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Chemical Characteristics of Water Hyacinth Pellet Fertilizer with Different Adhesive Materials

Nukhak Nufita Sari, Ronny Mulyawan*, Irvan Indra Resnawan

Department of Agroecotechnology, Faculty of Agriculture, Lambung Mangkurat University, Jalan Jenderal A. Yani KM 36 Simpang Empat, Banjarbaru 70714, Indonesia

*Correspondence author email: ronny.mulyawan@ulm.ac.id

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Abstract

High application of inorganic fertilizers can negatively affect soil fertility and environmental sustainability. Organic farming uses organic materials to improve soil quality and support sustainable crop production. Water hyacinth (*Eichhornia crassipes*), an invasive aquatic weed, has potential as a raw material for pellet organic fertilizer. This study aimed to evaluate the chemical characteristics of water hyacinth pellet fertilizer using different adhesive materials in accordance with SNI 7763:2024 and to determine the most suitable adhesive material. The research was conducted using a descriptive-experimental method with three adhesive treatments: ET1 = water hyacinth flour + tapioca flour; ET2 = water hyacinth flour + wheat flour; and ET3 = water hyacinth flour + rice bran flour. Each treatment was repeated three times. All treatments used a ratio of 1:2:4 (water: water hygienist: adhesive). Chemical analyses included pH, organic C, total N, total P, total K, total macronutrients, and the C/N ratio. The results showed that pellet fertilizers with tapioca and wheat flour adhesives met the SNI standards for pH and organic C but did not meet the standards for total macronutrients and the C/N ratio. Pellet fertilizer with rice bran flour adhesive met the SNI standards for pH, organic C, and total macronutrients, although its C/N ratio exceeded the maximum standard limit. Rice bran adhesive also produced the highest total N, P, K, and total macronutrient contents among the treatments. Overall, rice bran flour was identified as the most suitable adhesive for improving the chemical quality of water hyacinth pellet fertilizer, in accordance with SNI 7763:2024.

1. Introduction

The intensive use of inorganic fertilizers continues to dominate agricultural systems in Indonesia, particularly urea and NPK fertilizers. Fertilizer utilization data from the agricultural, plantation, and industrial sectors show that fertilizer consumption in Indonesia during 2017–2022 averaged 10 million tons per year, consisting of 5.8 million tons of urea fertilizer and 3.1 million tons of NPK fertilizer (Zainuddin et al., 2024). The continuous use of inorganic fertilizers in unbalanced doses can have negative effects on soil fertility, both physically, chemically, and biologically. From a physical perspective, long-term use of inorganic fertilizers can decrease soil organic matter content, resulting in a denser soil structure, reduced porosity, a decreased ability to retain air, and an increased risk of erosion and soil compaction. From a chemical perspective, the accumulation of certain fertilizer residues can cause nutrient imbalances, shift soil pH toward greater acidity, increase salinity under certain conditions, and reduce the cation exchange capacity (CEC), which plays a vital role in providing nutrients to plants. Meanwhile, from a biological perspective, excessive use of inorganic fertilizers can reduce the diversity and activity of soil microorganisms that play a role in organic matter decomposition, nitrogen fixation, phosphate dissolution, and other nutrient cycles. This decrease in soil biota activity can ultimately disrupt the balance of the

soil ecosystem, reduce the efficiency of nutrient utilization by plants, and lead to a continuous decline in land productivity (Abduh et al., 2024).

One effort to reduce these negative impacts is the implementation of organic farming, which uses organic materials as nutrient sources for plants. Organic fertilizers play an important role in improving soil structure, enhancing soil biological activity, and reducing the risk of environmental pollution caused by inorganic fertilizer residues (Adawiyah and Pakki, 2019). In addition to livestock manure and crop residues, organic materials for fertilizer production can also be obtained from plant biomass, including aquatic weeds that are abundantly available in aquatic environments. The abundance of water hyacinth (*Water hyacinth*) in swamp areas is influenced by ecological conditions that support its growth, such as abundant water availability, calm waters, and high nutrient content, especially nitrogen. High nitrogen concentrations in water, which generally come from agricultural fertilizer runoff, domestic waste, and other activities, stimulate the rapid vegetative growth of water hyacinth. These conditions increase the rate of reproduction and spread of water hyacinth, so this plant grows very rapidly and dominates the water surface.

Water hyacinth is an aquatic weed commonly found in rivers, swamps, and lakes, and it grows very rapidly. Uncontrolled growth of water hyacinth can cause various environmental problems, such as sedimentation, declining water quality, and disruption of water flow (Tobing and Harahap, 2024). Therefore, using water hyacinth as a raw material for organic fertilizer represents an alternative approach for managing aquatic weed biomass with added value. Previous studies have reported that water hyacinth has potential as an organic fertilizer due to its relatively high levels of nutrients and organic matter (Ismail and Staddal, 2020). Water hyacinth is a biomass with a relatively high nutrient content, making it potentially useful as a raw material for organic fertilizer. Based on dry weight, water hyacinth generally contains around 30–45% organic carbon (C-organic), 1.5–3.5% nitrogen (N), 0.2–1.2% phosphorus (P), and 1.5–5.0% potassium (K). In addition to these macronutrients, water hyacinth also contains secondary nutrients such as around 0.5–2.5% calcium (Ca) and 0.2–1.0% magnesium (Mg). Commonly found micronutrients include iron (Fe) at approximately 500–5,000 mg kg^{-1}, manganese (Mn) at 100–1,000 mg kg^{-1}, zinc (Zn) at 20–300 mg kg^{-1}, copper (Cu) at 5–50 mg kg^{-1}, and boron (B) at 10–80 mg kg^{-1}. The high organic carbon content and the presence of these macro and micronutrients make water hyacinth a potential raw material for organic fertilizer. However, some of these nutrients can still be lost through leaching, evaporation, or fixation in the soil, so the addition of binders or soil conditioners is necessary to increase nutrient retention and the efficiency of their utilization by plants.

During development, organic fertilizer should be practical, easy to apply, and have good storage stability. One processing option is to produce pellet fertilizer. Pellet fertilizer offers advantages such as a denser form, easier storage and application, and better consistency of chemical composition compared to conventional organic fertilizers (Santari et al., 2019). The quality of pellet fertilizer is influenced by both the raw materials and the adhesive agents used during the manufacturing process. Different adhesive materials may affect the chemical and physical characteristics of pellet fertilizer, including nutrient content, density, and product stability.

Commonly used adhesive materials include tapioca flour, wheat flour, and rice bran. Tapioca flour has been reported to increase N, P, and K contents as well as improve pellet density (Sastrawan and Erita, 2018). Wheat flour has good water absorption capacity and stability during pellet formation, whereas rice bran contains relatively high level of phosphorus and potassium, which may improve the nutrient quality of organic fertilizer (Supriyono et al., 2016). However, information on the effects of different adhesive materials on the chemical characteristics of water hyacinth-based pellet fertilizer, particularly in accordance with SNI 7763:2024 quality standards, remains limited. Therefore, this study was conducted to evaluate the chemical characteristics of water hyacinth-based pellet fertilizer produced with different adhesive materials and to determine which adhesive material best complies with the SNI 7763:2024 quality standard.

2. Research Methods

2.1. Study Area

The study was conducted over six months, from October 2024 to March 2025. Water hyacinth (*Eichhornia crassipes*) was collected from Kertak Baru, Cindai Alus, Martapura District, Banjar Regency, South Kalimantan, Indonesia. Pellet fertilizer production and laboratory analyses were carried out at the Integrated Laboratory, Production Laboratory of the Agroecotechnology Department, and Soil Laboratory of the Soil Science Department, Faculty of Agriculture, Universitas Lambung Mangkurat.

2.2 Experimental Design

The study employed a descriptive-experimental method with three adhesive material treatments in the production of water hyacinth-based pellet fertilizer, namely: ET1 = water hyacinth flour + tapioca flour; ET2 = water hyacinth flour + wheat flour; and ET3 = water hyacinth flour + rice bran flour. Each treatment was replicated three times.

2.3. Preparation of Water Hyacinth Flour

Fresh water hyacinth (42 kg) was selected based on relatively uniform size, green color, complete plant organs, and absence of physical damage. The water hyacinth was washed under running water to remove mud and impurities, then chopped into 2–3 cm pieces. The material was oven-dried at 90°C for 24 h. The dried material was ground using a blender to produce flour and sieved through a 60-mesh sieve to obtain a uniform particle size (Iriany et al., 2016). The resulting water hyacinth flour was stored in sealed containers prior to pellet production.

2.4. Pellet Fertilizer Production

Pellet fertilizer was prepared by mixing water hyacinth flour, adhesive material according to treatment, and distilled water at a ratio of 1:2:4. Each formulation consisted of 100 g water hyacinth flour, 200 g adhesive material, and 400 mL distilled water (Prasojo et al., 2022). The ingredients were mixed gradually until a homogeneous and cohesive dough was obtained. The dough was pelletized using an electric pelletizer equipped with an 8 mm die. The resulting pellets were subsequently dried in an oven at 70°C for 48 h.

2.5. Physical Analysis of Pellet Fertilizer

The cracking percentage of the pellet fertilizers was determined visually after drying. A total of 100 pellets were randomly collected from each treatment and evaluated for visible cracks on their surfaces. Pellets showing partial or complete surface fractures were categorized as cracked pellets. Observations were conducted under ambient laboratory conditions, and each treatment was evaluated in triplicate to ensure data reliability. The cracking percentage was then calculated using the following equation:

$$\text{Cracking Percentage}(\%) = \frac{\text{Number of cracked pellets}}{\text{Total number of pellets observed}} \times 100$$

2.6. Chemical Analysis of Pellet Fertilizer

Chemical analyses included pH, organic carbon (organic C), total nitrogen (total N), total phosphorus (total P), and total potassium (total K). The pH was determined using a water extraction method with a sample-to-water ratio of 1:5, followed by measurement with a calibrated pH meter. Organic carbon content was determined using the Walkley and Black method. Total N was analyzed using the Kjeldahl method, whereas total P and K were determined after wet digestion using a spectrophotometer and flame photometer, respectively.

2.7. Data Analysis

The chemical properties of the pellet fertilizers, as determined by laboratory analyses, were evaluated against the quality standards for solid organic fertilizers specified in SNI 7763:2024, issued by the National Standardization Agency of Indonesia. The data were tabulated and interpreted descriptively to assess the chemical characteristics of pellet fertilizers produced with different adhesive materials.

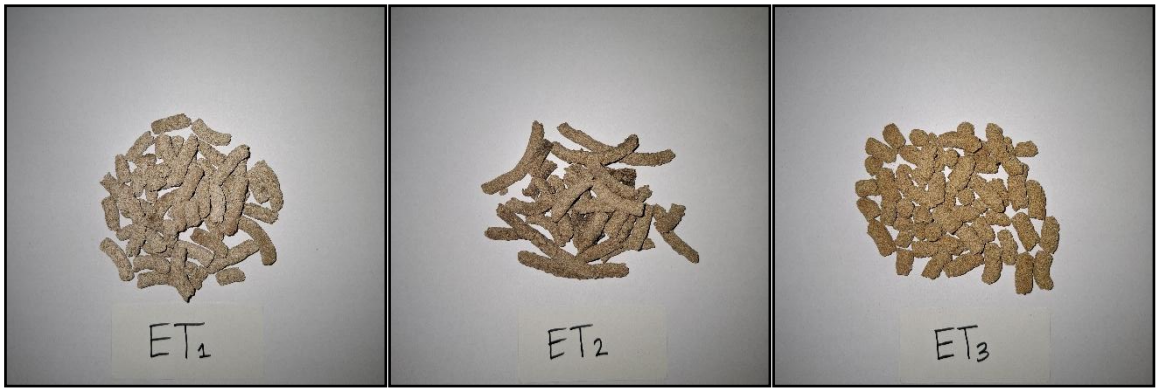
3. Results and Discussion

3.1. Chemical Characteristics of Pellet Fertilizer

Water hyacinth (*Eichhornia crassipes*) is a potential source of organic material for fertilizer production. The utilization of water hyacinth in pellet fertilizer form may improve soil fertility and enhance nutrient availability for plant uptake (Gulo et al., 2024). Water hyacinth pellet fertilizers produced using three different adhesive materials are presented in Figure 1. Treatment ET1 produced light brown pellets with an average length of 2.5 cm and a cracking percentage of 35%. Treatment ET2 produced dark brown pellets with an average length of 2.5 cm and a cracking percentage of 30%. In contrast, treatment ET3 produced brown pellets with an average length of 1.8 cm and a cracking percentage of 45%.

The chemical quality of water hyacinth-based pellet fertilizers varied depending on the type of adhesive material used. The chemical properties of pellet fertilizers from each treatment were compared with the quality standards for solid organic fertilizers established in SNI 7763:2024, as presented in Table 1. The pellet fertilizers exhibited pH values ranging from 5.1 to 6.2, organic C contents from 39.44% to 39.71%, total macronutrient contents from 0.90% to 3.88%, and C/N ratios ranging from 33.94 to 76.36.

According to SNI 7763:2024, the parameters of total N, P, and K are not evaluated separately in the quality assessment of solid organic fertilizers. Therefore, the interpretation of these nutrient contents was complemented using the soil chemical analysis. The chemical analysis results presented in Table 2 showed that total N content ranged from 0.52% to 1.17%, total P from 0.28% to 2.57%, and total K from 0.10% to 0.20%.



a b c

Figure 1. Water hyacinth-based pellet fertilizers using (a) tapioca flour, (b) wheat flour, and (c) rice bran flour as adhesive materials.

Table 1. Chemical properties of water hyacinth-based pellet fertilizers with different adhesive materials based on SNI 7763:2024

Parameter	Treatment			Standard*
	Tapioca flour adhesive	Wheat flour adhesive	Rice bran flour adhesive	
pH H_2O	6.2	5.8	5.1	4 - 9
	Eligible	Eligible	Eligible	
Organic C (%)	39.71	39.71	39.44	Minimum 15
	Eligible	Eligible	Eligible	
Total Macro Nutrient (N+P+K) (%)	0.90	1.76	3.88	Minimum 2
	Ineligible	Ineligible	Eligible	
C/N	76.36	33. 94	35.53	Minimum 25
	Ineligible	Ineligible	Ineligible	

Source: * Standar Nasional Indonesia (2024)

Table 2. Chemical properties of water hyacinth-based pellet fertilizers with different adhesive materials based on BPSITP standards.

Parameter	Treatment			Standard*
	Tapioca flour adhesive	Wheat flour adhesive	Rice bran flour adhesive	
Total N (%)	0.52	1.17	1.11	<0.1 until >0.75
	high	very high	very high	
Total P (%)	0.28	0.47	2.57	<0.01 until >0.06
	very high	very high	very high	
Total K (%)	0.10	0.12	0.20	<0.01 until >0.06
	very high	very high	very high	

Source: * Eviati et al. (2023)

The adhesive materials used in pellet fertilizer production have distinct chemical characteristics that may affect the quality of the resulting pellets. Chemical analyses reported by various sources indicated variations in pH, organic C, total N, P, and K among the three adhesive materials, as presented in Table 3. The pH values of the adhesive materials ranged from 5.9 to 6.1, organic C content from 25.10% to 48.89%, total N from 0.04% to 1.66%, total P from 0.03% to 1.31%, and total K from 0.03% to 0.65%.

Table 3. Chemical characteristics of adhesive materials reported from various sources.

Adhesive	pH	Organic C (%)	N (%)	P (%)	K (%)
Tapioca	6.1[a]	48.89[d]	0.04[f]	0.03[i]	0.03[l]
Wheat	5.9[b]	47.44[d]	1.65[g]	0.42[j]	0.13[l]
Bran	6[c]	25.10[e]	1.66[h]	1.31[k]	0.65[m]

Source: [a]Rahmadhia et al. (2022); [b]Fauzanin et al. (2013); [c]Astawan et al. (2013); [d]Sukenda et al. (2016); [e]Putra et al. (2015); [f]Kustyawati et al. (2013); [g]Imanningsih (2012); [h]Luthfianto et al. (2017); [i]Faridah and Thonthowi, (2020); [j]Lin et al. (2019); [k]Farid et al. (2019); [l]Forsido et al. (2013); [m]Mahfud et al. (2021).

3.2. pH

pH is an important parameter for determining the quality of pellet fertilizer because it reflects the material's acidity or alkalinity. Organic fertilizers generally exhibit an optimum pH range of 6.5–7.5 (Kusumadewi et al., 2020). The results showed that the pH values of water hyacinth-based pellet fertilizers ranged from 5.1 to 6.2, and all treatments met the quality standards for solid organic fertilizers specified in SNI 7763:2024, which requires a pH range of 4–9. Treatment ET1 (tapioca flour adhesive) produced the highest pH value, which was 1.07 times higher than ET2 (wheat flour adhesive) and 1.22 times higher than ET3 (rice bran flour adhesive). Meanwhile, the pH value of ET2 was 1.14 times higher than that of ET3. These findings indicate that pellet fertilizers produced with tapioca and wheat flour adhesives tended to have higher, comparable pH values, whereas those produced with rice bran flour adhesive had lower pH values. The pH values observed in ET1 and ET2 were relatively consistent with those reported by Rahmadhia et al. (2022), while the pH value of ET3 was lower than that reported by Astawan et al. (2013).

The pH values of the pellet fertilizers were likely influenced by the chemical characteristics of water hyacinth as the primary raw material. Albanjari et al. (2026) reported that water hyacinth had a pH value of 6.12 and was classified as slightly acidic due to the presence of various organic acids. Several organic acids identified in the roots, petioles, and leaves of water hyacinth include humic, malonic, linoleic, and palmitic acids, which belong to the carboxylic acid group (Fileto-Pérez et al., 2015). These compounds were presumed to contribute to the acidity of the resulting pellet fertilizers.

In addition to the main material, the type of adhesive also affected pellet fertilizer pH, particularly in the treatment using rice bran flour adhesive. Latuamury (2017) reported that rice bran application could reduce pH due to its organic acid content. Rice bran contains fatty acids such as palmitic, oleic, linoleic, and α-linolenic acids formed through the hydrolysis of triglycerides into glycerol and free fatty acids. These fatty acids contain carboxyl groups (-COOH) that can undergo deprotonation in water, releasing H^+ ions (Putri et al., 2023). The reaction can be described as follows:

$$-COOH \rightarrow -COO^- + H^+$$

An increase in H^+ ion concentration in solution increases acidity and consequently lowers pH values (Fiqri et al., 2024). Therefore, the organic acid content in both water hyacinth and rice bran was likely the main factor contributing to the lower pH observed in treatment ET3.

3.3. Organic-C

Organic C is a primary component of organic matter and plays a crucial role in maintaining soil fertility. High organic C content can improve soil porosity, thereby enhancing the soil's capacity to retain water and nutrients and supporting optimal plant growth. The results showed that the organic C content of water hyacinth-based pellet fertilizers ranged from 39.44% to 39.71%, and all treatments met the quality standards for solid organic fertilizers specified in SNI 7763:2024, which requires a minimum value of 15%. Treatments ET1 (tapioca flour adhesive) and ET2 (wheat flour adhesive) produced relatively similar organic C contents, whereas ET3 (rice bran flour adhesive) showed a value 0.27% lower than the other two treatments. The differences among treatments were relatively small, indicating that all adhesive materials produced comparable organic C contents.

The high organic C content in the pellet fertilizers was likely associated with the use of water hyacinth as the primary raw material. Water hyacinth is rich in organic compounds, particularly cellulose, hemicellulose, and lignin, which are major structural components of plant cell walls (Firmansyah et al., 2022). Lara-Serrano et al. (2016) reported that the roots, petioles, and leaves of water hyacinth contain 8.4–16% cellulose, 3–27.5% hemicellulose, and 4.5–14.3% lignin. These organic compounds are closely associated with high organic C content because increasing organic matter generally increases the amount of organic C within the material (Yulina and Ambarsari, 2021).

In addition to the main raw material, the adhesive materials used in pellet production were also likely to contribute to the high organic C content. Tapioca flour, wheat flour, and rice bran are rich in carbohydrates composed mainly of carbon, hydrogen, and oxygen (Fitri and Fitriana, 2020). The carbohydrate contents of tapioca flour, wheat flour, and rice bran were reported to be 86.9%, 77.3%, and 58.69%, respectively (Luthfianto et al.,

2017). These carbohydrates, primarily in the form of starch, may serve as additional carbon sources in pellet fertilizers. Lin et al. (2026) also reported that adding carbohydrate-rich materials can increase the organic C content of organic materials.

The increase in organic C content may also be associated with carbon polymerization processes during organic matter formation. This process involves the transformation of simple carbon molecules into more complex carbon compounds, thereby increasing the organic C content of the material (Oko et al., 2021). Therefore, the combination of water hyacinth and flour-based adhesive materials resulted in pellet fertilizers with high organic C content that complied with the quality standards for solid organic fertilizers.

3.4. Total-N

Nitrogen is an essential nutrient that plays a crucial role in supporting vegetative plant growth, particularly in the development of leaves, stems, and roots. Adequate nitrogen availability enhances plant metabolic activity, thereby promoting more optimal growth (Pramushinta and Yulian, 2020). The analysis results showed that the total N content of water hyacinth pellet fertilizer ranged from 0.52% to 1.17%, which was classified as high to very high. Treatment ET2 (wheat flour adhesive) produced the highest total N content, which was 0.65% higher than ET1 (tapioca flour adhesive) and 0.06% higher than ET3 (rice bran flour adhesive). Meanwhile, ET3 exhibited a total N content that was 0.59% higher than ET1. These results indicate that the use of wheat flour and rice bran flour adhesives tended to increase the nitrogen content of pellet fertilizer compared with tapioca flour adhesive. The total N values obtained in treatments ET2 and ET3 were relatively consistent but lower than those reported by Imanningsih (2012) and Luthfianto et al. (2017), whereas the value in ET1 was higher than that reported by Kustyawati et al. (2013).

The high nitrogen content in the pellet fertilizer was likely due to the use of water hyacinth as the primary raw material. The nitrogen content in water hyacinth may originate from its protein content, which ranges from 3.8% to 10.40% (Fileto-Pérez et al., 2013). In addition, water hyacinth is capable of absorbing nitrogen from aquatic environments in the form of nitrate (NO_3^-) and ammonium (NH_4^+) (Sasaqi et al., 2018). Juwitanti et al. (2013) further reported that the decomposition process of water hyacinth produced the highest nitrate content in the leaves and the lowest in the roots, indicating that all parts of the plant have the potential to serve as sources of organic nitrogen.

In addition to the primary raw material, the use of wheat flour and rice bran adhesives was also presumed to increase the nitrogen content of the pellet fertilizer. Wheat flour and rice bran contain relatively high protein levels, thereby serving as additional nitrogen sources (Nidhishree et al., 2024). Proteins are composed of amino acids containing amine groups (NH_2), carboxyl groups (-COOH), and carbon atoms (C) (Dewangan et al., 2023). The presence of amine groups indicates the presence of nitrogen, a characteristic component of proteins, and their absence from carbohydrates and lipids. Nitrogen content in proteins is estimated to account for approximately 16% of their total constituent components (Pangalila et al., 2023). Therefore, adhesives with higher protein contents tend to produce pellet fertilizers with greater total N levels.

The increase in nitrogen content observed in organic amendments is closely associated with the mineralization process, in which soil microorganisms decompose organic matter and enzymatically convert complex organic nitrogen compounds, such as proteins, amino acids, and nucleic acids, into inorganic forms, including ammonium (NH_4^+) and subsequently nitrate (NO_3^-), which are available for plant uptake. However, the mineralization dynamics differ substantially between pelletized organic fertilizer and conventional compost. Compost generally possesses a loose and porous structure with a large surface area that facilitates rapid microbial colonization, aeration, and moisture penetration, resulting in relatively faster decomposition and nutrient release after application. In contrast, pellet fertilizers are produced through compaction and binding processes that create denser particles with a lower exposed surface area. This compact structure can limit water infiltration and microbial access to the organic substrate, thereby slowing the breakdown of organic matter and producing a more gradual and sustained release of nitrogen. As pellets disintegrate over time, microorganisms progressively degrade the water hyacinth biomass and associated binder materials, leading to the sequential release of NH_4^+ and NO_3^- into the soil. Consequently, water hyacinth-based pellet fertilizer may function not only as a source of organic nitrogen but also as a slow-release organic amendment that helps maintain nitrogen availability for a longer period while potentially reducing nutrient losses through leaching and volatilization compared with less compact organic materials. These characteristics suggest that pelletization modifies the mineralization pathway primarily by altering the physical accessibility of the substrate to microbial activity, thereby influencing the rate and pattern of nitrogen release in the soil.

3.4. Total-P

Phosphorus is an essential nutrient that plays an important role in root development, flowering, and fruit formation in plants. Adequate phosphorus availability can enhance root growth, strengthen plant stems, and support flowering and fruiting processes (Shalehah et al., 2024). The analysis results showed that the total P content of

water hyacinth pellet fertilizer ranged from 0.28% to 2.57%, which was classified as very high. Treatment ET3 (rice bran flour adhesive) produced the highest total P content, which was 2.29% higher than ET1 (tapioca flour adhesive) and 2.10% higher than ET2 (wheat flour adhesive). Meanwhile, ET2 exhibited a total P content that was 0.19% higher than ET1. These findings indicate that using rice bran flour adhesive tends to increase the phosphorus content of pellet fertilizer compared with tapioca and wheat flour adhesives.

The high phosphorus content in the pellet fertilizer was likely due to the use of water hyacinth as the primary raw material. Lara-Serrano et al. (2016) reported that the roots, petioles, and leaves of water hyacinth contain phosphorus ranging from 1.81% to 8.61%. This phosphorus is absorbed from aquatic environments in the form of phosphate and may be released again during the decomposition process of organic matter (Juwitanti et al., 2013). Therefore, the decomposition of water hyacinth tissues was presumed to be one of the sources contributing to the increased phosphorus content in the pellet fertilizer.

In addition to the primary raw material, the use of rice bran flour adhesive was also presumed to contribute significantly to the high total P content. Rice bran is known to contain higher phosphorus mineral levels than wheat flour (Damayanthi and Listyorini, 2007). Supriyono et al. (2016) reported that the addition of rice bran to organic fertilizer could produce Total P contents of up to 1053.54 ppm. The high phosphorus content in rice bran is associated with the presence of phytic acid, which functions as a phosphorus storage medium within the material (Farid et al., 2019). Approximately 60–90% of the total P in rice bran is stored as phosphate bound to phytic acid (Coulibaly et al., 2010). This was presumably the reason why treatment ET3 produced the highest total P content among all treatments.

The increase in phosphorus content in organic materials may also result from mineralization. Organic phosphorus is decomposed into simpler inorganic phosphorus forms that are more readily available for plant uptake. In addition, the degradation of phytic acid during organic matter decomposition may enhance phosphate release, thereby increasing phosphorus availability (Sine and Soetarto, 2018). Therefore, the combination of water hyacinth and rice bran adhesive has considerable potential to produce pellet fertilizer with higher phosphorus content.

3.5. Total-K

Potassium is an essential nutrient that plays an important role in enhancing plant tolerance to both biotic and abiotic stresses. Adequate potassium availability strengthens plant tissue structure, thereby reducing the likelihood of leaf, flower, and fruit drop (Shalehah et al., 2024). The results showed that the total K content of water hyacinth-based pellet fertilizers ranged from 0.10% to 0.20%, which falls within the very high category. Treatment ET3 (rice bran flour adhesive) produced the highest total K content, which was 0.10% higher than ET1 (tapioca flour adhesive) and 0.08% higher than ET2 (wheat flour adhesive). Meanwhile, ET2 exhibited a total K content 0.02% higher than ET1. These findings indicate that using rice bran flour adhesive tends to increase the potassium content of pellet fertilizers compared with those using tapioca or wheat flour adhesives. The total K values observed in ET1 and ET2 were relatively consistent with those reported by Forsido et al. (2013), whereas the value observed in ET3 was lower than that reported by Mahfud et al. (2021).

The high potassium content in the pellet fertilizers was likely associated with the use of water hyacinth as the primary raw material. Zhou et al. (2007) reported that the roots, petioles, and leaves of water hyacinth contain potassium ranging from 0.31% to 2.69%. Water hyacinth is known to absorb potassium from aquatic environments as K^+ ions, with an absorption capacity of up to 69.7%. Therefore, water hyacinth biomass has considerable potential as a source of organic potassium in pellet fertilizer production.

In addition to the main material, the use of rice bran flour adhesive likely contributed to the increased potassium content of the pellet fertilizers. Damayanthi and Listyorini (2007) reported that potassium is the second most abundant mineral component in rice bran after phosphorus. Rice bran contains relatively high mineral concentrations ranging from 7.33% to 15.02% (Luthfianto et al., 2017), suggesting that its addition may enhance the total K content of pellet fertilizers. This may explain why treatment ET3 produced the highest potassium content among all treatments.

The increase in potassium content may also be related to mineralization processes occurring during organic matter decomposition. During decomposition, potassium is released in the form of K^+ ions that are more readily available for plant uptake (Marak et al., 2023). Therefore, the combination of water hyacinth and rice bran adhesive has the potential to produce pellet fertilizers with higher potassium content, thereby enhancing nutrient availability for plants.

3.6. Total Macronutrients

Total macronutrients represent the combined concentration of essential macronutrients required by plants in large quantities to support growth and productivity. Based on the calculation of total macronutrient content in water hyacinth-based pellet fertilizers, treatment ET3 (rice bran flour adhesive) produced the highest value, which was 2.98% higher than ET1 (tapioca flour adhesive) and 2.12% higher than ET2 (wheat flour adhesive). Meanwhile, ET2 exhibited a total macronutrient content 0.86% higher than ET1. These findings indicate that the use of rice

bran flour adhesive contributed more substantially to increasing total macronutrient content than the use of tapioca and wheat flour adhesives.

According to the quality standards for solid organic fertilizers specified in SNI 7763:2024, treatments ET1 and ET2 did not meet the required standard because their total macronutrient contents were below the minimum threshold of 2%. In contrast, the ET3 treatment met the standard, as its total macronutrient content exceeded 2%. These results suggest that the combination of water hyacinth and rice bran flour adhesive has greater potential to produce pellet fertilizers with superior chemical quality compared with formulations using tapioca or wheat flour adhesives.

The higher total macronutrient content observed in ET3 was likely associated with the relatively higher nutrient content of rice bran, particularly phosphorus and potassium. Previous studies have shown that the appropriate selection of adhesive materials can improve the chemical quality of pellet fertilizers (Juwaningsih and Pandjaitan, 2024). Therefore, rice bran flour may serve as a promising alternative adhesive to enhance the macronutrient content of pellet fertilizers that do not yet meet quality standards. The availability of essential macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) is critical for supporting optimal plant growth and development (Batubara et al., 2024). Organic fertilizers with macronutrient contents that comply with quality standards have considerable potential for application as organic nutrient sources in soil and crop management (Afsyah et al., 2021).

3.7. C/N Ratio

The C/N ratio represents the carbon-to-nitrogen ratio in organic materials and plays an important role in decomposition processes and in nutrient availability for plants. The results showed that the C/N ratios of water hyacinth-based pellet fertilizers in all treatments exceeded the maximum limit of 25 specified in SNI 7763:2024, indicating that none of the treatments met the quality standard for solid organic fertilizers. Treatment ET1 (tapioca flour adhesive) produced the highest C/N ratio, which was 2.25 times higher than ET2 (wheat flour adhesive) and 2.15 times higher than ET3 (rice bran flour adhesive). Meanwhile, the C/N ratio of ET3 was 1.05 times higher than that of ET2. These findings indicate that the use of tapioca flour adhesive tended to yield higher C/N ratios than wheat flour and rice bran flour adhesives.

A high C/N ratio indicates that the organic material still contains relatively high levels of complex carbon compounds, such as cellulose, lipids, and waxes, resulting in slower decomposition (Darma et al., 2021). In contrast, a lower C/N ratio suggests that organic material decomposes more readily, making nutrients available to plants more rapidly. The C/N ratio also influences nutrient availability in pellet fertilizers. High C/N ratios may reduce nutrient availability, particularly nitrogen, because microorganisms use available nitrogen during decomposition. Conversely, lower C/N ratios enhance nutrient availability, making fertilizers more effective in meeting plant nutrient requirements.

The high C/N ratios observed in this study were likely associated with the direct use of fresh water hyacinth processed into flour without prior composting. Water hyacinth contains relatively high levels of cellulose, hemicellulose, and lignin, which contribute to its elevated organic C content. One potential approach to reduce the C/N ratio of pellet fertilizers is to compost the raw material before pelletization. Dhairobi et al. (2022) reported that the use of composted organic materials in pellet fertilizer production reduced the C/N ratio of the resulting products. A decrease in the C/N ratio indicates improved decomposition and increased nitrogen availability. Therefore, composting water hyacinth prior to pellet production may improve the quality of pellet fertilizer and enhance compliance with SNI 7763:2024.

4. Conclusion

Based on the results of this study, the type of adhesive material significantly influenced the chemical characteristics of water hyacinth-based pellet fertilizers. Pellet fertilizers produced using tapioca and wheat flours as adhesives met the SNI 7763:2024 quality standards for pH and organic C; however, their total macronutrient content and C/N ratio did not meet the required standards. In contrast, pellet fertilizer produced using rice bran flour adhesive met the SNI 7763:2024 standards for pH, organic C, and total macronutrients, although its C/N ratio still exceeded the maximum allowable limit. The use of rice bran flour as an adhesive resulted in the highest levels of total N, P, K, and total macronutrients compared with adhesives made from tapioca and wheat flours, indicating its superior potential to improve the chemical quality of water hyacinth-based pellet fertilizers. Nevertheless, the consistently high C/N ratios observed across all treatments suggest that the organic material still requires a composting process prior to pelletization to enhance decomposition and improve compliance with solid organic fertilizer quality standards.

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