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Effects of pelletizing pressure and the addition of woody bulking agents on the physical and mechanical properties of pellets made from composted pig solid fraction

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ABSTRACT

This study reports the effects of the addition of different woody bulking agents and pelletizing pressure on the final bulk density, durability and compression resistance of pellets manufactured from composted pig solid fraction. Two pressure levels (3.5 and 5.0 MPa) and three different types of compost (SFC - pig solid fraction, BC - pig solid fraction mixed with woody biochar, and WC - pig solid fraction mixed with wood chips) were investigated. The study shows that the different pressures adopted - in the range of 3.5 to 5.0 MPa - and the addition of woody bulking agents did not significantly affect the physical and mechanical properties of the pellets. However, according to the results of the study, the particle dimension of the woody bulking agents plays a key role in the mechanical properties of the pellets; the smaller the particles, the higher the pellet mechanical properties. The pelletizing process increased the bulk density of the investigated composts, and pellet durability was always high (>80%). Nevertheless, when comparing the two bulking agents, the best results in terms of final quality were observed for pellets made from pig solid fraction mixed with woody biochar.

1. Introduction

Intensive pig breeding and the increased size of animal farms in European countries have resulted in the production of large quantities of liquid manure (slurry) in specific geographic areas. With reference to Italy, livestock farming activity is concentrated in the northern regions, such as Piedmont, Lombardy, Veneto and Emilia Romagna, where 86.3% of the total national assets of pigs are bred [1]. In this context, slurry storage followed by land application is the mostly commonly adopted management technique because it is technically simple with reduced costs compared with other available solutions [2]. However, the excessive application of pig manure, especially in areas classified as Nitrate Vulnerable Zones (NVZs) in accordance with European Regulation (91/676/EEC), causes nitrogen surpluses that lead to ammonia emissions [3,4] and nitrate water pollution in both surface and ground waters [5,6]. For this reason, the Nitrates Directive (91/676/EEC), in an effort to protect the environment, introduced a 170 kg ha^{-1} y^{-1} spread rate limit for animal manure nitrogen (N) in the NVZs. Considering that the agricultural surface available for land spreading is limited, the slurry has to be transported to fields at greater distances, increasing the transport costs.

Several methods of slurry processing have been developed for various purposes, including environment protection, ease in handling, energy production or soil amelioration. One of the most common processes is the mechanical separation of the slurry. The results of the process are a liquid fraction (LF) with a low dry matter content and a minor solid fraction (SF) that contains most of the nutrients [7].

SF can be easily stored and used as a soil amendment on farms. However, the low bulk density (<500 kg m^{-3}) [8] makes its transport expensive from production sites to areas where it could be effectively utilized as a value-added soil fertilizer. To increase the agronomical use of SF on larger areas and off-farm as a fertilizer, it is necessary to increase its density, and pelletizing is the most common process to achieve this goal. SF pelletizing has been previously investigated, and the results of the study showed that it is possible to increase the bulk density from an initial value of <200 kg m^{-3} to a final value >1000 kg m^{-3} [9]. Pelletizing is recognized as a process that could reduce the costs of transportation, handling and storage of solid manure [10].

The moisture content of SF is the most important limiting factor for pelletizing; a moisture content higher than 75–80% makes SF unsuitable for the process. According to Alemi et al. [11], the optimal moisture content for SF pelletizing varies between 20% and 40%. Previous studies [2,12] noted that a simple and affordable method to reduce the moisture content of SF is composting in windrows. This process produces the

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heat required to dry the material, making SF suitable for pelletizing. The addition of lignocellulosic bulking agents, such as wood-chips and sawdust, to the SF improves the effectiveness of reducing the moisture content in the composting process. The addition of these carbon (C)-rich by-products can also enhance the optimization of the substrate properties, such as C/N ratio, air space and pH, positively affecting the composting process [13,14].

The initial characteristics of the composting mixture significantly affect the final physical and mechanical properties of the produced pellet. In this context, Karamchandani et al. [15] and Castellano et al. [16] considered pellet density and durability as two important physical properties of the produced pellets. Ishii and Furuichi [17] reviewed the studies on the production of solid fuel from agricultural residues, highlighting the factors affecting the strength and durability of densified biomass products. Stelte et al. [18,19] evaluated the fundamental forces keeping the biomass of the pellet together to improve the strength and durability of different biomass resources. Moreover, as reported by Young et al. [20], densified products must meet consumer requirements and market standards and must withstand the rigors of handling and transportation. The same authors [20] divided the forces that cause damage (i.e., fragmentation and abrasion of pellets) on pellets (or any densified product) during handling, transportation, and storage into three general classes: compression, impact and shear. Compression forces result in a crushing action. Impact forces result in shattering the surface of the pellet and along any natural cleavage planes of the pellet, and shearing forces result in the abrasion of pellet edges and surfaces.

Most of the above-mentioned studies analysed the variables affecting the physical and mechanical final quality of lignocellulosic pellets for energy production. On the other hand, few studies have investigated the physical and mechanical properties of pellets from biomasses for agronomical uses as fertilizer. Centrifugal spreaders are the most common fertilizer application devices [21,22], and fertilizer distribution patterns are largely affected by material properties [23,24].

This study addresses the effects of different woody bulking agents and pelletizing pressure on the mechanical properties of pellets obtained from composted pig solid fraction. The study focused on pellet density, durability and compression resistance, being the properties that, according to previous studies [25–27], mostly affect pellet quality during handling, transportation and storage.

2. Materials and methods

2.1. Feedstock and pellet preparation

This study was carried out on pellets obtained from three different batches of composted pig SF. The first batch was a mixture of SF and 10% biochar obtained from the gasification of wood residues (BC), the second batch was a mixture of SF and 20% wood chips (WC) obtained from processing residues from park maintenance, and the third batch was SF without the addition of any bulking agent (SFC). Table 1 presents additional information on the 3 different mixtures.

Following literature recommendations [16,28,29], the wood chips were ground in a hammer mill with a screen size of 4 mm before undergoing composting.

Table 1
Composition of the 3 investigated compost windrows: SFC - pig solid fraction from a screw press separator; BC - pig solid fraction from a decanting centrifuge mixed with biochar; and WC - pig solid fraction from a decanting centrifuge mixed with wood chips.

Compost ID	Pig solid fraction		Bulking agent	
	Separator type	Quantity (kg)	Typology	Quantity (kg)
SFC	Screw press	8000	None	
BC	Decanting centrifuge	8000	Woody biochar	800
WC	Decanting centrifuge	8000	Wood chips	1600

Table 2
Pellet compositions and the applied process pressure included in the experiment.

Pellet ID	Compost type	Applied pressure (MPa)
SFC3.5	Pig solid fraction	3.5
SFC5.0	Pig solid fraction	5.0
WC3.5	Pig solid fraction + wood chip	3.5
WC5.0	Pig solid fraction + wood chip	5.0
BC3.5	Pig solid fraction + woody biochar	3.5
BC5.0	Pig solid fraction + woody biochar	5.0

At composting windrow initiation, organic materials were mixed to obtain a theoretical C/N ratio equal to 30 to optimize the composting process. This also minimized the negative effects of ammonia volatilization (C/N < 20) on composting performance and nitrogen loss [13].

The experimental composting process was observed for 150 days. At the beginning of the composting trial, the initial moisture content of the three investigated mixtures was 72.8%, 65.6% and 66.2% for SFC, WC and BC, respectively. To reduce the moisture content of the organic mixtures, making the materials suitable for pelletizing, windrows were composted with a turned strategy [2,12]. At the end of the composting process, the moisture content of SFC, BC and WC was 34.6%, 31.9% and 33.1%, respectively, and suitable for pelletizing [11]. However, many studies indicated that the production of high-quality pellets is possible only if the moisture content of the particulate materials is between 8 and 12% [30–33]. For this reason, the moisture content of the samples (10 kg for each compost type) was further reduced to 10% by drying in an oven at 50 °C [30]. The samples were subsequently stored in plastic bags and kept in a cold room at 4 °C for a minimum of 72 h [34].

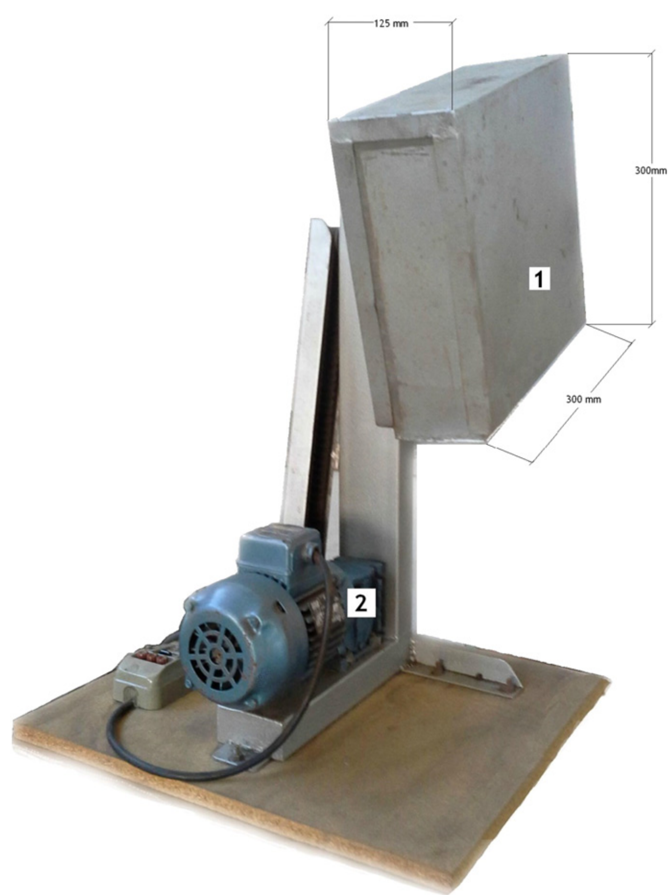

Fig. 1. Apparatus for the durability testing of the pellets (1: tumbling device; 2: electric motor) according to ASAE S269.4 (2007).