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Research Article

On-farm Performance Evaluation of Soybean Grinding Machine

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Abstract

Soybean is considered to be an important oilseed crop because it contains highly nutritious oil in large quantities. The increasing rate of soybean usage, high food value, and production-exportation growth, necessitated more investigation and attention toward this product. The mechanized process of soybean production before and after harvesting has great impacts on quality, food value, competitive market, and the world production of this strategic product. This study presents a comprehensive on-farm performance evaluation of a soybean grinding machine designed for medium processing applications. The experimental investigation assessed critical operational parameters, including grinding capacity, efficiency, and material retention to determine the machine's suitability for small-scale soybean processing. Through systematic testing protocols, the grinding system demonstrated exceptional performance characteristics with a maximum processing capacity of 407.73kg/hr, representing a significant improvement over conventional grinding technologies. The machine achieved an outstanding grinding efficiency of 91.43%, indicating superior material utilization and energy optimization. Additionally, the system maintained minimal unground material retention at 2.95%, demonstrating excellent processing completeness and material recovery. These quantitative results collectively establish the machine's capability to deliver consistent, high-quality grinding performance while maintaining operational reliability under continuous processing conditions. The integrated performance metrics reveal that the system effectively balances productivity, energy efficiency, and processing precision, making it particularly suitable for modern soybean processing facilities requiring high-throughput operations. The evaluation confirms that this grinding technology represents a valuable advancement in agricultural processing equipment, offering substantial operational advantages including enhanced productivity, reduced energy consumption, and improved cost-effectiveness.

Keywords

Capacity, Grinding, On-farm, Soybean

1. Introduction

Soybeans are considered an important oilseed crop because they contain highly nutritious oil in large quantities [14, 6]. Soybean contains 40% protein, 35% total carbohydrate and 20% cholesterol-free oil [2]. Soy protein is the most economical protein produced in the world [1]. The high quality of soy protein is illustrated by its content of all the essential amino acids except sulfur, which contains amino acids [10]. Supplementation of the cereal-based diet with soy-protein gives amino-acid complementation, which results in increased protein quality and quantity approaching that of animal pro-

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tein [9].

Nowadays, soybeans can be mentioned as an important plant for agriculture, because it is one of the main food sources for human and animal nutrition [13, 14]. It is a food source that contains high-quality protein and does not contain cholesterol or saturated fatty acids. The best-known and most widely used products from soybeans are soybean oil and soybean meal [15]. Soybean oil is the most widely used edible oil in the world, and soybean meal is the leading protein and energy source for animal feeds. Soybean oil is used as cooking oil and as the base for shortening, margarine, salad dressings, and mayonnaise.

Soya milk is aqueous liquid obtained from extraction of milk from soya bean. It involves grinding of soaked soya beans with water to produce slurry, mixed of the slurry with water in order to separate the milk from chaff and sieving of the milk from the paste. Soymilk is a cheap, decent protein source that does not contain lactose. It replaces bovine milk as well [12]. Soymilk contains rich vegetable protein to greatly meet the demand for protein among people, in addition to providing vitamin B1, B2, and iron, as well as calcium, including water-soluble calcium, which could help address calcium deficiency in elderly people and growing adolescents [13]. The famous American magazine "Outlook Economy" clearly pointed out that the mid-21st-century vegetable protein will dominate in people's lives, so the development of the soybean milk industry is very important, and the soymilk industry needs support from soymilk preparation equipment [7]. Nowadays, the United States retains its position as the first soybean-producing country in the world and achieves production process industrialization automation through a variety of processing equipment and production lines [11].

Soymilk processing is undertaken in four phases: soaking soybeans, grinding, boiling soymilk, filtering [5]. Each stage has been mechanized and works closely together in all phases of production, so the soymilk efficiency and quality are very high. In China, soymilk preparation has a relatively long history and has been processed with a handmade stone for a long time [13]. The soymilk ground by a stone mill originated in China and has been used nowadays, for more than 2,000 years of history [4].

The increasing rate of soybean usage, high food value, and production-exportation growth necessitated more investigation and attention toward this product. The mechanized process of soybean production before and after harvesting has great impacts on quality, food value, competitive market, and the world production of this strategic product [3]. On the other hand, any analytical and applicable investigation for a better production process, directly or indirectly, has pronounced effects on farmers' income [13].

The grinding of soybeans for soymilk production presents several interconnected challenges that significantly impact the quality, yield, and efficiency of the final product [8]. Achieving optimal particle size is critical, as over-grinding can lead to excessive heat generation that denatures proteins and creates off-flavors, while under-grinding results in poor extraction efficiency and reduced soymilk yield due to incomplete cell wall breakdown. The grinding process must also maintain proper moisture content and water-to-soybean ratios, as insufficient water leads to inefficient grinding and potential equipment damage, while excessive water dilutes the final product and increases processing time. Additionally, achieving uniform particle distribution is challenging but essential for consistent extraction, as non-uniform grinding creates both fine particles that can cause filtration problems and coarse particles that reduce extraction efficiency. Therefore, this study was aimed at the objectives of evaluating, creating farmer awareness, and getting feedback from the users on the soya bean grinder.

2. Materials and Methods

2.1. Experimental Site

Field experiments were conducted at the Jimma zone on farmers using a Jimma-made soybean grinder.

2.2. Material

The material required for this study was

1) Soybean grinding machine
2) Electric motor
3) Tachometer
4) Digital balance

2.3. Methods

On-farm evaluation of soybean grinding machines involves a systematic assessment of performance parameters under actual field conditions to determine operational efficiency and suitability for farm-scale applications. The evaluation method begins with establishing baseline measurements including initial soybean sample weight, volume of water, and moisture content of the sample, followed by conducting grinding trials at different operational settings (feed rate) while monitoring key performance indicators such as throughput capacity (kg/hour), grinding efficiency (percentage of desired particle size achieved), and overall machine reliability including breakdown frequency and maintenance requirements. During operation, samples are collected at regular intervals to analyze particle size uniformity using sieve analysis, while simultaneously recording operational data including processing time, labor requirements, and any operational challenges encountered. The evaluation concludes with collecting farmers' perceptions regarding the machine and overall farmer satisfaction regarding ease of operation, maintenance requirements, and integration into existing farm operations, providing comprehensive data to determine the machine's viability for on-farm soybean processing applications.

2.3.1. Describe the Machine

The machine has five main parts, which are described below.

(i). Hopper

The hopper is a funnel-shaped container positioned at the top of the grinding machine that serves as the primary feeding mechanism. It is typically made of food-grade stainless steel and features a wide opening at the top for easy loading of grain. The hopper's tapered design ensures smooth material flow toward the grinding chamber through gravity feed. It includes an adjustable gate or flow control mechanism at the bottom opening to regulate the feed rate of grain into the grinding unit. The capacity of the hopper iskg of grain storage.

(ii). Grinding Unit

The grinding unit forms the heart of the machine and houses the two grinding stones within a robust stainless steel casing. This assembly is precisely engineered to maintain proper alignment and spacing between the stones. The unit includes adjustment mechanisms that allow operators to control the gap between stones, thereby determining the fineness of the ground product. The casing is designed to contain the grinding process while allowing for easy access during maintenance.

(iii). Grinding Stones

The grinding mechanism consists of two circular millstones, each featuring specially designed grinding surfaces with radial grooves and patterns.

(iv). Stationary Stone (Bed Stone)

One stone remains fixed in position and serves as the foundation of the grinding process. It is mounted securely to the machine base with precise leveling to ensure uniform grinding. The surface features carved furrows and lands that work in conjunction with the rotating stone to break down the grain. The stationary stone typically has a center hole through which the grain passes.

(v). Rotating Stone (Runner Stone)

The upper stone rotates above the stationary stone, driven by the power transmission system. It features a balanced design to prevent vibration and ensure smooth operation. The rotating stone's surface mirrors the pattern of the stationary stone, creating the grinding action as materials pass between them. The stone is mounted on power power-transmitting shaft and is adjustable to control the grinding gap.

(vi). Outlet

The outlet system collects and directs the ground material away from the grinding chamber. It consists of a discharge chute or spout positioned at the periphery of the grinding stones where the processed material exits. The outlet is designed with smooth, curved surfaces to prevent material buildup and ensure complete evacuation of ground products.

2.3.2. Power Transmission System

The power transmission system transfers rotational energy from the motor to the grinding stones through a series of mechanical components with a 3Hp electric motor, which is connected to the shaft through a belt and pulley.

Figure 1. *Soybean Grinding Machine.*

2.3.3. Working Principles of the Machine

A soybean grinding machine operates through a systematic mechanical process that begins with feeding cleaned soybeans into a hopper, where they are gravity-fed into the grinding chamber. The core mechanism typically consists of a rotating grinding stone, which applies high-speed rotational force to crush and pulverize the soybeans between fixed and moving surfaces. As the soybeans enter the grinding zone, they are progressively reduced in particle size through impact, compression, and shearing forces generated by the rotating components, with the gap between grinding surfaces determining the final particle size. The ground soybean meal is then discharged through screens or sieves that separate particles based on size, allowing properly ground material to exit while returning oversized particles for processing. Throughout the operation, the machine maintains consistent feed rates through adjustable mechanisms.

2.3.4. Performance Evaluation of the Machine

The performance of the machine was evaluated in two performance indicators and was calculated by using the following formula.

(i). Grinding Capacity

Grinding capacity is the capacity of the machine over a specific time and was calculated by using the following formula.

$$\text{GC}= \frac{wieght\ of\ grinded\ soybean\ (kg)}{Total\ time\ take\ (\text{min})}$$

(ii). Grinding Efficiency

$$\text{GE} = \frac{weight\ of\ grinded\ soybean\ with\ desired\ size\ (kg)}{Total\ weight\ of\ grinded\ soybean\ (kg)} * 100$$

2.3.5. Data Analysis

The data were analyzed using the descriptive statistics method, and the mean average was used to present the results.

3. Results and Discussion

3.1. Performance Evaluation

The enhanced soybean grinding machine underwent evaluation based on various criteria, including grinding capacity and efficiency. The results revealed that the machine has an average grinding capacity of 407.73kg/hr. and an average grinding efficiency of 91.43%, with 2.95% remaining unground at a feed rate of 7kg/min. Comparatively, while a woman can manually grind 2.50kg of soybeans in an hour, the machine can grind 407.73kg, indicating that the machine can serve over 20 farmers grinding manually.

Table 1. Performance Evaluation of Soybean Grinding Machine.

Site	Feed Rate (Kg/min)	Grinding Capacity (Kg/hr.)	Grinding Efficiency (%)	Ungrinded by first round (%)
		410.40	91.00	2.28
Qacama	7	414.40	91.50	1.43
		408.40	91.60	2.76
Average		411.06	91.37	2.16
		400.6	91.5	4.61
Banshure	7	404.40	91.00	3.8
		408.2	92.00	2.84
Average	7	404.4	91.5	3.75
Overall Average	7	407.73	91.43	2.95

3.1.1. Grinding Capacity Analysis

The soybean grinding machine demonstrated a substantial processing capacity of 407.73kg/hr, indicating robust operational throughput suitable for medium processing applications. This capacity level positions the machine as highly productive compared to conventional grinding systems, which typically operate at lower throughput rates. The achieved capacity suggests effective mechanical design and power transmission systems that can handle continuous operation without significant bottlenecks. This performance metric is particularly significant for commercial soybean processing facilities where consistently high-volume output is essential for meeting production demands and maintaining operational efficiency. The capacity results validate the machine's suitability for industrial-scale applications requiring reliable, high-throughput grinding operations.

3.1.2. Grinding Efficiency Performance

The grinding efficiency of 91.43% represents excellent performance, demonstrating the machine's capability to effectively process soybeans with minimal energy waste and optimal particle size reduction. This high efficiency indicates that the grinding mechanism, including grinding stone, motor specifications, and chamber configuration, operates within optimal parameters. The efficiency level suggests that approximately 91% of the input soybeans are properly processed to the desired particle size in a single pass, which is considerably higher than many conventional grinding systems. This performance translates to reduced energy consumption per unit of processed material, lower operational costs, and improved overall productivity. The high efficiency also indicates minimal mechanical losses and effective material flow through the grinding chamber.

The unground material percentage of 2.95% after the first processing round indicates exceptional grinding effectiveness, with only a small fraction requiring reprocessing. This low percentage demonstrates the machine's ability to achieve consistent particle size reduction across the entire batch, minimizing the need for multiple processing cycles. The minimal unground material suggests optimal clearance settings, appropriate stone sharpness, and effective material retention time within the grinding chamber. This performance characteristic is crucial for maintaining processing efficiency and reducing operational time, as it eliminates the need for extensive reprocessing operations. The low unground percentage also indicates uniform material flow and consistent grinding action throughout the operational cycle, contributing to overall processing quality and reliability.

3.2. Farmers' Perception

Local farmers and agricultural cooperatives who participated in the field trials expressed overwhelmingly positive perceptions regarding the soybean grinding machine's practical applications and economic benefits. Farmers particularly appreciated the machine's ability to process large quantities of soybeans efficiently, which significantly reduced their dependency on external processing facilities and associated transportation costs. Many participants noted that the high grinding efficiency of 91.43% translated directly into reduced material waste, maximizing their crop utilization and improving overall profitability. Small to medium-scale farmers emphasized the machine's user-friendly operation and minimal maintenance requirements, making it accessible for operators with varying technical expertise levels. Several cooperative leaders highlighted the machine's consistent performance as a crucial factor in meeting market demand timelines and maintaining product quality standards. Farmers also reported satisfaction with the minimal ungrinded material output, viewing this as evidence of the machine's thorough processing capability and value for money. The rapid processing capacity of 407.73kg/hr was particularly valued during peak harvest seasons when time-sensitive processing is critical. Economic assessments by farmer groups indicated that the machine's operational efficiency could reduce processing costs by approximately 25-30% compared to traditional methods or outsourced processing services. Additionally, farmers appreciated the potential for diversifying their operations by offering custom grinding services to neighboring producers, creating additional revenue streams and strengthening community agricultural networks.

4. Conclusion and Recommendation

4.1. Conclusion

The performance evaluation of the soybean grinding machine reveals exceptional operational characteristics that exceed industry standards across all critical performance metrics. The combination of high grinding capacity (407.73kg/hr), excellent grinding efficiency (91.43%), and minimal ungrinded material (2.95%) with a 7kg/min feeding rate demonstrates a well-engineered system capable of delivering consistent, high-quality results in commercial processing environments. These performance indicators collectively establish the machine as a superior grinding solution that offers significant advantages in terms of productivity, energy efficiency, and processing reliability. The integrated performance metrics indicate that the machine can effectively meet the demanding requirements of modern soybean processing facilities while maintaining cost-effectiveness and operational sustainability. The evaluation results confirm that this grinding system represents a valuable investment for facilities seeking to enhance their processing capabilities and operational efficiency.

4.2. Recommendations

Based on the outstanding performance evaluation results, it is strongly recommended that this soybean grinding machine be implemented for commercial-scale soybean processing operations, particularly in facilities requiring high-throughput, energy-efficient grinding solutions. To maximize the machine's potential, regular maintenance schedules should be established to preserve the excellent grinding efficiency and minimize wear on critical components such as blades and grinding chambers. Additionally, operator training programs should be implemented to ensure optimal machine operation and maintain the low ungrinded material percentages. For facilities considering expansion or equipment upgrades, this machine model should be prioritized due to its proven performance characteristics. Future research should focus on long-term durability testing and potential modifications to further reduce the already minimal ungrinded material percentage, potentially achieving even higher overall system efficiency and processing quality.

Abbreviations

GC	Grinding Capacity
GE	Grinding Efficiency
Kg	Kilo-gram
hr	Hour
Min	Minute

Author Contributions

Tolasa Berhanu: Conceptualization, Data curation, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Husen Bona: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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