.86
Cane	(Mixed)	0.04	0.05	0.10	0.35	0.54	0.58
Cane	(Only wooden)	0.04	0.01	0.06	0.12	0.47	0.43
Cane	(Only bark)	0.04	0.10	0.12	0.38	0.64	0.62
Cardboard		0.10	0.10	0.27	0.48	0.54	0.66
Sheep wool		0.04	0.10	0.14	0.36	0.73	0.94
Sheep wool		0.06	0.15	0.28	0.66	0.95	0.94
SSFC		0.03	0.01	0.08	0.38	0.62	0.48
WCC		0.03	0.02	0.14	0.41	0.38	0.44

It can be seen from Table 1 that the investigated materials at a 125 Hz frequency have absorption properties which are similar to those of hemp and cane (only wooden). At a 250 Hz frequency, SSFC presents absorption coefficient value similar to those of wood (mineralized) and cane (only wooden), while the absorption coefficient value of WCC is similar to those of hemp and cane (only bark). At a 500 Hz frequency, both SSFC and WCC have absorption properties which are comparable to those of coconut, cane (mixed), cane (only bark), and sheep wool (0.04 m thickness). At a 1000 Hz frequency, SSFC and WCC are characterized by different absorption properties. In particular, SSFC has an absorption coefficient value similar to those of wood (fibres) and cane (only bark), while the absorption coefficient value of WCC is comparable to that of cork. Considering a 2000 Hz frequency, both SSFC and WCC present absorption properties which are similar to those of wood (mineralized) and cane (only wooden).

5. Conclusions

The current study investigated the physical and acoustical properties of compacts made from agricultural waste, the pig slurry solid fraction, composted itself (SSFC) and mixed with wood chips (WCC). The compacts were obtained without the addition of any binder.

The obtained results indicated that the addition of wood chips significantly affected the physical properties of the investigated compacts. Particle dimension of the composted materials played a key role in the quality of compacts; the smaller the particles, the higher the quality of the compacts.

Both materials presented an absorption coefficient comparable to those from other natural materials, providing an alternative environmentally sustainable raw material for manufacturing sound insulation systems. Future developments of the study are to continue to explore in a reverberation room the acoustic properties of panels made from composted pig slurry solid fraction.

Author Contributions: Niccolò Pampuro, Christian Preti, and Eugenio Cavallo conceived the study and designed the experiments; Niccolò Pampuro and Christian Preti performed the experiments and analyzed the data; Niccolò Pampuro, Christian Preti, and Eugenio Cavallo drafted the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Arenas, J.P.; Crocker, M.J. Recent trends in porous sound absorbing materials for noise control. *J. Sound Vib.* **2010**, *44*, 12–17.
2. Glé, P.; Gourdon, E.; Arnaud, L. Acoustical properties of materials made of vegetable particles with several scales of porosity. *Appl. Acoust.* **2011**, *72*, 249–259. [CrossRef]
3. Oldham, D.J.; Egan, C.A.; Cookson, R.D. Sustainable acoustic absorbers from the biomass. *Appl. Acoust.* **2011**, *72*, 350–353. [CrossRef]
4. Berardi, U.; Iannace, G. Acoustic characterization of natural fibers for sound absorption applications. *Build. Environ.* **2015**, *94*, 840–852. [CrossRef]
5. Fouladi, M.H.; Nor, M.J.M.; Ayub, M.; Leman, Z.A. Utilization of coir fiber in multilayer acoustic absorption pane. *Appl. Acoust.* **2010**, *71*, 241–249. [CrossRef]
6. Bansod, P.V.; Mohanty, A.R. Inverse acoustical characterization of natural jute sound absorbing material by the particle swarm optimization method. *Appl. Acoust.* **2016**, *112*, 41–52. [CrossRef]
7. Gori, P.; Guattari, C.; Asdrubali, F.; de Lieto Vollaro, R.; Monti, A.; Ramaccia, D.; Bilotti, F.; Toscano, A. Sustainable Acoustic Metasurfaces for Sound Control. *Sustainability* **2016**, *8*, 107. [CrossRef]
8. Pampuro, N.; Facello, A.; Cavallo, E. Pressure and specific energy requirements for densification of compost derived from swine solid fraction. *Span. J. Agric. Res.* **2013**, *11*, 678–684. [CrossRef]
9. United States International Trade Commission. Pork and Swine. Industry & Trade Summary. 2014; Publication ITS-11. Available online: http://www.usitc.gov/publications/332/pork_and_swine_summary_its_11.pdf (accessed on 20 September 2017).
10. Segat, J.C.; Alves, P.R.L.; Baretta, D.; Cardoso, E.J.B.N. Ecotoxicological evaluation of swine manure disposal on tropical soils in Brazil. *Ecotoxicol. Environ. Saf.* **2015**, *122*, 91–97. [CrossRef] [PubMed]
11. Marquer, P.; Rabade, T.; Forti, R. Pig Farming Sector—Statistical Portrait 2014. Statistics in Focus. ISSN: 2314-9647. Available online: http://ec.europa.eu/eurostat/statistics-explained/index.php/Pig_farming_sector-statistical_portrait_2014 (accessed on 21 September 2017).
12. Chen, K.; Wang, J. Hog farming in transition: The case of China. In *Asian Livestock Challenges Opportunities and Responses, Proceedings of the International Policy Forum, Bangkok, Thailand, 16–17 August 2012*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2012.

13. Italian National Statistical Institute (ISTAT). *Farm Structure Survey—Year 2013*; ISTAT: Rome, Italy, 2015; Available online: http://censimentoagricoltura.istat.it (accessed on 20 September 2017).
14. Pampuro, N.; Dinuccio, E.; Balsari, P.; Cavallo, E. Gaseous emissions and nutrient dynamics during composting of swine solid fraction for pellet production. *Appl. Math. Sci.* **2014**, *8*, 6459–6468. [CrossRef]
15. Miner, J.R. Alternatives to minimize the environmental impact of large swine production units. *J. Anim. Sci.* **1999**, *77*, 440–444. [CrossRef] [PubMed]
16. Hirel, B.; Tétu, T.; Lea, P.J.; Dubois, F. Improving Nitrogen Use Efficiency in Crops for Sustainable Agriculture. *Sustainability* **2011**, *3*, 1452–1485. [CrossRef]
17. Troy, S.M.; Lawlor, P.G.; O'Flynn, C.J.; Healy, M.G. Impact of biochar addition to soil on greenhouse gas emissions following pig manure application. *Soil Biol. Biochem.* **2013**, *60*, 173–181. [CrossRef]
18. Vazquez, M.A.; De La Varga, D.; Plana, R.; Soto, M. Integrating liquid fraction of pig manure in the composting process for nutrient recovery and water re-use. *J. Clean. Prod.* **2015**, *104*, 80–89. [CrossRef]
19. Fangueiro, D.; Senbayran, M.; Trindade, H.; Chadwick, D. Cattle slurry treatment by screw press separation and chemically enhanced settling: Effect on greenhouse gas emissions after land spreading and grass yield. *Bioresour. Technol.* **2008**, *99*, 7132–7142. [CrossRef] [PubMed]
20. Hanserud, O.S.; Lyng, K.-A.; Vries, J.W.D.; Øgaard, A.F.; Brattebø, H. Redistributing Phosphorus in Animal Manure from a Livestock-Intensive Region to an Arable Region: Exploration of Environmental Consequences. *Sustainability* **2017**, *9*, 595. [CrossRef]
21. Kaliyan, N.; Vance Morey, R. Factors affecting strength and durability of densified biomass products. *Biomass Bioenergy* **2009**, *33*, 337–359. [CrossRef]
22. Alemi, H.; Kianmehr, M.H.; Borghaee, A.M. Effect of pellet processing of fertilizer on slow-release nitrogen in soil. *Asian J. Plant Sci.* **2010**, *9*, 74–80. [CrossRef]
23. Pampuro, N.; Dinuccio, E.; Balsari, P.; Cavallo, E. Evaluation of two composting strategies for making pig slurry solid fraction suitable for pelletizing. *Atmos. Pollut. Res.* **2016**, *7*, 288–293. [CrossRef]
24. Bernal, M.P.; Alburquerque, J.A.; Moral, R. Composting of animal manures and chemical criteria for compost maturity assessment: A review. *Bioresour. Technol.* **2009**, *100*, 5444–5453. [CrossRef] [PubMed]
25. Zafari, A.; Kianmehr, M.H. Effect of temperature, pressure and moisture content on durability of cattle manure pellet in open-end die method. *J. Agric. Sci.* **2012**, *5*, 203–208. [CrossRef]
26. Jiang, L.; Liang, J.; Yuan, X.; Li, H.; Li, C.; Xiao, Z.; Huang, H.; Wang, H.; Zeng, G. Co-pelletization of sewage sludge and biomass: The density and hardness of pellet. *Bioresour. Technol.* **2014**, *166*, 435–443. [CrossRef] [PubMed]
27. Carone, M.T.; Pantaleo, A.; Pellerano, A. Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of *Olea europea* L. *Biomass Bioenergy* **2011**, *35*, 402–410. [CrossRef]
28. Castellano, J.M.; Gomez, M.; Fernandez, M.; Esteban, L.S.; Carrasco, J.E. Study on the effects of raw materials composition and pelletization conditions on the quality and properties of pellets obtained from different woody and non woody biomasses. *Fuel* **2015**, *139*, 629–636. [CrossRef]
29. Bernhart, M.; Fasina, O.O. Moisture effect on the storage, handling and flow properties of poultry litter. *Waste Manag.* **2009**, *29*, 1392–1398. [CrossRef] [PubMed]
30. Adapa, P.; Tabil, L.; Schoenau, G. Compaction characteristics of barley, canola, oat and wheat straw. *Biosyst. Eng.* **2009**, *204*, 335–344. [CrossRef]
31. American Society of Agricultural and Biological Engineers (ASABE). ASAE S358.2—Moisture Measurement—Forages. In *American Society of Agricultural and Biological Engineers Standards*; ASABE: St. Joseph, MI, USA, 2006; p. 608.
32. Li, Y.; Liu, H. High-pressure densification of wood residues to form an upgraded fuel. *Biomass Bioenergy* **2000**, *19*, 177–186. [CrossRef]
33. Mani, S.; Tabil, L.G.; Sokhansanj, S. Specific energy requirement for compacting corn stover. *Bioresour. Technol.* **2006**, *30*, 648–654. [CrossRef] [PubMed]
34. Obernberger, I.; Thek, G. Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. *Biomass Bioenergy* **2004**, *27*, 653–669. [CrossRef]
35. Allaire, S.E.; Parent, L.E. Physical properties of granular organic-based fertilizers, Part 1: Static properties. *Biosyst. Eng.* **2004**, *87*, 79–87. [CrossRef]

36. American Society of Agricultural and Biological Engineers (ASABE). ASAE S269.4—Cubes, pellets, and crumbles—Definitions and methods for determining density, durability, and moisture content. In *American Society of Agricultural and Biological Engineers Standards*; ASABE: St. Joseph, MI, USA, 2006; p. 608.
37. Zafari, A.; Kianmehr, M.H. Application of densification process in organic waste management. *Waste Manag. Res.* **2013**, *31*, 684–691. [CrossRef] [PubMed]
38. International Organization for Standardization. *ISO 10534-2*; Acoustics. Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes—Part 2: Transfer-Function Method; ISO: Geneva, Switzerland, 1998.
39. Ruiz Celma, A.; Cuadros, F.; Lopez-Rodriguez, F. Characterization of pellets from industrial tomato residues. *Food Bioprod. Process.* **2012**, *90*, 700–706. [CrossRef]
40. Adapa, P.K.; Schoenau, G.J.; Tabil, L.G.; Sokhansanj, S.; Crear, B.J. *Pelleting of Fractionated Alfalfa Products*; ASABE Pap. No. 036069; ASABE: St. Joseph, MI, USA, 2003.
41. Zhou, B.; Ileleji, K.E.; Ejeta, G. Physical property relationships of bulk corn stover particles. *Am. Soc. Agric. Biol. Eng.* **2008**, *51*, 581–590. [CrossRef]