

Design and Fabrication of a Hammer Mill with Dual Cyclone Separator for Flour Production

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ABSTRACT

A hammer mill integrated with a dual-cyclone separation system was designed, fabricated, and evaluated for flour production from dried cassava, yam, and potato. The machine, driven by a 15 hp electric motor, was tested using a uniform screen aperture of 250 μm at three feed moisture contents (9%, 10%, and 11%) and three hammer speeds (1200, 1300, and 1400 rpm), with a fixed batch size of 5 kg. Performance was assessed in terms of milling time, flour recovery from the primary and secondary cyclones, material retained on the screen and hammer chamber, moisture gain, spillage/dust loss, milling efficiency, cyclone separation efficiency, dual-cyclone capture effectiveness, and throughput. Results showed that milling efficiency and throughput increased with hammer speed but decreased with increasing moisture content across all three materials, with cassava consistently recording the highest efficiency and potato the lowest. Milling efficiency ranged from 87.7% to 91.2%, while the dual-cyclone system achieved a flour capture effectiveness exceeding 95% in all trials, confirming that the secondary cyclone significantly reduced product loss relative to a conventional single-cyclone design. A hammer speed of 1400 rpm combined with a feed moisture content of 9% gave the best overall performance. The study demonstrates that the dual cyclone hammer mill is an effective, reduced loss solution for small to medium scale flour production from tuber crops.

Keywords: Hammer mill; Dual cyclone separator; Flour production; Milling efficiency; Moisture content; Cassava, yam and potato; Throughput capacity; Machine performance evaluation

INTRODUCTION

Cassava, yam, and potato are among the most widely cultivated root and tuber crops in tropical and sub-tropical regions, and their conversion into stable, storable flour is an important value-addition step that reduces post-harvest losses and extends shelf life beyond that of the fresh, highly perishable roots. Post-harvest losses of these crops in sub-Saharan Africa are estimated in the region of 30% and 60% of total production, arising mainly from rapid physiological deterioration, poor storage infrastructure, and limited processing capacity (Lawrence et al., 2025). Flour milling of these tubers is typically the final and most energy-intensive stage of processing, following peeling, washing, chipping, and drying, and the design of the milling equipment used at this stage has a direct bearing on flour yield, particle fineness, and overall processes.

The hammer mill remains one of the most widely adopted machines for this purpose because of its simplicity, relatively low cost, versatility across different feed materials, and ability to produce a broad range of particle sizes by simply changing the screen aperture (Dominguez, 2021). In a hammer mill, dried feed material is reduced in size through repeated impact from freely swinging or rigidly mounted hammers rotating at high speed within a perforated screen housing; particles are retained and re-struck until they are small enough to pass through the screen apertures. However, conventional single-cyclone hammer mills often lose an appreciable fraction of the finest flour particles as airborne dust, since the lightest particles are the most easily entrained in the exhaust air stream and escape a single separation stage (Perry and Chilton, 1973). This represents a direct economic loss to the processor and, if released to the environment, pollution and potential

occupational-health hazard from airborne flour dust will be the issue of the day.

A dual cyclone arrangement, in which a secondary cyclone is placed downstream of the primary cyclone to recapture the finer particles that escape the first separation stage, offers a practical means of reducing this loss without a major increase in machine complexity or cost. Despite the demonstrated benefits of multi-stage cyclone separation in general dust-control and pneumatic-conveying applications, comparatively little published work has evaluated a dual cyclone hammer mill specifically for cassava, yam, and potato flour production under varying feed moisture content and rotor speed (Shittu *et al.*, 2013). This study therefore presents the design, fabrication, and performance evaluation of such a machine, with the results reported in this document intended to establish its milling efficiency, cyclone separation performance, and throughput capacity across the tested range of operating conditions.

LITERATURE REVIEW

Hammer Mill Design and Operating Principles

Size reduction in a hammer mill is achieved primarily by impact, with attrition and shear playing a secondary role as particles collide with the hammers, the mill casing, and one another before passing through the screen (McCabe *et al.* 2005). Several researchers have designed and evaluated hammer mills for processing cereals, grain legumes, and root/tuber crops. Dominguez (2021) designed and fabricated a hammer mill for small-scale corn milling incorporating a milling chamber, suction fan, and cyclone separator, and reported that machine productivity increased and specific energy consumption decreased as hammer rotor speed increased, with the best performance recorded at the highest tested speed of 1440 rpm. Similarly, Opadotun *et al.* (2017) developed a hammer mill for pulverizing dried yam and evaluated it at two screen sizes and two operating speeds; the results showed that increasing the operating speed reduced milling time and altered output fineness modulus, confirming that rotor speed is one of the dominant factors governing hammer mill throughput and product fineness.

Feed Moisture Content

Feed moisture is a key factor in hammer mill performance. Probst *et al.* (2013) found that higher moisture in corn/corncoobs reduced throughput and breakage rate, producing coarser, broader particle distributions, since moist material is more plastic and fracture-resistant than dry, brittle material. Higher moisture also promotes agglomeration and screen clogging, increasing material retention and reducing fine flour output. Based on this, the study expects cassava, yam, and potato milling efficiency and flour recovery to be highest at 9% moisture and decline toward 11%.

Cyclone Separation for Fine Particle Recovery

Cyclones separate particles from air via centrifugal vortex action (Perry & Chilton, 1973), but single-stage cyclones lose capture efficiency for very fine, lightweight particles, which escape as dust. Adding a secondary, smaller cyclone downstream is a standard dust-control technique which improves fine-particle capture without much added pressure drop. Applied to the hammer mill studied here, this dual cyclone design is expected to recover more fine flour and improve overall recovery versus a single cyclone system.

Principle of Operation of the Machine

The hammer mill with dual cyclone separator operates as an integrated size-reduction and pneumatic separation system comprising a feed hopper, a milling chamber housing a high-speed hammers, a perforated screen, a primary cyclone, a secondary cyclone, an induced-draught fan, and a 15 hp electric motor as the prime mover.

Dried chips are fed through the hopper into the milling chamber of the machine where a motor-driven rotor spins hammers at high speed continuously against the fed chips. The chips get smashed into smaller pieces mainly by impact, attrition and shear forces. Particles of chips small enough pass through the perforated screen

that surrounds the milling chamber of the machine, the oversized bits stay inside and keep getting hit until they're fine enough to pass through the screen. A suction fan sucks the fine particles through ducting into Cyclone 1. The air spins in a vortex, flinging denser/coarser flour particles to the outer wall, where they fall and be collected. The lightest, finest particles that escape Cyclone 1 get carried into the Cyclone 2, which captures more flour that would otherwise be lost as dust.



Plate 1: The fabricated Hammer Mill

Effect of Hammer Speed on Milling Efficiency

At a fixed moisture content of 9%, milling efficiency increased with rotor speed for all three materials, as faster hammer rotation produced more intense impact and shear, reducing particle size and improving flour recovery through the cyclone system. Cassava consistently recorded the highest efficiency, followed by yam, with potato showing the lowest efficiency owing to its comparatively higher fibrous/starch content, which increased resistance to size reduction.

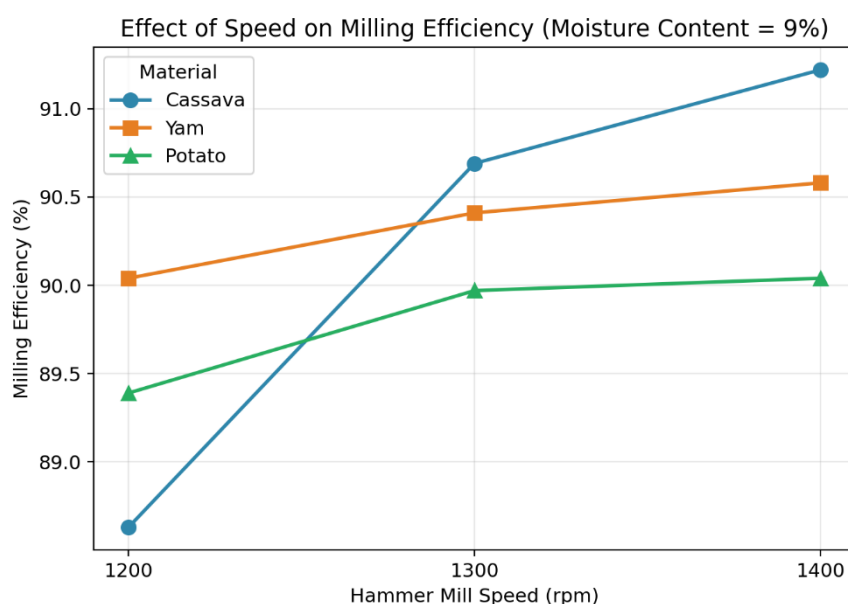


Figure 1: Effect of Speed on Milling Efficiency (Moisture Content = 9%)

Effect of Moisture Content on Flour Recovery

At a fixed speed of 1300 rpm, total flour recovery declined slightly as moisture content increased from 9% to 11% for all materials. Higher moisture content promoted agglomeration of particles, increasing the proportion of material retained on the screen and within the hammer chamber, and reducing the mass that passed through the screen into the cyclone system.

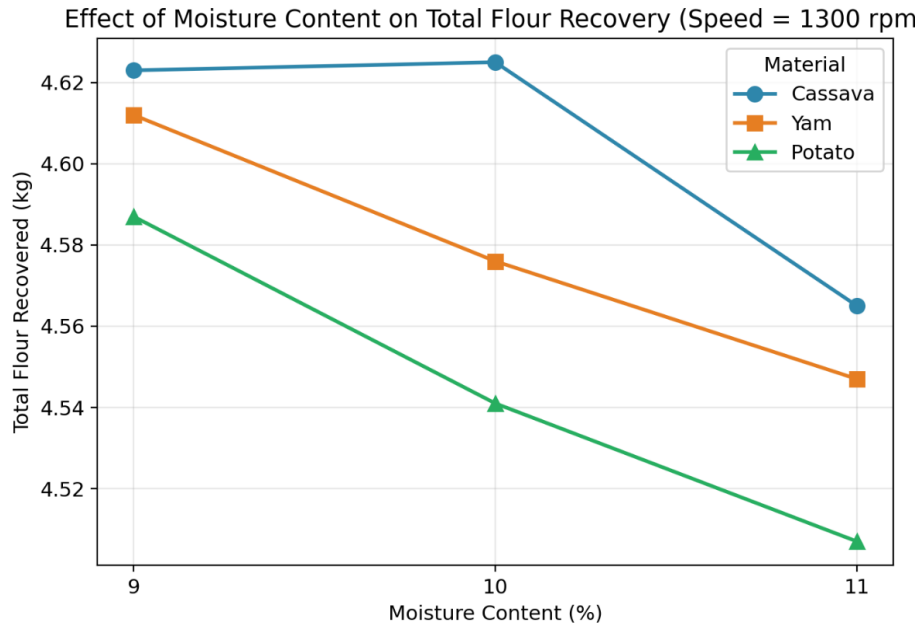


Figure 2: Effect of Moisture Content on Total Flour Recovery (Speed = 1300 rpm)

Effect of Speed on Throughput

Throughput, defined as the mass of feed material processed per unit time, increased consistently with rotor speed for all three materials, since higher speeds reduced the milling time required per batch. Cassava recorded the highest throughput at all speeds, consistent with its lower resistance to size reduction relative to yam and potato.

Effect of Speed on Machine Throughput Capacity (Averaged over Moisture Levels)

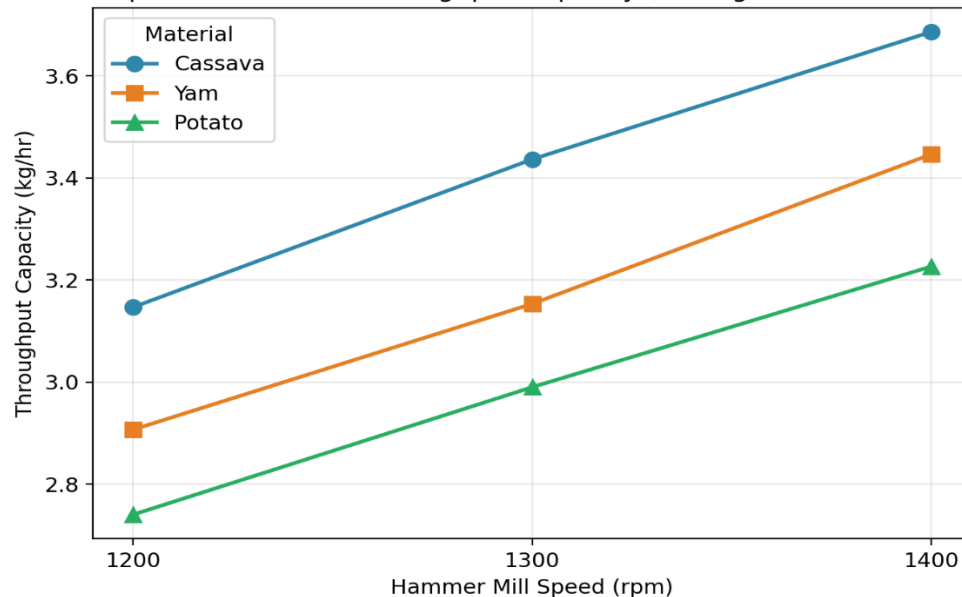


Figure 3: Effect of Speed on Machine Throughput Capacity (Averaged over Moisture Levels)

Cyclone 1 versus Cyclone 2 Flour Recovery

The primary cyclone (Cyclone 1) consistently recovered the larger share of milled flour across all materials, while the secondary cyclone (Cyclone 2) recovered the finer fraction that escaped the primary separator. This confirms the value of the dual cyclone configuration in capturing fine flour particles that would otherwise be lost as airborne dust in a single cyclone system.

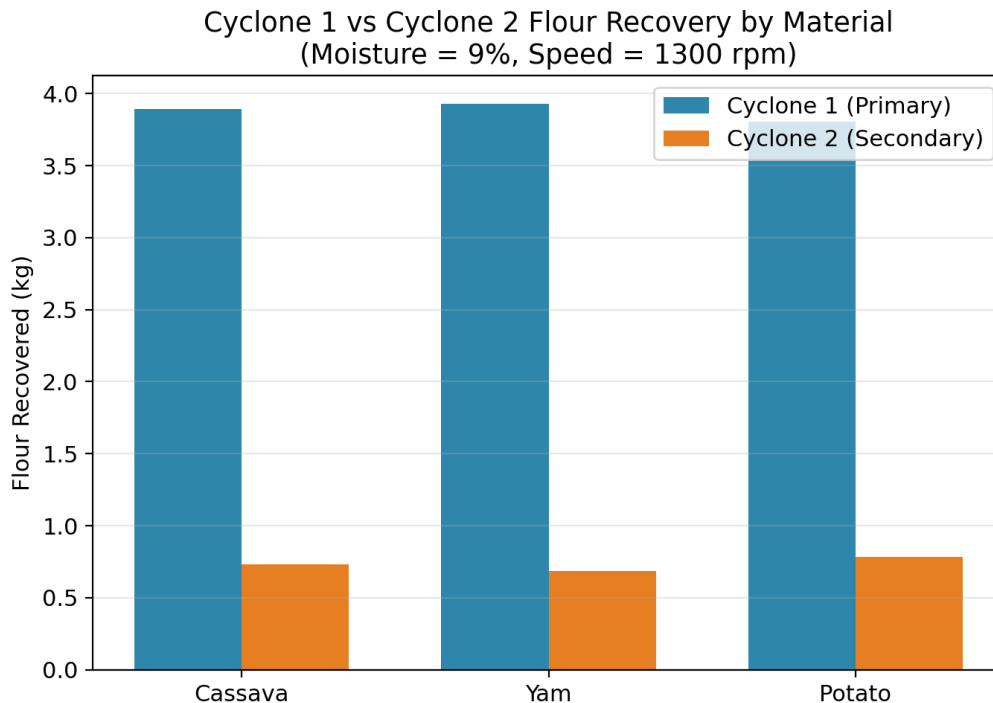


Figure 4: Cyclone 1 vs Cyclone 2 Flour Recovery by Material (Moisture = 9%, Speed = 1300 rpm)

DISCUSSION

The results demonstrate that the fabricated hammer mill with dual cyclone separation performs effectively across the tested range of feed materials, moisture contents, and operating speeds. Milling efficiency and throughput were both maximized at the highest tested speed (1400 rpm) and lowest tested moisture content (9%), while increasing moisture content consistently reduced performance across all materials due to increased particle cohesion and screen clogging. Among the three tuber materials, cassava was the easiest to mill, followed by yam, with potato requiring the longest milling time and yielding the lowest recovery, attributable to its higher starch and moisture retention characteristics even after drying.

The inclusion of a secondary cyclone proved beneficial in improving overall flour capture, recovering between 0.53 kg and 0.91 kg of otherwise-escaping fine flour per batch across the tested conditions, which corresponds to a dual-cyclone capture effectiveness of over 95% in all runs. This confirms that the dual cyclone design meaningfully reduces product loss compared to a conventional single cyclone hammer mill.

CONCLUSION

The performance evaluation confirms that the designed and fabricated hammer mill with dual cyclone separator achieves high milling efficiency (up to 91.2%) and effective fine flour capture (over 95% dual cyclone effectiveness) across dried cassava, yam, and potato at moisture contents between 9% and 11%, and hammer speeds between 1200 and 1400 rpm. A hammer speed of 1400 rpm combined with a feed moisture content of 9% is recommended for optimum machine performance, while the dual cyclone configuration is validated as an effective means of minimizing flour loss during milling.

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