

Formulation of Granular Fertilizer from Elephant Grass Ash and Urea with Tapioca Binder

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ABSTRACT

Elephant grass remains underutilized, despite its ash containing high levels of potassium and its potential as a raw material for fertilizer production. This study aims to evaluate the effect of mixing ratios of elephant grass ash and urea with tapioca starch binder on fertilizer composition in accordance with quality standards, and to examine how binder concentration influences the characteristics of the resulting granules. The process began by burning elephant grass into charcoal, followed by ashing in a furnace at 600°C for 4 hours. The ash was then mixed with urea and tapioca starch at various compositions. The variables included urea additions of 20%, 25%, 30%, 35%, and 40% (w/w), and binder concentrations of 6%, 7%, 8%, 9%, and 10% (w/w). The resulting granules were analyzed for N, P₂O₅, and K₂O content to determine the optimal formulation. The study found that granules with 20% urea met the standard of Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018, while granules with 10% tapioca binder had the longest disintegration time at 413 minutes. This research contributes to the development of sustainable fertilizers derived from elephant grass biomass waste.

INTRODUCTION

The continuous and rapid growth of the global population has intensified the demand for agricultural products, necessitating the adoption of effective and sustainable approaches to enhance land productivity (Wang, 2022). One of the key strategies employed to meet this demand is the use of fertilizers, particularly granular fertilizers, which have garnered increasing attention due to their controlled nutrient release, ease of application, and improved storage stability compared to traditional formulations (González-Feijoo et al., 2024). Granular fertilizers are typically produced through granulation, a process that aggregates fine particles into larger, free-flowing granules, thereby enhancing their physical handling properties (Tungadi, 2018).

Despite their benefits, the widespread and often excessive application of synthetic inorganic fertilizers has raised significant environmental concerns. These include soil degradation, waterway eutrophication, and the long-term depletion of soil organic matter (Azzahra et al., 2022). In light of these challenges, there is an urgent need to develop innovative fertilizer solutions that are not only agronomically efficient but also environmentally responsible.

One such promising avenue involves the utilization of agricultural biomass waste, such as elephant grass (*Pennisetum purpureum*), as a raw material for fertilizer production. Rich in essential nutrients—particularly potassium (K), phosphorus (P), and silica (Si)—elephant grass ash has been identified as a valuable input for sustainable fertilizer formulations (Morais et al., 2024).

Chemical composition analyses of elephant grass report significant levels of dry matter (20.49%), crude protein (11.23%), crude fat (2.42%), crude fiber (31.56%), and ash (12.76%) (Dumadi et al., 2021). Transforming elephant grass into ash through controlled combustion—initial charring followed by dry ashing at 600°C for four hours—concentrates its mineral content, thereby enhancing its agronomic value (Rachmayani, 2023; Prabawa, 2016). The resulting ash residue, representing the total mineral content, serves as a key parameter in fertilizer quality assessment (Wilmulda, 2021).

To enhance the nitrogen (N) content of the formulation, urea is commonly incorporated as a supplementary nutrient source. Urea is widely favored in agriculture due to its high nitrogen concentration, typically around 46%, and its rapid solubility in soil water (Gorung, 2022; Swify et al., 2024). Nitrogen plays a critical role in plant physiological processes, including chlorophyll production and protein synthesis, which are essential for vigorous vegetative growth (Zayed et al., 2023). Additionally, integrating urea with organic or semi-organic materials has been shown to reduce nitrogen losses via volatilization and denitrification, thus improving nutrient use efficiency (Jia et al., 2021; Kong et al., 2022).

The structural integrity of granular fertilizers is another crucial aspect of formulation design. In this regard, natural binders such as tapioca starch have emerged as environmentally friendly alternatives to synthetic polymers. Tapioca starch, with its high amylose content and water-binding capacity, promotes inter-particle cohesion and enhances granule stability (Rahayu & Zulaika, 2017). Its biodegradability and renewable origin further support sustainable fertilizer production practices (Chittora et al., 2023).

This study aims to develop a granular fertilizer formulation utilizing elephant grass ash as the primary nutrient source, enhanced with urea for nitrogen enrichment and tapioca starch as a natural binder. The research focuses on evaluating how variations in component composition influence the resulting granules' nutrient profile, physical characteristics, and structural stability. The findings are expected to contribute to the development of locally sourced, sustainable fertilizer technologies that can support high agricultural productivity while minimizing environmental impact.

RESEARCH METHODS

This research employed an experimental design using a factorial approach to evaluate the effects of urea addition and tapioca starch binder concentration on the quality of granular fertilizer produced from elephant grass ash. The sample consisted of elephant grass collected from Madiun Regency, Indonesia. The sampling technique was purposive, targeting mature elephant grass suitable for ashing.

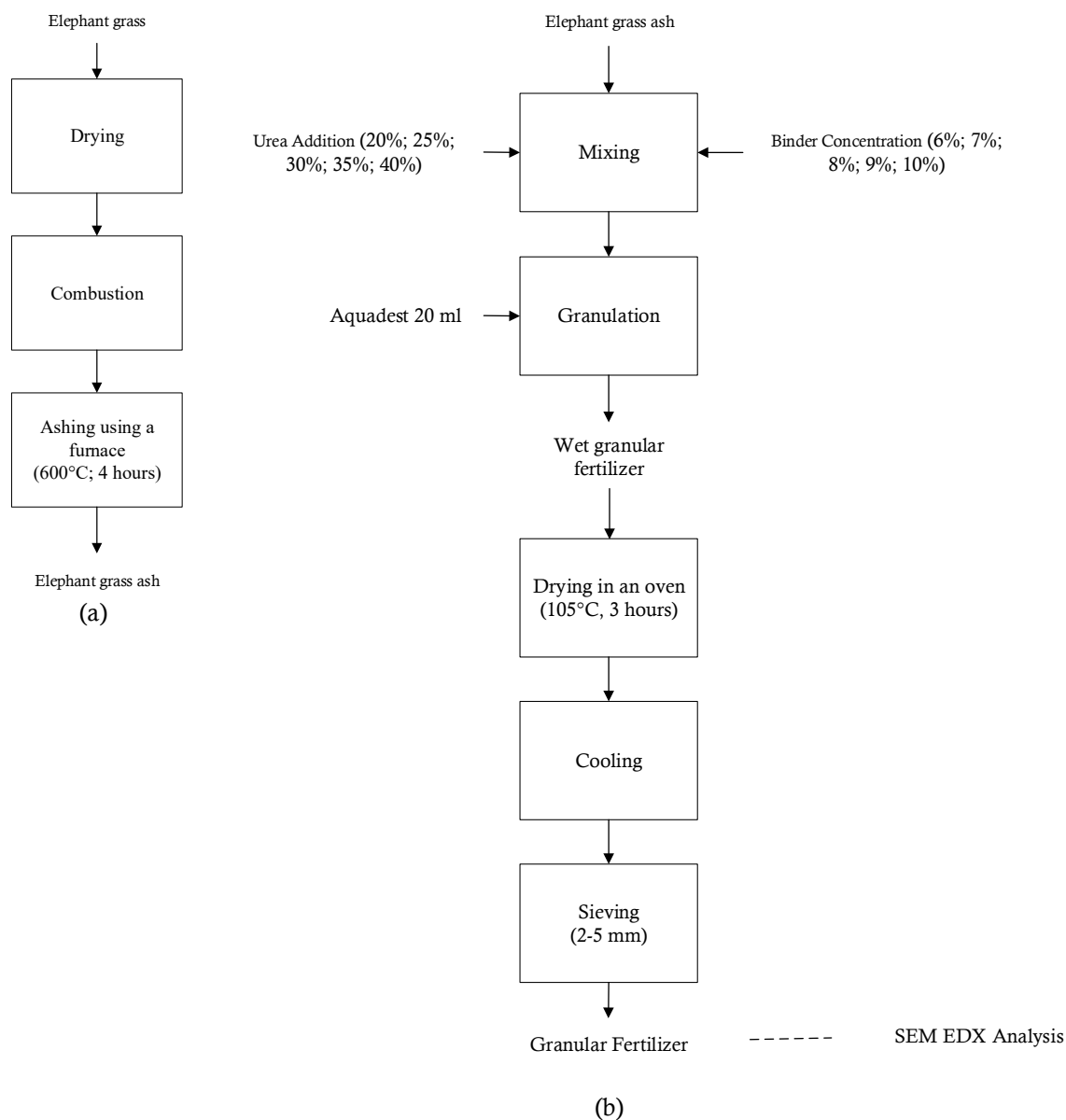


Figure 1. (a) Process flow diagram for the production of granular fertilizer from elephant grass ash, (b) Urea with the addition of tapioca starch binder

The study involved several stages: (1) preparation of raw materials, including cleaning, drying, combustion, and ashing of elephant grass at 600°C for 4 hours; (2) formulation of fertilizer mixtures with variable urea concentrations (20%, 25%, 30%, 35%, and 40% w/w) and binder concentrations (6%, 7%, 8%, 9%, and 10% w/w); (3) granulation by mixing the materials while spraying 20 mL of distilled water and agitating the container; (4) drying of granules at 105°C, followed by cooling and sieving to obtain particles sized 2–5 mm.

According to the Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018, the minimum required nitrogen content is 6%. Based on a 50-gram basis, the required amount of nitrogen is therefore 3 grams. In the production of granular fertilizer from elephant grass ash and urea using tapioca starch as a binder, urea with a nitrogen content of 46% is employed. Based on the calculation, the minimum amount of urea fertilizer that must be added is 6.52 grams. Consequently, if the urea content variable is set at 20%, the amount of urea fertilizer added is 10 grams.

According to Utari (2015), the production of granular organic fertilizer involved the use of tapioca starch and clay as binders, with binder concentrations at three levels: 5%, 8%, and 11%. The study found that the most optimal binder composition, in terms of the ratio between bulk organic fertilizer and clay, was 89% to 11% (Utari, 2015).

The observed parameters included nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) contents, moisture content, and dispersion time. Technical analyses were conducted using SEM-EDX for elemental characterization and the oven-drying method for moisture analysis. Dispersion time was measured in water to assess granule disintegration performance. Results were evaluated against standards in Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018.

RESULTS AND DISCUSSION

Material Composition Analysis

The composition of the material, namely elephant grass ash, was analyzed prior to the fertilizer production process in order to determine the influence of its chemical content on the levels of nitrogen (N), phosphorus (P), and potassium (K) in the resulting granular fertilizer. The results of the analysis of the elephant grass ash content are presented in the following table:

Table 1. Analysis Results of Elephant Grass Ash Content (5 grams)

<i>Oxides</i>	<i>Total (%)</i>	<i>Elements</i>	<i>Total (%)</i>
SiO ₂	29,9	Si	17,5
P ₂ O ₅	10,5	P	6,13
SO ₃	0,8	S	0,5
K ₂ O	56,5	K	72,9
MnO	0,12	Mn	0,16
Fe ₂ O ₂	1,59	Fe	1,97
CuO	0,068	Cu	0,097
ZnO	0,11	Zn	0,16
Rb ₂ O	0,30	Rb	0,49
MoO ₃	0	Mo	0,1
Re ₂ O ₇	0,06	Re	0,09

(Materials Laboratory, Universitas Negeri Malang, 2024)

Following the preparation of raw materials, the elephant grass was dried for seven days and then incinerated in a furnace. The next step was the granulation process using tapioca starch as a binder and urea as an additive. After granulation, the product was dried at 105°C for 3 hours, and then sieved using a 5-mesh screen. Each sample point was weighed to 5 grams for analysis of N, P_2O_5 , and K_2O content. The results obtained from the analysis of nitrogen, phosphorus, and potassium content after the production of the granular fertilizer are as follows:

Effect of Urea Addition and Binder Concentration on Nitrogen (N) Content

The nitrogen content (%) in the granular fertilizer made from elephant grass ash and urea using tapioca starch as a binder is presented in table 2:

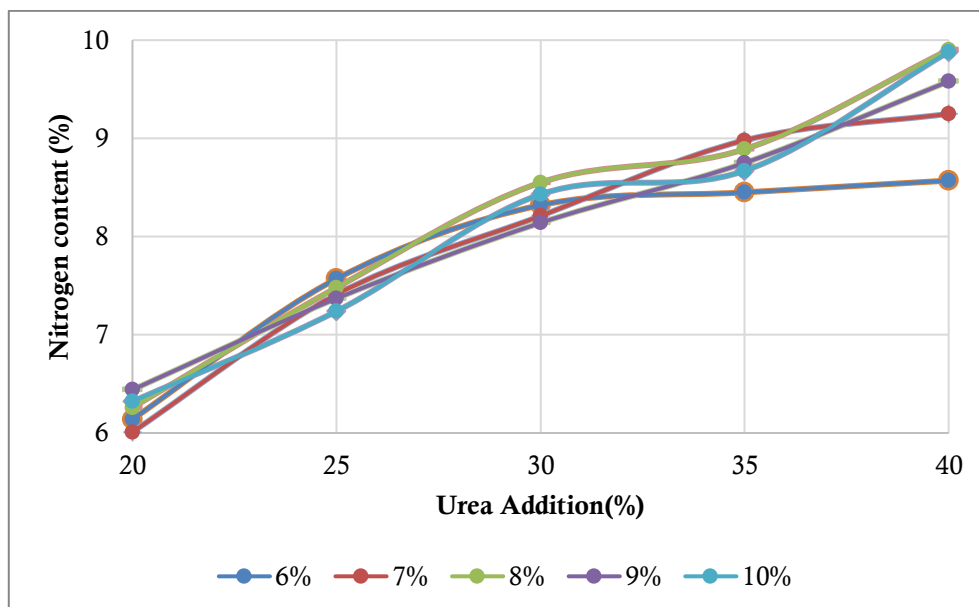
Table 2. Nitrogen Content Analysis (% by weight) Based on the Ratio of Binder Concentration and Elephant Grass Ash

Binder Concentration	Urea Addition				
	20%	25%	30%	35%	40%
6%	6,14	7,57	8,32	8,45	8,57
7%	6,01	7,41	8,21	8,98	9,25
8%	6,26	7,48	8,55	8,89	9,9
9%	6,44	7,37	8,14	8,75	9,58
10%	6,32	7,24	8,43	8,67	9,88

(Integrated Testing Laboratory, UPN “Veteran” East Java, 2024)

The raw material used in the production of this granular fertilizer is elephant grass ash, which contains macronutrients such as nitrogen (N), essential for the growth of shoots, stems, and leaves. Following granule formation with varying urea additions, nitrogen content was tested in each 5-gram sample.

The analysis results indicate a directly proportional relationship between the amount of urea added and the resulting nitrogen content—the higher the urea addition, the higher the nitrogen content. This effect is illustrated in Figure IV.1:

**Figure 2.** Effect of Urea Addition on Nitrogen Content

Based on figure 1, it is evident that the lowest nitrogen content occurred at 20% urea addition, while the highest was found in the sample with 40% urea. All urea addition variations (20%, 25%, 30%, 35%, and 40%) meet the standards of inorganic fertilizer as defined by Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018. The increasing nitrogen content is attributed to urea, which contains 46% nitrogen. According to Walidaini (2016), the increase in total nitrogen is influenced by urea's high nitrogen content (46.196%).

Binder concentration did not significantly influence nitrogen content, as neither tapioca starch nor elephant grass ash contains nitrogen. Even with a decrease in binder concentration and an increase in ash content, nitrogen levels remained unchanged. The only influencing factor for

nitrogen content was the amount of urea added. The highest nitrogen level, 9.9%, was obtained at 40% urea addition with 10% binder concentration.

Effect of Urea Addition and Binder Concentration on P_2O_5 Content

The phosphorus content (P_2O_5) in the granular fertilizer made from elephant grass ash and urea with tapioca starch binder is shown in table 3:

Table 3. P_2O_5 Content Analysis (% by weight) Based on the Ratio of Binder Concentration and Elephant Grass Ash

Binder concentration	Urea Addition				
	20%	25%	30%	35%	40%
6%	7,35	6,27	5,04	4,51	3,98
7%	7,19	5,74	4,28	4,12	2,98
8%	6,60	5,31	4,03	3,78	2,77
9%	6,30	4,95	3,25	3,18	2,40
10%	6,05	4,79	2,70	2,59	2,22

(Integrated Testing Laboratory, UPN "Veteran" East Java, 2024)

Elephant grass, as the raw material for this granular fertilizer, contains phosphorus in the form of P_2O_5 , which plays a role in stimulating root development and enhancing plant resistance to drought. The analysis of P_2O_5 content under variations in urea and binder concentration is shown below.

The results indicate an inverse relationship: as the amount of urea increases, the P_2O_5 content decreases. This is depicted in Figure IV.2:

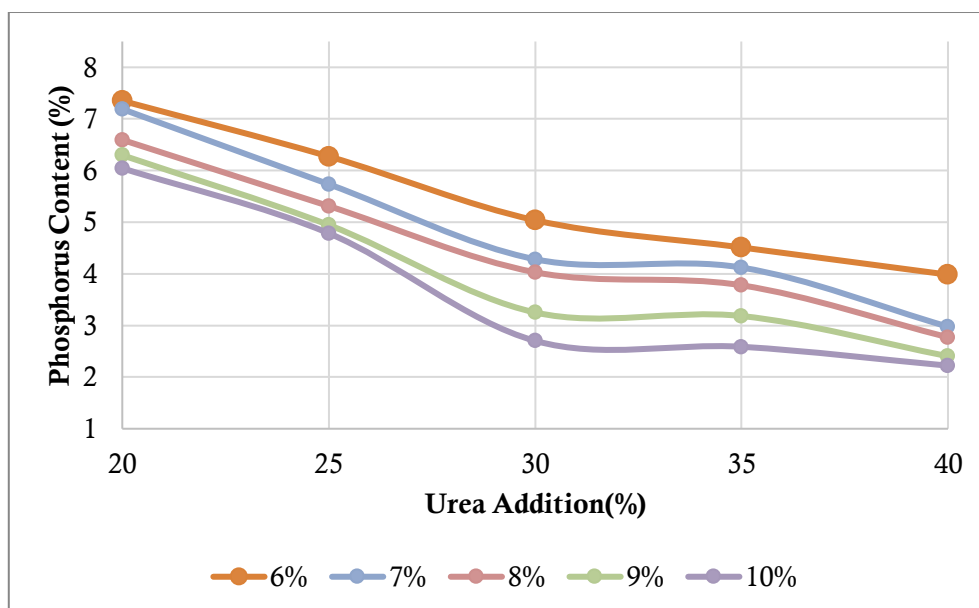


Figure 3. Effect of Urea Addition on P_2O_5 Content

Based on figure 2, it can be observed that there is an inverse relationship between urea addition and P_2O_5 content. The highest P_2O_5 content was recorded in the granular fertilizer with 20% urea addition, while the lowest phosphorus content was found in the sample with 40% urea addition. This trend can be attributed to the initial P_2O_5 content in elephant grass ash, which is

10.5%. According to Walidaini (2016), the decrease in total phosphorus (P) in leaf waste compost enriched with urea is presumed to be due to the addition of nitrogen (N) derived from urea. In this case, the leaf compost used was elephant grass. Therefore, increasing the amount of urea added is likely to result in a reduction of phosphorus content in the fertilizer.

When compared to the standards set by the Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018, which stipulates a minimum P_2O_5 content of 6% for inorganic granular fertilizers, only the 20% urea addition meets this requirement. The highest P_2O_5 content—7.35%—was achieved with 20% urea and a binder concentration of 6%.

Effect of Urea Addition and Binder Concentration on K_2O Content

The potassium content (K_2O) in the fertilizer was analyzed based on urea, binder, and elephant grass ash ratios, as shown in Table 4:

Table 4. K_2O Content Analysis (% by weight) Based on the Ratio of Urea Addition and Tapioca Binder with Elephant Grass Ash

Binder concentration	Urea Addition				
	20%	25%	30%	35%	40%
6%	54,85	51,91	48,97	42,37	35,76
7%	52,75	47,38	41,77	39,57	34,54
8%	47,67	41,24	39,89	38,15	34,05
9%	42,58	38,92	37,93	35,02	31,84
10%	40,13	37,76	35,07	32,13	30,66

(Integrated Testing Laboratory, UPN “Veteran” East Java, 2024)

The raw materials used in the production of this granular fertilizer are elephant grass ash and urea, both of which contain macronutrients such as potassium (K), which plays an important role in enhancing plant resistance to pest attacks. Based on the experimental results, the addition of urea and tapioca starch binder influences the resulting K_2O content. As the amount of urea increases, the K_2O content decreases. Similarly, increasing the amount of binder also leads to a reduction in K_2O content. This occurs because greater additions of urea and binder result in a lower proportion of elephant grass ash in the mixture, thereby reducing the overall potassium content. Thus, the K_2O concentration is affected by both the amount of urea and the binder concentration.

Marafon et al. (2021) reported that elephant grass ash contains between 3.21% and 6.14% ash, with a significant proportion of potassium present within this fraction, underscoring its potential as a valuable potassium source for fertilizer formulations. The data in the table demonstrate how varying binder concentrations and urea additions affect nutrient release, where higher binder concentrations consistently correspond to lower nutrient availability across all urea levels. Specifically, at 25% urea addition, nutrient availability decreases from 51.91 at 6% binder to 37.76 at 10% binder concentration. This trend suggests that while elephant grass ash contributes substantial potassium, the increasing binder concentration may impede nutrient diffusion, reducing the effective release of potassium and other nutrients. Therefore, optimizing binder content is essential to fully utilize the potassium-rich ash and enhance fertilizer efficiency, with lower binder concentrations (around 6–7%) combined with moderate urea additions (20–25%) yielding the highest nutrient availability in this study.

The analysis results indicate that the relationship between urea addition and binder concentration with potassium content is inversely proportional. This trend can be observed in figure 3 below:

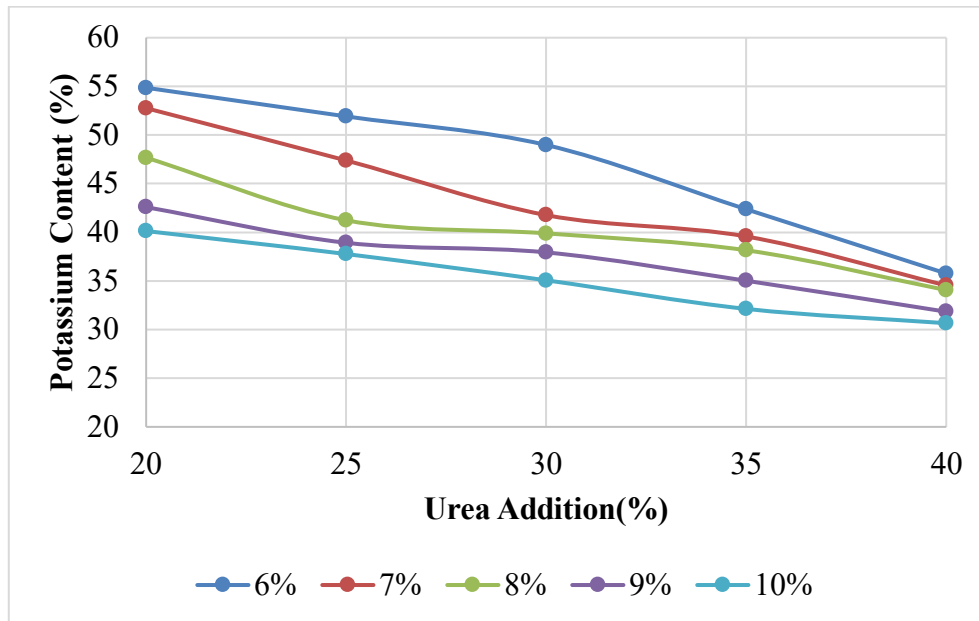


Figure 4. Effect of Urea Addition and Binder Concentration on K_2O Content

The presented figure illustrates the effect of urea addition and variations in tapioca starch binder concentration on the K_2O content in granular fertilizer made from elephant grass ash. Based on the graph, it is evident that the potassium content decreases as the amount of urea increases, with a clear variation depending on the binder concentration. A 6% binder concentration yields the highest K_2O content, followed by binder concentrations of 7%, 8%, 9%, and finally 10%. The optimal potassium content was obtained with 20% urea addition, resulting in a K_2O concentration of 54.85%.

One of the factors influencing the potassium content in this granular fertilizer is the choice of raw material, specifically elephant grass ash, as each material naturally contains different levels of potassium. Elephant grass ash contains 56.5% K_2O (Advanced Materials Laboratory, Universitas Negeri Malang, 2024). Based on this composition, the potassium content in the granular fertilizer meets the requirements of the Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018, which sets the minimum K_2O content for granular inorganic fertilizers at $\geq 6\%$

Table 5. Total Content Analysis of N, P_2O_5 , and K_2O (% by weight) Based on Urea and Tapioca Binder Ratios with Elephant Grass Ash

Binder concentration	Urea Addition				
	20%	25%	30%	35%	40%
6%	68,34	65,75	62,33	55,33	48,31
7%	65,95	60,53	54,25	52,67	46,77
8%	60,53	54,03	52,47	50,82	46,72
9%	55,32	51,24	49,32	46,95	43,82
10%	52,5	49,79	46,2	43,39	42,76

(Integrated Testing Laboratory, UPN "Veteran" East Java, 2024)

Based on the table of total N, P₂O₅, and K₂O content above, when compared to the standard for solid fertilizers as stipulated in the Regulation of the Minister of Agriculture No. 209/Kpts/SR.320/3/2018, which requires a minimum total nutrient content of 30%, the analysis results indicate that the standard has been met. The lowest total nutrient content was observed with the addition of 20% urea, amounting to 42.76%, while the highest content was obtained with the addition of 10% urea, reaching 68.34%.

Effect of Binder Concentration on Dispersion Time

Dispersion time refers to the time required for the fertilizer granules to dissolve in water. This was tested by adding 5 grams of granular fertilizer into a beaker containing 100 mL of water, and measuring the time taken for the granules to disintegrate. A longer dispersion time indicates stronger physical characteristics.

Table 6. Dispersion Time (minutes) for Each Sample Based on Urea and Binder Ratio with Elephant Grass Ash

Binder concentration	Urea Addition				
	20%	25%	30%	35%	40%
6%	4	9	15	27	40
7%	46	74	103	148	210
8%	71	151	200	273	295
9%	200	236	263	311	332
10%	261	294	326	349	413

The dispersion time analysis was conducted to evaluate the disintegration time of granules under various binder concentration variables. Based on the table of dispersion time results, it can be observed that the higher the binder concentration, the longer the granules take to disintegrate when immersed in water. The analysis results are presented in Figure 4 below.

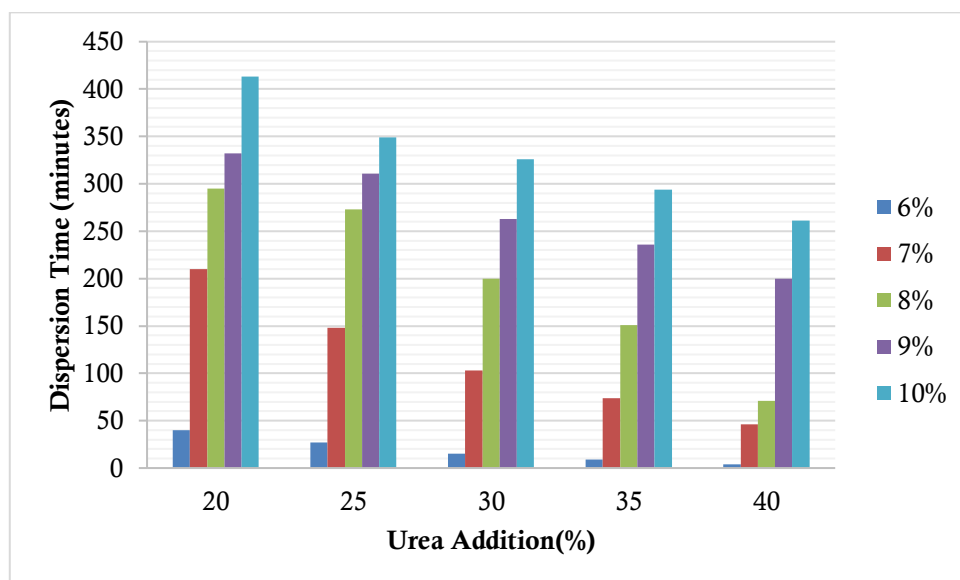


Figure 5. Effect of Binder Concentration on Dispersion Time

The figure presents a bar chart illustrating the effect of adhesive concentration on dispersion time (in minutes). The highest bar is observed in the fertilizer with 40% urea addition and 10% adhesive concentration, with a dispersion time of 413 minutes. This indicates that the adhesive strength between the granules is stronger, resulting in a longer disintegration time. Conversely, the fastest disintegration time occurs in the granular fertilizer with 6% adhesive

concentration. According to Chen (2021), tapioca starch contains amylopectin, which allows it to absorb water. This leads to the adhesion of raw material particles, forming a granular structure. Therefore, as the adhesive concentration increases, the adhesive strength becomes stronger. On the other hand, a lower adhesive concentration results in faster granule disintegration, which leads to a quicker release of nutrients.

The solubility of compounds in granular fertilizers, such as nitrogen (N), phosphate (P_2O_5), and potassium oxide (K_2O), plays a crucial role in the effectiveness and rate of nutrient release for plants (Utari, 2015). Based on the provided data, the solubility of nitrogen (N) is 20 mg/L, phosphate (P_2O_5) is 100 mg/L, and potassium oxide (K_2O) is 112 mg/L (Diaz, 1994). Based on this solubility, it is evident that K_2O has the highest solubility, followed by P_2O_5 , and then N. The higher the solubility of a compound, the faster it will dissolve in water and become available for absorption by plants. This means that fertilizers containing K_2O release nutrients to plants more quickly.

Moreover, urea-based fertilizers, which contain nitrogen, are water-soluble with a low solubility of 20 mg/L in water. Thus, the higher the nitrogen content in the fertilizer, the more difficult it becomes to dissolve in water, resulting in a longer dispersion time. Therefore, the longest dispersion time is found in the granular fertilizer with the highest urea addition (40%) and the highest adhesive concentration (10%).

CONCLUSION

These findings suggest that elephant grass ash has the potential to serve as a nutrient-rich base material for eco-friendly granular fertilizers. The use of 20% urea not only meets regulatory nitrogen content but also enhances nutrient availability. Elephant grass ash contains macronutrients including phosphorus (6.13%), potassium (72.9%), and sulfur (0.5%), as well as micronutrients such as silica (17.5%), manganese (0.16%), copper (0.097%), iron (1.97%), and zinc (0.16%). The granular fertilizer that meets the standard of Indonesian Ministry of Agriculture Regulation No. 209/Kpts/SR.320/3/2018 is the one with 20% urea addition. Granular fertilizer with 6% tapioca starch binder exhibited the fastest dispersion time (4 minutes), while the one with 10% binder had the slowest dispersion time (413 minutes or 6 hours and 53 minutes). Future research should focus on field performance evaluations of these fertilizers, including nutrient release dynamics, plant uptake efficiency, and their impact on crop yield and soil health over time. Moreover, investigating the use of alternative natural binders or combinations thereof could further optimize the physical and agronomic properties of the granules.

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