Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 23, No 1, 2026, 1-14
Article available at homepage presipitasi

Original Research Article

The Potential of Bioplastic Waste Made From Polybutylene Adipate-Co-Terephthalate (PBAT) as Compost Mixtures

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Abstract

Biodegradable bioplastics offer an environmentally friendly alternative. One type of bioplastic being developed is Polybutylene Adipate-Co-Terephthalate (PBAT), an aliphatic-aromatic polyester capable of decomposing through microbial activity. This study aimed to analyze the potential of bioplastic waste as a compost mixture ingredient and determine the optimal composition of bioplastic waste mixtures for compost production. The study utilized a Completely Randomized Design (CRD). The quality of the compost made from bioplastic waste mixtures was evaluated based on SNI 7763:2024 standards, with parameters including pH, temperature, additional substances, and chemical content, such as nitrogen (N), phosphorus (P), potassium (K), and organic carbon (C-organic). The composting process lasted 60 d, using mixtures of bioplastics and cow manure organic waste in proportions of 95:5, 90:10, 85:15, 80:20, 75:25, and 70:30, each weighing 1 kg. Some mixtures were supplemented with 30 mL of activated EM4 to accelerate decomposition, whereas the control group used only cow manure. The results indicate that the compost produced generally met the SNI 7763:2024 standards. The most effective composition was 80% organic waste, 20% bioplastic, and 30 mL EM4. This composition achieved $N+P_2O_5+K_2O$ levels of 2.88%, C-organic content of 30.46%, moisture content of 24.60%, and pH of 7.60.

Keywords: Bioplastic; compost; PBAT

1. Introduction

The problem of plastic waste has become a main focus in the effort to preserve the global ecosystem in an increasingly global era, aware of the importance of environmental sustainability. Conventional plastics are made from petrochemicals and have long been known as one of the biggest contributors to environmental pollution because of their difficult-to-decompose nature (Jambeck et al., 2015). Environmee environment caused by plastic waste have become an increasingly urgent global issue (UNEP, 2018). According to the Ministry of Environment and Forestry (KLHK), the amount of plastic waste generated in Indonesia reaches approximately 6.8 million tons each year, with more than 60% of it not going through the recycling process (Putra et al., 2025). Conventional plastics, which are made from petrochemical materials, are non-biodegradable, causing long-term accumulation in the environment. Because of the difficulty of decomposition, plastic waste tends to pile up in the installation processing waste end and can damage the environment (Haryanto, 2017).

Bioplastics have emerged as promising alternatives to address this crisis. Bioplastics are a type of plastic made from natural ingredients that can unravel in a biological way in a relatively short time (Shen et al., 2009). Bioplastics are viewed as an innovation that can reduce dependence on standard fossil materials as the negatande impact of plastic waste on ecosystem. Fossil raw materials are not only non-renewable but also contribute to greenhouse gas emissions that cause climate change (Alkhajar and Luthfia 2020). The raw materials used for making bioplastics generally originate from renewable power sources, such as starch, cellulose, lignin, and chitosan. The ingredients for the can are obtained from agricultural results, agroindustrial waste, and side results from food processing (Saputra & Supriyo, 2020). Indonesia, as an agricultural country with abundant potential for agriculture and bioplastic development, has significant opportunities. One of the material standard potentials that can be utilized for bioplastic production is the cassava starch. Cassava is an easy commodity to cultivate and has a high starch content; therefore, it can be used to make environmentally friendly bioplastics (Rahman et al., 2013). Bioplastics not only reduce dependence on standard fossil materials but also produce greenhouse gas emissions more slowly during production (Van der Zee et al., 2013).

Biodegradable bioplastics are environmentally friendly alternatives. One of the many ingredients developed is poly(butylene adipate-co-terephthalate) (PBAT), an aliphatic-aromatic polyester that can be unraveled naturally by microorganisms (Ferreira et al., 2019). In addition to being used for material packaging, PBAT has potential applications in the agricultural sector, particularly as a material wrapping for compost or even as a component fertilizer. Some studies have shown that degraded PBAT can donate organic compounds that are beneficial for land, such as sour adipate and butanediol, which can increase soil fertility (Wei et al., 2021). However, the effectiveness of PBAT as a compost still needs to be reviewed, especially in terms of degradation speed, impact on microorganisms, and its influence on plant growth. On the other hand, waste agriculture, such as cassava sludge (dregs from processing cassava flour), is high in starch and fib; therefore,so it has the potential to be combined with PBAT to create more bioplasticsthat are easily unraveled at a time orth plus as fertilizer (Suryadi et al., 2021). This study aimed to determine the content of compost fertilizer made from a mixture of bioplastic waste and the most optimal treatment conditions in the composting process according to the Indonesian National Standard (SNI) 7763:2024. By identifying the optimal treatment conditions, this study provides new insights into the potential use of bioplastic waste as a raw material for composting.

2. Methods

2.1. Research Time and Location

This study was conductedfourfor 4 namely from January to March 2025, in the Laboratory Faculty of Soil Biology Agriculture and in the Soil Chemistry Laboratory of the Faculty of Agriculture and CV Sinar Jaya Plastindo. PBAT bioplastics were sampled at CV Sinar Jaya Plastindo, a plastic industry located in Sukoharjo, Central Java.

2.2. Tools and Materials

The tools used in this study included compost containers, polybags, thermometers, and scales. The study employed materials such as EM4 bacteria, organic waste, bioplastics, and soil.

2.3. Data Collection

This study employed a completely randomized design (CRD). The next amount of sample fertilizer organic compost that will conduct a content test of macronutrients is as many as 26 samples with details of 13 treatments and 2 repetitions in each sample fertilizer, determining the total number and frequency of repetitions done withse of a formula equation (1) Federer's reference (1963)

$$(t-1)\ (r-1) \geq 15 \quad (1)$$

Information:

t = number of treatments
r = number of repetitions

A1	B1	C1	D1	E1	F1	G1	H1	I1	J1	K1	L1	M1
A2	B2	C2	D2	E2	F2	G2	H2	I2	J2	K2	L2	M2

Information:
A (1,2) = Organic waste 100%
B (1,2) = Organic waste 95% bioplastic 5%
C (1,2) = Organic waste 90% bioplastic 10%
D (1,2) = Organic waste 85% bioplastic 15%
E (1,2) = Organic waste 80% bioplastic 20%
F (1,2) = Organic waste 75% bioplastic 25%
G (1,2) = Organic waste 70% bioplastic 30%
H (1,2) = Organic waste 95% bioplastic 5% eM4 30 ml
I (1,2) = Organic waste 90% bioplastic 10% eM4 30 ml
J (1,2) = Organic waste 85% bioplastic 15% eM4 30 ml
K (1,2) = Organic waste 80% bioplastic 20% eM4 30 ml
L (1,2) = Organic waste 75% bioplastic 25% eM4 30 ml
M (1,2) = Organic waste 70% bioplastic 30% eM4 30 ml

2.4. Data Analysis

Types of research conducted in this study with the experimental test method and data used were obtained from results of observation and laboratory tests, and the data generated were processed using software. The data used were based on observational results and laboratory tests. Observations were conducted during the compost fertilizer production, after the compost fertilizer matured within a period of 2 months, or until the compost condition was similar to that of generally mature compost. Subsequently, laboratory tests were conducted based on the national standardization body (BSN) guidelines related to solid organic fertilizers, specifically SNI 7763:2024. Observations were done at the time of making fertilizer compost; after the material bioplastic was capable of being degraded by fertilizer compost, laboratory tests were conducted with reference latest from the National Standardization Agency (BSN) related to fertilizer organic congestion, namely SNI 7763:2024, with parameters for knowing C-organic uses UV-Vis, N-Total with Kjeldahl Distillation method, phosphorus with the UV-Vis method, potassium with the AAS Flame test method, pH with the pH meter method, water content Gravimetry, and materials joined in with the Sieving method.

3. Result and Discussion

Waste bioplastics are polymer materials based on life that come from renewable sources such as starch plants, cellulose, or the results of fermentation microbes, which can theoretically be unraveled in a way experienced through the biodegradation process by microorganisms (Emadian et al., 2017). Bioplastic polybutylene adipate terephthalate (PBAT) was designed for its biodegradable or compostable properties, although its decomposition is highly dependent on environmental conditions such as temperature, humidity, and the presence of specific decomposer microbes (Ruggero et al., 2019). The degradation of bioplastics begins with enzymatic hydrolysis. Extracellular enzymes, such as lipase and esterase, produced by bacteria (e.g., Pseudomonas and Bacillus) or mushrooms (such as Aspergillus), break chain polymers into simpler oligomers and monomers, which can then be assimilated by microorganisms to become carbon dioxide, water, and biomass under aerobic conditions (Shah et al., 2020). Figure 1 shows the bioplastic made from a mixture of polybutylene adipate terephthalate (PBAT).

Figure 1. PBAT bioplastic

3.1. Contents of Compost Made from Mixture of Bioplastic Waste

Contents quality compost made from mixture of bioplastic waste presented in Table 1, which illustrates the physicochemical properties, nutrient composition, and potential agronomic value of the resulting product.

Table 1. The quality of compost made from mixture of bioplastic waste

Parameter	Sample												
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
C- organic (%)	25.72	17.99	20.18	24.25	26.26	19.5	19.51	18.54	15.96	23.87	30.46	23.93	22.13
N-Total (%)	1.14	0.93	1.08	1.13	1.18	0.93	0.96	0.8	0.74	1.03	1.22	1.06	0.92
Phosphorus (%)	1.14	0.91	1	1.04	0.97	1.08	1.03	0.91	0.94	0.99	1.19	1.02	0.96
Potassium (%)	0.59	0.6	0.43	0.34	0.34	0.5	0.57	0.62	0.35	0.5	0.58	0.53	0.35
(N+P+K) (%)	2.86	2.44	2.5	2.51	2.49	2.51	2.56	2.33	2.03	2.52	2.98	2.6	2.22
Water content (%)	21	19.46	22.88	23.55	19.25	21.99	23.54	15.98	21.7	20.81	24.6	14.31	18.05
Associated Materials (%)	0	0	0	0.01	0.02	0.06	0.04	0	0.02	0.01	0.01	0.05	0.05
pH	7.25	6.3	6.45	7.25	7.25	7.35	7.5	7.25	7.55	7.05	7.6	7.2	7.5

3.2. C-Organic Content

Based on the test results in Table 1, the content of C-organic macronutrients in treatments A to M was 15.96% to 30.46% (within the minimum limit of SNI 7763:2024). Through C-organic content test results from all types of treatment, it can be seen that C-organic content is highest in treatment K, namely 30.46%, with treatment organic waste 80%, bioplastic 20%, and eM4 30 ml. This is because it enters the minimum limit of SNI 7763:2024 and has a C-organic content higher than that of the treatment control. High C organic levels in all treatments were due to the presence of starch in bioplastics, which contributed to an increase in organic C in the land because starch is an easily decomposed organic compound by microorganisms. The degradation process of starch in bioplastics can be unraveled with a fast on-theground potential increase in organic C content, as well as a potential increase in fertility land and microbial activity (Syuhada, 2019; Nafilah & Sedyadi, 2019).

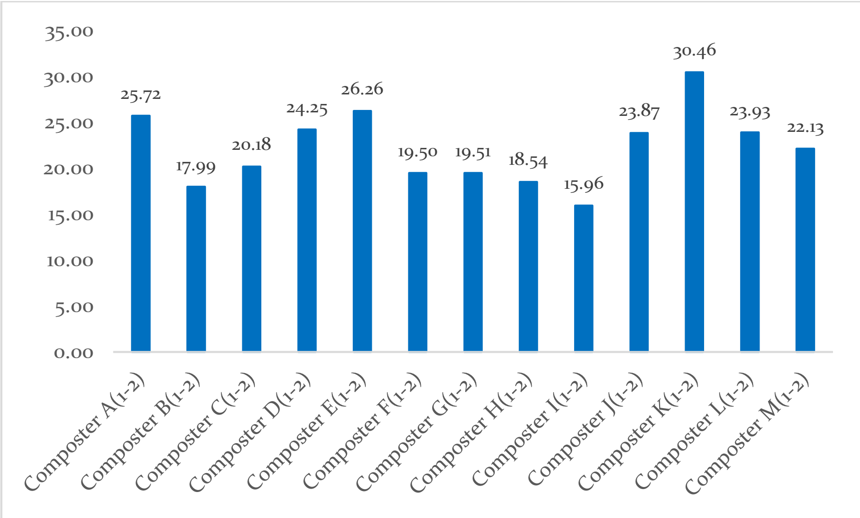

Figure 2. Graph C- Organic content (%)

Organic carbon, or organic material, is an important element in soil. C- Organic Alone is formed from various organic materials that have been decomposed by microorganisms. The higher the C-organic content in the fertilizer, the higher the nutrient content that can be provided to the land and plants that receive treatment (Siregar, 2017). The composting process involves the decomposition of organic material, which is marked by a decrease in the organic carbon content. C-organic is used as an indicator to evaluate the level of compost maturity (Mirwan, 2015). During decomposition, microorganisms use carbon as an energy source for growth and development (Fangohoi & Wandasari, 2017). The higher the movement of microorganisms, the higher the organic C content. This plays an important role in maintaining soil quality and supporting the productivity of plants that utilize it (Nopriandi et al., 2024).

3.3. Total N Content

The macronutrient nitrogen content in each treatment ranged from 0.74% to 1.22%. Fertilizer I is the fertilizer with the lowest N-total content compared to the 12 other fertilizers, while H, M, B, F, G, J, L, C, D, E, A, and K fertilizers are variation fertilizers that are consecutively higher in total N content, with the highest content in fertilizer K, namely 1.22%, with 80% organic waste, 20% bioplastic, and 30 ml of EM4, because it enters the minimum limit of SNI 7763:2024 and has a total N content that is higher than the treatment control. The higher the amount of organic matter available in animal feces, the higher the nitrogen content (Indrawaty, 2017). With so much on the treatment fertilizer, K compost has marked material high in organic matter and nitrogen, although there is a bioplastic material. The addition of EM4 at a dose of 5% volume can increase total nitrogen retention by 18-22% compared to a control without the inoculant (Jusoh et al., 2013). The nitrogen content in cow manure is also valued for its real influence on cultivation, which is good for plant agriculture (Setyaningrum, 2019). Therefore, nitrogen nutrients play a very important role in supporting stability, and the land becomes more fertile.

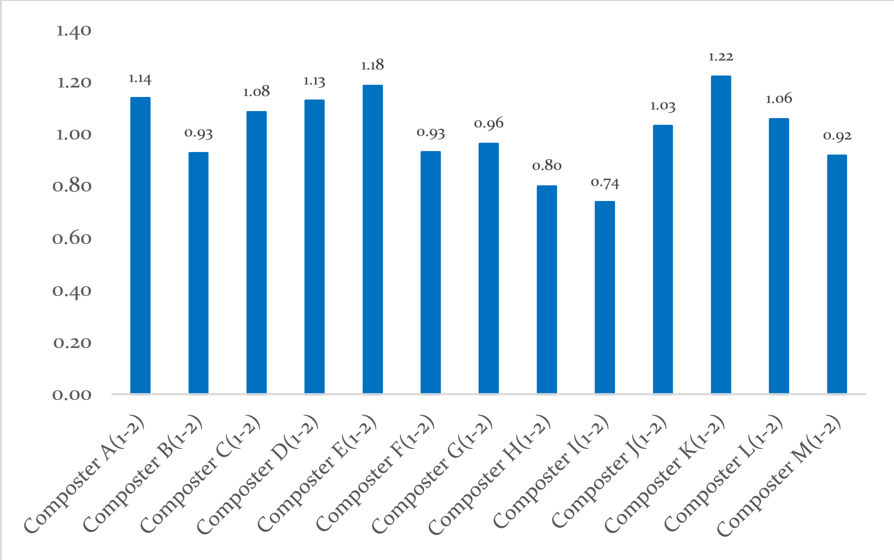

Figure 3. Graph N-total content (%)

Nitrogen is a macronutrient required by plants for optimal growth fertile and maximal. In addition, microorganisms require nitrogen; the higher the nitrogen content, the faster the decomposition of organic material (Kaswinarni and Nugraha, 2020). Organic ingredients that are rotten will decompose and become nutrients, one of which is nitrogen. The main source of nitrogen in the compost fertilizer in this study was plant litter mixed with goat manure, which contains ammonia. The decomposition process that produces nitrogen in compost involves three main reaction stages: amination, ammonification, and nitrification (Surtinah, 2013). The aminase reaction breaks down proteins in organic matter into amino acids. Subsequently, through the amonification reaction, these amino acids are converted into ammonia (NH_3) and ammonium (NH_4^+). The final stage is nitrification, which is the conversion of ammonia into nitrate (NO_3^-) with the help of bacteria such as Nitrosomonas and Nitrosocooccus. Nitrogen is a main component of protein and amino acids and is a macronutrient that is important for plant growth (Dappa and Hambakodu., 2013).

3.4. Phosporus Content

The content of macronutrient phosphorus in every treatment was in the range of 0.91% to 1.19%. Fertilizer B is fertilizer with the lowest phosphorus level compared to the other 12 fertilizers, while H, I, M, E, J, C, L, G, D, F, A, and K fertilizers are variation fertilizers that are consecutive, with a total N content higher on each variation fertilizer, with the highest content in K fertilizer , namely 1.19% with treatment waste organic 80% bioplastic 20% eM4 30 ml because it enters the minimum limit of SNI 7763:2024 and has a phosphorus content higher than the treatment control. The influence of phosphorus height in compost is the fusion of macronutrients (Marlina and Asngad., 2016). Compost contains beneficial nutrients such as nitrogen, potassium, iron, and calcium. The influence of tall, low-content phosphorus is technically influenced by time, temperature, substance addition, and others. Low phosphorus levels result from a lack of balanced energy, which hinders the ability of microbes to break down organic matter (Qaramaleki et al., 2020; Marlina, 2016).

Phosphorus This becomes afunctions asoexisting macronutrientswith macronutrientsgen and potassium (Hapsari and Welasi, 2013). Organic dirt could be one of the places where phosphorus exists in the material. Therefore, when producing organic fertilizer, cow dung is typically added as a primary material to optimize the macronutrient and phosphorus content (Fikdalillah et al., 2016). The addition of EM4 with a dose of 10% volume can increase the content of available phosphorus (P-Olsen) by 35–40% compared to the control without the inoculant, with the most significant improvement occurring in the thermophilic composting phase (days 14–21) when the activity of the enzyme phosphatase reaches its peak (Zhang et al., 2021).

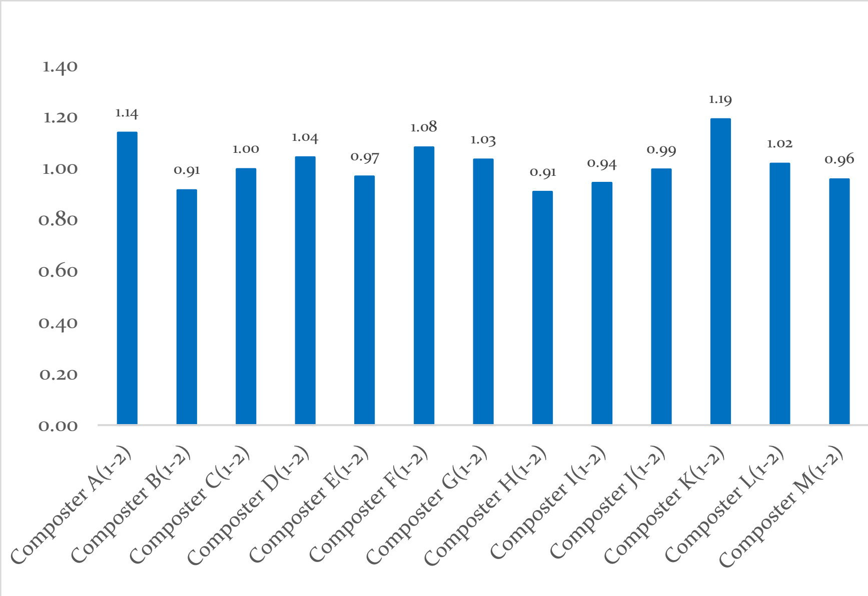

Figure 4. Graph contents phosphorus (%)

Phosphorus levels are one of the balancing nutrients in the layered land. In addition, phosphorus can also be found in plants and animal feces. The source of phosphorus in compost fertilizer comes from the decomposition of organic materials derived from waste, including animal manure, plant residues, and kitchen waste (Indrawan et al., 2016). The more varied the compost materials, the higher the phosphorus content (Akbari et al., 2022). Function of Phosphorus: This becomes a balancer coexisting mamacronutrientith nitrogen and potassium (Hapsari and Welasi, 2013). The more sufficient phosphorus in plants and soil, the more optimal the fertility level is. However, if a plant lacks phosphorus, then what will happen is the leaf will experience damage, productivity will decline, and plants will easily be attacked by disease (Nezamivand et al., 2023). Phosphorus can stimulate root development, allowing plants to withstand drought and accelerate the harvest period (Elfiati, 2005). Phosphorus plays a role in the formation of roots, flowers, and fruit and also increases the energy required in the metabolic process of plants.

3.5. Potassium Content

The potassium in every treatment was content in the range of 0.34% to 0.62%. Fertilizer D is the fertilizer with the lowest potassium levels compared to the 12 other fertilizers, while fertilizers E, I, M, C, F, J, L, H, K, A, B, and G are variation fertilizers that consecutively have higher potassium content, with the highest content in fertilizer H, namely 0.62%, with treatment waste organic 95% bioplastic 5% eM4 30 ml, because it enters the minimum limit of SNI 7763:2024 and has a higher potassium content than the treatment control. The mineral content in compost is the potassium needed for plants, as much as 0.5% (Ginting, 2018).

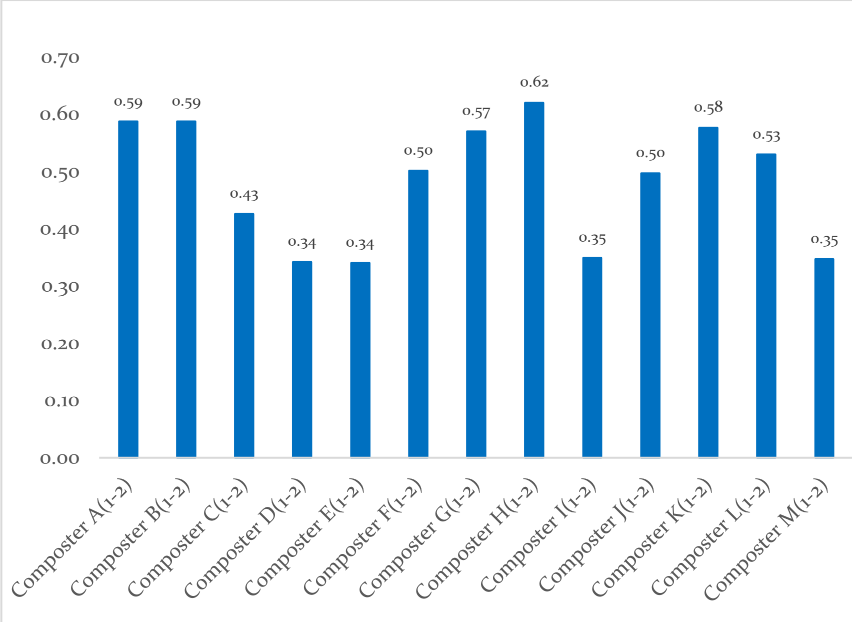

Figure 5. Graph potassium content (%)

The addition of EM4 with a dose of 7.5% volume can increase the potassium content available by 28-35% compared to the control without inoculant, with the most significant improvement occurring in the thermophilic phase (day 10 to 20) when the production of sour organic matter reaches its peak (Chen et al., 2021). Potassium is an abundant macronutrient needed by plants and absorbed by plants in the form of K+ ions. Potassium in cytoplasm and chloroplasts is required to neutralize the solution so that it has a pH of 7-8 (Shabala & Pottosin, 2014). Potassium has a role as a catalyst that is an assembler and disassembler of carbohydrates, especially in the conversion of proteins and amino acids. When plants have potassium deficiency, then accumulation of carbohydrates, decreasing levels of starch, and accumulation of nitrogen compounds happen so that the plant easily collapses (Hasanuzzaman , 2018). The microbes contained in EM4 utilize potassium in green vegetables when decomposing complex organic matter into simpler organic matter, making potassium available for plants (Kaswinarni and Nugraha, 2020). The adding dirt combined with potassium provides good and real influence on plants (Kesuma and Saputra., 2022). This is reinforced with existence change evident on the trunk , leaves , twigs/branches, and weight of the fruit produced. The cow dung could be one of the alternative potassium providers as well as give good influence and improvement to the physical structure of vegetable plants (Lukmana and Abdillah., 2022).

3.6. Water Content

The water content in each treatment is in the range of 14.31% to 24.60%. The minimum and maximum limits for water content are 8-25%. L fertilizer is fertilizer with the lowest water content compared to the 12 other fertilizers, while H, M, E, B, J, A, I, F, C, G, D, and K fertilizers are variation fertilizers that are consecutive with their own content higher in water content on each variation fertilizer with the highest content in K fertilizer , namely 24.60% with treatment waste organic 80% bioplastic 20% eM4 30 ml because it meets the minimum and maximum limits of SNI 7763:2024 and has content higher water content tall from treatment control .

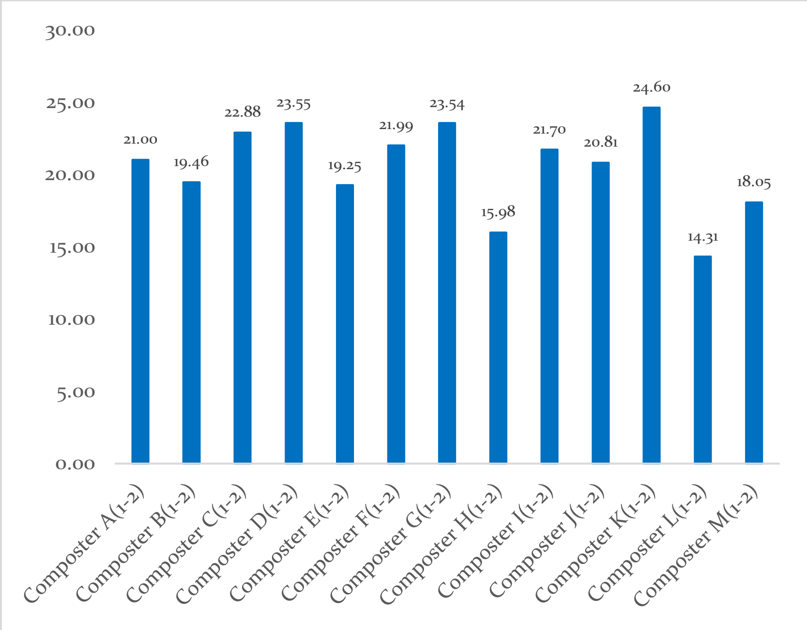

Figure 6. Graph water content (%)

This result is in line with the research by Setiawan et al. (2024), which found that the moisture content in compost is in the range of 16-21% to support the process of microbial dispersion into the pores of the compost material through oxygen circulation. The optimal water content is a crucial factor in reaching the success of the composting process; the right water content will facilitate the activity of microorganisms that play a role in transforming organic material into compost so that, at the optimum water content, decomposer microorganisms work well (Widarti et al., 2015). The water content is too high; low can hinder activity in microbes, while too much water content can cause anaerobic conditions and trigger the emergence of unpleasant smells.

Water content is one of the physical parameters in land and also organic fertilizer. Indicator water content is the level of moisture contained in an object that has undergone a process that is indicated by the intensity of the water in it (Daud et al., 2019). In addition, water content is also found in the feces of animals like cows, goats, and cattle, among others. The high water content in the substrate dirt cow is caused by the presence of lots of pores as well as still contains composition chemistry in the form of hemicellulose, cellulose, and lignin (Santosa and Anugrah, 2015). Water content is an important indicator to show how much water is contained in a material. Testing water content is a good use method for heavy dry and also heavy wet; it is important for being carried out on various types of materials, including fertilizer.

3.7. Additional Materials

Based on test results and calculations, there are several material follow-ups found in every treatment: fertilizer, compost, and bioplastic. By-products include plastic, rocks, and gravel. While material joins in the form of glass and metal, none is found in every treatment fertilizer compost. The accompanying material in each treatment is in the range of 0 % to 0.05719%. The maximum limit for material joining is 2%. Fertilizer F is fertilizer with material joined in most compared to the 12 other fertilizers, while M, L, G, I, E, K, D, J, B, H, C, and A fertilizers are variation fertilizers that are consecutively low in content and high in water content in every variation fertilizer, with the content the lowest in fertilizers A & C , namely 0%, with treatment of 100% organic waste & 90% organic waste and 10% bioplastic. The by-products in each fertilizer variation are categorized as safe because they do not exceed the maximum limit of SNI 7763:2024.

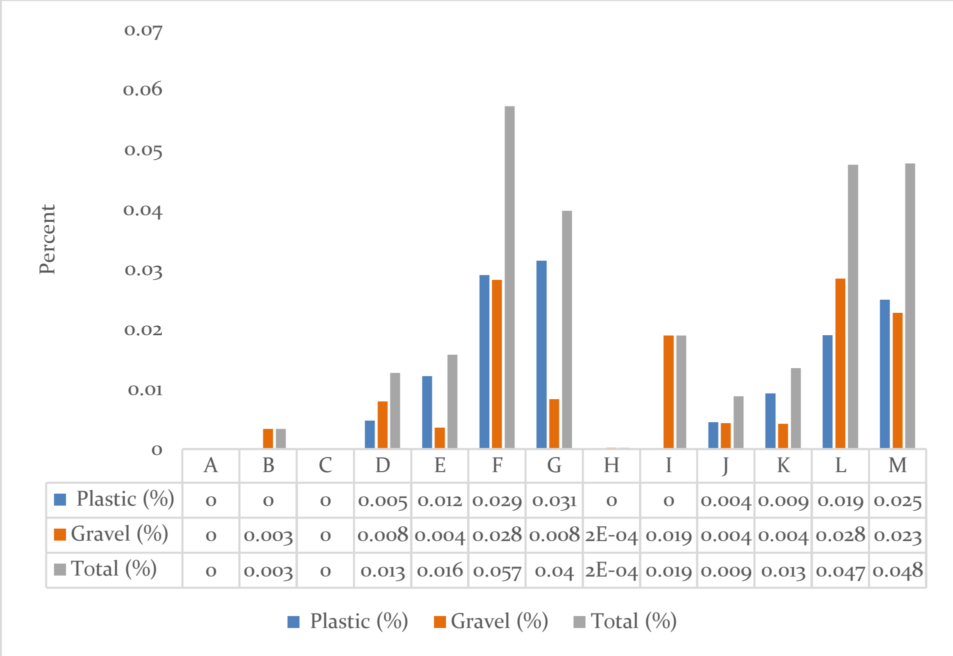

Figure 7. Graph additional materials (%)

Supporting materials are one of the parameters set in making fertilizer organically dense. This is because the minimum level of accompanying materials mixed up in organic fertilizer as densely as possible influences the quality and quantity of the fertilizer unit (Bernal, 2017). The fewer contaminants found in organic fertilizer indicate that its quality is better (Zuhro et al., 2019). Analysis of materials joined in This is done with the method of inquiry with a manual mesh sieve with an accuracy of 0.2 mm. To support this, supporting materials, foreign substances, or by-products contained in the unfiltered bioplastic compost will be analyzed.

3.8. pH

The pH content test results for each treatment fall within the range of 6.30 to 7.60. The minimum and maximum pH limits are 4-9%. Fertilizer B is the fertilizer with the lowest pH compared to the 12 other fertilizers, while fertilizers C, J, L, D, H, A, E, F, G, M, I, and K are variations of fertilizer that are consecutively higher in pH content, with the highest content in fertilizer K, namely 24.60%, with treatment waste organic 80%, bioplastic 20%, and eM4 30 ml, because it meets the minimum and maximum limits of SNI 7763:2024 and has a higher water content than the treatment control. said that added starch modified in bioplastic can affect the pH because it releases hydroxyl compounds during degradation (Ghanbarzadeh et al., 2010).

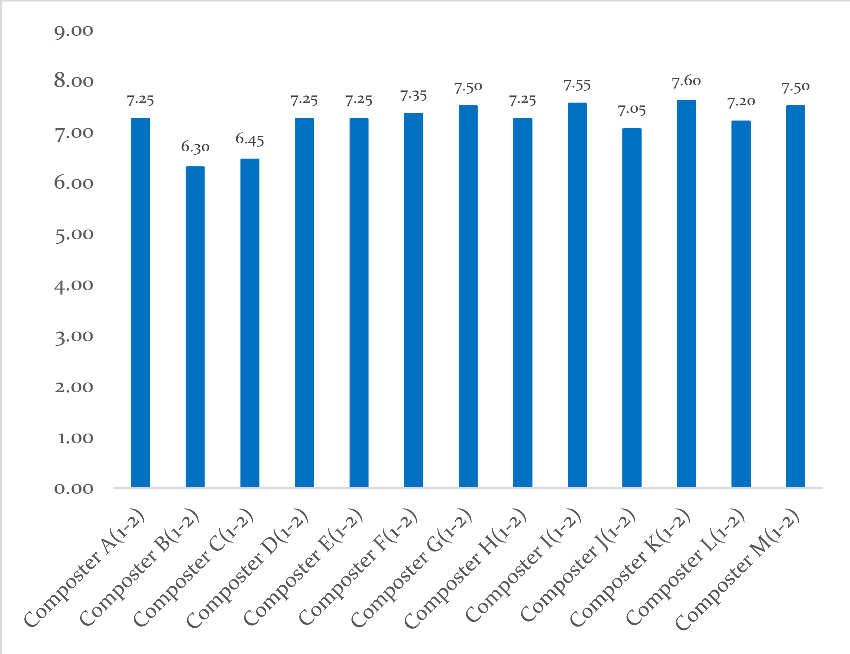

Figure 8. Graph pH content (%)

Acidity level in the composting process is an important factor. Because this pH change shows the existence of activity of microorganisms to degrade organic material. pH is a condition of sourness or basicity owned by the material. Conditions are sour if pH < 7, whereas a pH level > 7 indicates one material is currently in condition language. Condition sour language owned a material lot influenced by other factors that can cause tall low pH. During the composting process, the pH conditions fluctuate due to several factors, especially anaerobic conditions and the nitrogen content in the compost materials (Natsir et al., 2022). At the beginning of composting, the pH tends to be acidic due to bacterial activity, which produces acidic organic matter. The microorganisms work to decompose the organic matter, and the pH eventually reaches neutral during the decomposition process (Damayanti et al., 2018; Witasari et al., 2021).

4. Conclusions

The content of macro nutrients in fertilizers and compost produced from bioplastics and organic waste generally meets the standards set by SNI 7763:2024 based on the parameters of C-organic, N-total, phosphorus, potassium, pH, moisture content, and accompanying materials. Based on the 13 treatment variations studied, the variation that produced the best macro nutrient content, thus having high potential as compost fertilizer, was found in treatment K with an organic waste composition of 80%, bioplastics 20%, and EM4 30 ml. Treatment K has met 90% of the quality parameters set by SNI 7763:2024 regarding solid organic fertilizers with C-Organic content of 30.46%, macro nutrients 2.88%, moisture content 24.60%, accompanying materials 0.01%, and neutral pH 7.60.

Acknowledgement

This research was fully funded by the Universitas Sebelas Maret Surakarta, Indonesia, with the following statement letter number 369/UN27.22/PT.01.03/2025.

Ethics Statement

This study did not involve human participants, animals, or sensitive data; therefore no ethical approval was required.

CRediT Author Statement

Siti Rachmawati: Conceived and Designed Analysis, Collected Data, Performed Analysis, Wrote Paper. **Hashfi Hawali Abdul Matin:** Conceived and Designed Analysis, Collected Data, Performed Analysis. **Sapta Suhardono:** Conceived and Designed Analysis, Collected Data, Performed Analysis. **Agnar Pradipa Daniswara:** Conceived and Designed Analysis, Contributed and Analysis Tools, Wrote Paper. **Ririn Nur Fadhilah:** Conceived and Designed Analysis, Collected Data, Wrote Paper. **Siti Nurlita:** Contributed and Analysis Tools, Performed Analysis.

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