

Performance Evaluation of a Modified Granulator Based on Operating Parameters for Bioherbicide Granule Production

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Article History:

Received : 26 November 2025

Revised : 6 February 2026

Accepted : 3 March 2026

Keywords:

Granule diameter uniformity,
Granule diameter,
Pan inclination angle,
Pan rotational speed,
Spraying duration.

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ABSTRACT

Bioherbicide granules is a new innovation in weed control produced using a granulator machine. This study aimed to evaluate the performance of a modified pan granulator prototype intended for bioherbicide granule production. Wheat flour and tapioca flour were used as starch-based substitute materials to assess the mechanical performance of the granulator. Granulation performance was evaluated by varying the pan inclination angle, pan rotational speed, and spraying duration. The experimental treatments consisted of two inclination angles (40° and 45°), two rotational speeds (15 rpm and 35 rpm), and three spraying durations (20 s, 30 s, and 40 s). The results showed that the machine produced granules with an average diameter ranging from 4.01 mm to 6.08 mm and diameter uniformity between 90.80% and 96.23%. Increasing the spraying duration enhanced inter-particle bonding, resulting in larger granule diameters, while increasing the pan rotational speed from 15 rpm to 35 rpm reduced granule size due to stronger material–scraper interactions. The most favorable granulation performance among the tested conditions was obtained at pan inclination angle of 40° and rotational speed of 35 rpm, producing average granule diameters <5 mm that in accordance with SNI 7698:2011. Higher rpm resulted in more stable granule diameter uniformity, indicating improved particle homogeneity.

1. INTRODUCTION

Weeds are a major constraint in agricultural crop production, causing yield losses of up to 20–40% due to competition for water, nutrients, and light. Weed infestation interferes with crop growth and limits the achievement of production targets, making weed control an essential component of agricultural management (Chozin *et al.*, 2023). Currently, weed control predominantly relies on synthetic herbicides because of their high efficacy. However, excessive use of synthetic herbicides can lead to soil and water contamination and disrupt ecological balance. These concerns have driven the development of environmentally friendly weed control alternatives, including bioherbicides derived from natural plant-based compounds.

Bioherbicides operate through allelopathic mechanisms, whereby plants release secondary metabolites that suppress the growth of other species. Nutgrass (*Cyperus rotundus*), locally called *rumpu teki*, is a promising source of bioherbicide active compounds, as it contains phenolic and terpenoid compounds that inhibit the germination of broadleaf weed seeds (Kusuma *et al.*, 2017; Dewi *et al.*, 2017; Nuryana *et al.*, 2019). The primary active constituents of

essential oils are terpenes, including monoterpenes ($C_{10}H_{16}$) and sesquiterpenes ($C_{15}H_{24}$), predominantly in oxygenated forms (Hotmian *et al.*, 2021). Active compounds derived from nutgrass are biodegradable, safe for cultivated crops, and abundantly available in Indonesia, making them a sustainable and cost-effective local resource. To enhance application efficiency and storage stability, bioherbicides derived from nutgrass tubers have been formulated into granular form (Sulistiani *et al.*, 2020).

The bioherbicide granulation process faces technical challenges because most available granulation technologies, such as rotary drum, pan granulator, and fluidized-bed granulator, generally require synthetic binders, high operating temperatures, and high energy consumption. These conditions make them less suitable for organic materials such as nutgrass tuber flour. The bioherbicide granulator developed in this study is an innovation derived from an organic fertilizer granulation machine designed in accordance with SNI 7698:2011. Therefore, it is necessary to develop a granulation machine capable of processing nutgrass tuber flour into granules without degrading its bioactive compounds. This study focuses on the design and development of a bioherbicide granulator that operates using an organic-based system, low energy input, and a simple design. The developed machine is expected to produce granules with uniform and stable size, be easy to apply, and be efficiently and environmentally friendly operated by farmers and small-scale industries.

2. MATERIALS AND METHODS

This study was conducted at the Agricultural Machinery and Infrastructure Testing Laboratory (LAMPP), Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Technology, IPB University, Bogor, Indonesia, from September to November 2025. The equipment used in this study consisted of a bioherbicide granulator machine, an electric backpack sprayer, a stopwatch, and sieves with mesh sizes of 3 mm and 6 mm. The materials used were wheat flour, tapioca flour, and clean water. The functions of the equipment and materials are presented in Table 1.

Table 1. Functions of tools and materials

Tools and Materials	Function
Granulator machine	Producing granules
Knapsack electric sprayer	Generating and spraying liquid droplets
Stopwatch	Measuring spraying time
Wheat flour*	Test material
Tapioca flour*	Test material
Clean water	Binder material
3 mm sieve	Separating granules < 3 mm
6 mm sieve	Separating granules < 6 mm

Note : *Due to the limited availability of nutgrass tubers, substitute materials in the form of a mixture of wheat flour and tapioca flour were used.

Nutgrass tubers contain starch, which plays a crucial role in forming interparticle bonds during the wet granulation process (Sulistiani *et al.*, 2020). Tapioca flour contains a high starch content and exhibits plastic properties and agglomeration behavior similar to that of nutgrass tuber flour when mixed with water (Handayani *et al.*, 2023). Wheat flour was used as a filler material because of its fine particle size and stable response to water addition during granulation (Mahours *et al.*, 2017). According to Gluba (2012), starch-based materials exhibit comparable granulation behavior when processed using a pan granulator. Therefore, the use of wheat flour and tapioca flour as substitute materials was considered representative for evaluating the mechanical performance of the bioherbicide granulator.

2.1. Laboratory Testing of the Granulator

The performance testing of the granulator machine was conducted using a mixture of wheat flour, tapioca flour, and water. Performance evaluation focused on two main parameters, namely granule diameter (mm) and granule diameter uniformity (%), which are important indicators for determining granulation quality. Granule size uniformity plays a critical role in improving product quality (Adam *et al.*, 2025). Based on SNI 7698:2011, pan inclination angles of 40° and 45° and pan shaft rotational speeds of 15 rpm and 35 rpm fall within the recommended operational parameter range for granulation of organic-based materials (BSN, 2011). These parameters were selected because they are defined as

effective operating conditions in the quality standards and testing methods for organic fertilizer granulation machines. A moderate pan inclination angle helps maintain a balance between gravitational and centrifugal forces, thereby supporting material circulation and stable granule formation (Hidayat *et al.*, 2024). Pan rotational speed within the recommended range controls interparticle collision intensity and influences granule size distribution (Macho *et al.*, 2021). The prototype and technical specifications of the bioherbicide granulator used in this study were shown in Figure 1 and Table 2.

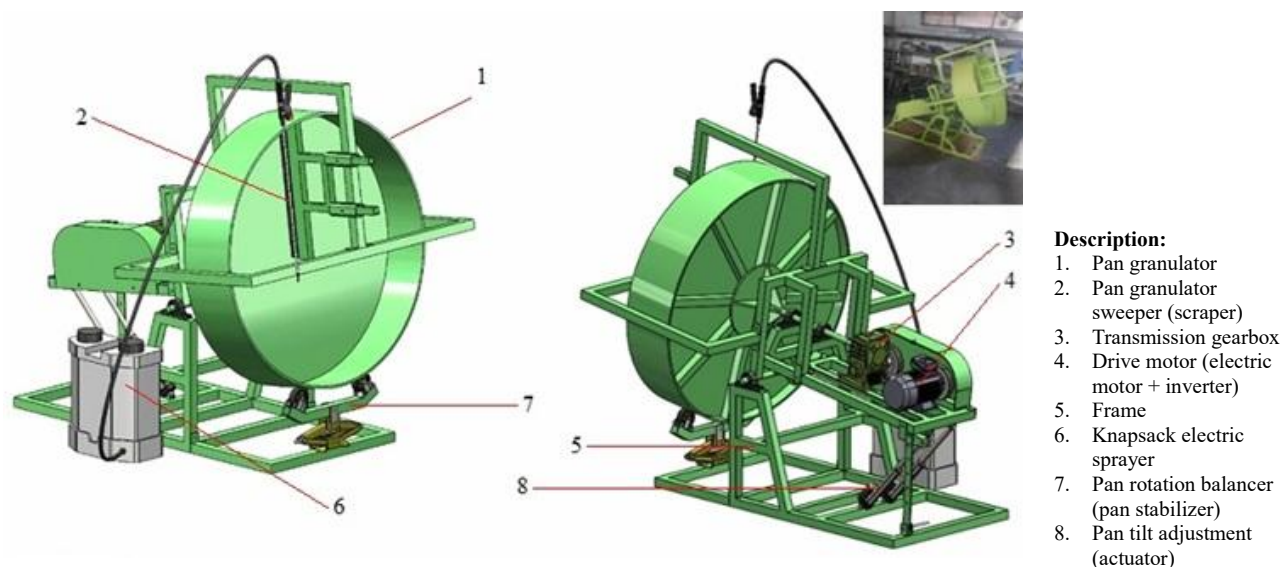


Figure 1. Prototype of the bioherbicide granulator machine

Table 2. Technical specifications of the bioherbicide granulator machine

Parameter	Unit	Value
Granulator dimensions		
Overall length	mm	1740
Overall width	mm	1265
Overall height	mm	1635
Empty weight	kg	165
Drive motor (electric motor)		
Rated power	kW	2.2
Rotational speed	rpm	1410
Transmission system		
Transmission type	-	Gearbox
Pan granulator		
Diameter	mm	1100
Height	mm	255
Inclination	°	10 – 60
Rotational speed	rpm	0 – 47
Pan scraper		
Length	mm	565
Height	mm	510
Additional components		
Pan rotation stabilizer	-	Available
Pan inclination regulator	-	Available

Performance testing was carried out using a mixture of wheat flour and tapioca flour at a ratio of 1:4, with a total material mass of 2 kg for each treatment. During the granulation process, clean water droplets were sprayed onto the material mixture for spraying durations of 20 s, 30 s, and 40 s for each treatment. The total granulation time was set to 15 minutes for each treatment.

Sieving using 3 mm and 6 mm sieves was performed to obtain granules with diameters larger than 3 mm and smaller than 6 mm. This target granule size complies with SNI 7698:2011, which specifies a granule diameter range of 2–5 mm. The mass of granules retained on the 6 mm sieve was recorded as granules with diameters greater than 6 mm, while the mass of granules passing through the 3 mm sieve was recorded as granules with diameters smaller than 3 mm. The mass of granules with diameters between 3 mm and 6 mm was also determined.

Average granule diameter was calculated using the dry sieving method as shown in Equation (1), while granule diameter uniformity was calculated using Equation (2) according to SNI 7698:2011.

$$D_R = \frac{(7.0 w_1 + 4.5 w_2 + 1.5 w_3)}{(w_1 + w_2 + w_3)} \tag{1}$$

$$K_D = (1 - CV) \times 100\% \tag{2}$$

where D_R is average granule diameter (mm), w_1 is mass of granules passing the 8 mm sieve and retained on the 6 mm sieve (g), w_2 is mass of granules retained on the 3 mm sieve (g), and w_3 is mass of granules passing the 3 mm sieve (g), K_D is granule diameter uniformity (%) and CV is coefficient of variation of 10 average granule diameter (D_R) data (%).

The bioherbicide granulator was developed as an innovation of a granulator machine originally designed for organic fertilizer production (SNI 7698:2011). The innovation involved modifications by adding an inverter, a pan stabilizer, and an actuator. The inverter (variable frequency drive) functions to control the frequency and voltage supplied to the electric motor, enabling electrical regulation of shaft speed and torque (Mehrgou *et al.*, 2018). The pan stabilizer maintains rotational and inclination stability of the pan granulator to ensure efficient and uniform granule formation. The actuator regulates the pan position or inclination, enhancing uniform granule formation and maximizing granule quality (Hermawan *et al.*, 2024). Figure 2 shows the performance testing process of the granulator machine.

3. RESULTS AND DISCUSSION

The performance test results indicate that the granulator machine was able to produce granules with average diameters ranging from 4.01 mm to 6.08 mm and granule diameter uniformity ranging from 90.80% to 96.23%, as presented in Tables 3. The target granule diameter specified in SNI 7698:2011 ranges from 2 mm to 5 mm. Increasing the duration of clean water spraying enhanced interparticle bonding between wheat flour and tapioca flour, resulting in larger granule diameters. This indicates that water addition accelerates the agglomeration process, allowing smaller particles to merge more easily into larger granules. According to Mahours *et al.* (2017), increasing the volume of sprayed liquid increases the likelihood of forming larger granules. Insufficient spraying duration leads to incomplete granule formation, while excessive spraying may produce oversized and non-uniform granules (Hu *et al.*, 2025). Increasing the pan shaft rotational speed from 15 rpm to 35 rpm resulted in smaller granule diameters due to increased collision intensity between the material and the scraper. Higher rotational speeds increase centrifugal forces and particle collisions, accelerating granule size reduction. Hidayat *et al.* (2024) reported that increasing pan speed improves material circulation but may reduce granule homogeneity if the speed exceeds the optimum limit.

Table 3. Average granule diameter under various pan inclination angles, pan shaft rotational speeds, and water spraying durations

Pan angle (°)	Rotation speed (rpm)	Spraying time (s)	Granule weight (g)			D_R (mm)	CV (%)	K_D Uniformity (%)
			w_1	w_2	w_3			
40	15	20	122	182	23	5.22	9.20	90.80
		30	208	71	17	6.08	7.90	92.10
		40	353	36	2	6.74	4.32	95.68
40	35	20	26	108	52	4.01	7.10	92.90
		30	106	262	29	4.95	6.12	93.88
		40	108	445	57	4.66	4.07	95.93
45	15	20	64	146	27	4.83	7.19	92.81
		30	320	133	23	6.04	6.90	93.10
		40	266	216	14	5.76	3.77	96.23
45	35	20	31	115	20	4.61	5.45	94.55
		30	152	181	12	5.50	4.69	95.31
		40	341	234	15	5.87	3.94	96.06

Note: w_1 , w_2 , and w_3 refer to mass of granules passing the 8 mm, 6 mm, and 3 mm sieve, respectively; CV = coefficient of variation of D_R

At a relatively low pan speed (15 rpm), increasing the pan inclination angle from 40° to 45° altered particle motion dynamics asymmetrically. On one side of the pan, the steeper angle accelerated downward particle movement due to increased gravitational force components, reducing particle residence time in the collision zone. On the opposite side, upward particle movement slowed, leading to unbalanced particle circulation. This condition reduced effective collision frequency and limited the growth of larger granules.

The combination of a 40° pan inclination angle and a pan shaft speed of 35 rpm resulted in the best granulation performance among the tested treatments due to a balance between adhesive and separation forces during granulation. At a 40° inclination, particles experienced sufficient residence time to undergo collisions and gradual layer formation, while a speed of 35 rpm enhanced particle circulation and collision frequency without causing excessive centrifugal disintegration. This combination produced average granule diameters below 5 mm, meeting SNI 7698:2011 requirements, with stable size uniformity, as shown in Figure 2.

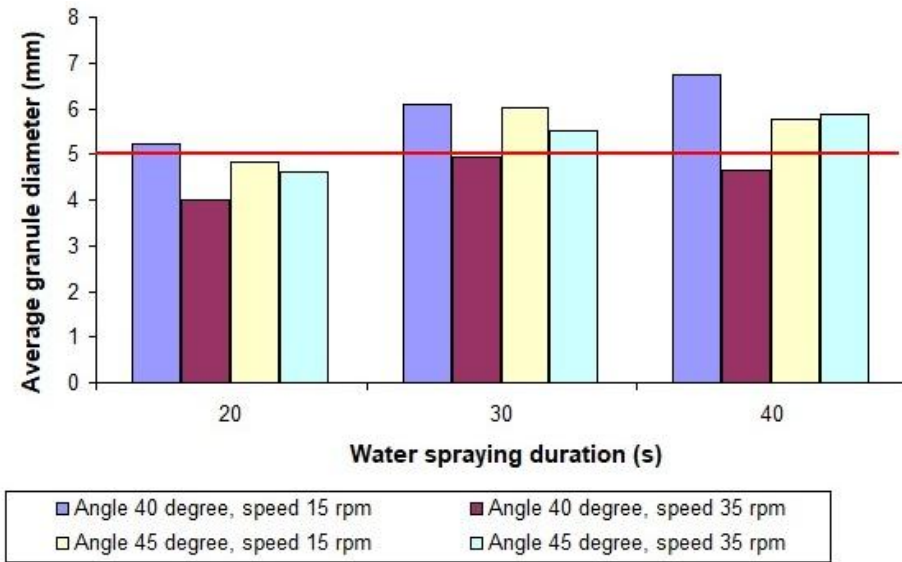


Figure 2. Relationship between spraying duration and average granule diameter

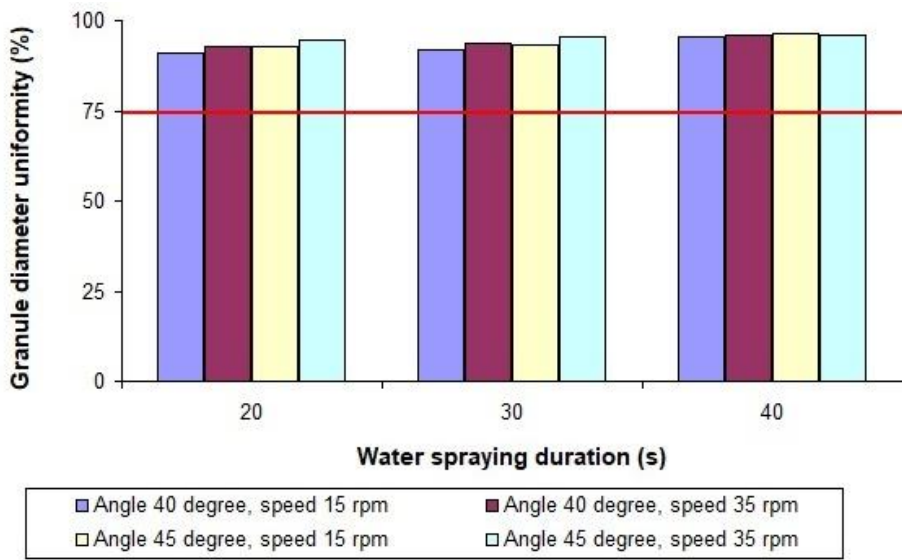


Figure 3. Relationship between spraying duration and granule diameter uniformity

All treatments produced granule diameter uniformity values above 75%, meeting the SNI 7698:2011 standard, indicating good granulator performance. Figure 3 shows the relationship between spraying duration and granule diameter uniformity. Shorter water spraying durations resulted in lower granule diameter uniformity due to uneven water distribution, causing incomplete agglomeration of some particles and reduced size uniformity (Takehara *et al.*, 2022). This finding highlights the importance of sufficient spraying duration in providing optimal moisture for particle bonding. At a pan shaft speed of 35 rpm, granule diameter uniformity ranged from 92.90% to 96.06%, indicating smaller size distribution variation compared to 15 rpm, resulting in more consistent granule size distribution (Vo *et al.*, 2018). This stability is reflected in the narrow uniformity range across spraying durations, indicating low granule size fluctuation during granulation (de Souza *et al.*, 2025). Higher pan speeds also reduced average granule diameter, keeping it below 5 mm and meeting SNI 7698:2011 requirements (Hidayat *et al.*, 2024). These conditions suggest that higher rotational speeds are able to increase the intensity of the collision between the particles and the scraper, which contributes to the formation of smaller and uniform granules (Fungaro & Bertolini, 2023). Relatively more stable granule size uniformity is achieved when there is a balance between the supply of water as a wetting liquid and the dynamics of particle motion in the granulator pan, so that the agglomeration process takes place in a controlled manner (Przywara *et al.*, 2021).

Water sprayed during granulation acted as a wetting liquid, enabling the formation of liquid bridges between particles, which supports agglomeration and gradual granule growth (Takehara *et al.*, 2022). At higher pan speeds, improved particle circulation and collision frequency promoted more uniform water distribution on particle surfaces, reducing irregular agglomerate formation (Vo *et al.*, 2021). The nature of water flow as a wetting liquid with a relatively low viscosity interacts with the centrifugal force arising from pan rotation, thus playing a role in controlling the thickness of the particle layer on the growing granule and maintaining the uniformity of the granule size (Mahours *et al.*, 2017). The interaction between evenly distributed water, particle dynamics, and centrifugal forces contributed to more homogeneous granule formation, indicating that proper control of spraying duration and pan rotational speed significantly enhances granule quality (Nandi *et al.*, 2021). The interaction between evenly distributed water, particle dynamics, and centrifugal forces contributed to more homogeneous granule formation, indicating that proper control of spraying duration and pan rotational speed significantly enhances granule quality. Thus, appropriate spraying timing and pan rotation speed can improve the quality and homogeneity of the resulting granules. This bioherbicide granulator is expected to be used effectively and efficiently to produce nutmeg flour-based bioherbicides with optimal shape and size, namely spherical with a diameter of 0.5 cm, as reported by Rohman & Chozin (2025).

4. CONCLUSION

Water spraying duration and pan rotational speed were identified as critical parameters controlling granule size and uniformity. Increasing spraying duration from 20 s to 40 s increased average granule diameter due to enhanced moisture-induced agglomeration. A higher pan speed of 35 rpm resulted in smaller and more uniform granules, with diameter uniformity ranging from 92.90% to 96.06%, indicating stable size distribution. The combination of a 40° pan inclination angle and a 35 rpm pan speed provided the best granulation performance, producing granules that satisfied SNI 7698:2011 requirements. Although starch-based substitute materials were used, the results are representative for evaluating the mechanical performance of the bioherbicide granulator and provide a solid basis for subsequent testing using nutgrass tuber flour as the primary raw material.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
GP	✓	✓	✓		✓	✓			✓					
MAC	✓			✓			✓					✓		✓
EG				✓		✓								
VA							✓			✓			✓	
KD							✓	✓					✓	
C: Conceptualization	Fo: Formal Analysis			O: Writing - Original Draft				Fu: Funding Acquisition						
M: Methodology	I: Investigation			E: Writing - Review & Editing				P: Project Administration						
So: Software	D: Data Curation			Vi: Visualization										
Va: Validation	R: Resources			Su: Supervision										

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the Applied Research Program – Prototype Output (PT-LP), Ministry of Higher Education, Science, and Technology (KEMDIKTISAINTEK), Fiscal Year 2025, for the financial support provided for this research through Grant No. SK 0419/C3/DT.05.00/2025 and Agreement/Contract No. 006/C3/DT.05.00/PL/2025. The authors also express their appreciation to IPB University for providing laboratory facilities and technical assistance.

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