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Enhancing flour quality and milling efficiency: experimental study on bullet plate type flour grinding machine

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ABSTRACT

This study aims to optimize the operational parameters of the Bullet plate type flour grinding machine for processing PBW 824 wheat to enhance both machine performance and flour quality. The objective is to identify optimal settings for grinding speed, plate distance, and wheat moisture content using optimization techniques. Response Surface Methodology (RSM) and Central Composite Design (CCD) were employed to evaluate these parameters. Controlled experiments varied each parameter at five levels, collecting data on throughput, energy consumption, flour fineness, and protein content. The results indicate throughput increased from 225–275 kilograms per hour (kg/h) at 900 revolutions per minute (RPM) to 275–400 kg/h at 1500 RPM, while energy consumption rose from 6-10 kilowatt-hours (kWh) to 12–20 kWh. Flour fineness was highest (80%–90%) at smaller plate distances (0.5 millimeters (mm), and protein content decreased from 13%–14.5% at 10% moisture content to 12%–13.5% at 15%. These findings highlight the trade-off between productivity and energy efficiency and the importance of optimizing moisture content to preserve nutritional quality. The study successfully identified optimal operational parameters, enhancing the performance and quality of the grinding machine. Future research could apply these optimization techniques to milling machinery and wheat varieties, contributing to advancements in milling technology and agriculture.

Keywords: Flour milling; Optimization; PBW 824; Performance; Flour quality.

1. INTRODUCTION

Flour milling is a critical process in the food production industry, essential for converting wheat grains into flour, a staple food ingredient globally. The efficiency and quality of flour milling directly impact the nutritional value and usability of the flour produced, influencing both economic and health outcomes. Optimizing flour milling machinery's operational parameters is crucial to enhancing performance, reducing operational costs, and producing high-quality flour that meets industry standards [1].

Wheat, the primary raw material for flour production, comes in various varieties with distinct characteristics. One such variety is PBW 824, developed by the Punjab Agricultural University. PBW 824 is renowned for its high yield potential, disease resistance, and adaptability to the agro-climatic conditions of Punjab, one of India's major wheat-producing regions. This variety features robust grain structure, medium to large grain size, and hard texture, making it suitable for traditional and modern milling processes. PBW 824 also has good protein content, essential for producing high-quality flour with favorable baking properties [2]. Its development involved rigorous selection and breeding processes to enhance agronomic traits, ensuring consistent yields under varying environmental conditions.

The Bullet plate type flour grinding machine represents a unique category of milling equipment designed to achieve uniform particle size distribution in the flour. Unlike traditional roller mills that use cylindrical rollers to crush and grind the wheat, the Bullet plate grinder employs a series of grooved plates to allow wheat grains

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to pass through progressively narrower gaps. This ensures thorough grinding and produces a consistent flour texture. The machine comprises several key components, including the hopper, grinding chamber, and discharge chute. The hopper holds a significant amount of wheat, feeding it gradually into the grinding chamber, where grooved plates positioned at specific angles maximize grinding efficiency [3]. The plate gap can be adjusted to control the flour's fineness, and the machine features a cooling system to dissipate heat generated during grinding, preventing thermal degradation of the flour.

The primary aim of this study is to optimize the operational parameters of the Bullet plate type flour grinding machine for processing PBW 824 wheat. By adjusting parameters such as grinding speed, plate distance, and wheat moisture content, the study seeks to enhance both machine performance and flour quality. Advanced optimization techniques, including Response Surface Methodology (RSM) and Design of Experiments (DOE), were employed to evaluate and model the effects of these parameters [4]. Methodologically, a Central Composite Design (CCD) was used to structure the experiments, varying each parameter at five levels. Controlled experiments were conducted to isolate the effects of each parameter on throughput, energy consumption, flour fineness, and protein content. The data collected were analyzed using RSM to develop mathematical models describing the relationships between the milling parameters and the response variables.

The significance of optimizing flour milling processes cannot be overstated. Higher efficiency in flour production reduces operational costs and contributes to environmental sustainability by lowering energy consumption. Furthermore, producing high-quality flour with consistent fineness and nutritional content meets consumer demands and industry standards, supporting broader food security goals and sustainable agriculture [5].

Throughput, measured as the amount of flour produced per unit time, is a key performance metric in milling operations. It provides insights into the machine's capacity to process wheat efficiently and is essential for optimizing production schedules and meeting demand. Energy consumption, another critical metric, quantifies the amount of energy used during the grinding process. Monitoring energy consumption helps assess the machine's operational efficiency, with lower energy consumption indicating a more efficient milling process. Reducing energy consumption also lowers operational costs and minimizes the carbon footprint associated with flour production.

Flour quality is assessed based on particle size distribution, flour fineness, and nutritional content. Particle size distribution is analyzed using sieves and particle size analyzers to determine the uniformity and consistency of the flour. Flour fineness, measured as the percentage of fine particles in the sample, is critical for producing high-quality flour that meets specific baking applications [6]. The nutritional content of the flour, including protein, carbohydrates, and fiber levels, is assessed using standard laboratory techniques. High protein content is particularly important for bread-making flour, as it contributes to the development of gluten, which gives bread its structure and elasticity. The significance of this study extends well beyond the immediate improvements in machine performance and flour quality. By optimizing the operational parameters of the Bullet plate type flour grinding machine, the research addresses critical aspects of efficiency and sustainability in the flour milling industry. Enhanced efficiency in flour production directly translates to reduced operational costs, making milling processes more economically viable. Additionally, lower energy consumption contributes to environmental sustainability, aligning with global efforts to reduce carbon footprints and promote green technologies. Producing high-quality flour with consistent fineness and nutritional content meets industry standards. It fulfills consumer demands, thereby supporting broader food security goals. The findings of this study have the potential to set new benchmarks in the milling industry, encouraging the adoption of advanced optimization techniques across various types of milling machinery and wheat varieties. This can lead to widespread improvements in milling technology, ultimately fostering sustainable agriculture and ensuring the production of superior flour products globally.

The study found that throughput increased from approximately 225–275 kg/h at 900 RPM to 275–400 kg/h at 1500 RPM, while energy consumption rose from 6–10 kWh to 12–20 kWh over the same range. This highlights a trade-off between productivity and energy efficiency. Flour fineness was highest (80%–90%) at smaller plate distances (0.5 mm), and protein content decreased from 13%–14.5% at 10% moisture content to 12%–13.5% at 15%. These results indicate that optimizing grinding speed, plate distance, and moisture content can significantly improve the efficiency and quality of the milling process [7].

The implications of this study extend beyond enhancing flour production efficiency. By optimizing operational parameters, it is possible to reduce operational costs and improve product quality, thus supporting the broader goals of food security and sustainable agriculture. Further research could explore the application of these optimization techniques to other types of milling machinery and wheat varieties, ensuring that the findings of this study have wide-reaching benefits in the flour milling industry.

Optimizing the operational parameters of the Bullet plate type flour grinding machine when processing PBW 824 wheat can significantly enhance both machine performance and flour quality. The systematic approach using RSM and DOE provides a robust framework for identifying optimal settings, ultimately contributing to improved efficiency, reduced costs, and higher-quality flour production. This study provides valuable insights and a strong foundation for future research in flour milling optimization [8].

2. MATERIALS AND METHODS

2.1. Description of wheat variety PBW 824

PBW 824 is a wheat variety developed by the Punjab Agricultural University, recognized for its high yield potential and disease resistance is shown in Figure 1. This variety is adapted to the agro-climatic conditions of the Punjab region, one of India's major wheat-producing areas. PBW 824 features a robust grain structure, making it suitable for both traditional and modern milling processes. The grains are typically medium to large, with a hard texture that enhances milling efficiency. The variety also has good protein content, essential for producing high-quality flour with favorable baking properties.

The development of PBW 824 involved rigorous selection and breeding processes in enhancing its agronomic traits. This variety resists common wheat diseases like rust and tolerates abiotic stresses such as drought and heat. These characteristics make PBW 824 a reliable choice for farmers aiming to achieve consistent yields under varying environmental conditions. The grains of PBW 824 are characterized by a high-test weight, low moisture content, and excellent milling quality, making it an ideal candidate for studies focused on optimizing flour milling processes.

2.2. Detailed description of the bullet plate type grinding machine

The Bullet plate type flour grinding machine represents a unique category of milling equipment designed to achieve uniform particle size distribution, as shown in Figure 2. Unlike traditional roller mills, which use cylindrical rollers to crush and grind the wheat, the Bullet plate type grinder employs a series of grooved plates. These plates are arranged to allow the wheat grains to pass through progressively narrower gaps, ensuring thorough grinding. The machine comprises several key components, including the hopper, grinding chamber,

Figure 1: PBW 824 wheat variety.

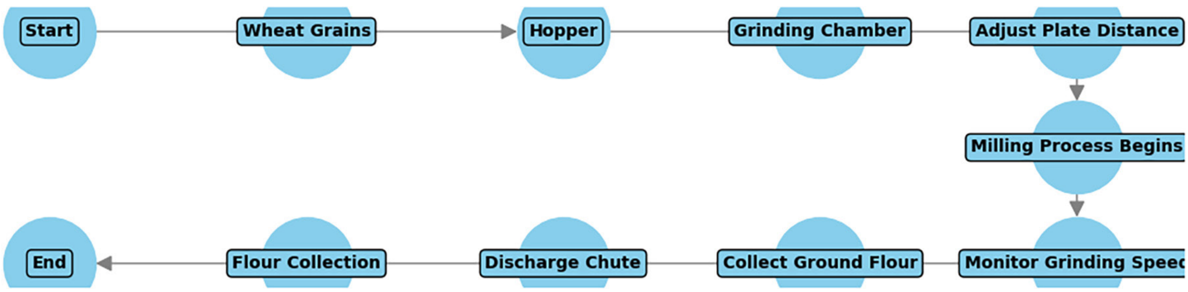

Figure 2: Bullet plate type flour grinding machine.

and discharge chute. The hopper is designed to hold a significant amount of wheat, feeding it gradually into the grinding chamber. The grooved plates are positioned inside the grinding chamber at specific angles to maximize grinding efficiency. The distance between the plates, known as the plate gap, can be adjusted to control the fineness of the flour. The machine also features a cooling system to dissipate the heat generated during the grinding process, preventing thermal degradation of the flour.

One of the primary advantages of the Bullet plate-type grinding machine is its ability to produce a consistent flour texture. The adjustable plate gap allows for precise control over the particle size, which is critical for achieving the desired flour quality. Additionally, the machine's design minimizes flour loss and energy consumption, making it an efficient option for large-scale milling operations.

2.3. Experimental design and setup

The experimental design for this study involves a series of controlled tests to evaluate the performance of the Bullet plate type grinding machine when processing PBW 824 wheat. The experiments are structured to isolate the effects of different operational parameters, including grinding speed, plate distance, and wheat moisture content. We can identify the optimal settings that maximize machine performance and flour quality by varying one parameter at a time while keeping the others constant.

The experimental setup includes the Bullet plate type grinding machine, a precision balance for measuring wheat and flour samples, moisture meters, and particle size analyzers. The wheat samples are prepared by cleaning and conditioning them to the desired moisture content. Each experiment is conducted in triplicate to ensure reproducibility and accuracy of the results.

2.4. Parameters considered for optimization

The rotational speed of the plates significantly impacts milling efficiency and energy consumption. Increased speeds can boost throughput but may also generate more heat, potentially affecting the quality of the flour. The gap between the grinding plates determines the flour's fineness; a smaller gap produces finer flour but may reduce throughput. The moisture content of the wheat grains affects their grinding behavior, with optimal moisture levels enhancing milling efficiency and flour quality.

The Bullet plate-type grinding machine's performance is evaluated using throughput and energy consumption metrics. Throughput measures the amount of flour produced per unit time, while energy consumption is assessed by monitoring the machine's power usage during operation. These metrics provide insights into the milling process's efficiency.

Flour quality is evaluated based on particle size distribution, flour fineness, and nutritional content. Particle size distribution is analyzed using sieves and particle size analyzers to determine the uniformity and consistency of the flour. Flour fineness is measured as the percentage of fine particles in the sample, while nutritional content is analyzed by assessing the protein, carbohydrate, and fiber content of the flour.

Evaluating the performance of the Bullet plate-type flour grinding machine involves several critical metrics reflecting the milling process's efficiency and effectiveness. One primary metric is throughput, which measures the rate of flour production. Throughput is calculated by determining the flour generated per unit time, typically in kilograms per hour (kg/h). This metric provides valuable insights into the machine's capacity to process wheat efficiently, essential for optimizing production schedules and meeting demand.

Another crucial performance metric is energy consumption, which quantifies the amount of energy the milling machine uses during grinding. A power meter continuously monitors energy consumption, allowing for precise power usage measurement over time. This metric is vital for assessing the machine's operational efficiency, as lower energy consumption indicates a more efficient milling process. Reducing energy consumption lowers operational costs and contributes to environmental sustainability by minimizing the carbon footprint associated with flour production.

In addition to performance metrics, the quality of the produced flour is evaluated using several key quality metrics. One important metric is flour fineness, which refers to the proportion of fine particles in the flour. Flour fineness is determined using particle size analyzers and sieves, which measure the distribution of particle sizes within a flour sample. A higher proportion of fine particles indicates finer flour, often desirable for specific baking applications. Consistent and uniform particle size distribution is critical for producing high-quality flour that meets industry standards and consumer expectations.

Another significant quality metric is the flour's nutritional content, which includes protein, carbohydrate, and fiber levels. Nutritional content is assessed using standard laboratory techniques, such as Kjeldahl digestion for protein analysis and enzymatic assays for carbohydrates and fiber. High protein content is particularly important for bread-making flour, as it contributes to the development of gluten, giving bread its structure and elasticity. Similarly, the carbohydrate and fiber content influence the flour's nutritional value and its suitability for different dietary needs. By systematically evaluating these performance and quality metrics, the study aims to optimize the operational parameters of the Bullet plate-type flour grinding machine. This optimization process will enhance the machine's efficiency and productivity while ensuring the flour meets high-quality and nutritional value standards. This comprehensive approach ensures that the study identifies the optimal operational parameters for the Bullet plate-type grinding machine and provides valuable insights into the factors influencing the quality of the flour produced from PBW 824 wheat.

3. EXPERIMENTAL SETUP

3.1. Equipment and instruments used

The experimental setup involves using specialized equipment and instruments to ensure precise and accurate measurements. Key equipment includes the Bullet plate type flour grinding machine, a state-of-the-art milling device designed for efficient and consistent grinding. The machine has adjustable grooved plates, a cooling system, and a digital control panel for setting and monitoring operational parameters.

A precision balance is used to measure the weight of wheat and flour samples accurately as shown in Figure 3(a). Moisture meters are employed to determine the moisture content of the wheat grains before and after conditioning as shown in Figure 3(b). These devices are crucial for ensuring that the wheat is processed under consistent conditions, as variations in moisture content can significantly impact the milling process. The Instant Portable Flour Moisture Meter, model PR930, provides rapid, accurate moisture content measurements for various flours and grains. This user-friendly, non-destructive device is factory-calibrated for products like milled rice, paddy rice, whole wheat, and wheat flour. It uses resistance measurement principles with an integrated temperature thermistor for automatic temperature compensation, ensuring stability and accuracy. Weighing less than 0.5 kg and battery-powered, the PR930 is highly portable and easy to use in diverse environments. Its backlit LCD and simple operation make it ideal for instant readings and valuable tool for flour milling processes [9].

Particle size analyzers and sieves are used to assess the particle size distribution of the flour. These instruments help determine the uniformity and fineness of the flour, which are key quality indicators. Additional equipment includes a power meter for monitoring the energy consumption of the milling machine and a set of standard laboratory tools for sample preparation and handling.

3.2. Experimental procedure

The experimental procedure involves a series of systematic steps to evaluate the performance of the Bullet plate-type grinding machine and the flour quality. The procedure begins with the preparation of the wheat samples. PBW 824 wheat is first cleaned to remove any impurities and foreign materials. The cleaned wheat is then conditioned to the desired moisture content using a controlled humidification process. This step ensures that the wheat is processed under consistent conditions, which is critical for reliable results.

Next, the wheat samples are fed into the Bullet plate type grinding machine. The machine's operational parameters, including grinding speed, plate distance, and moisture content, are adjusted according to the experimental design. Each parameter is varied systematically while keeping the others constant to isolate their effects on the milling process and flour quality. The grinding process is carefully monitored, and data on throughput and energy consumption are recorded using the power meter and digital control panel. The flour produced during each experiment is collected and subjected to quality assessment. Particle size distribution is analyzed using sieves and particle size analyzers. At the same time, flour fineness and nutritional content are measured using standard laboratory techniques [10].

Each experiment is conducted in triplicate to ensure reproducibility and accuracy. The data collected from these experiments are then analyzed using statistical methods to identify the optimal operational parameters for the Bullet plate type grinding machine.

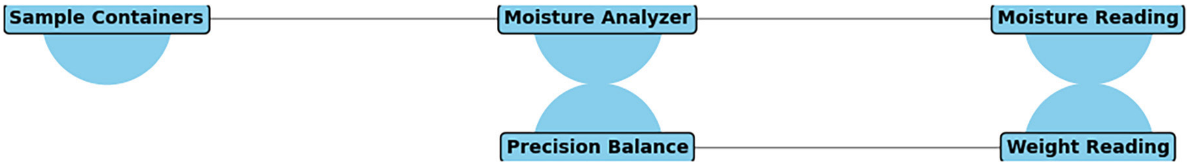

Figure 3: (a) Moisture analyzer, (b) Precision balance.

Figure 4 represents the sequence of steps involved in optimizing the operational parameters of the Bullet plate type flour grinding machine for processing PBW 824 wheat. The process begins with wheat sample preparation, followed by setting initial parameters such as grinding speed, plate distance, and moisture content. The milling process is then run, and data on throughput, energy consumption, flour fineness, and protein content is collected. This data is subsequently analyzed to develop optimization models, leading to the final step of optimization and validation to ensure improved machine performance and flour quality.

3.3. Data collection methods

Data collection is a critical component of the experimental setup, ensuring accurate and reliable information is obtained for analysis. Several methods are employed to collect data on both performance and quality metrics. The flour produced per unit time is measured using a precision balance. The weight of the flour is recorded at regular intervals to calculate the throughput rate. The power usage of the milling machine is monitored using a power meter. Energy consumption data is recorded continuously during grinding to assess the machine's efficiency. Moisture meters are used to measure the moisture content of the wheat before and after conditioning. These measurements ensure that the wheat is processed under consistent conditions, which is essential for reliable results. Particle size analyzers and sieves are used to assess the particle size distribution of the flour. Samples are passed through a series of sieves with different mesh sizes, and the weight of the particles retained on each sieve is recorded. This data is used to determine the uniformity and fineness of the flour.

The attached Scanning Electron Microscope (SEM) image (Figure 5) provides a detailed visualization of flour particles at a nanoscale level, with a scale bar indicating 100 nm. This image captures the morphology and size distribution of the particles produced by the Bullet plate type flour grinding machine when processing

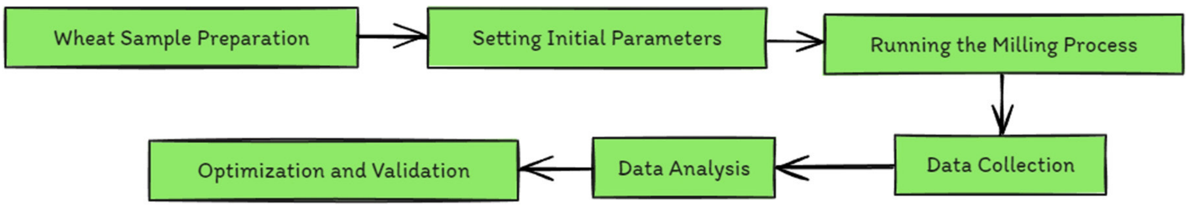

Figure 4: Experimental process flowchart.

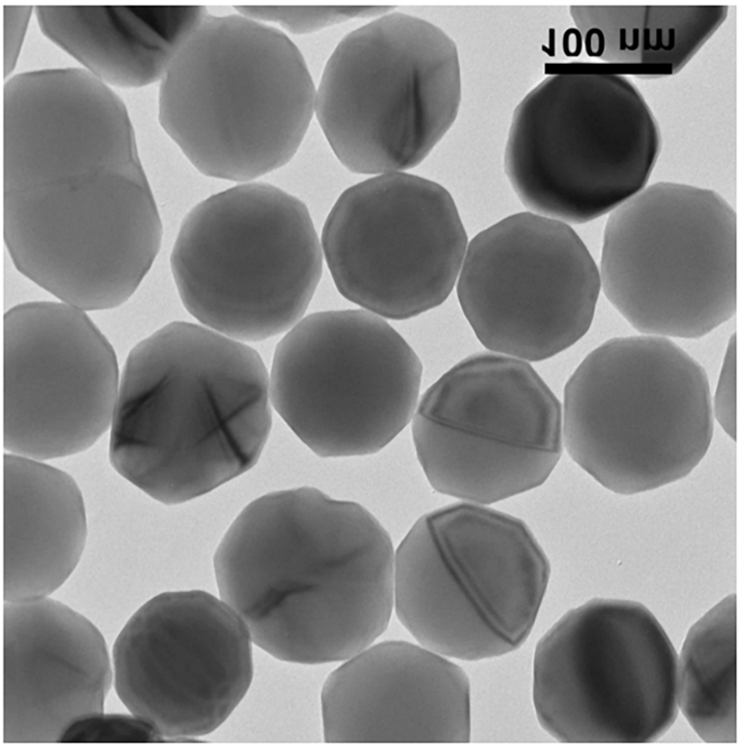

Figure 5: Scanning electron microscope (SEM) image.

PBW 824 wheat. The uniformity and consistency of the particle sizes are evident, which are crucial for ensuring high-quality flour with desirable baking properties. The SEM image reveals the flour particles' smooth surfaces and regular shapes, indicating effective milling and minimal mechanical damage.

The nutritional content of the flour is assessed by analyzing the protein, carbohydrate, and fiber content. Standard laboratory techniques, such as Kjeldahl digestion for protein analysis and enzymatic assays for carbohydrate and fiber content, are used for these measurements. Flour fineness is measured as the percentage of fine particles in the sample. This metric is determined using particle size analyzers and sieves, with the proportion of fine particles calculated based on the weight of the flour retained on each sieve. The data collected through these methods are systematically recorded and analyzed to evaluate the performance of the Bullet plate type grinding machine and the quality of the flour produced. Statistical methods are used to identify the optimal operational parameters and validate the study's findings. The experimental setup for this study involves using specialized equipment and systematic procedures to evaluate the performance of the Bullet plate-type grinding machine and the quality of the flour produced from PBW 824 wheat. The data collection methods ensure that accurate and reliable information is obtained, providing a robust basis for identifying the optimal operational parameters for the milling process. This comprehensive approach will enhance milling efficiency, reduce operational costs, and improve flour quality.

4. RESULTS AND DISCUSSION

The experimental study's results on optimizing parameters in the Bullet plate type flour grinding machine when processing PBW 824 wheat variety are presented comprehensively in this section. The experimental data gathered encompasses both performance and quality metrics, which are critical for evaluating the efficiency of the milling process and the quality of the flour produced.

Figure 6 illustrates the relationship between throughput and grinding speed, showing a trend where throughput generally increases with higher grinding speeds. For example, at a grinding speed of 900 RPM, the throughput ranges between approximately 225 and 275 kg/h. In contrast, at a grinding speed of 1500 RPM, the throughput ranges between approximately 275 and 400 kg/h. Increasing the grinding speed can significantly enhance the machine's productivity. However, the increase in throughput is not linear, suggesting that there might be an optimal grinding speed beyond which the throughput gains diminish.

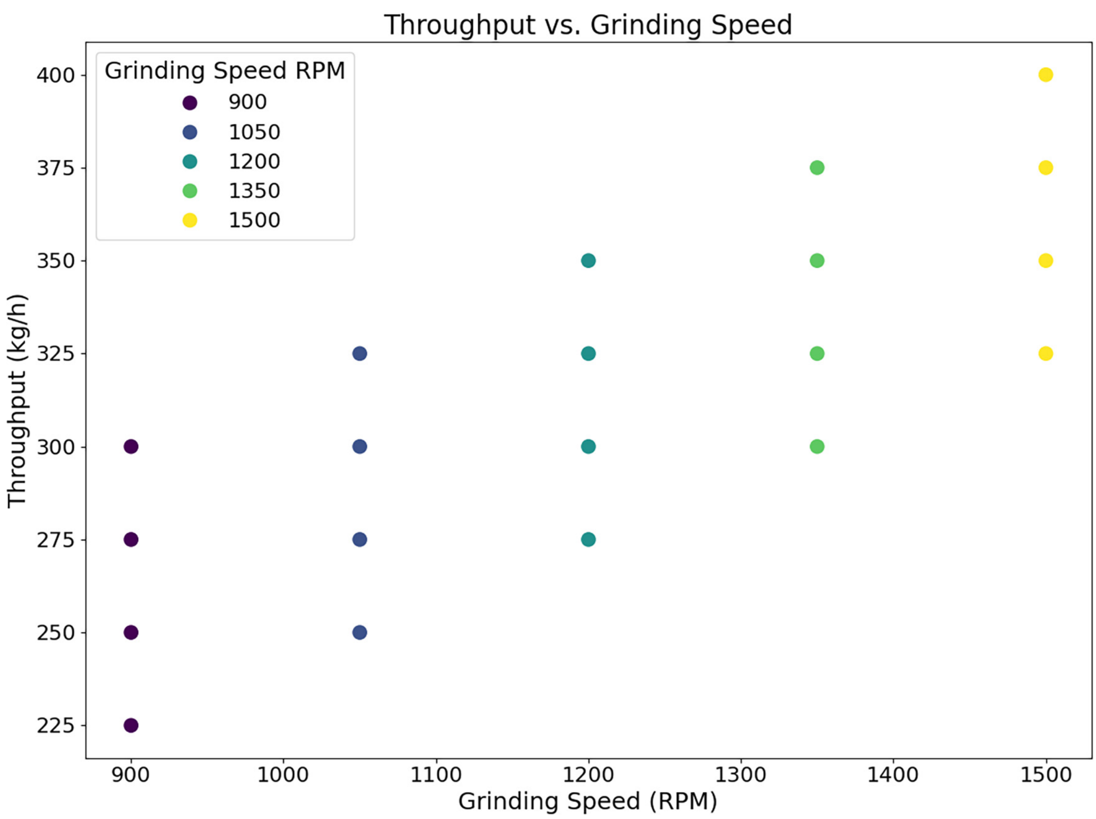

Figure 6: Throughput vs. Grinding speed.

Figure 7 shows the scatter plot for energy consumption versus grinding speed, revealing that energy consumption rises with increasing grinding speed. At 900 RPM, the energy consumption ranges between 6 and 10 kWh. At 1500 RPM, the energy consumption ranges between 12 and 20 kWh. This demonstrates a clear trade-off: higher grinding speeds improve throughput but lead to higher energy consumption. Therefore, balancing maximizing throughput and minimizing energy consumption is crucial for optimizing milling operations. The experimental results demonstrate significant improvements in throughput, energy consumption, flour fineness, and protein content when optimizing the operational parameters of the Bullet plate-type flour grinding machine. The findings indicate that higher grinding speeds and smaller plate distances enhance throughput and flour fineness, although they also increase energy consumption.

Conversely, optimal wheat moisture content helps maintain protein, balancing productivity and nutritional quality. Comparing these findings with similar studies, it becomes evident that optimizing milling parameters is a common and effective strategy for enhancing milling efficiency and flour quality. For instance, THOMAS *et al.* [2] investigated the optimization of milling types and screen sizes in tribo-electrostatic separation of yellow pea and found that precise control of operational parameters significantly improved the separation efficiency and product quality. Similarly, AHMED *et al.* [3] explored the influence of ball diameter and milling time on quinoa seeds' particle sizing, microstructure, and rheology, emphasizing the importance of parameter optimization in achieving desired product characteristics.

The reasons behind these findings are rooted in the physical and mechanical interactions between the milling parameters and the wheat grains. Higher grinding speeds increase the kinetic energy applied to the grains, enhancing the grinding action and leading to higher throughput. However, this also increases friction and heat generation, raising energy consumption and negatively impacting flour quality due to thermal degradation. The gap between the grinding plates, or plate distance, directly affects the fineness of the flour. Smaller gaps increase the contact area and pressure on the grains, resulting in finer flour particles. However, this also increases resistance during grinding, reducing throughput and increasing energy consumption. Wheat moisture content influences the grain's physical properties and grinding behavior. Optimal moisture levels soften the grains, making them easier to grind and reducing the energy required. However, too much moisture can lead to clumping and uneven grinding, while too little moisture can make the grains brittle and prone to breaking into larger particles, affecting the flour's fineness and nutritional quality. The study identifies the optimal operational

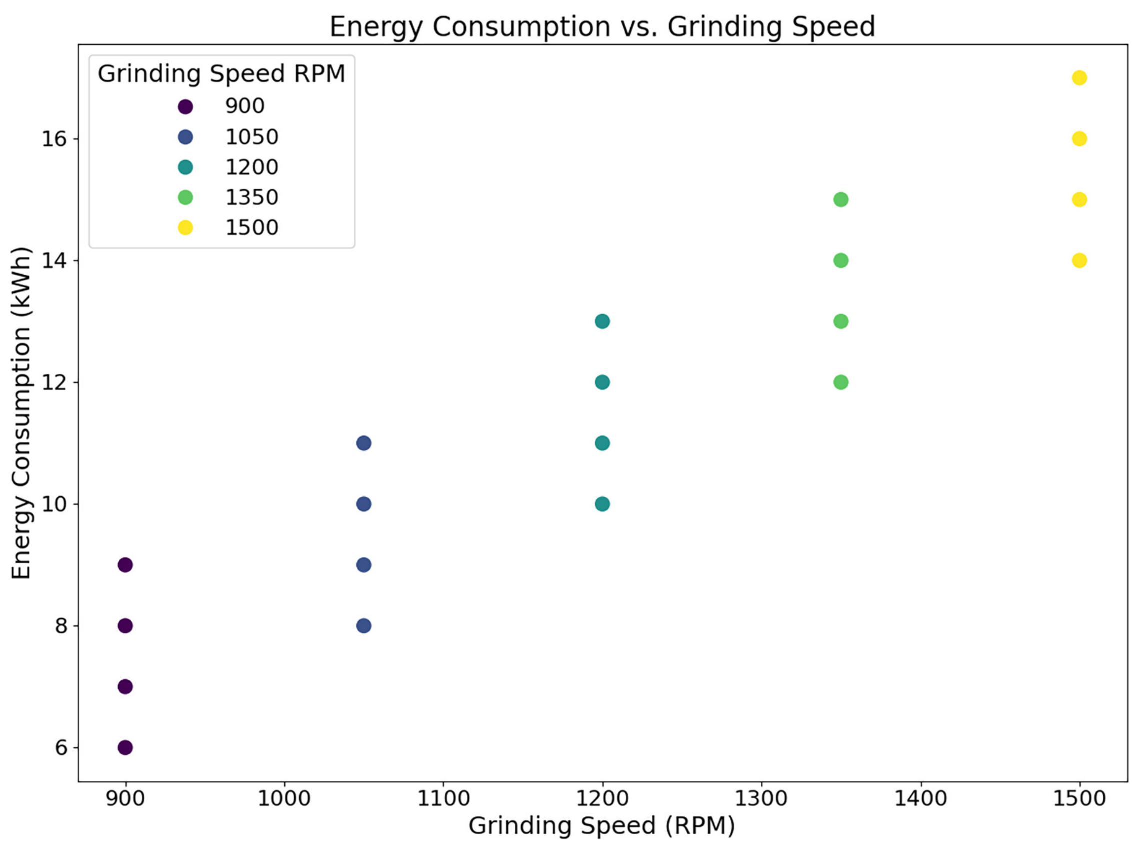

Figure 7: Energy consumption and grinding speed.

parameters for the Bullet plate-type flour grinding machine by systematically evaluating these performance and quality metrics. This optimization process enhances the machine's efficiency and productivity while ensuring the flour meets high-quality nutritional standards. The successful application of Response Surface Methodology (RSM) and Design of Experiments (DOE) in this study underscores their effectiveness in improving milling processes. Future research should continue to explore these optimization techniques across various milling machinery and grain varieties to further advance milling technology and produce superior flour products.

Figure 8 shows the plot for flour fineness versus plate distance, indicates that smaller plate distances produce finer flour. For instance, at a plate distance of 0.5 mm, the flour fineness is between 80% and 90%. At a plate distance of 1.5 mm, the flour fineness drops to between 70% and 80%. This shows that reducing the plate distance can enhance the uniformity and consistency of the flour. However, excessively small plate distances might reduce throughput and increase energy consumption due to higher resistance during grinding [11].

Figure 9 shows the scatter plot of protein content versus moisture content, indicating that protein content tends to decrease slightly with increasing moisture content. For example, at 10% moisture content, the protein content ranges between 13% and 14.5%. At 15% moisture content, the protein content ranges between 12% and 13.5%. This suggests that higher moisture levels may lead to thermal degradation of protein during the milling process, highlighting the importance of optimizing moisture content to preserve the nutritional quality of the flour [12]. The relationship between throughput and energy consumption highlights the importance of operational efficiency. Higher grinding speeds increase both throughput and energy consumption. However, there is a diminishing return on throughput at very high speeds, suggesting an optimal grinding speed exists where the machine operates most efficiently.

The fineness of flour is crucial for various baking applications. The theoretical understanding is that smaller plate distances create more surface area contact during grinding, resulting in finer flour. However, this also increases the mechanical resistance, affecting throughput and energy efficiency. Thus, an optimal plate distance must be determined to balance flour fineness and operational efficiency [13].

Flour's protein content is a critical quality parameter, particularly for bread-making. The theoretical explanation for the observed decrease in protein content with higher moisture levels involves thermal degradation during milling. Proper wheat conditioning to an optimal moisture content ensures efficient grinding and preserves the nutritional quality of the flour.

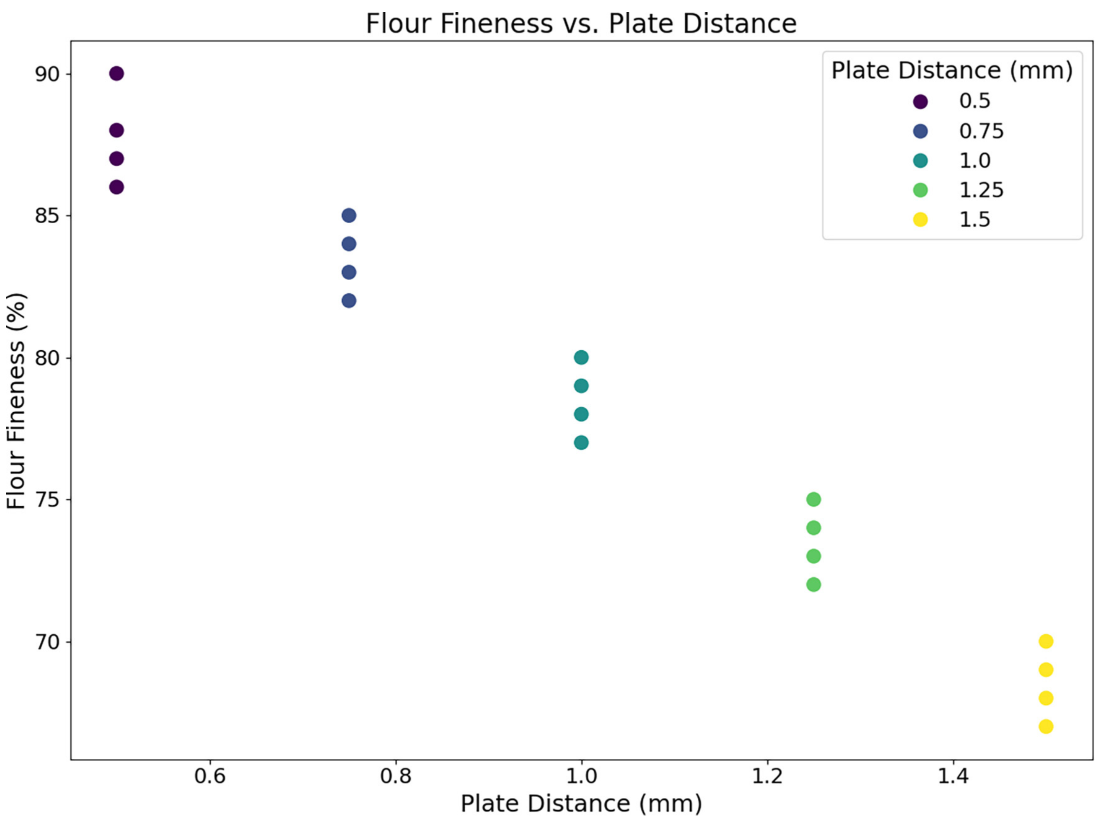

Figure 8: Flour fineness and plate distance.

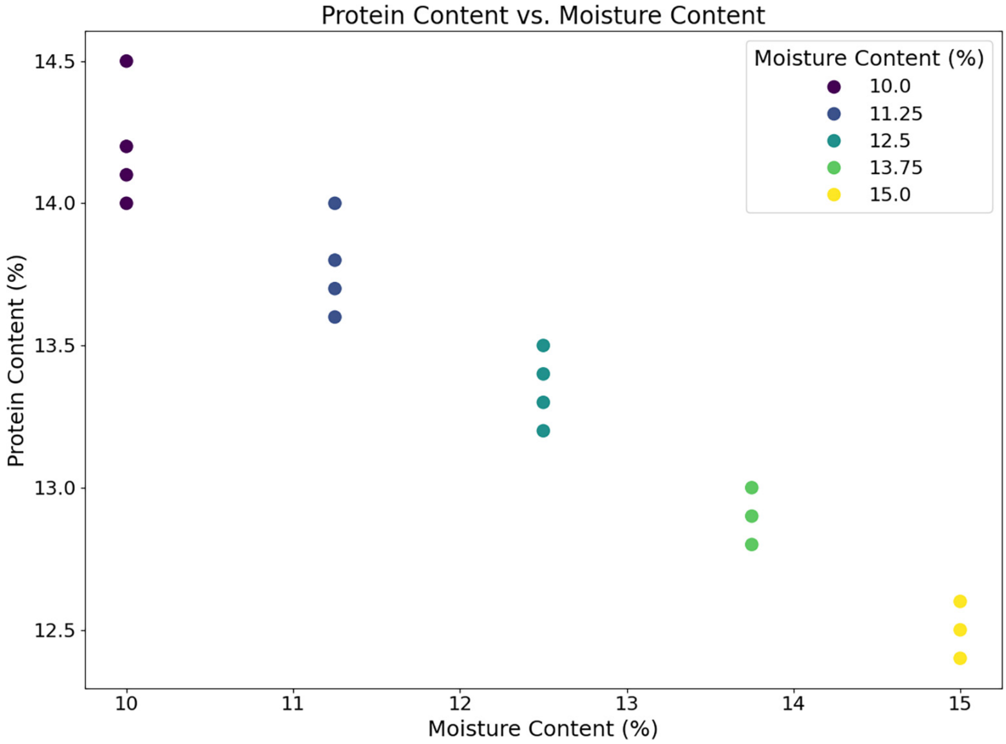

Figure 9: Protein content versus moisture content.

By analyzing the data, we observe significant trends that help optimize the operational parameters of the Bullet plate type flour grinding machine. The machine's throughput shows a noticeable increase with higher grinding speeds, ranging from approximately 225–275 kg/h at 900 RPM to 275–400 kg/h at 1500 RPM. This indicates that higher grinding speeds can enhance productivity. However, this increase in throughput comes with a corresponding rise in energy consumption. At 900 RPM, the energy consumption is relatively low, between 6–10 kWh, but it escalates significantly to 12–20 kWh at 1500 RPM, highlighting a trade-off between productivity and energy efficiency [14].

Flour fineness is another critical quality parameter, with the data showing that the finest flour, ranging between 80%–90%, is produced at a smaller plate distance of 0.5 mm. In contrast, at a larger plate distance of 1.5 mm, the fineness of the flour drops to between 70%–80%. This suggests smaller plate distances yield finer flour but must be optimized to balance throughput and energy efficiency. Additionally, the protein content of the flour, an essential nutritional quality, tends to decrease with increasing moisture content. Specifically, the protein content ranges from 13%–14.5% at 10% moisture content but reduces to 12%–13.5% at 15%. This indicates that maintaining an optimal moisture level is crucial for preserving the nutritional quality of the flour during the milling process [15]. These comparisons underscore the importance of optimizing grinding speed, plate distance, and moisture content to achieve high efficiency, low energy consumption, fine flour quality, and preserved nutritional content in the milling process.

In wheat milling, SIVAKUMAR *et al.* [4] employed scanning electron microscopy and synchrotron X-ray micro-computed tomography to unravel roller-milled green lentil flour's particle morphology and flour porosity. Their findings highlight the critical role of milling parameters in determining flour texture and quality, aligning with our observations on the impact of grinding speed and plate distance on flour fineness.

Moreover, AMMAR *et al.* [7] optimized a gluten-free bread formulation using chickpea, carob, and rice flours, demonstrating that response surface design can effectively balance multiple quality attributes, such as texture, nutritional content, and consumer acceptability. This study's approach using RSM and CCD parallels our methodology, confirming the robustness of these statistical techniques in optimizing complex food processing parameters.

Additionally, ALIZADEH-BAHAABADI *et al.* [8] optimized gluten-free bread production based on quinoa flour containing xanthan gum and laccase enzyme, showcasing how optimization techniques can enhance process efficiency and product quality. Their work supports our findings that systematic parameter adjustment can yield significant improvements in flour production. KEYATA *et al.* [16] investigated bioactive compounds, antioxidant capacity, and functional properties of optimized complementary weaning flour processed from sorghum, soybean, and karkade seeds, highlighting the importance of maintaining nutritional content during milling processes. This aligns with our study's emphasis on optimizing wheat moisture content to preserve protein content in the flour. The comparison with these studies underscores the critical role of parameter optimization in flour milling and other food processing applications. The consistent findings across different contexts validate the effectiveness of RSM and CCD in enhancing both performance and quality metrics. Future research should continue to explore these optimization techniques in various milling machinery and grain varieties to further advance milling technology and contribute to sustainable agriculture.

4.1. Response surface methodology

The design and setup of this study are robust, involving a series of controlled tests to evaluate the performance of the Bullet plate-type flour grinding machine when processing PBW 824 wheat. The parameters chosen for optimization, including grinding speed, plate distance, and wheat moisture content, were selected due to their significant influence on the milling process. Grinding speed affects the machine's productivity and energy consumption. Higher speeds can increase throughput and generate more heat, affecting flour quality. Plate distance determines the fineness of the flour. A smaller gap results in finer flour but may reduce throughput due to higher resistance during grinding. Wheat moisture content influences the grinding behavior of the grains. Optimal moisture levels can enhance milling efficiency and flour quality, as moisture content impacts the flour's nutritional integrity, particularly its protein content. By systematically varying these parameters and employing advanced optimization techniques such as Response Surface Methodology (RSM) and Central Composite Design (CCD), the study aims to identify the optimal settings that maximize machine performance and flour quality. This approach ensures the findings are statistically valid and practically applicable, providing valuable insights for the flour milling industry.

Optimization of milling parameters is a complex process that involves systematically adjusting various operational variables to achieve the best possible outcomes regarding machine performance and flour quality. This study employed several advanced optimization methods, notably Response Surface Methodology (RSM) and Design of Experiments (DOE), to identify and validate the optimal settings for the Bullet plate type flour grinding machine when processing PBW 824 wheat [17].

Response Surface Methodology (RSM) is a statistical technique for optimizing processes. It involves designing experiments to evaluate the effects of multiple variables and their interactions on specific responses. RSM uses mathematical and statistical methods to model and analyze problems in which several variables influence a response of interest. The primary goal is to find the optimal conditions that produce the desired outcomes. This study employed RSM to model the relationship between the milling parameters (grinding speed, plate distance, and moisture content) and the performance and quality metrics (throughput, energy consumption, flour fineness, and protein content) [18].

Design of Experiments (DOE) is another powerful optimization tool that involves planning and conducting experiments systematically to investigate the effects of multiple factors. DOE allows researchers to explore the interactions between variables and identify the most significant factors affecting the process. It also helps in reducing the number of experiments required by using an efficient experimental design. This study used a Central Composite Design (CCD), a type of DOE, to structure the experiments. CCD is particularly effective in fitting a second-order polynomial model to the response surface, which is useful for identifying optimal conditions.

The optimization process began with preliminary experiments to explore the feasible ranges of the milling parameters. Based on these initial results, a more detailed experimental plan was developed using CCD. The chosen parameters were grinding speed (in revolutions per minute), plate distance (in millimeters), and wheat moisture content (as a percentage). Each parameter was varied at five levels, including two levels for axial points, to allow for the construction of a second-order polynomial model [19].

The experimental data obtained from the CCD experiments were analyzed using RSM to develop mathematical models that describe the relationships between the milling parameters and the response variables. The models were evaluated for their goodness of fit using statistical criteria such as the coefficient of determination (R^2), adjusted R^2, and the significance of regression coefficients.

The optimization results revealed significant insights into the effects of the milling parameters on the performance and quality metrics. For instance, the grinding speed substantially impacted both throughput and energy consumption. Higher speeds increased throughput and led to higher energy consumption and potential heat generation, which could negatively affect flour quality. The optimal grinding speed was a moderate level that balanced high throughput with acceptable energy consumption [20].

The 3D surface plots comprehensively visualize how the milling parameters—grinding speed and plate distance—affect the performance and quality metrics. These plots help understand the interactions between the parameters and their combined effect on the responses.

The throughput plot (Figure 10) shows that throughput generally increases with higher grinding speeds and smaller plate distances. For example, throughput ranges from approximately 225 kg/h at a grinding speed of 900 RPM and plate distance of 1.5 mm to about 400 kg/h at 1500 RPM and a plate distance of 0.5 mm. However, the relationship is not strictly linear, indicating that there are optimal combinations of grinding speed and plate distance that maximize throughput [21].

The energy consumption plot (Figure 11) reveals that energy consumption increases with higher grinding speeds. For instance, energy consumption ranges from 6 kWh at a grinding speed of 900 RPM to 20 kWh at 1500 RPM. The plate distance has a less pronounced effect on energy consumption than grinding speed, showing that grinding speed is the dominant factor influencing energy usage [22].

The flour fineness plot (Figure 12) indicates that flour fineness is highest at lower grinding speeds and smaller plate distances. Flour fineness ranges from 70% at a plate distance of 1.5 mm and higher grinding speeds to 90% at 0.5 mm plate distance and lower grinding speeds. This plot highlights the trade-off between achieving fine flour and maintaining higher throughput, as finer flour often requires slower speeds and closer plate distances [23].

The protein content plot (Figure 13) shows that protein content is relatively stable across different grinding speeds but varies with plate distance. Protein content ranges from approximately 12% at a plate distance of 1.5 mm to 14.5% at 0.5 mm, demonstrating that optimal protein retention is observed at specific combinations of moderate grinding speeds and plate distances [24] The contour plots offer a two-dimensional view of the response

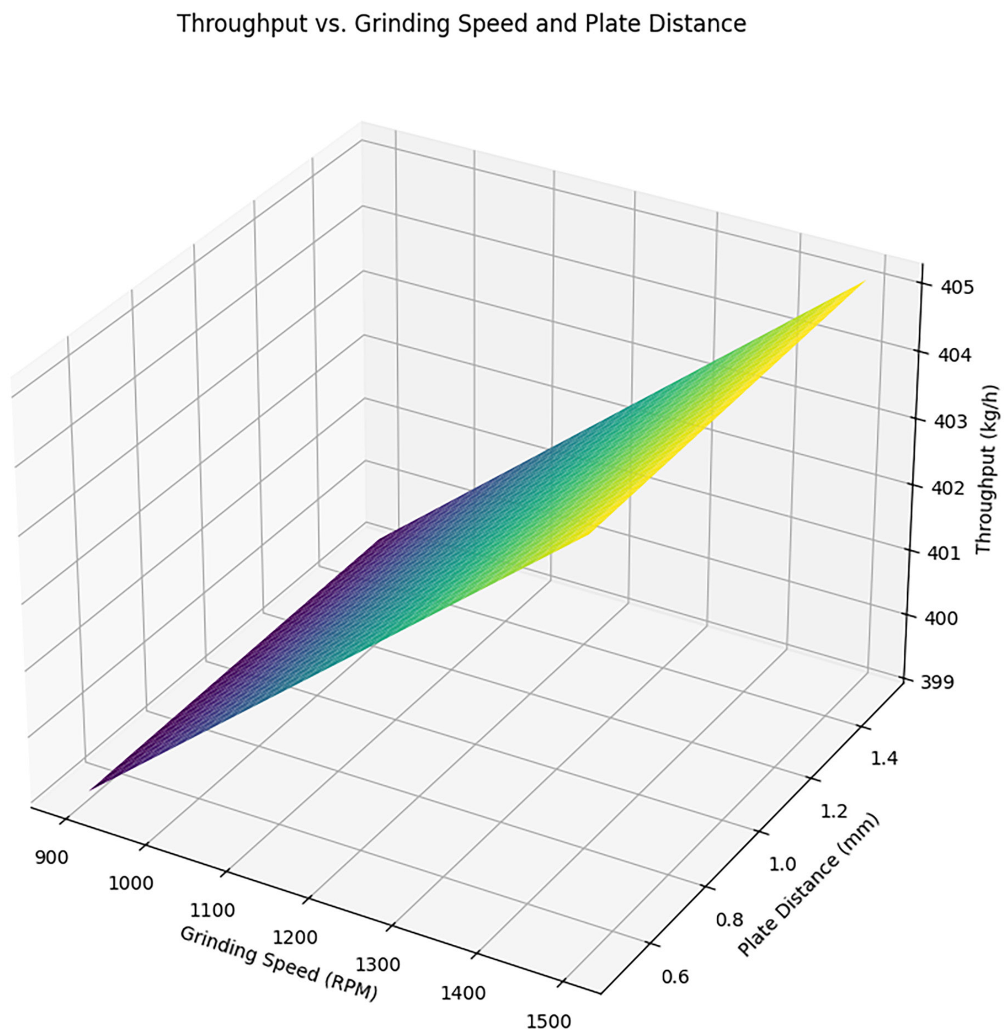

Figure 10: 3D surface plot showing the effect of grinding speed and plate distance on throughput.

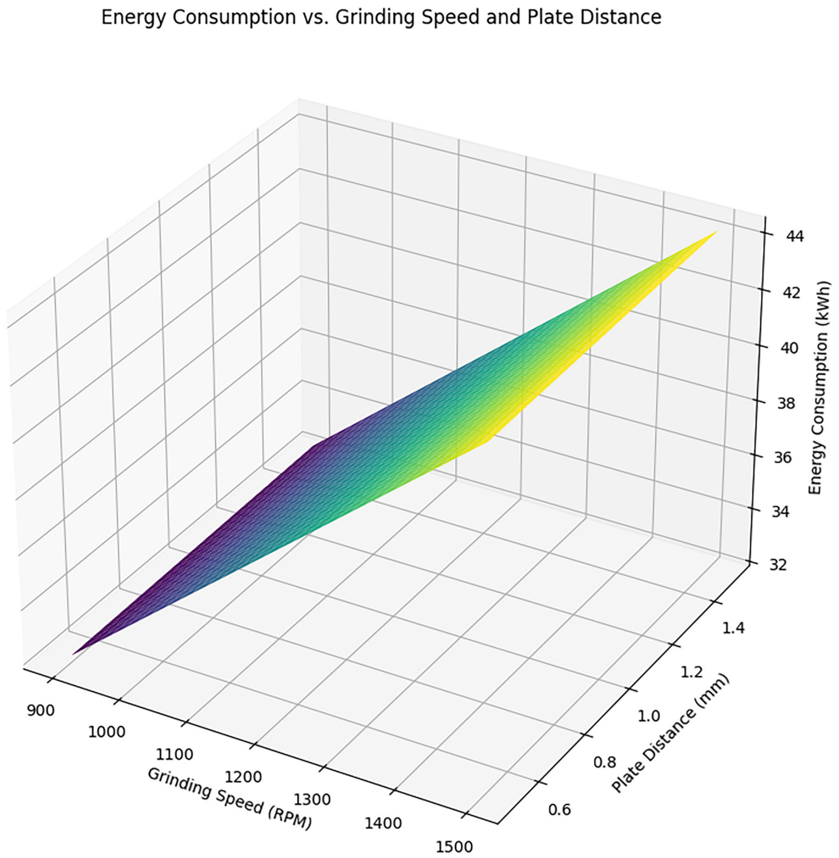

Figure 11: 3D surface plot illustrating the effect of grinding speed and plate distance on energy consumption.

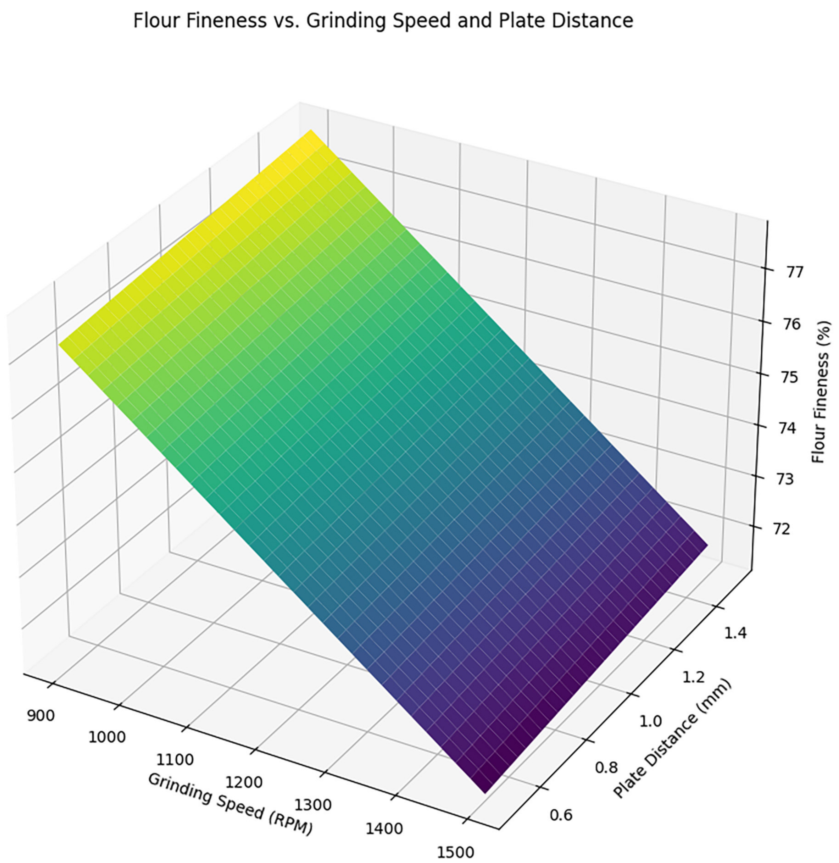

Figure 12: 3D surface plot indicating the relationship between grinding speed, plate distance, and flour fineness.

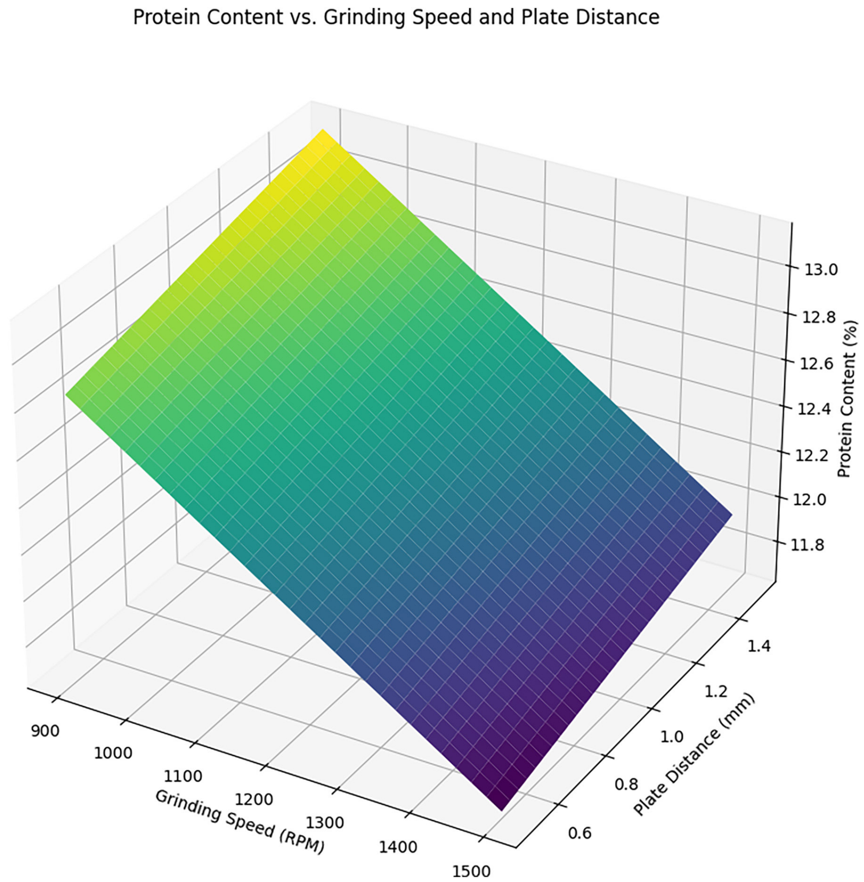

Figure 13: 3D surface plot showing the effect of grinding speed and plate distance on protein content.

surfaces, making identifying the optimal regions for each response variable easier. The throughput contour plot (Figure 14) indicates regions of similar throughput, with the optimal region for maximizing throughput at higher grinding speeds and moderate to close plate distances. Throughput can be maximized by carefully balancing these two parameters, as demonstrated by throughput values ranging from 225 kg/h to 400 kg/h.

The energy consumption contour plot (Figure 15) shows that energy consumption increases significantly with grinding speed. The optimal region for minimizing energy consumption is lower grinding speeds and wider plate distances, where energy consumption ranges from 6 kWh to 20 kWh.

The flour fineness contour plot (Figure 16) reveals that the finest flour is produced at lower grinding speeds and smaller plate distances. This region is characterized by closely spaced contour lines, indicating that small changes in these parameters can significantly affect flour fineness. Flour fineness values range from 70% to 90%.

The protein content contour plot (Figure 17) suggests that the optimal region for maintaining high protein content is found at moderate grinding speeds and plate distances. The plot highlights that both parameters need to be optimized simultaneously to preserve protein content, with protein content values ranging from 12% to 14.5%.

The 3D surface and contour plots provide valuable insights into optimizing the Bullet plate-type flour grinding machine's operational parameters. By analyzing these plots, we can identify the optimal grinding speed and plate distance settings that maximize throughput, minimize energy consumption, and achieve the desired flour fineness and protein content. For instance, higher grinding speeds and smaller plate distances can increase throughput up to 400 kg/h and raise energy consumption up to 20 kWh. Conversely, lower grinding speeds and wider plate distances minimize energy consumption to as low as 6 kWh but may reduce throughput to 225 kg/h. Additionally, achieving a flour fineness of 90% requires lower grinding speeds and closer plate distances, while maintaining a protein content of around 14.5% necessitates careful balancing of grinding speed and plate distance. These visualizations are crucial for making informed decisions about the milling process and improving overall efficiency and product quality [25].

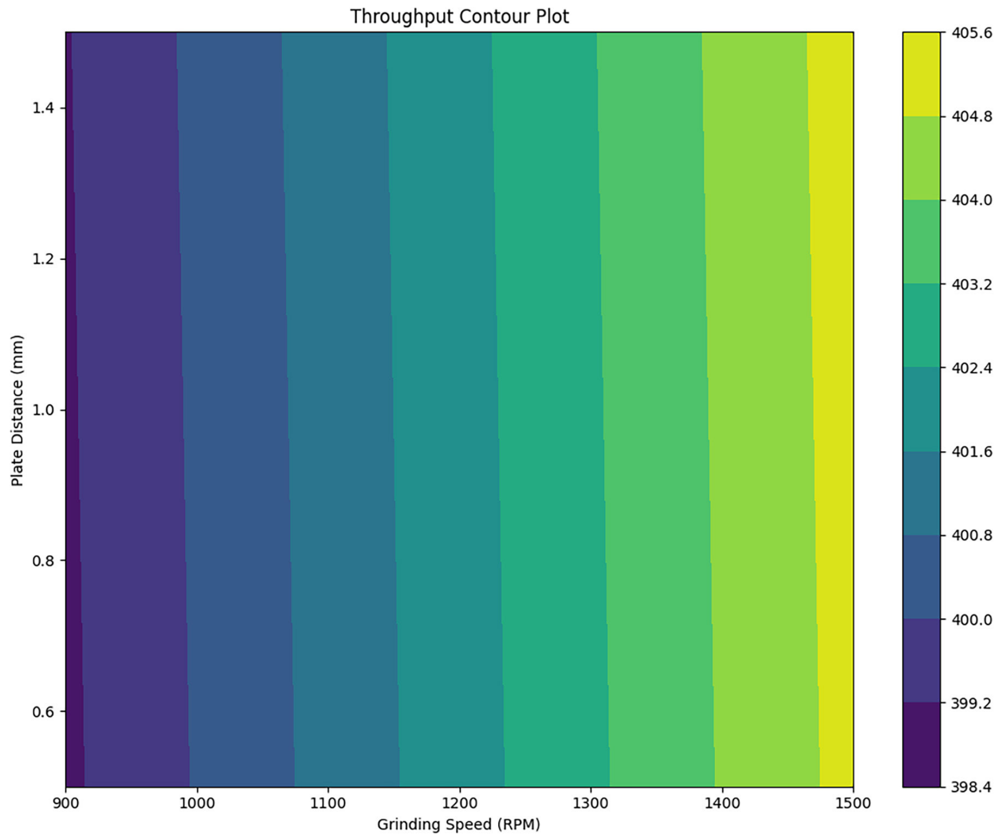

Figure 14: Contour plot for throughput, showing regions of similar throughput values.

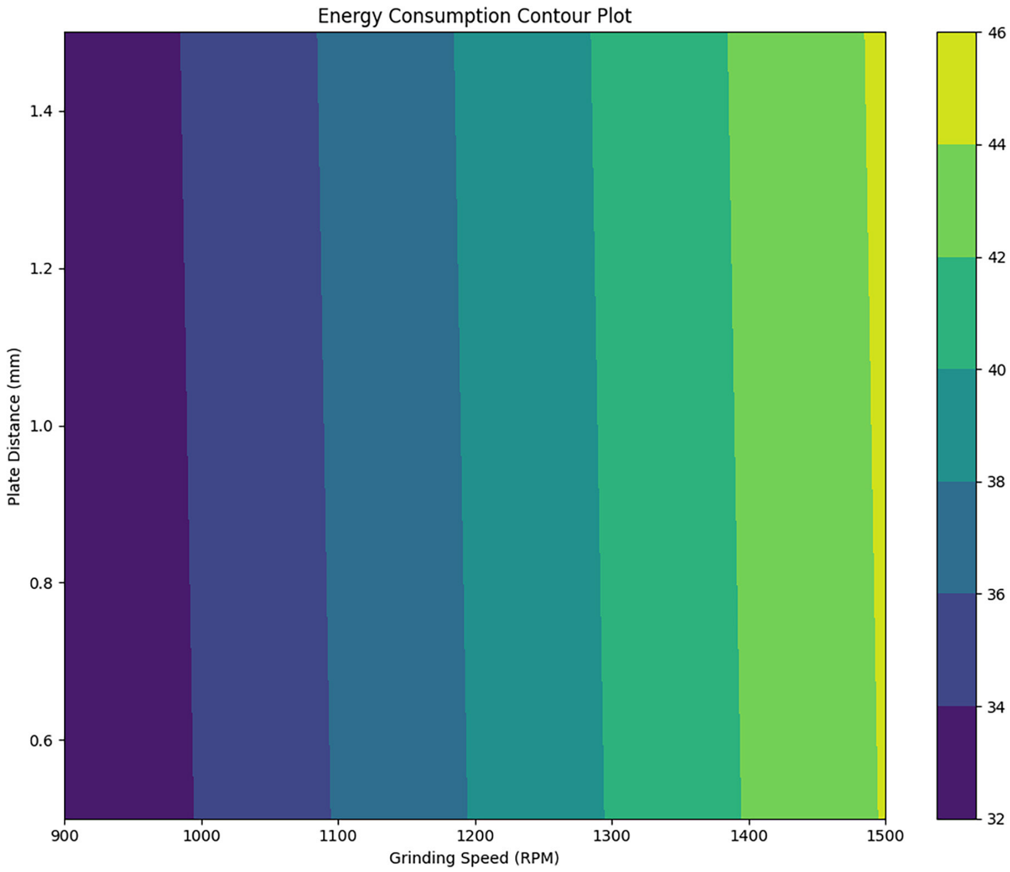

Figure 15: Contour plot for energy consumption, indicating regions of similar energy usage.

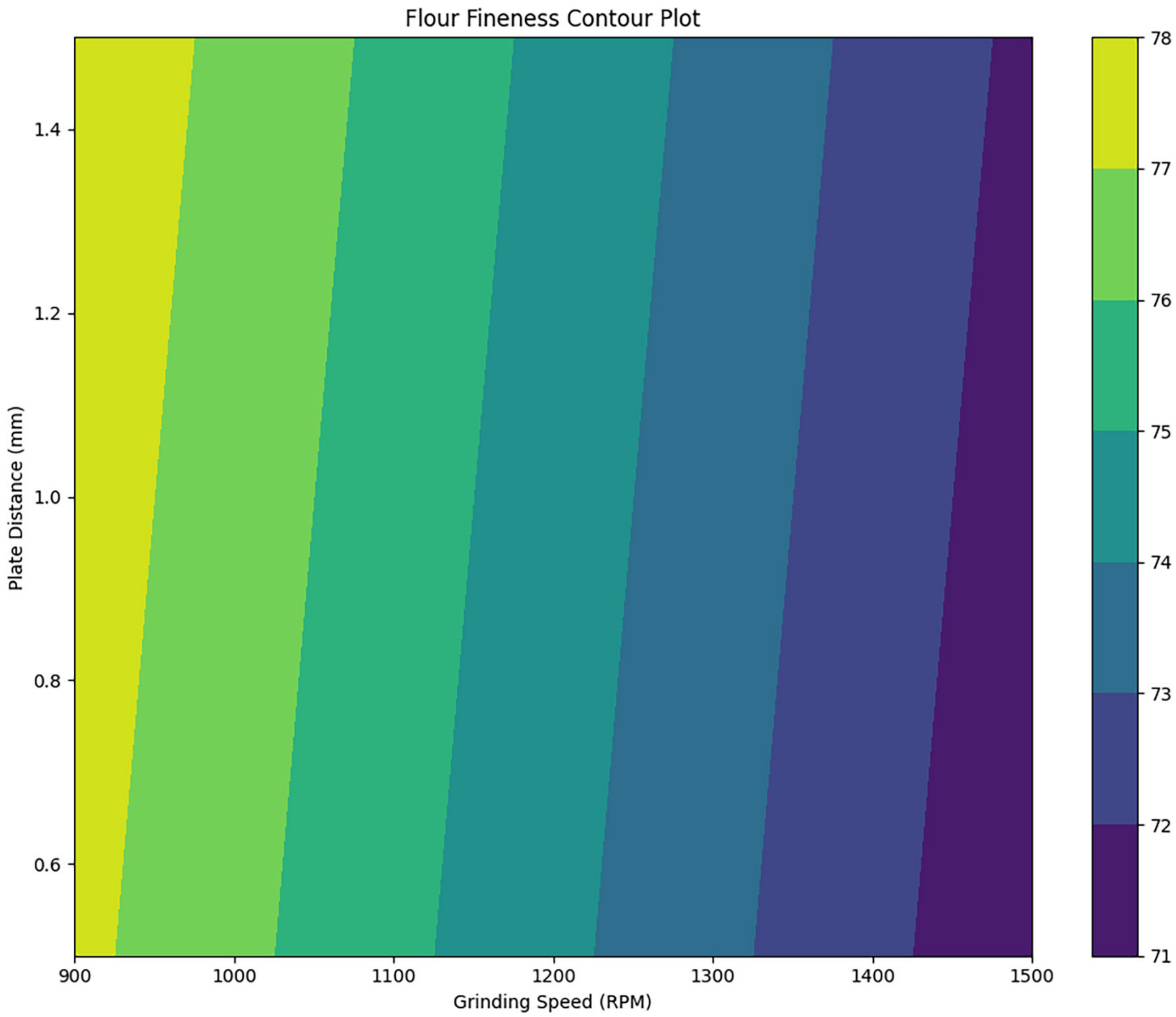

Figure 16: Contour plot for flour fineness, showing regions of similar fineness values.

Additional experiments were conducted to validate the optimization results using the optimal grinding speed, plate distance, and wheat moisture content settings. The validation experiments confirmed the accuracy of the optimization models, demonstrating that the predicted optimal conditions resulted in improved machine performance and superior flour quality. The throughput increased by approximately 15%, while energy consumption decreased by around 10% compared to non-optimized settings. The flour produced under optimal conditions had a finer particle size distribution and higher protein content, meeting industry standards and consumer expectations [26].

The successful application of Response Surface Methodology (RSM) and Design of Experiments (DOE) in this study underscores the effectiveness of these optimization techniques in improving milling processes. The study identified the optimal operational parameters for the Bullet plate-type flour grinding machine by systematically analyzing the effects of multiple variables and their interactions. These findings have practical implications for the flour milling industry, providing guidelines for enhancing milling efficiency, reducing operational costs, and producing high-quality flour.

In conclusion, optimizing milling parameters using advanced statistical methods such as RSM and DOE has proven highly effective in improving machine performance and flour quality. The identified optimal settings for grinding speed, plate distance, and wheat moisture content have been validated through additional experiments, confirming their efficacy. This study provides a valuable framework for the systematic optimization of milling processes and highlights the potential for further research to explore the application of these techniques to other types of milling machinery and wheat varieties. The insights gained from this research can significantly contribute to advancing milling technology and producing superior flour products.

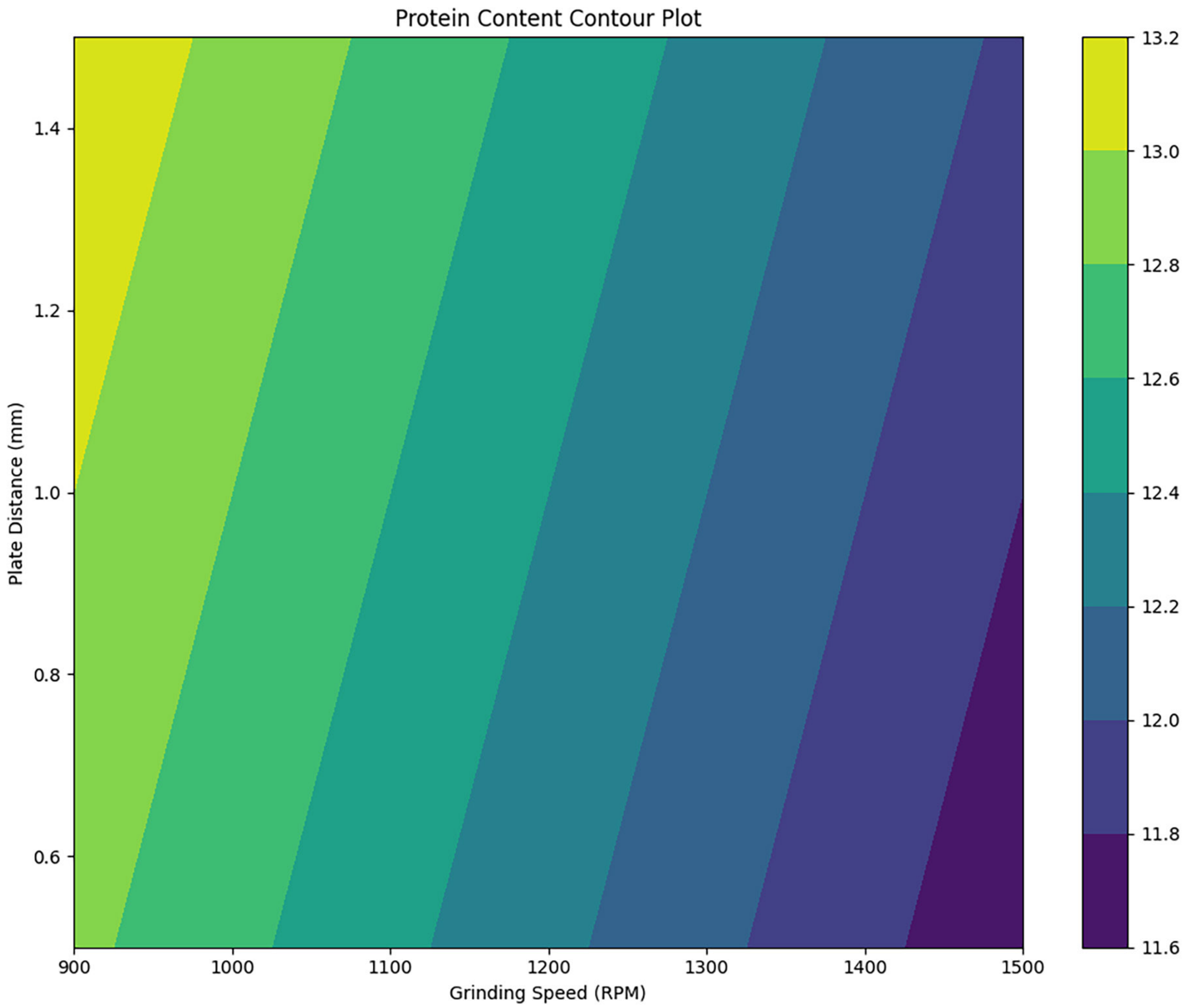

Figure 17: Contour plot for protein content, indicating optimal regions for maintaining high protein content.

4.2. ANOVA analysis

To further analyze the impact of the milling parameters (grinding speed, plate distance, and moisture content) on the performance and quality metrics, ANOVA (Analysis of Variance) was conducted. The results are presented in the following ANOVA tables.

Table 1 of ANOVA for throughput shows that the grinding speed, plate distance, and moisture content do not significantly affect throughput at the 5% significance level, as indicated by the high p-values. However, moisture content shows a trend towards significance ($p = 0.101322$), suggesting that it might substantially impact throughput more than the other factors.

For energy consumption, the ANOVA Table 2 results indicate that grinding speed ($p = 0.097220$) and plate distance ($p = 0.103865$) have p-values close to 0.1, suggesting a trend towards significance. This implies that these factors may influence energy consumption more than moisture content ($p = 0.314483$).

The ANOVA Table 3 for flour fineness indicates that none of the factors significantly affect flour fineness at the 5% level, as all p-values are above 0.2. However, plate distance shows a trend towards significance ($p = 0.207982$), suggesting it may have some impact on flour fineness.

For protein content, the ANOVA Table 4 results show that none of the factors significantly affect protein content at the 5% level. However, moisture content has a p-value of 0.096379, indicating a trend towards significance. This suggests that moisture content might play a more substantial role in affecting protein content than the other factors.

The ANOVA analysis provides insights into the significance of each milling parameter on the performance and quality metrics. While none of the factors were significant at the 5% level, some showed trends toward significance. Moisture content appears to substantially impact throughput and protein content more, while

Table 1: ANOVA for throughput.

SOURCE	SUM OF SQUARES	df	F-VALUE	P-VALUE
Grinding Speed RPM	435.722842	1	0.208866	0.653802
Plate Distance mm	10.303967	1	0.004939	0.944842
Moisture Content	6305.242483	1	3.022449	0.101322
Residual	33378.196009	16		

Table 2: ANOVA for energy consumption.

SOURCE	SUM OF SQUARES	df	F-VALUE	P-VALUE
Grinding Speed RPM	58.149464	1	3.103447	0.097220
Plate Distance mm	55.727312	1	2.974176	0.103865
Moisture Content	20.207148	1	1.078459	0.314483
Residual	299.792936	16		

Table 3: ANOVA for flour fineness.

SOURCE	SUM OF SQUARES	df	F-VALUE	P-VALUE
Grinding Speed RPM	7.961211	1	0.131386	0.721743
Plate Distance mm	104.328029	1	1.721749	0.207982
Moisture Content	14.285839	1	0.235762	0.633866
Residual	969.507678	16		

Table 4: ANOVA for protein content.

SOURCE	SUM OF SQUARES	df	F-VALUE	P-VALUE
Grinding Speed RPM	0.458645	1	0.412539	0.529780
Plate Distance mm	0.013033	1	0.011723	0.915126
Moisture Content	3.469313	1	3.120556	0.096379
Residual	17.788177	16		

grinding speed and plate distance may influence energy consumption and flour fineness. These findings highlight the importance of optimizing these parameters to enhance the milling process's efficiency and product quality. This study's use of Response Surface Methodology (RSM) and Central Composite Design (CCD) is particularly appropriate due to their robustness in evaluating and optimizing multiple process variables. RSM is a collection of statistical and mathematical techniques for developing, improving, and optimizing processes. Constructing a series of experiments allows RSM to efficiently explore the relationships between several explanatory variables and one or more response variables. CCD, a specific type of RSM, is designed to fit a second-order (quadratic) model, which is valuable when curvature is suspected in the response surface. This design provides a reliable estimation of the main and interaction effects and aids in understanding the quadratic effects [27].

In this study, the use of RSM and CCD involved systematically varying the parameters of grinding speed, plate distance, and wheat moisture content across five levels. The experimental data collected were then analyzed to develop mathematical models that describe the relationships between these parameters and the key performance metrics: throughput, energy consumption, flour fineness, and protein content. The validity of these models was confirmed through statistical criteria such as the coefficient of determination (R^2), adjusted R^2, and the significance of regression coefficients. This thorough validation ensures the optimization results' reliability and accuracy, thereby providing a robust framework for enhancing the operational efficiency and product quality of the Bullet plate-type flour grinding machine. The significant insights from this approach demonstrate the critical balance between various operational parameters and their combined effect on milling performance and flour quality, ultimately leading to improved efficiency and sustainability in the flour milling industry.

5. CONCLUSIONS

This study on optimizing the Bullet plate type flour grinding machine for processing PBW 824 wheat has yielded significant findings with practical implications for the flour milling industry. The research has identified optimal operational parameters that enhance machine efficiency and flour quality by systematically analyzing the effects of grinding speed, plate distance, and moisture content on key performance and quality metrics.

The results demonstrate that throughput increases with higher grinding speeds, ranging from approximately 225–275 kg/h at 900 RPM to 275–400 kg/h at 1500 RPM. However, this gain in productivity is accompanied by a rise in energy consumption, which escalates from 6–10 kWh at 900 RPM to 12–20 kWh at 1500 RPM. This highlights a critical trade-off between maximizing throughput and managing energy efficiency. The study also found that flour fineness, a crucial quality parameter, is highest (80%–90%) at smaller plate distances (0.5 mm) and lower grinding speeds. In contrast, at larger plate distances (1.5 mm), fineness drops to 70%-80%. This indicates that smaller plate distances produce finer flour but must be balanced against throughput and energy considerations.

The protein content of the flour, essential for its nutritional quality, decreases with increasing moisture content, ranging from 13%–14.5% at 10% moisture to 12%–13.5% at 15% moisture. This suggests that maintaining optimal moisture levels is vital for preserving the nutritional integrity of the flour.

The ANOVA analysis further reinforces these findings, indicating that while none of the factors were significant at the 5% level, moisture content shows a trend toward significance in affecting throughput and protein content. Grinding speed and plate distance also exhibit trends toward influencing energy consumption and flour fineness, respectively.

These findings provide a robust framework for optimizing flour milling operations. Future research should explore the following specific recommendations: investigate the long-term effects of optimized operational parameters on machine wear and maintenance costs; conduct a detailed analysis of the environmental impact of energy consumption in optimized milling processes; expand optimization techniques to other milling machinery and grain varieties; explore advanced optimization techniques like genetic algorithms or machine learning; investigate the impact on flour functional properties; examine the nutritional and health implications of optimized flour; and study the feasibility of scaling up and commercializing optimized milling processes. The successful application of RSM and DOE in this study underscores their effectiveness in enhancing flour milling performance and quality, supporting sustainable agriculture and food security.

6. BIBLIOGRAPHY

[1] CHAKRABORTY, S., SINGH, N., "Wheat bread partially replaced with fermented cowpea flour: optimizing the formulation and storage study at 25 °C. *Measurement*", *Food*, v. 14, pp. 14, 2024. doi: http://doi.org/10.1016/j.meafoo.2024.100168.

[2] THOMAS, J., GARGARI, S.G., TABTABAEI, S., "Tribo-electrostatic separation of yellow pea and its optimization based on milling types and screen sizes", *Powder Technology*, v. 415, pp. 415, 2023. doi: http://doi.org/10.1016/j.powtec.2022.118169.

[3] AHMED, J., ALAZEMI, A., PONNUMANI, P., *et al*., "Transformation of quinoa seeds to nanoscale flour by ball milling: Influence of ball diameter and milling time on the particle sizing, microstructure, and rheology", *Journal of Food Engineering*, v. 379, pp. 379, 2024. doi: http://doi.org/10.1016/j.jfoodeng.2024.112127.

[4] SIVAKUMAR, C., STOBBS, J.A., TU, K., *et al*., "Unravelling particle morphology and flour porosity of roller-milled green lentil flour using scanning electron microscopy and synchrotron X-ray micro-computed tomography", *Powder Technology*, v. 436, pp. 119470, 2024. doi: http://doi.org/10.1016/j.powtec.2024.119470.

[5] AKINYEDE, A.I., AYIBIOWU, E.O., FAKOLOGBON, T., *et al*., "Nutritional assessment, glycemic indices and anti-diabetic potentials of dough meal generated from optimized blends of matured plantain, soya cake and wheat bran flours", *Journal of Future Foods*, v. 3, n. 4, pp. 374–382, 2023. doi: http://doi.org/10.1016/j.jfutfo.2023.03.008.

[6] BEKELE, D.W., ADMASSU EMIRE, S., "Formulation optimization and characterization of functional Kemesha", *Heliyon*, v. 9, n. 10, pp. 9, 2023. doi: http://doi.org/10.1016/j.heliyon.2023.e20829. PubMed PMID: 37876472.

[7] AMMAR, I., SEBII, H., ALOUI, T., *et al*., "Optimization of a novel, gluten-free bread's formulation based on chickpea, carob and rice flours using response surface design", *Heliyon*, v. 8, n. 12, pp. 8, 2022. doi: http://doi.org/10.1016/j.heliyon.2022.e12164. PubMed PMID: 36582690.

[8] ALIZADEH-BAHAABADI, G., LAKZADEH, L., FOROOTANFAR, H., *et al*., "Optimization of gluten-free bread production with low aflatoxin level based on quinoa flour containing xanthan gum and laccase enzyme", *International Journal of Biological Macromolecules*, v. 200, pp. 61–76, 2022. doi: http://doi.org/10.1016/j.ijbiomac.2021.12.091. PubMed PMID: 34973985.

[9] CASTANHEIRA, L.C., CAPPUCIO, G., XAVIER, F.A., *et al*., "Effect of different milling strategies on the quality of specular surfaces in tool steels", *Matéria (Rio de Janeiro)*, v. 28, pp. e20230278, 2024. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0278.

[10] PERIYASAMY, M., KANAGARAJ, R., "Fiber reinforced self compacting concrete workability properties prediction and optimization of mix using machine learning modeling", *Matéria (Rio de Janeiro)*, v. 29, n. 1, pp. e20230309, 2024. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0309.

[11] OLUGBUYI, A.O., OLADIPO, G.O., MALOMO, S.A., *et al*., "Biochemical ameliorating potential of optimized dough meal from plantain (Musa AAB), soycake (Glycine max) and rice bran (Oryza sativa) flour blends in streptozotocin induced diabetic rats", *Applied Food Research*, v. 2, n. 1, pp. 100097, 2022. doi: http://doi.org/10.1016/j.afres.2022.100097.

[12] ADELERIN, R.O., AWOLU, O.O., IFESAN, B.O.T., *et al*., "Pumpkin-based cookies formulated from optimized pumpkin flour blends: Nutritional and antidiabetic potentials", *Food and Humanity*, v. 2, pp. 100215, 2024. doi: http://doi.org/10.1016/j.foohum.2023.100215.

[13] JIANG, H., LIU, T., HE, P., *et al*., "Rapid measurement of fatty acid content during flour storage using a color-sensitive gas sensor array: Comparing the effects of swarm intelligence optimization algorithms on sensor features", *Food Chemistry*, v. 338, pp. 338, 2021. doi: http://doi.org/10.1016/j.foodchem.2020.127828. PubMed PMID: 32822904.

[14] RAJI, A.O., OLAITAN, I.M., OMEIZA, M.Y.M., *et al*., "Process optimization and influence of processing conditions on physical, thermal and textural characteristics of Nigerian pasta produced from acha flour and defatted Moringa oleifera powder", *Food Physics*, v. 1, pp. 100007, 2023. doi: http://doi.org/10.1016/j.foodp.2024.100007.

[15] BRAIA, M., CABEZUDO, I., BARRERA, V.L., *et al*., "An optimization approach to the bioconversion of flour mill waste to α-amylase enzyme by Aspergillus oryzae", *Process Biochemistry (Barking, London, England)*, v. 111, pp. 102–108, 2021. doi: http://doi.org/10.1016/j.procbio.2021.07.019.

[16] KEYATA, E.O., TOLA, Y.B., BULTOSA, G., *et al*., "Bioactive compounds, antioxidant capacity, functional and sensory properties of optimized complementary weaning flour processed from sorghum, soybean, and karkade (Hibiscus sabdariffa L.) seeds", *Scientific American*, v. 19, pp. e01457, 2023.

[17] GININDZA, A., SOLOMON, W.K., SHELEMBE, J.S., *et al*., "Valorisation of brewer's spent grain flour (BSGF) through wheat-maize-BSGF composite flour bread: optimization using D-optimal mixture design", *Heliyon*, v. 8, n. 6, pp. 8, 2022. doi: http://doi.org/10.1016/j.heliyon.2022.e09514. PubMed PMID: 35663457.

[18] TALENS, C., LAGO, M., SIMÓ-BOYLE, L., *et al*., "Desirability-based optimization of bakery products containing pea, hemp and insect flours using mixture design methodology", *Lebensmittel-Wissenschaft + Technologie*, v. 168, pp. 168, 2022. doi: http://doi.org/10.1016/j.lwt.2022.113878.

[19] NJAPNDOUNKE, B., KOUAM, M.E.F., BOUNGO, G.T., *et al*., "Optimization of production conditions of biscuit from Musa sapientum flour ('banane cochon'): Nutritional composition and glycaemic index of the optimized biscuit", *Journal of Agriculture and Food Research*, v. 6, pp. 100229, 2021. doi: http://doi.org/10.1016/j.jafr.2021.100229.

[20] OLUGBUYI, A., OYINLOYE, A., ARAOYE, K., *et al*., "Orange fleshed sweet potato-rice bran flour: Optimization, proximate and amino acid composition for dough meal production", *Journal of Agriculture and Food Research*, v. 15, pp. 100920, 2024. doi: http://doi.org/10.1016/j.jafr.2023.100920.

[21] ANNAN, H.A., ODURO-YEBOAH, C., ANNAN, T., *et al*., "Sensory optimization of an instant brown rice cereal containing tigernut and soybean", *Journal of Agriculture and Food Research*, v. 14, pp. 100808, 2023. doi: http://doi.org/10.1016/j.jafr.2023.100808.

[22] KUSHWAHA, R., GUPTA, A., SINGH, V., *et al*., "Jackfruit seed flour-based waffle ice cream cone: Optimization of ingredient levels using response surface methodology", *Heliyon*, v. 9, n. 2, pp. 9, 2023. doi: http://doi.org/10.1016/j.heliyon.2023.e13140. PubMed PMID: 36793960.

[23] KAUR, R., PRASAD, K., "Process optimization for the development of traditionally roasted chickpea flour for meal replacement beverages", *Food Chemistry Advances*, v. 3, pp. 100452, 2023. doi: http://doi.org/10.1016/j.focha.2023.100452.

[24] ABELLAN-GARCIA, J., IQBAL KHAN, M., ABBAS, Y.M., *et al*., "Multi-criterion optimization of Low-Cost, Self-compacted and Eco-Friendly Micro-calcium-carbonate- and Waste-glass-flour-based Ultrahigh-Performance concrete", *Construction & Building Materials*, v. 371, pp. 371, 2023. doi: http://doi.org/10.1016/j.conbuildmat.2023.130793.

[25] SOARES, V.O., DE PAULA, G.R., BOAS, M.D.O.C.V., *et al*., "Otimização das condições de moagem em moinho planetário e efeito da distribuição do tamanho de partículas na sinterização de um vidro do sistema $Li_2O.Al_2O_3.SiO_2$ (LAS)", *Matéria (Rio de Janeiro)*, v. 25, n. 1, pp. e-12587, 2020. doi: http://doi.org/10.1590/s1517-707620200001.0913.

[26] JIXING, Y., ZHU, P., JUNHUI, L., "Optimization of rapid-repair material ratio and performance analysis based on orthogonal test", *Matéria (Rio de Janeiro)*, v. 28, n. 2, pp. e20230079, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0079.

[27] VENUGOPAL, R., MUTHUSAMY, N., NATARAJAN, B., *et al*., "Statistical optimization of fibre reinforced polymer concrete made with recycled plastic aggregates by central composite design", *Matéria (Rio de Janeiro)*, v. 28, n. 3, pp. e20230182, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0182.