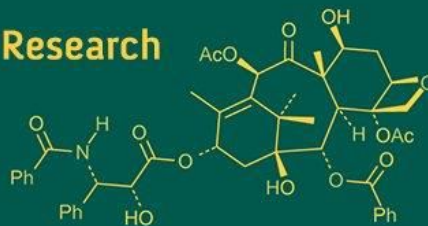
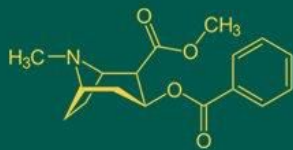


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Production and characterization of exhausted fire-extinguishing powder bioenriched pressmud compost

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Abstract

The objective of this research was production of EFP bioenriched pressmud compost and to study the some of the chemical and physical properties of exhausted fire-extinguishing powder (EFP) bioenriched pressmud composts. These properties include pH, EC, organic carbon, organic matter, nitrogen, phosphorus, potassium, C:N ratio, bulk density and moisture content. The pH of the bioenriched pressmud composts ranged from 5.99 (C₂) to 7.26 (C₁) and EC of composts ranged from 0.63 dS m⁻¹ (C₁) to 0.84 dS m⁻¹ (C₂). The organic carbon content ranged from 23.40 percent (C₄) to 25.05 percent (C₂) in bioenriched pressmud composts. The organic matter content ranged from 40.24 percent (C₄) to 43.08 percent (C₂) in bioenriched pressmud composts. The nitrogen content ranged from 2.10 percent (C₁) to 3.85 percent (C₂), phosphorus content ranged from 1.59 percent (C₁) to 8.29 percent (C₂), potassium content ranged from 0.67 percent (C₁) to 0.79 percent (C₂) in bioenriched pressmud composts. The C:N ratio ranged from 6.52 (C₂) to 11.71 (C₁) in bioenriched pressmud composts. The bulk density in bioenriched pressmud compost treatments ranged from 0.45 Mg m⁻³ (C₂) to 0.57 Mg m⁻³ (C₄). The moisture content in bioenriched pressmud compost treatments ranged from 32.26% (C₂) to 40.42% (C₁).

Keywords: Exhausted fire-extinguishing powder, pressmud, EFP bioenriched compost

Introduction

The increasing prices of inorganic phosphate fertilizers and the extensive use of chemical fertilizers in agriculture, is also under debate due to environmental concerns and for consumer health reasons (Elkoca *et al.*, 2010) [8]. The cost of phosphatic fertilizers is very high in India. This is mainly due to increase in foreign exchange for importing raw materials like high-grade rock phosphate (>30% P₂O₅) required for manufacturing of phosphatic fertilizers. Presently, about 160 Mt of rock phosphate (RP) deposit is available in India. Unfortunately, most of them are designated as low grade material containing less than 20% P₂O₅ and considered unsuitable for manufacturing of conventional commercial phosphatic fertilizers. Reduction of agrochemicals for crop production is of great concern for sustainable agriculture (Aydin *et al.*, 2020) [4]. Moreover, high dose application of chemical fertilizers creates negative impacts such as changes in soil pH through alkalization and acidification, pollution of water resources through runoff, suppression of microorganisms and friendly insects, fixation of nutrients, degradation of soil structure due to increased decomposition of organic matter (Ali and Xie, 2019) [1]. The research workers are required to look for substitutes to inorganic fertilizers (Khan and Bano, 2019) [17] which are cost-effective and environmentally friendly. The use of exhausted fire-extinguishing powder (EFP) as an alternative for P fertilizer is gaining attention in sustainable agriculture through microbial solubilisation (Reddy *et al.*, 2002) [22] and preparation of EFP bioenriched compost. The fire extinguisher ABC powder is a dry fire-extinguishing agent represent the most critical fire safety equipment. It is composed of 50 to 80% mono-ammonium phosphate (MAP). After 3 years, fire extinguisher undergoes for refilling process by the fire extinguisher industry. After refilling, the waste generated from the industry is known as Exhausted Fire-extinguishing Powder (EFP). Disposing of EFP safely is challenging due to its high hydrophobicity and fine powder texture (Pratico *et al.*, 2010) [19]. One possible solution is composting with agricultural wastes such as pressmud.

The sugar industry in India is the second largest agro-processing sector, after the textile industry, with a total production of about 105 lakh tonnes (2022-2023). Pressmud is the byproducts of the sugar industry, producing 8.5 million tonnes each year, respectively (National Federation of Co-operative Sugar Factories Ltd 2016; Dotaniya *et al.* 2016) [7]. Pressmud is rich in organic matter and vital nutrients especially phosphorus. Pressmud compost has beneficial impacts on the physical, chemical, and biological characteristics of soil in addition to having a large ability to give nutrients. By applying 20 t ha⁻¹ of press mud, reduces the application of 25% of recommended fertilizer. By the application of pressmud saves 15% and 20% price of inorganic fertilizers thus enhances the soil's texture, structure, and quality. This potent source of organic matter and nutrients, however, could be recycled back to agricultural fields, if converted into quality compost like enriched compost using EFP for crop production as well as maintaining soil fertility.

Waste composting is crucial in advanced circular economy models as it provides economically and environmentally friendly method for providing various ecosystem services, including reducing landfilling, recovering nutrients, energy and transforming organic waste into valuable industrial products (Mikula *et al.*, 2020) [18]. In fact, during composting, metabolically active microbial communities play a crucial role in breaking down organic compounds (Guo *et al.*, 2019) [9], more soluble P is released due to the action of organic acids produced by the microbes (Puente *et al.*, 2004) [20].

Composting provides a way not only reducing the amount of waste that needs to be disposed off, but also converting it into a product that is useful for increasing the productivity of crops as well as maintaining soil fertility. Compost is an organic fertilizer that can be made on the farm at very low cost. In order to increase soil fertility in the short run, nutrients need to be added to the soil through chemical fertilizers, which is expensive for the small and marginal farmers.

The phosphorus present in EFP waste is insoluble in nature. Availability of P in EFP can be increased due to inoculation the compost with phosphate solubilizing microorganisms like *Aspergillus awamori*, *Pseudomonas striata*, which are known to produce organic acids e.g. citric, oxalic, tartaric, acetic, lactic, gluconic and ketogluconic. These acids are the sources of H⁺ ions that are primarily responsible for solubilizing P from EFP and enhance P availability to the plants. Organic acid anions can also solubilize EFP through chelation. Acid phosphatases and phytases secreted by the microorganisms play an important role in P solubilisation of EFP to available form.

The beneficial effects of compost on crop production and soil quality reported in literature (Hoitink *et al.*, 1997; Atiyeh *et al.*, 2001) [11, 2] are directly related to the physical, chemical and biological properties of the composts (He *et al.*, 1995) [10]. The physical and chemical properties of organic wastes and the factors that affect their performance in composting require easily identifiable and reliable methods to control the process in situ, in order to make proper decisions about its performance (Hurerta-Pujol *et al.*, 2010) [12]. To produce a sound and a good quality compost, chemical and physical properties of the compost should be determined by the end of processing period, therefore, the main objective of this research was to produce EFP

bioenriched pressmud compost and their characterization for chemical and physical properties. These properties include: pH, EC, total organic carbon, total organic matter, N, P, K, C:N ratio, bulk density and moisture content.

Material and methods

The compost experiment was carried out at Green house, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bangalore with four compost treatments by using different grades of EFP i.e. 90% (EFP_A), 40% (EFP_B) and 0% (EFP_C) and which were replicated four times.

Raw materials used for composting: Pressmud obtained from sugarcane processing industry (Mandya), EFP was obtained from Usha Armour Private Limited, Bangalore, cow dung was obtained from FS unit, GKVK, Bangalore. Phosphorus solubilizers and microbial decomposers were obtained from Bio fertilizer lab, Department of Agricultural Microbiology, UAS, GKVK, Bangalore.

Table 1: Treatment Details

C ₁	Pressmud (1000 kg) + Cow dung (100 kg) + Microbial decomposer (5 kg)
C ₂	C ₁ + EFP _A @ 10%
C ₃	C ₁ + EFP _B @ 10%
C ₄	C ₁ + EFP _C @ 10%

Preparation of EFP bioenriched pressmud compost

For the preparation of composts, 200 litre capacity plastic drums were used. For each drum 1000 kg of pressmud, 100 kg of cow dung and 5 kg of microbial decomposer were added after proper mixing. Microbial decomposer contains *Pleurotus sajor caju*, *Phanerochaete chrysosporium* and *Aspergillus niger* and *Trichoderma*. EFP of different grades were added according to treatments at the rate of 100 kg and mixed completely. For aeration purpose 4" pipes with holes on surface were inserted in the middle of the drum. Moisture content was maintained about 50 to 60% of field capacity throughout the composting period by periodic watering and temperature at 50- 60 °C for few weeks. Turning was carried out periodically (monthly interval) for faster decomposition. After 3 months of composting microbial consortia (*Bacillus megaterium*, *Aspergillus awamori* and *Pseudomonas fluorescence*) @ 5 kg was added to the 1000 kg of matured compost. Composting was terminated after 90 days. Samples were taken at the end of the composting process to determine the chemical and physical properties.

Chemical analysis of compost

Compost samples from drums were collected and were oven dried at 70 °C and ground to pass through a 20-mesh sieve size. Then the sieved samples were used for chemical analysis.

pH (1:10): pH was determined by glass electrode pH meter as described by (Jackson, 1973) [13]. The position of the electrode was adjusted in the clamp. The electrode was immersed into partly settled solution suspension and pH was measured.

Electrical conductivity: The EC of collected compost samples was determined conductometrically (1:10 sample: water ratio) by a conductivity meter using 0.01 M KCL

solution to calibrate the meter following the procedure as described by Jackson, 1973^[13].

Total carbon and organic matter content: The total carbon and organic matter content in the samples were determined by using dry combustion method reported by Jackson, 1973^[13].

Total Nitrogen: Nitrogen in organic materials was estimated by following the micro Kjeldahl method as outlined by Jackson (1973)^[13] using Kjeldhal distillation apparatus.

Total Phosphorus and Potassium: 1 g of compost samples was digested with 10 ml of diacid mixture ($\text{HNO}_3\text{:HClO}_4$ in 9:4 ratio). Using an aliquot of diacid extract, P was estimated by following vanadomolybdic yellow colour method and potassium content in an aliquot of diacid extract with suitable dilutions was estimated by using flame photometer (Jackson, 1973)^[13].

Moisture content (wet basis) was measured by drying at 105 °C for approximately 24 h or at constant weight.

Bulk density was measured by keen's cup method as reported by Keens and Raczkowski (1921)^[16].

Results and Discussion

The total nitrogen and phosphorus content were higher in EFP_A (13.25% and 20.90%) followed by EFP_B (4.76% and 6.09%) and lowest in EFP_C (0.71% and 0.93%) hence, it can be a good source of phosphorus. The undecomposed pressmud had pH of 7.34, EC 1.94 dS m⁻¹, 32.48 percent OC, 55.86 percent organic matter, 1.31 percent nitrogen, 1.13 percent phosphorus, 0.37 percent potassium and C:N ratio was 24.79. The raw cow dung had pH of 5.40, EC 1.26 dS m⁻¹, 47.55 percent OC 81.76 percent organic matter, 1.22 percent nitrogen, 0.21 percent phosphorus, 0.30 percent potassium and C:N ratio was 38.98 (Table 2).

Table 2: Chemical composition of raw materials

Properties	Pressmud	Cow dung	EFP _A	EFP _B	EFP _C
Moisture (%)	45.97	37.45	-	-	-
pH (1: 10)	7.34	5.40	-	-	-
EC (dS m ⁻¹)	1.94	1.26	-	-	-
Organic carbon (%)	32.48	47.55	-	-	-
Organic matter (%)	55.86	81.76	-	-	-
Nitrogen (%)	1.31	1.22	13.25	4.76	0.71
Phosphorus (%)	1.13	0.21	20.90	6.09	0.93
Potassium (%)	0.37	0.30	-	-	-
C:N Ratio	24.79	38.98	-	-	-

Chemical properties

The highest pH of 7.26 was found in C₁ and lowest (5.99) was found in C₂ at maturity. Among the different grades of EFP used for compost enrichment, EFP_A (C₂) recorded lower pH when compared to EFP_C (C₄). The EC of the bioenriched pressmud compost treatments ranged from 0.63 dS m⁻¹ to 0.84 dS m⁻¹. The highest EC was measured in C₂ (0.84 dS m⁻¹) and lowest in C₁ (0.63 dS m⁻¹). Among the different grades of EFP used for compost enrichment, EFP_A

(C₂) recorded higher EC when compared to EFP_C (C₄). The organic carbon (OC) values of bioenriched pressmud compost treatments ranged from 23.40 percent to 25.05 percent at maturity. The highest OC was measured in C₂ (25.05 percent) and lowest in C₄ (23.40 percent). Among different grades of EFP used for compost enrichment, EFP_A (C₂) recorded higher OC when compared to EFP_C (C₄) and EFP_B (C₃). The organic matter (OM) values of bioenriched pressmud compost treatments ranged from 40.24 percent (C₄) to 43.08 percent (C₂) at maturity. In bioenriched pressmud compost treatments, the C:N ratio ranged from 6.52 (C₂) to 11.71 (C₁) at maturity. Among the different grades of EFP used for compost enrichment, EFP_A (C₂) recorded lower C:N ratio followed by EFP_B (C₃). and EFP_C (C₄).

The percent N, P and K of all compost treatments increased with composting. In the bioenriched pressmud compost treatments, the N content ranged from 2.10 to 3.85 percent at maturity. The highest N was recorded in C₂ (3.85 percent) and lowest in C₁ (2.10 percent). The P content ranged from 1.59 to 8.29 percent at maturity. The highest P was recorded in C₂ (8.29 percent) and lowest in C₁ (1.59 percent). The K content ranged from 0.67 to 0.79 percent at maturity. The highest K was recorded in C₂ (0.79 percent) and lowest in C₁ (0.67 percent). Among the different grades of EFP used for compost enrichment, EFP_A (C₂) recorded higher N, P and K content followed by EFP_B (C₃) and EFP_C (C₄).

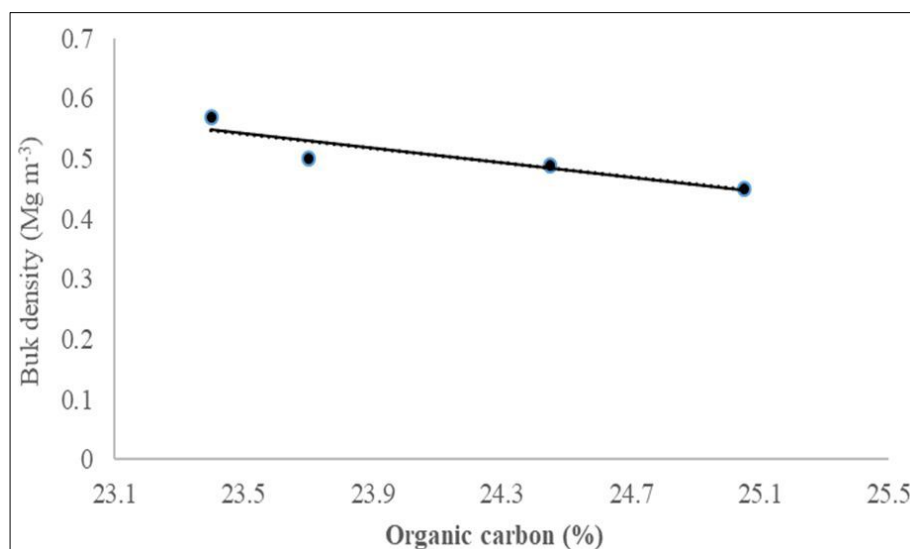
The release of organic acids, ammonia, and CO₂, along with the combined activities of microorganisms, cause the pH to shift toward neutral or acidic pH throughout the composting process (Zhang *et al.*, 2015; Ramnarain *et al.*, 2019; Yuvaraj *et al.*, 2019; Karmegam *et al.*, 2021)^[25, 21, 24, 6]. pH was lower in EFP - 90% treatment which was due to their acidic pH of that material compared to others. The decrease in organic carbon in all composts is due to loss of organic carbon as CO₂ during composting process as a result of mineralization of the organic matter (Atkinson *et al.*, 1996)^[3]. Respiration and assimilation activities of microbes are associated with reductions in organic carbon during composting (Karmegam *et al.*, 2019)^[15]. There was increase in total N, P and K content of composts during the process of decomposition, which could be due to mass loss carbon as CO₂ during the period of decomposition. Other researchers have also indicated that phosphatase activity, mobilization of organic matter and mineralization of microorganisms are the main causes of progressive changes in macro nutrient status of compost (Balachandar *et al.*, 2020; Karmegam *et al.*, 2019; Yadav and Garg, 2019)^[14, 15, 23].

Physical properties

The bulk density (BD) in bioenriched pressmud compost treatments ranged from 0.45 Mg m⁻³ (C₂) to 0.57 Mg m⁻³ (C₄) at maturity. Among the different grades of EFP used for compost enrichment, EFP_A (C₂) recorded lower BD followed by EFP_B (C₃) and EFP_C (C₄). The moisture content in bioenriched pressmud compost treatments ranged from 32.26% (C₂) to 40.42% (C₁) at maturity. Among the different grades of EFP used for compost enrichment, EFP_A (C₂) recorded lower moisture content followed by EFP_C (C₄) and EFP_B (C₃).

Table 3: Chemical and physical properties of the EFP bioenriched pressmud compost after maturity

Treatments	C ₁	C ₂	C ₃	C ₄
pH	7.26	5.99	6.57	6.86
EC (dS m ⁻¹)	0.63	0.84	0.74	0.69
Organic carbon (%)	24.45	25.05	23.70	23.40
Organic matter (%)	42.05	43.08	40.76	40.24
Nitrogen (%)	2.10	3.85	3.18	2.76
Phosphorus (%)	1.59	8.29	3.51	3.05
Potassium (%)	0.67	0.79	0.69	0.70
C:N Ratio	11.71	6.52	7.47	8.59
Bulk density (Mg m ⁻³)	0.49	0.45	0.50	0.57
Moisture (%)	40.42	32.26	36.00	35.28

**Fig 1:** The relationship between bulk density and organic carbon

EFP bioenriched compost production is helpful for managing huge quantity of EFP waste by converting it into useful material. It reduces the farmer's dependence on expensive chemical fertilizers and is an environmentally sound and economically feasible solution to the problems of waste management. Substantial amounts of EFP and pressmud may be recycled back in agriculture. It reduces the risk of environmental pollution due to indiscriminate use of chemical fertilizers. The rate of nutrient release is slow. Thus, EFP bioenriched pressmud compost acts as slow release fertilizer and supply nutrients to crops for longer time.

Conclusion

Enriched compost was prepared using pressmud, EFP and P solubilizing microbes. Enriched compost helps in enhancing mobilization of unavailable P and N in EFP into their available forms and thus improves the quality of compost in terms of its total N, P and K contents. Enriched compost is a long term source of nutrients, which are readily available to the plants. Enriched compost could be an alternative option for sustainable management of agricultural wastes and a potential avenue for utilization of exhausted fire-extinguishing powder into a value added organic product for sustainable crop production and maintaining soil fertility.

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