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Simulation-Assisted Design and Fabrication of A Small Rotary Drum Dryer for Coconut Meat Residue (SAPAL)

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Abstract- Coconut meat residue (sapal) is a by-product of coconut processing that contains high moisture content, making it susceptible to spoilage and limiting its utilization in agricultural and feed-processing applications. This study aimed to design, fabricate, and evaluate a simulation-assisted small-scale rotary drum dryer equipped with internal spiral agitating flights for drying coconut sapal. The Discrete Element Method (DEM) was employed to analyze particle movement and mixing behavior within the rotary drum and support the optimization of the dryer design. Experimental testing was conducted at rotational speeds of 13, 15, and 17 RPM under a drying temperature of approximately 65–70 °C. Additional trials were performed using loading capacities ranging from 5 kg to 30 kg. Drying performance was evaluated in terms of moisture content reduction and drying efficiency. The results indicated that both rotational speed and loading capacity influenced the drying performance of the developed system. Among the tested conditions, 17 RPM produced more consistent drying behavior and greater moisture reduction. The developed rotary drum dryer achieved an average drying efficiency of 60%, while the computed dryer efficiency reached 75.38%. Furthermore, DEM simulation results showed particle movement characteristics that were comparable with experimental observations, demonstrating the effectiveness of the simulation-assisted design approach. The developed rotary drum dryer exhibited satisfactory drying performance and shows potential for small-scale agricultural and feed-processing applications involving coconut meat residue.

Keywords: Coconut Sapal, Rotary Drum Dryer, Drying Efficiency, Discrete Element Method, Agricultural By-Products.

I. INTRODUCTION

The coconut industry is one of the major agricultural sectors in the Philippines and generates substantial quantities of by-products during the processing of coconut-based products such as coconut milk, virgin coconut oil, and desiccated coconut [1]. One of the most common by-products is coconut meat residue, locally known as "*sapal*", which remains after the extraction of coconut milk or oil from grated coconut meat. Although often regarded as a low-value residue, *sapal* contains dietary fiber, carbohydrates, protein, and residual oil, making it a potential resource for agricultural and feed-processing applications [2][3][4].

The utilization of coconut sapal is often limited by its high moisture content, which promotes microbial growth, accelerates spoilage, and reduces storage stability [3], [5]. Consequently, large quantities of *sapal* are discarded despite their potential economic value. Drying is a widely used preservation technique that reduces moisture content, improves product stability, and extends shelf life [5], [6]. However, traditional drying methods are highly dependent on weather conditions and may result in inconsistent drying performance.

Rotary drum dryers are commonly employed for drying particulate agricultural materials because of their continuous operation, efficient heat and mass transfer characteristics, and effective mixing capabilities [7]. The incorporation of internal flights enhances particle movement and improves material exposure to heated air, thereby promoting more uniform drying. Furthermore, advances in computational tools such as the Discrete Element Method (DEM) provide opportunities to analyze particle behavior and optimize equipment performance before fabrication [8].

Despite the increasing application of simulation-assisted equipment design, limited studies have investigated the development of small-scale rotary drum dryers specifically intended for drying coconut meat residue. Moreover, information regarding the effects of rotational speed and loading capacity on the drying performance of sapal remains limited.

Therefore, this study aimed to design, fabricate, and evaluate a simulation-assisted small-scale rotary drum dryer equipped with internal spiral agitating flights for drying coconut meat residue (*sapal*). Specifically, the study investigated particle movement through DEM simulation and evaluated the effects of rotational speed and loading capacity on moisture reduction and drying efficiency.

II. LITERATURE REVIEW

Rotary Drum Dryers. Rotary drum dryers are among the most widely used drying systems for granular and particulate materials due to their continuous operation, high throughput capacity, and efficient heat and mass transfer characteristics [7]. The drying process occurs as the rotating drum continuously tumbles and transports material while exposing it to a heated drying medium. The combined effects of particle movement, mixing, and heat transfer contribute to moisture removal and product stabilization.

Several studies have reported that the performance of rotary drum dryers is strongly influenced by drum geometry, rotational speed, inclination angle, loading capacity, and internal flight configuration [7]. These parameters affect particle residence time, material distribution, and exposure to heated air, ultimately influencing drying efficiency and product quality.

Internal Flights and Particle Cascading Behavior. Internal flights are essential components of rotary drum dryers because they lift and distribute materials within the drum during rotation. As the material is elevated by the flights and subsequently released, a cascading curtain of particles is formed, increasing the contact area between the particles and the drying medium. This cascading mechanism enhances heat and mass transfer, improves particle dispersion, and contributes to more uniform drying performance [30], [31], [36].

Previous studies have shown that flight design significantly influences particle residence time, material distribution, and mixing behavior within the drum [31], [33]. Effective flight configurations promote greater particle exposure to the drying medium and improve overall dryer efficiency by reducing stagnant regions and enhancing particle circulation [30], [36].

Discrete Element Method (DEM) in Rotary Dryer Design. The Discrete Element Method (DEM) has become an important numerical tool for analyzing particle behavior in rotating equipment. DEM simulates the motion and interaction of individual particles by calculating contact forces, collision behavior, and particle trajectories under specified operating conditions [29].

In rotary drum applications, DEM has been widely used to investigate particle flow patterns, mixing characteristics, residence time distribution, and velocity profiles. Researchers have utilized DEM to evaluate the effects of rotational speed, drum loading, and flight geometry on particle behavior [30], [33]. The method provides detailed information regarding particle movement that is difficult to obtain through direct experimental observation.

Several studies reported that DEM can effectively predict cascading, rolling, cataracting, and centrifuging particle regimes within rotating drums [30], [33]. These particle flow behaviors significantly influence material mixing and drying performance. Through simulation, engineers can identify operating conditions that maximize particle exposure to the drying medium while minimizing energy losses and material segregation [30].

DEM-Based Evaluation of Flight Designs. Recent research has demonstrated the effectiveness of DEM in evaluating and optimizing flight configurations before prototype fabrication. Different flight geometries have been analyzed using DEM to determine their influence on particle lifting behavior, mixing intensity, and material redistribution [31]. Simulation results showed that properly designed flights improve particle dispersion and increase the frequency of particle-air contact, thereby enhancing drying efficiency [31].

The integration of DEM into equipment development reduces design uncertainty and allows engineers to assess multiple design alternatives with lower cost and shorter development time [29], [30]. Consequently, DEM has become a valuable tool in the design optimization of rotary dryers and other particulate processing equipment.

Although previous studies have established the importance of flight geometry and DEM analysis in rotary drum performance [30], [31], limited research has focused on the application of simulation-assisted rotary drum dryers for drying coconut meat residue (*sapal*). Furthermore, the use of internal spiral agitating flights in combination with DEM-based analysis remains insufficiently explored for small-scale drying systems. Therefore, this study utilized DEM simulation to evaluate particle movement and optimize the design of a rotary drum dryer equipped with internal spiral agitating flights for the efficient drying of coconut sapal.

III. METHODOLOGY

Research Design

This study employed a simulation-assisted engineering design approach for the development of a small-scale rotary drum dryer intended for drying coconut meat residue (*sapal*). The methodology consisted of design computation, DEM simulation, fabrication, assembly, and experimental performance evaluation. The integration of numerical simulation and experimental testing enabled the assessment of particle behavior and drying performance under different operating conditions.

DEM Simulation and Evaluation of Spiral Agitating Flights

The Discrete Element Method (DEM) was employed to investigate particle movement, mixing behavior, and velocity distribution inside the rotary drum dryer prior to fabrication. DEM simulation was performed using EDEM software to analyze the interaction between coconut *sapal* particles and the internal spiral agitating flights under varying operating conditions. The Hertz–Mindlin no-slip contact model was adopted to represent particle-particle and particle-wall interactions because of its suitability for granular material simulations [26].

The rotary drum was equipped with spiral agitating flights designed to promote continuous particle redistribution and reduce dead zone formation. The flight configuration consisted of six flights per row, five axial rows, a circumferential spacing of 60°, an axial pitch of 200 mm, a flight height of 50 mm, and an effective flight width of 35 mm. The spiral arrangement was intended to provide continuous agitation and axial transport of particles throughout the drum.

Figure 1. Rotary Drum with Internal Spiral Agitating Flights

Simulation trials were conducted under three loading conditions (15 kg, 20 kg, and 30 kg) and three rotational speeds (5 RPM, 10 RPM, and 15 RPM). These operating conditions were selected to evaluate the influence of rotational speed and material loading on particle mobilization, mixing intensity, and velocity distribution within the rotary drum.

Particle flow behavior was analyzed through visualization of particle trajectories and movement patterns. At 15 kg and 5 RPM, particle motion was dominated by rolling behavior, resulting in poor circulation and the formation of large dead zones. As rotational speed increased to 10 RPM, particle agitation improved and stagnant regions were reduced. At 30 kg and 15 RPM, the particle bed became fully mobilized, exhibiting continuous circulation and minimal dead zone formation. The spiral agitating flights effectively maintained particle movement throughout the drum and promoted uniform material redistribution.

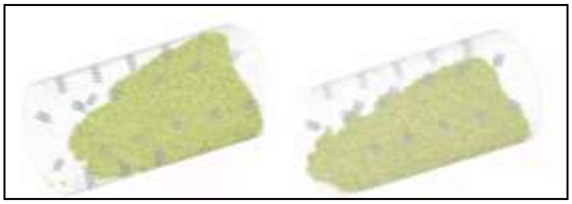


Figure 2. Particle Flow Behavior at 15 kg and 5 RPM

Figure 3. Particle Flow Behavior at 20 kg and 10 RPM

Figure 4. Particle Flow Behavior at 30 kg and 15 RPM

Mixing behavior was further evaluated by examining particle distribution throughout the drum. Results showed that increasing rotational speed improved particle interaction and reduced inactive regions. The spiral agitating flights continuously disturbed the particle bed, resulting in more uniform mixing compared with conventional lifting-based flight designs. At the highest operating condition, the dead zone was nearly eliminated and particle distribution became highly uniform.

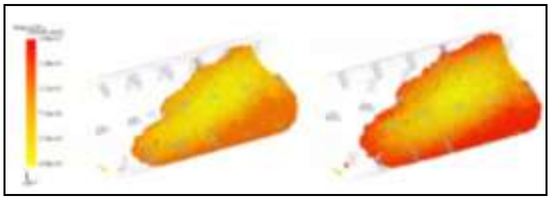


Figure 5. Mixing Behavior at 15 kg and 5 RPM

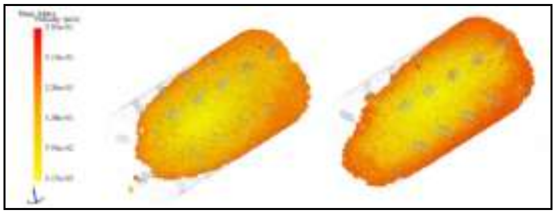


Figure 6. Mixing Behavior at 20 kg and 10 rpm

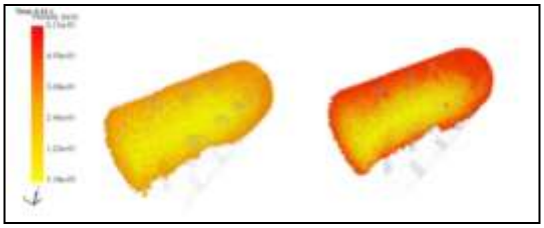


Figure 7. Mixing Behavior at 30 kg and 15 RPM

Velocity distribution analysis revealed that particle velocities increased and became more uniformly distributed as rotational speed increased. At 15 RPM, the appearance of high-velocity regions throughout the particle bed indicated effective momentum transfer and continuous particle motion. The spiral agitating flights contributed to a more balanced velocity profile by minimizing stagnant regions and maintaining consistent particle interaction.

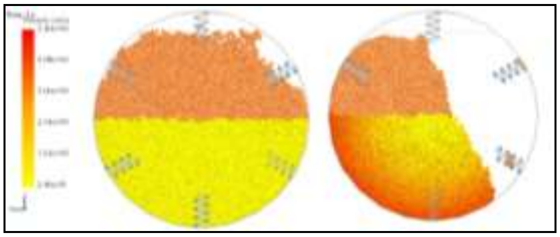


Figure 8. Velocity Distribution at 15 kg and 5 RPM

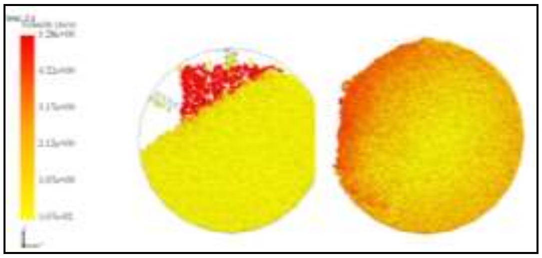


Figure 9. Velocity Distribution at 20 kg and 10 RPM

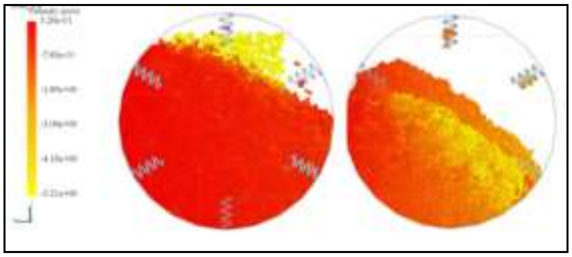


Figure 10. Velocity Distribution at 30 kg and 15 RPM

The DEM results demonstrated that increasing rotational speed enhanced particle circulation, reduced dead zone formation, improved mixing uniformity, and promoted more consistent velocity distribution. These findings supported the selection of spiral agitating flights for the developed rotary drum dryer and provided the basis for subsequent fabrication and experimental evaluation.

Fabrication and Assembly

Following the completion of the design and simulation stages, the rotary drum dryer was fabricated using locally available materials. The major components, including the drum, frame, support rollers, drive mechanism, heating system, and internal spiral agitating flights, were manufactured and assembled according to the finalized design specifications. Particular attention was given to the installation of the spiral flights to ensure proper particle lifting, redistribution, and transport within the rotating drum.

Figure 11. Final Assembly of the Rotary Drum Dryer Prototype

Experimental Procedure

Experimental testing was performed using fresh coconut meat residue as the drying material. Drying trials were conducted at rotational speeds of 13 RPM, 15 RPM, and 17 RPM under a drying temperature of approximately 65–70 °C. Moisture content measurements were obtained before and after each drying cycle to determine moisture reduction performance.

Additional experiments were conducted to evaluate the influence of loading capacity on drying behavior. Loading capacities of 5 kg, 10 kg, 15 kg, 20 kg, and 30 kg were tested under selected operating conditions. Prior to each trial, the dryer was preheated to establish a stable drying temperature and ensure consistent drying conditions.

Figure 12. Process Flow of the Drying Operation and Experimental Trial

Performance Evaluation

The performance of the developed rotary drum dryer was evaluated using moisture content reduction and drying efficiency as primary performance indicators. Experimental observations were compared with DEM simulation results to assess the relationship between particle movement characteristics and drying performance. The collected data were analyzed to determine the effects of rotational speed and loading capacity on the efficiency of the drying process.

IV. RESULTS AND DISCUSSION

DEM Simulation Results

The DEM simulation successfully evaluated the particle movement, mixing behavior, and velocity distribution of coconut *sapal* inside the rotary drum under different operating conditions. The results demonstrated that both rotational speed and loading capacity significantly influenced particle flow behavior within the system.

At the low operating condition of 15 kg and 5 RPM, particle motion was dominated by rolling behavior, resulting in poor circulation and the formation of large dead zones. Most particles remained concentrated at the lower portion of the drum, indicating insufficient rotational energy to mobilize the entire particle bed. Consequently, particle redistribution and mixing performance were limited.

As rotational speed increased to 10 RPM with a loading capacity of 20 kg, particle movement became more active. Improved interaction between the particles and the spiral agitating flights promoted greater material redistribution and reduced the extent of dead zone formation. The flow regime transitioned from simple rolling behavior to a combination of rolling and agitation, resulting in improved circulation throughout the drum.

The highest operating condition of 30 kg and 15 RPM exhibited the most effective particle behavior. The particle bed became fully mobilized, with continuous circulation occurring throughout the drum cross-section. Dead zones were significantly minimized, and particles were more uniformly distributed. The spiral agitating flights continuously disturbed the material, maintaining active particle interaction and promoting consistent redistribution.

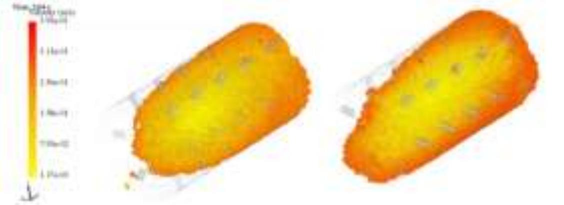


Figure 13. DEM Mixing Behavior & Velocity Distribution

The mixing analysis further confirmed the effectiveness of the spiral agitating flights. Increasing rotational speed improved particle interaction, reduced stagnant regions, and enhanced mixing uniformity. Unlike conventional lifting-based flight designs that rely primarily on cascading behavior, the spiral configuration provided continuous agitation, resulting in more stable and consistent particle movement.

Velocity distribution analysis supported these observations. At higher rotational speeds, particle velocities became more uniformly distributed throughout the particle bed, indicating improved momentum transfer and energy propagation. The reduction of low-velocity regions corresponded to the observed decrease in dead zone formation and enhanced mixing performance.

Overall, the DEM simulation demonstrated that the internal spiral agitating flights effectively improved particle circulation, mixing behavior, and material redistribution within the rotary drum. These findings provided a theoretical basis for the subsequent experimental evaluation of the dryer.

Drying Performance at Different Rotational Speeds

The developed rotary drum dryer was experimentally evaluated at rotational speeds of 13 RPM, 15 RPM, and 17 RPM under a drying temperature of approximately 65–70 °C. The results showed that rotational speed significantly influenced moisture reduction and drying efficiency.

Table 1. Drying Performance at 13 RPM

PARAMETER	TEST 1	TEST 2	TEST 3
Initial Weight (kg)	30	30	30
Initial MC (%)	46.88	46.88	46.88
Final Weight (kg)	21.00	21.25	20.95
Final MC (%)	24.11	25.01	23.93
Max Air Temp (°C)	70.2	70.5	70.5
Drying Time (hrs)	3	3	3
Efficiency (%)	48.57	46.65	48.96
Result	Did not meet desired moisture range	Did not meet desired moisture range	Did not meet desired moisture range
Observation	Limited drying due to low agitation	Residual moisture remained high	Non-uniform drying behavior observed

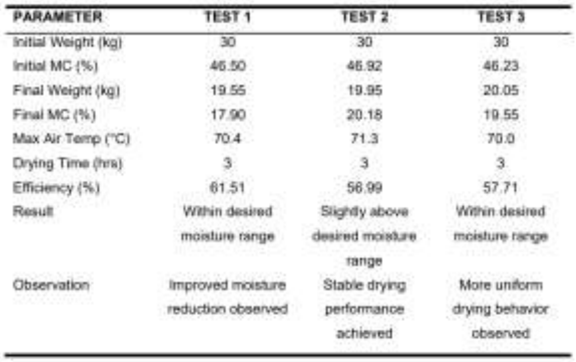
At 13 RPM, the dryer exhibited the lowest drying performance. The average final moisture content remained above the desired moisture range of 15–19%, indicating insufficient moisture removal within the 3-hour drying period. Drying efficiencies ranged from approximately 46.65% to 48.96%, suggesting that lower rotational speed limited particle agitation and reduced contact between the sapal and heated air.

Table 2. Drying Performance at 13 RPM Under Extended Drying Durations

Parameter	Test 1	Test 2	Test 3
Initial Weight (kg)	30	30	30
Initial MC (%)	46.70	46.70	46.70
Final Weight (kg)	19.10	19.55	18.89
Final MC (%)	16.28	18.21	15.35
Max Air Temp (°C)	70.3	70.4	70.5
Drying Time (hrs)	3.5	3.5	4
Efficiency (%)	65.14	61.01	67.13
Result	Met desired moisture range	Met desired moisture range	Met desired moisture range
Observation	Improved moisture reduction observed	More uniform drying behavior	Desired moisture level achieved

Additional testing conducted at 13 RPM with extended drying durations of 3.5 to 4 hours resulted in moisture contents within the target range. This finding indicates that lower rotational speeds can still achieve satisfactory drying performance when sufficient drying time is provided.

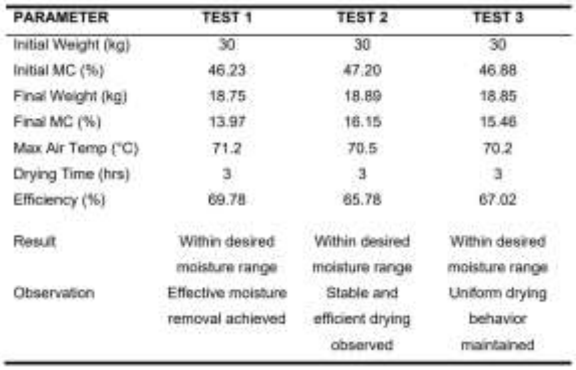
Table 3. Drying Performance at 15 RPM



PARAMETER	TEST 1	TEST 2	TEST 3
Initial Weight (kg)	30	30	30
Initial MC (%)	46.50	46.92	46.23
Final Weight (kg)	19.55	19.95	20.05
Final MC (%)	17.90	20.18	19.55
Max Air Temp (°C)	70.4	71.3	70.0
Drying Time (hrs)	3	3	3
Efficiency (%)	61.51	56.99	57.71
Result	Within desired moisture range	Slightly above desired moisture range	Within desired moisture range
Observation	Improved moisture reduction observed	Stable drying performance achieved	More uniform drying behavior observed

At 15 RPM, improved drying performance was observed. Most trials achieved moisture contents within or close to the desired range, while drying efficiencies increased compared with the 13 RPM condition. Greater particle movement inside the drum promoted improved exposure of the material to heated air, resulting in more effective moisture removal.

Table 4. Drying Performance at 17 RPM



PARAMETER	TEST 1	TEST 2	TEST 3
Initial Weight (kg)	30	30	30
Initial MC (%)	46.23	47.20	46.88
Final Weight (kg)	18.75	18.89	18.85
Final MC (%)	13.97	16.15	15.46
Max Air Temp (°C)	71.2	70.5	70.2
Drying Time (hrs)	3	3	3
Efficiency (%)	69.78	65.78	67.02
Result	Within desired moisture range	Within desired moisture range	Within desired moisture range
Observation	Effective moisture removal achieved	Stable and efficient drying observed	Uniform drying behavior maintained

Among all tested conditions, 17 RPM produced the most consistent drying performance. Enhanced particle agitation and material redistribution improved heat and mass transfer throughout the drying process, resulting in lower final moisture content and more uniform drying behavior.

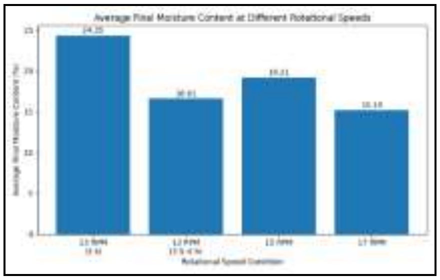


Figure 14. Average Final Moisture Content at Different Rotational Speeds

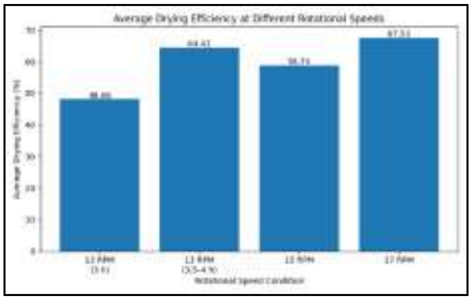


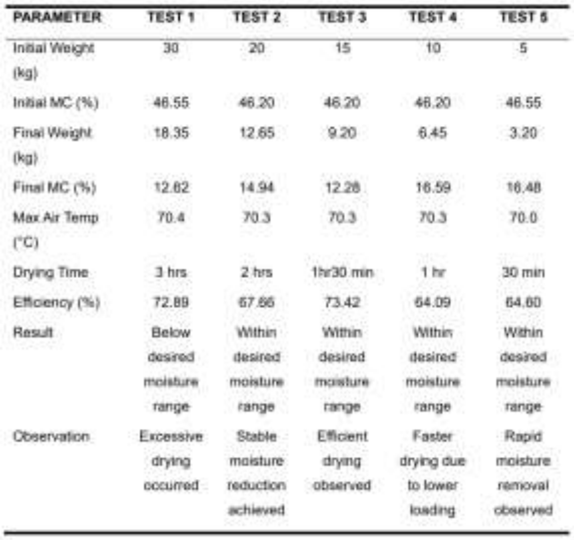
Figure 15. Average Drying Efficiency at Different Rotational Speeds

The experimental observations were consistent with the DEM simulation results, which predicted improved particle mobilization and mixing behavior at higher rotational speeds. The agreement between simulation and experimental findings indicates that particle dynamics play an important role in determining drying effectiveness.

Effect of Loading Capacity

Additional experiments were conducted to evaluate the effect of loading capacity on dryer performance at the selected operating condition. Loading capacities of 5 kg, 10 kg, 15 kg, 20 kg, and 30 kg were tested.

Table 5. Drying Performance at Different Loading (17rpm)



PARAMETER	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5
Initial Weight (kg)	30	20	15	10	5
Initial MC (%)	46.55	46.20	46.20	46.20	46.55
Final Weight (kg)	18.35	12.65	9.20	6.45	3.20
Final MC (%)	12.62	14.94	12.28	16.59	16.48
Max Air Temp (°C)	70.4	70.3	70.3	70.3	70.0
Drying Time	3 hrs	2 hrs	1hr30 min	1 hr	30 min
Efficiency (%)	72.89	67.86	73.42	64.09	64.60
Result	Below desired moisture range	Within desired moisture range	Within desired moisture range	Within desired moisture range	Within desired moisture range
Observation	Excessive drying occurred	Stable moisture reduction achieved	Efficient drying observed	Faster drying due to lower loading	Rapid moisture removal observed

The results showed that increasing loading capacity generally increased the drying time required to achieve the desired moisture content. Larger quantities of material required greater heat input and longer exposure to heated air before sufficient moisture removal could occur. However, the developed rotary drum dryer maintained acceptable drying performance across all tested loading conditions.

The spiral agitating flights contributed to maintaining material movement and preventing excessive particle accumulation, even under higher loading conditions. Continuous redistribution of the sapal improved exposure to heated air and helped maintain drying uniformity throughout the drum.

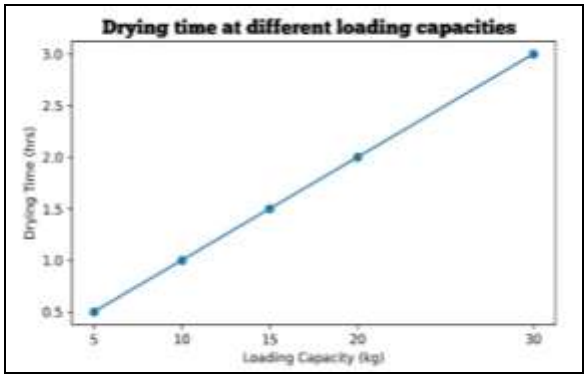


Figure 16. Drying Time at Different Loading Capacities

Dryer Efficiency Analysis

The performance evaluation demonstrated that the developed rotary drum dryer achieved an average drying efficiency of approximately 60%, while the computed dryer efficiency reached 75.38%. These values indicate that the system was capable of effectively transferring heat to the drying material and reducing moisture content to levels suitable for feed-processing applications.

The combination of DEM-assisted design, optimized rotational speed, and internal spiral agitating flights contributed to improved particle circulation and more efficient utilization of thermal energy. The agreement between simulation predictions and experimental observations further validated the effectiveness of the developed design.

Overall, the results demonstrate that the developed rotary drum dryer is capable of providing efficient and uniform drying of coconut meat residue and has potential for small-scale agricultural and feed-processing applications.

V. CONCLUSION

The study successfully designed, fabricated, and evaluated a simulation-assisted small-scale rotary drum dryer equipped with internal spiral agitating flights for drying coconut meat residue (*sapal*). The Discrete Element Method (DEM) simulation effectively analyzed particle movement, mixing behavior, and velocity distribution within the rotary drum, providing valuable insights for design optimization prior to fabrication.

The simulation results showed that increasing rotational speed improved particle circulation, enhanced mixing behavior, reduced dead zone formation, and promoted more uniform material distribution. The internal spiral agitating flights contributed significantly to continuous particle agitation, resulting in improved particle mobility and interaction within the drum.

Experimental testing demonstrated that rotational speed significantly affected drying performance. Among the evaluated operating conditions, 17 RPM produced the most consistent moisture reduction and drying behavior. The developed rotary drum dryer achieved an average drying efficiency of 60% and a computed dryer efficiency of 75.38%, indicating its capability to effectively dry coconut *sapal* for feed-processing and other agricultural applications.

Furthermore, the agreement between DEM simulation results and experimental observations validated the effectiveness of the simulation-assisted design approach and highlighted the importance of particle dynamics in improving drying performance. Future studies may incorporate coupled DEM-CFD simulations to evaluate the combined effects of particle movement, airflow, and heat transfer within the rotary drum. Additional investigations on alternative flight configurations, improved thermal insulation, and automated process control are also recommended to further enhance drying efficiency and broaden the application of the developed dryer to other agricultural materials.

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