

## Article

# Pelletization of Compost from Different Mixtures with the Addition of Exhausted Extinguishing Powders

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**Abstract:** Today, in Europe, there is still no industrial process to favor the distribution of exhausted extinguishing powders (EEP). Extinguishing powders (EP) are the most common extinguishing agents and are composed of very fine particles (90% is less than 0.250 mm, with at least 40% less than 0.040 mm). Illegal processes of disposal or reuse of EEP are currently taking place throughout Europe. In fact, often maintenance companies illegally dispose of and/or reuse spent extinguishing powders with enormous environmental damage. This is partly due to prohibitive costs, of which a large part is due to transport. The demand for fertilizers is increasing; phosphorus is a key raw material, and a possible solution could be mixing it with compost and other organic biomass and agricultural residues. In general, both compost and EEP powder have a low density and can take up a great deal of storage volume, so thickening this compost would help reduce the required storage capacity. Furthermore, a danger represented by the handling of compost and EEP is the dispersion of dust that can potentially carry pathogens and toxic organic substances which, if inhaled, could cause respiratory problems during distribution and handling. The aim of this study was to produce compost pellets using exhausted EP in different formulations and to observe the quality of different compost pellet products with respect to different factors affecting handling, storage, and distribution. For the first time, the pelletizing of EEP with compost was performed successfully using five different blends, each with different properties. The results showed that qualitative variables could be controlled to optimize production efficiency and improve the quality of the finished product depending on the type of distribution, handling, and storage. The five compost mixes could be applied in different agricultural crops as fertilizer. Furthermore, this use of exhausted EP allows for positive ecological and economic effects, avoiding the disposal costs required by specialized companies.

**Keywords:** agricultural fertilizer; circular economy; pellet compost; durability; wood; *Jatropha curcas*



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## 1. Introduction

### 1.1. The Use of Exhausted Extinguishing Powders (EEP) in Compost

Extinguishing powders (EP) are the most common extinguishing agents and are composed of 40 to 50% mono-ammonium phosphate (MAP), ammonium sulfate, coloring additives, and fluxing agents. Once freed from additives applied to guarantee flowability and water-repellent features, this material can be used in agriculture as, for example, fertilizer [1]. The main sources of raw materials, such as mono-ammonium phosphate, are from outside Europe, and these raw materials are also used in agriculture due to their specific nature of releasing nitrogen and phosphorus. Monoammonium phosphate ( $\text{NH}_4\text{H}_2\text{PO}_4$ ) is the most widely used solid phosphate fertilizer in agriculture as it releases a large amount of nitrogen and phosphorus essential for plant nutrition [1,2]. In fact, the EP is a chemical

salt that dissolves from nitrogen in the form of ammonia and phosphorus, which, by pedogenesis through the liquid phase, are absorbed by plants. The transformation process of the raw material in extinguishing powders involves the micro-grinding (pulverization) of phosphate and sulfate and the addition of additives to ensure flowability during use. After its whole service life has expired (36 months, under current legislation), the problem arises of how to manage the exhausted extinguishing powders (EEP), allowing the recovery of a high-value, non-renewable raw material (phosphate) in an almost pure form [1]. The European Sustainable Phosphorus Platform (ESPP) has estimated that, at the EU level, 36 million kilograms should be the annual quantity of exhausted extinguishing powders that are treated and disposed of [1]; however, it was only in 2019 that the European Union authorized the European market for recycled fertilizers with the EU Fertilising Products Regulation (FPR). For this reason, evaluating the annual volume production of EEP, their recovery could be a valid substitute for fertilizers from primary raw materials. One of the most problematic aspects of utilizing this exhausted EP is its high volatility that does not permit a correct distribution in the field, sometimes generating problems regarding pollution control [2]. Some farms distribute the extinguishing powders directly onto the field via a manure spreader [2] but their efficiency is not guaranteed and can cause environmental problems because the microscopic dimensions of particles, with a variable range between 0.250 and 0.040 mm, can generate dust emissions, increasing the risk of respiratory symptoms [3]. As reported in several studies [1,4], the EEP is highly volatile, which very often complicates storage and transport operations; it could be necessary to compact or incorporate the EEP together with other matrices into a single solid and resistant agglomerate to make management much easier. One possible solution is mixture with compost and other organic biomasses and agricultural residues. Composting is a favorable solution for the disposal of organic waste, above all in the management of urban waste. It is an aerobic process that helps to reduce the volume of waste, kill the pathogens that may be present in the waste and, most importantly, reduces the generation of leachate during decomposition [5]. Compost can contain decomposed plants and animal manure with various types and quantities of nutrients necessary for the growth of plants and, therefore, has great potential in agricultural production. The compost, once produced, can be used as a soil improver, typically destined for agronomic uses or for horticulture. Its use, with the addition of organic matter, improves the soil structure and the availability of nutritional elements (phosphorus and nitrogen compounds) [6]. Compost generally has a low density and can take up a great deal of storage volume, so its densification would help to reduce the required storage capacity [6,7]. In addition, a danger represented by handling compost is the dispersion of dust, which can potentially carry pathogens and toxic organic substances [7,8] that, if inhaled, could cause respiratory problems similar to EEP distribution. Therefore, compost densification is necessary to overcome these risks, where pelletizing represents one example of a densification process.

### *1.2. Pelletization as a Compost Densification Process*

Pelletization is the process of compressing biomass by mechanical pressure [8,9]. The purposes of compost pelletizing are to produce pellets that are the densified form of compost or other mixtures, simplifying handling, transport, and storage operations. One of the other benefits of compost pelletizing is the ability of adding chemical materials to increase the quality. Compaction into pellets, on the one hand, enhances the uniformity and fertilizing/amending properties and, on the other hand, increases the distribution precision with spreaders, curtailing the emission of dust or pollution into the environment. The pelletization process is a complex interaction between particles, their constituents, and forces. Animal feed and energy pellet production have long been practiced and have been extensively studied, but rarely for compost [5]. Pelletizing of compost is an emerging area that requires an in-depth understanding. Mani et al. [10] evaluated the compaction mechanism of straws, stover and switchgrass using different compaction models. Zafari et al. [11] investigated the compost pellet densification process, concluding

that all independent variables, such as particle size, significantly affect durability. In this context, Kit Wayne Chew et al. [12] assessed the effects of moisture content and waste additives of milk powder on the quality of compost pellets, indicating that adding lactose-containing powdered dairy additives is highly beneficial in improving the rate of pellet production and the properties of the pellets [13]. The knowledge of the basic compaction properties of particles of different biomass species, sizes, shapes, and chemical compositions represents the first step to optimize the densification processes as reported by Tabi et al. [14]. It is also important to understand the effects of various process variables on densification and pellet life. Hence, the parameters that can be changed to affect the strength and size (length) of the pellet are the particle size, moisture content, and the type and amount of binding agent. However, studies on the physical properties of compost pellets manufactured from exhausted EP as the added component have not yet been carried out. Therefore, in this work, the authors compared the physical and chemical characteristics of five pelleted composts manufactured with exhausted EP and other organic materials with different formulations to determine which mixture constitutes the best way to apply exhausted EP in agricultural applications. The aim of this study was (i) to produce compost pellets using exhausted EP in different formulations and (ii) to observe the quality of different compost pellet products with respect to several factors that affect handling, storage, and distribution.

## 2. Materials and Methods

This study used different residues of agricultural production; as well as being manufactured from compost, Table 1 shows the chemical characteristics of the compost used and enriched with the exhausted EP. The compost pellets, in addition to being enriched with EEP, were produced with the addition of woody biomass and extruded seed cake of *Jatropha curcas* L. The seed of this plant is suitable for the production of biofuels and the residual seed cake produced from mechanical pressing can be used as fertilizer. In recent years, several studies [15,16] have tested this residue as a source of organic nutrients to further nurture the growth of crops; with this in mind, this source of organic matter was considered in this study as a co-formulate. In some mixtures, corn starch was added to favor pellet durability and hardness [17]. The extinguishing EP used in this experimental test was ABC-E supplied by CADI s.r.l. as part of the FIRE COMPOST project.

### 2.1. Pellet Processing

For this study, dried municipal solid waste (MSW) compost was used in accordance with legal requirements. The compost pellet was produced at the laboratory of the Department of AGRARIA using a rotary roller pelletizing machine (Green Technik, 11 kW petrol engine—Figure 1) mounted on a die of 6 mm diameter holes. The pellet machine used a H-24 rotating flat die, with 24 mm long channels; the channels were equipped with a pre-compression chamber thanks to a 60° angle flaring present at the channel entrance. The pelletizing process adopted in this work is shown as a block diagram in Figure 2.

First of all, the compost was sieved to obtain favorably sized particles using, in sequence, three different size meshes (8, 4 and 2 mm). The produced pellets were cooled at ambient temperature without using a dryer and their MC (Moisture Content) reached approximately 12% ( $\pm 1.0$ ) after approximately one day. In fact, as reported by Protic [18], the cooling phase is essential to improve the mechanical life and reduce the moisture content in the pellets.

Five different mixtures were devised containing a different percentage of the matrices. The dissimilar concentration, expressed as a weight percentage, was derived from a careful behavioral examination of the unadulterated matrices. The only limit imposed was that the exhausted EP should not exceed 10% of the total mass; this limit was defined as an excessive content of EEP that, according to some authors [1,19], could cause phytotoxicity. The prepared content for each mixture was:

- Mixture 1: 50% compost + 30% *Jatropha* + 10% EEP + 10% corn starch;

- Mixture 2: 50% compost + 40% Jatropha + 10% EEP;
- Mixture 3: 50% compost + 20% Jatropha + 10% EEP + 10% corn starch + 10% wood chips;
- Mixture 4: 50% compost + 40% wood chips + 10% EEP;
- Mixture 5: 40% compost + 50% wood chips + 10% EEP.

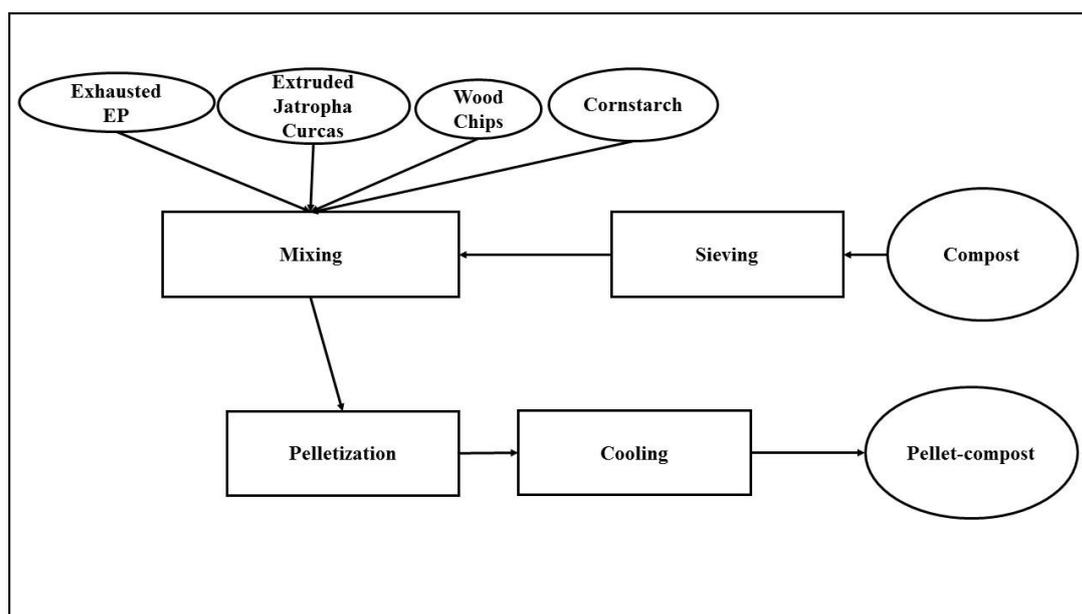
For each mixture, a total of six kilograms of pellet were produced on average.

**Table 1.** Chemical characteristics of compost enriched with EEP and used in pelletizing.

Parameter	Value
Moisture content (%)	25 ± 0.8
pH (25 °C)	7.5 ± 0.2
EC/dS·m <sup>-1</sup>	4.2 ± 1
Total organic carbon (%)	27 ± 0.8
Total nitrogen (%)	2.85 ± 1.2
Organic nitrogen (% total)	85 ± 0.5
C/N	9.47 ± 0.6
C humic and fulvic (%)	10.2 ± 2
Cr <sub>VI</sub> (mg Kg <sup>-1</sup> )	<0.1
Cd (mg Kg <sup>-1</sup> )	0.51
Cu (mg Kg <sup>-1</sup> )	68 ± 10
Hg (mg Kg <sup>-1</sup> )	<0.1
Ni (mg Kg <sup>-1</sup> )	15 ± 2
Pb (mg Kg <sup>-1</sup> )	20 ± 1
Zn (mg Kg <sup>-1</sup> )	235 ± 41
<i>Salmonella</i> spp.	not found
<i>Escherichia coli</i> (CFU g <sup>-1</sup> )	<100 UFC



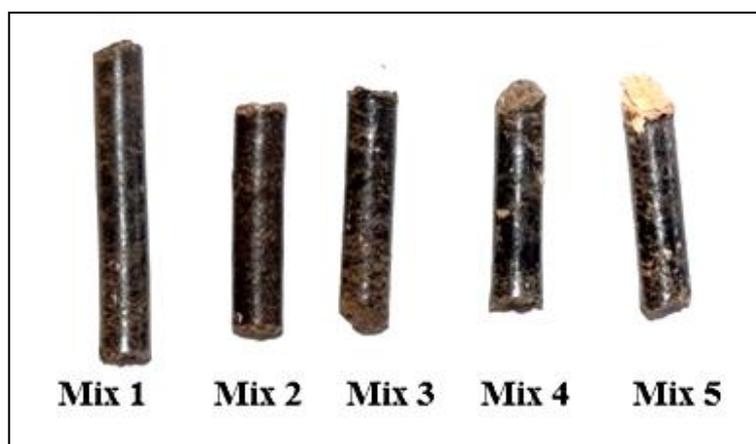
**Figure 1.** Green Technik PTM 50 pellet machine.



**Figure 2.** Schematic block diagram of process used for pelletization of compost.

## 2.2. Qualitative Analyses

In the same laboratory, specific qualitative analyzes of the five blends of pellets produced were carried out (Figure 3). Fifty individual pellets were selected from each mixture, for a total of 250 samples. All specimens were selected and handled with great care in order to ensure a certain homogeneity of the samples. Similar to other studies [8,11,13,20], the selected samples were subjected to laboratory tests, such as measurements of weight, diameter, length, bulk density, water content and dry matter content.



**Figure 3.** Pellet samples of some mixtures ready for experimental tests.

For each single sample, the weight was measured using a Nimbus<sup>®</sup> analytical balance present in the laboratory, by the accuracy of this scale up to 0.0001 g. The diameter and length of each pellet were measured with an ABSOLUTE Digimatic ID-C Mitutoyo<sup>®</sup> digital comparator (acc. 0.003 mm) equipped with a granite support. The bulk density of the samples of the different mixtures obtained was determined using a volumetric cylinder. As has been shown in several studies [8,21], bulk compost pellets were poured into a cylindrical container 115 mm in diameter and 112 mm high with a total volume of 0.001162 m<sup>3</sup>. The different pellet samples were poured into the cylinder up to a height of the top edge of the container and the excess material on the top surface was leveled. The elemental composition, carbon content (C), hydrogen content (H), and nitrogen content (N)

were measured on dried samples, with a Costech ECS 4010 CHNSO elemental analyzer, according to the EN ISO 16948:2015.

The oxygen content (O) was calculated from elemental composition as  $O = 100 - C - H - N - \text{ash}$ . Ash content was measured by a Lenton EF11/8B muffle furnace, according to the EN ISO 18122:2015.

The water content was calculated following the weight loss of the sample after drying, as required by EN ISO 18134-1:2015. A drying oven (Memmert UFP800) was set up at 105 °C for 24 h.

$$MC = \frac{P_1 - P_2}{P_1 - P_0} \times 100 \quad (1)$$

where,  $P_0$  = tare weight (g),  $P_1$  = wet weight (g), and  $P_2$  = anhydrous weight (g).

Another important parameter evaluated in this study was the moisture resistance assessed using the Wettability Index (WI). This index shows the quantity of water adsorbed by the pellet and, consequently, its degradation. Depending on the mixture used, the pellets tend to absorb moisture when placed in humid or wet conditions. For example, prolonged moisture absorption will weaken the resistance of the pellets and promote fungal growth, leading to decomposition of the pellets during storage [22]. For this test, the pellet was weighed and then submerged in water for 30 s. A video camera was used to document the behavior during the observed time. After submerging, the pellet was reweighed and WI was taken as the percentage of the difference in weight of the pellet before and after submerging from the initial weight.

$$WI = \frac{M_f - M_i}{M_i} \quad (2)$$

where  $M_f$  = final weight of pellet after submerging in water (g), and  $M_i$  = initial weight of pellet before submerging in water (g).

The durability test was subsequently performed. This test consists of applying stress to the pellet to prove its resistance to shocks and abrasions caused during handling, distribution, and transport. From the various mixtures, 2 kg of pellets were taken and divided into 20 samples of 100 g each, with which mechanical durability tests were carried out. The sample of each mixture was sieved to remove excess dust with a 3.15 mm mesh sieve. Subsequently, the sample to be analyzed was weighed (100 g) using the Holmen NHP200 durability machine, equipped with a digital internal scale with a resolution of 0.1 g, for weight control of the sample. Durability is indicated with the acronym PDI (*Percentage of Durability Index*), which specifies the percentage of durability of materials [23,24].

The last test was the image analysis through Scanning Electron Microscope—SEM (ZEISS EVO MA 10). Such analysis permitted to evaluate the morphology of the various pellet mixes produced. The specimens were selected and cross-sectioned with the aim to evaluate the morphological composition and heterogeneity after the pelletization process of different materials. The samples were coated with a thin layer of gold to enhance the conductivity and improve visibility with the Scanning Electron Microscope. The SEM was coupled with the energy dispersive X-ray QUANTAX EDS for the chemical identification and quantitative analysis of very small amounts of chemical substances. The microanalysis permitted to understand the composition of particular bodies found in pellet mixtures.

### 2.3. Statistical Analysis

Statistical analysis was conducted using SPSS version 25. Descriptive statistical analyzes were performed for all samples. Moreover, a linear correlation was considered between the length (L) and weight (Wr) of the pellets produced by the different mixtures. Analysis of variance (ANOVA) was performed to conclude significant difference at a 95% confidence level and was used to evaluate the significant difference of the durability and wettability index (WI) results of compost pellets after they were produced. Multiple comparisons were conducted using Tukey's honestly significant difference (HSD) tests, which identify any significant differences between groups.

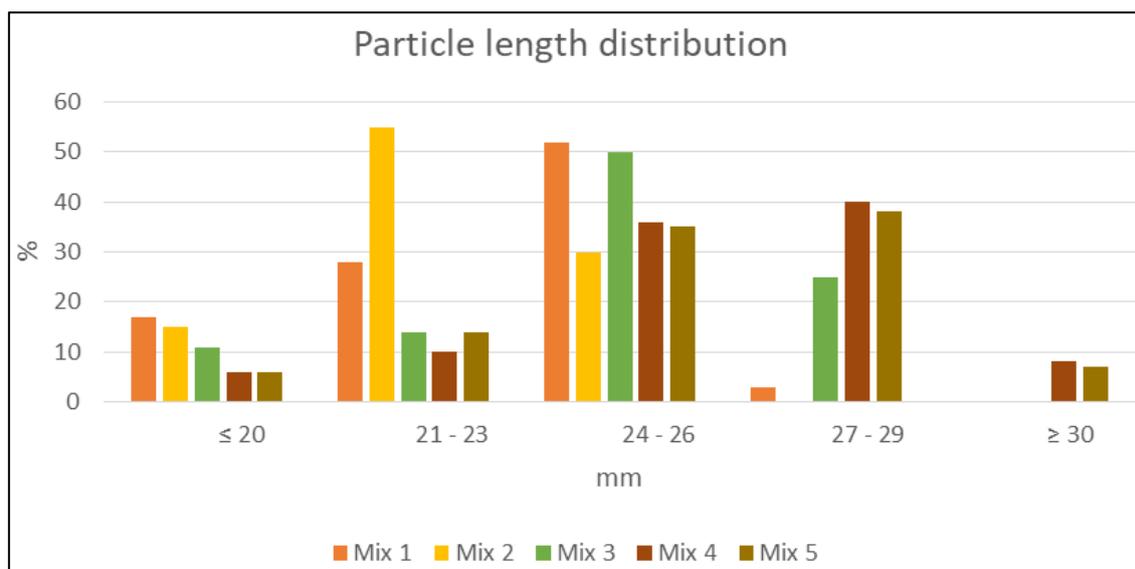
### 3. Results and Discussion

#### Physicochemical Characterization of the Pellet

The physical–chemical characteristics of the compost pellet are presented in Table 2. The elemental analysis did not reveal any differences between the mixtures for the nitrogen and hydrogen content. Differences were found regarding the carbon content; in particular, mixtures three, four, and five had a higher carbon content than mixtures one and two. As observed in several studies [25], the contribution of lignin contributes to the increase in the carbon percentage, as observed in mixtures three, four, and five. As confirmed in previous studies [26], the bulk density of the compost pellet represents an important parameter that affects the integrity of the pellet during handling and storage procedures [27,28]. The results of the experiments showed average bulk density values for each mixture, which were approximately, 698, 712, and 688 kg m<sup>-3</sup>, respectively, for mixtures three, four, and five. These values were slightly higher than those of mixtures one and two, which were, respectively, 658 and 632 kg m<sup>-3</sup>. The initial MC of the compost for each mixture was found to be suitable for pelletizing (25% ± 0.12) and, successively, the MC of the produced pellet was reduced to 11% ± 0.14. As reported in similar studies [29], the moisture content is a key factor that can significantly affect the operational properties of the pelletizer as well as the strength and formation of the pellets produced. Figure 4 shows the distribution in percentages of the lengths of the individual pellets produced. The higher percentage is for pellets with a length of around 26 to 30 mm. This parameter confirms the correct dimensions of the compost pellets produced compared to similar studies [11,30]. Table 3 shows the physical characteristics catalogued for each mixture.

**Table 2.** Physicochemical characteristics of pellets from different mixtures.

Compound	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
C (%)	28.78 ± 5.24	28.13 ± 4.22	43.72 ± 3.40	37.07 ± 2.85	37.93 ± 2.41
N (%)	3.08 ± 0.45	3.56 ± 0.25	2.70 ± 0.84	3.33 ± 1.12	2.04 ± 0.71
H (%)	4.79 ± 0.82	3.84 ± 1.12	4.10 ± 0.47	3.53 ± 0.66	4.96 ± 0.22
O (%) dry basis	30.91 ± 0.36	25.97 ± 0.67	24.92 ± 1.8	29.79 ± 0.45	12.97 ± 1.42
Ash (%)	32.43 ± 1.2	38.49 ± 0.90	24.55 ± 2.32	26.27 ± 1.52	42.09 ± 0.50
Moisture content (%)	11 ± 0.4	11 ± 0.9	12 ± 0.3	12 ± 0.2	11 ± 0.7
Bulk density (kg m <sup>-3</sup> )	658 ± 3.21	632 ± 5.55	698 ± 2.12	712 ± 4.52	688 ± 6.44



**Figure 4.** Dimensional characteristics of pellets from different mixtures.

**Table 3.** Physical characteristics of the compost pellet divided into mixtures.

	Mixture	Minimum	Maximum	Mean	Std. Dev.
Mix 1	Durability %	90.00	93.00	91.5000	1.08012
	WI %	0.30	0.96	0.5700	0.21792
	D mm	5.89	6.27	6.0560	0.11433
	L mm	21.71	26.32	23.9200	1.46649
	W gr	0.95	1.04	0.9980	0.03155
Mix 2	Durability %	84.00	87.00	85.3000	0.94868
	WI %	0.31	1.08	0.6590	0.26274
	D mm	5.22	5.55	5.3510	0.09469
	L mm	15.65	24.07	20.7060	2.48754
	W gr	0.80	0.90	0.8527	0.02811
Mix 3	Durability %	94.00	96.00	94.6000	0.69921
	WI %	0.78	1.22	1.0380	0.13555
	D mm	5.95	6.21	6.1320	0.08715
	L mm	24.38	27.35	25.4850	0.97270
	W gr	0.86	1.08	0.9696	0.07319
Mix 4	Durability %	89.00	92.00	90.7000	0.94868
	WI %	0.22	0.51	0.3430	0.10446
	D mm	5.89	6.06	5.9720	0.04917
	L mm	24.15	35.78	29.9080	4.79557
	W gr	1.07	1.69	1.3440	0.21629
Mix 5	Durability %	90.00	93.00	91.7000	0.94868
	WI %	0.22	0.83	0.5640	0.20430
	D mm	5.89	6.06	5.9480	0.05350
	L mm	24.21	34.10	28.5740	3.74838
	W gr	0.94	1.38	1.1640	0.17283

Figure 5 confirms that mixtures one, two and three produced pellets with almost homogeneous but reduced weights and lengths in each group, while the pellets produced with mixtures four and five had dimensions and weights distributed over a wider range and with values predominantly higher than in the other groups. This could be due to the absence of binding agents, which resulted in poorly homogeneous pellets instead of those obtained with mixtures one, two and three, which contained *J. curcas* or corn starch powders.

From the statistical analysis carried out, the results of ANOVA (Table 4) indicate that there are significant differences between the starting mixes in terms of the durability of the compost pellet. In detail, from the Tukey's test (honestly significant difference test, HSD test), it was found that mixtures two and three were significantly different from the others. However, the durability test on compost produced with mixture two revealed that it had the lowest performance, as can also be seen in Figure 6.

**Table 4.** Statistical analysis of variance (ANOVA) for the results of the durability and wettability index (WI) of the pellets.

		Sum of Squares	df	Mean Square	F	Sig.
Durability %	Between groups	459.920	4	114.980	131.992	0.000
	Within groups	39.200	45	0.871		
	Total	499.120	49			
WI %	Between groups	2.575	4	0.644	17.164	0.000
	Within groups	1.688	45	0.038		
	Total	4.263	49			

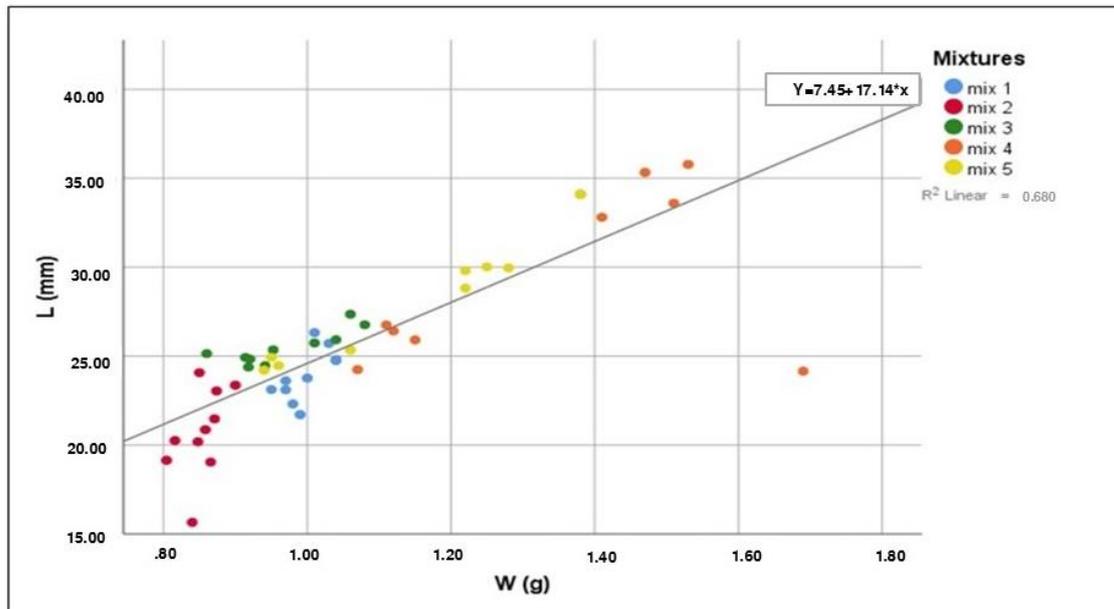


Figure 5. Pellet samples of some mixtures ready for experimental tests.

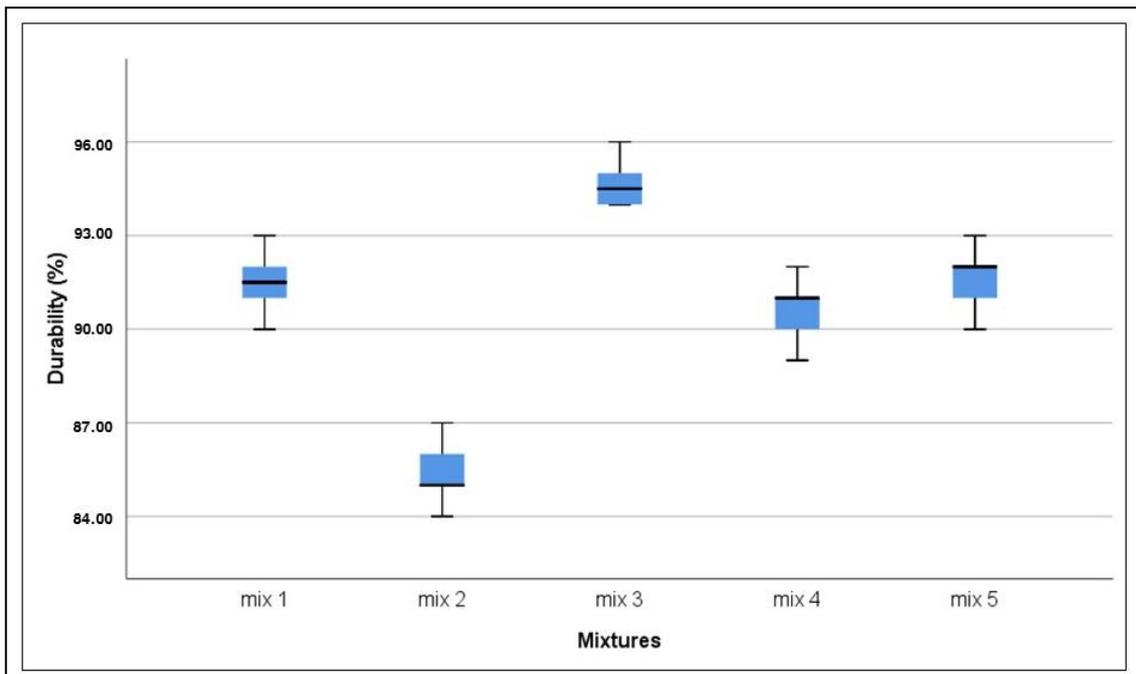


Figure 6. Compost pellet durability for the different mixtures tested.

This means that it is not suitable for withstanding shocks during handling and transport because of its tendency to crumble easily.

With regard to the wettability index (Figure 7), the pellet derived from mixture three showed the highest values, while values lower than 90% of this index were obtained from the other blends. In fact, only mixture three proved to be significantly different from the other blends. It performed well in both its durability and wettability index, while, on the contrary, the compost pellet of mixture two had a rather low wettability index and durability. In general, the values obtained from the WI tests show that the compost pellet can withstand a certain storage period without deteriorating but must be stored in closed warehouses or under covered conditions before being used (Figure 8).

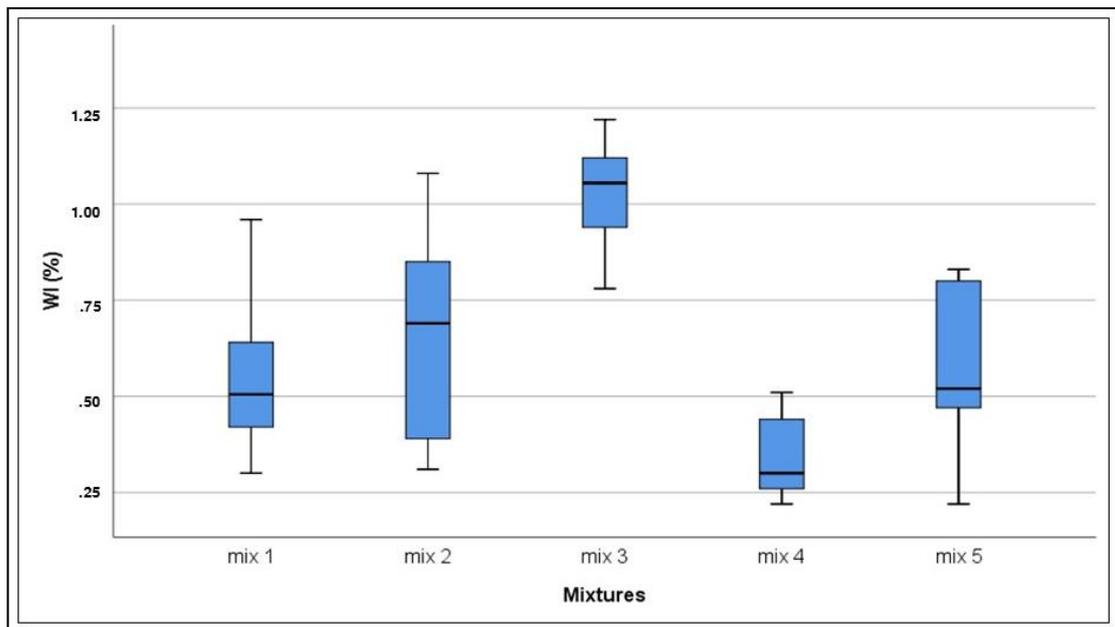


Figure 7. Wettability index of compost pellets.

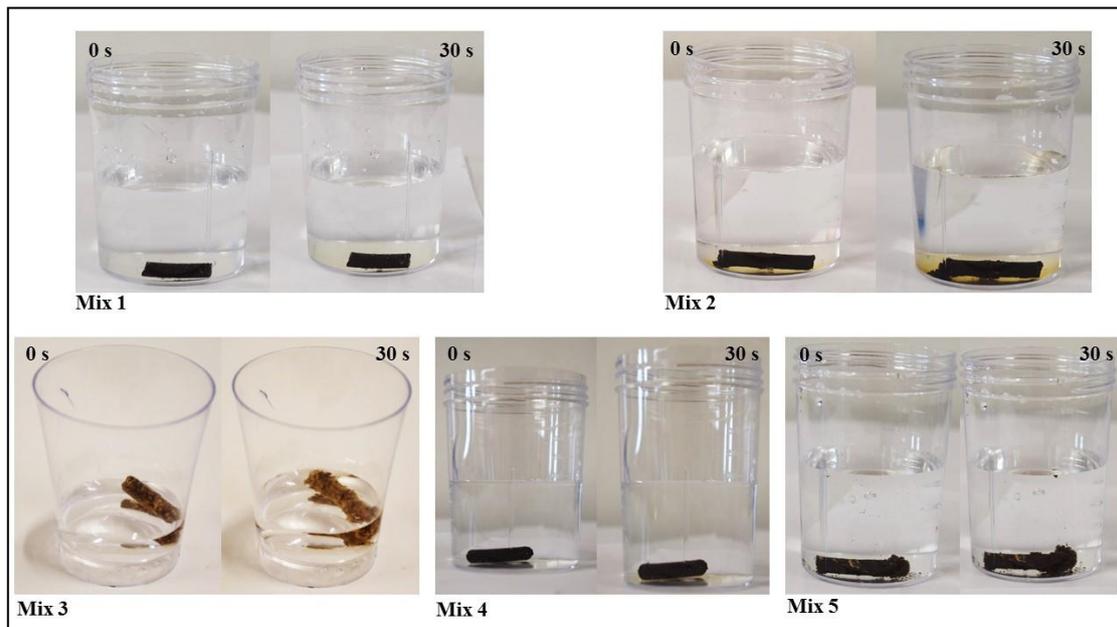


Figure 8. Wettability Index of the samples submerged in water for 30 s.

Figure 9 shows SEM images of the transverse surface of the compost pellet samples of various blends. In mixture one, a crystalline form is seen on the center right. The microanalysis confirms that it is mainly composed of Mg, Ca, O and some C. One could hypothesize something about its origin, perhaps a carbonate of Ca and Mg, coming from EEP. In mixtures two and five, it is possible to observe that there are many clusters in the pellet containing different matrix additives compared to the pellets produced with only wood. The EEP particles are homogeneously dispersed thanks to the mixing carried out before pelletizing. It is possible that the corn starch particles crystallized and bound to the pellet at high temperatures, creating a more compact and robust structure [31,32]. The application of high temperatures during pelletization can lead to the development of solid bridges through the interaction of molecules [17]. Following the crystallization of some materials, the solid bonds that are formed increase the hardening and solidification

properties of the molten components, which, following cooling, form highly densified products with a very often vitrified external surface [33]. Furthermore, the lignin content present in mixtures four and five created solid bridges that guaranteed the physical quality of the pellet in terms of durability, even without the corn starch additive [34,35].

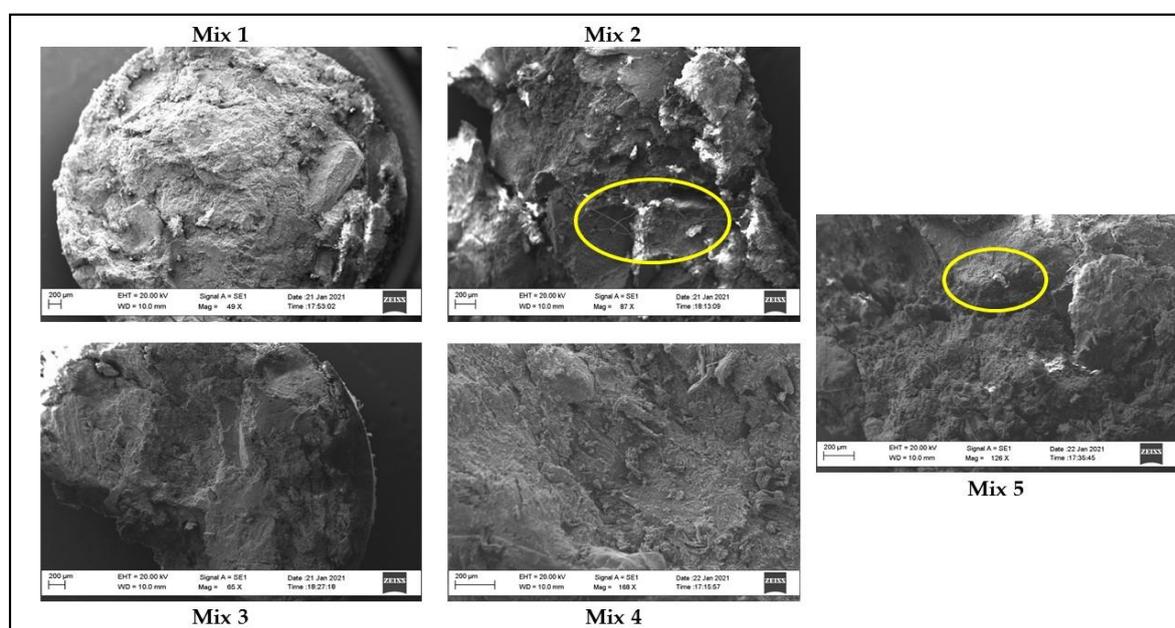


Figure 9. SEM images on the compost pellet.

#### 4. Discussion

In the last decade, the densification of compost or other composted solid fraction processes has minimized the required storage capacity and has also contributed to reducing respiratory problems caused by dust dispersion during distribution. For these reasons, several studies have investigated the effects of several parameters on pellet quality identification; the results of this study indicate that organic matter can be pelletized, but it is necessary to add a binding agent [12,36]. Considering the market relevance of the fertilizer production industry, this study aimed to identify a method to utilize exhausted EP. For the first time, the pelletization of EEP with compost was successfully performed using five different mixes, each one with different properties. The results have shown that these variables can be controlled to optimize production efficiency and improve the quality of the finished product depending on the type of distribution, handling, and storage. The values obtained do not suggest a superior mixture with respect to the others, but simply the different modality of application of each mixture. This co-compost pelletizing study was conducted using a conventional domestic pellet machine, which proved to be cheaper and simpler than pelletizing with experimental methods. Pelletizing increased the bulk density of the compost pellets due to compaction; in fact, as confirmed by Pampuro [8], the different physical properties of the materials most likely affected the densification process. Good compaction provides strength during the pellet processing. In particular, by mixing different compounds adjusted to the correct percentages by weight, the physical characteristics of the pellets were increased in terms of the length and weight of mixtures four and five. This result is probably due to the presence of wood chips in those mixtures, as also observed in many other studies [5], even if they presented inhomogeneous values due to the absence of binding agents among the components of the mixtures. Several studies [8,37] have indicated that durability is high when the computed value is above 80% and medium when the value is between 70% and 80%. Knowing that the studied material will be used as a fertilizer, low pellet durability is not desirable since it can cause problems such as creating a disturbance within the mechanical distribution systems and inducing

dust production [8]. The five different mixes showed results of high durability (between 84 and 94 PDI) and, therefore, a good capacity to be stored and transported commercially; in particular, mixture three showed a higher value thanks to the use of wood chips and corn starch, where lignin worked as one of the binders during compost pelletization. In the same mixture, the highest wettability index value was found, in accordance with previous studies [6,12] that noted the influence of wood and compost as regulatory agents of WI. This parameter allows the compost pellet to be able to disintegrate in the presence of water in an acceptable time frame and, therefore, to be able to quickly release the nutrients necessary for agricultural crops.

## 5. Conclusions

In the present study, pelletizing was considered as a method to valorize exhausted extinguishing powders with a recovery process, favoring the recovery of a high-value, non-renewable raw material as phosphate into fertilizer. This research demonstrated the possibility of utilizing exhausted EP in compost pellets, producing different formulations. The benefits of this are numerous and can be summarized as follows: Pelletizing enables the reduction or complete elimination of the volatility of both the extinguishing powder and compost during the handling, storage and distribution phases and reuse of EEP in the agriculture sector as recycled fertilizers. In addition, the use of compost pellets can reduce the potential health problems during the distribution owing to the dusty nature of compost and EEP. Respiratory diseases in agricultural workers, defined as “farmer’s lung”, are frequent; as pathogenic organisms such as *Escherichia coli* and *Salmonella* sp. could be present in composts [38], the high temperature achieved during pelletizing ensures hygiene safety. The five compost mixtures could be applied in different agricultural crops; for example, a pellet that degrades slowly releases nutrients gradually, whilst a pellet with a fast degradation phase may be useful for horticultural agriculture. Furthermore, this use of exhausted EP could have positive ecological and economic impacts, avoiding the disposal costs required by specialized companies.

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