Journal of Engineering Science and Technology
Special Issue on Development of Sustainability Systems - III, 163 - 173

EXPERIMENTAL ASSESSMENT OF A MODIFIED GRAIN FLOW BALANCER IN AN IRAQI FLOUR MILL

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Abstract

This experimental study evaluates and compares the performance of electronic and non-electronic grain flow balancers under real operating conditions in an Iraqi flour mill. Although mechanical (non-electronic) balancers are often promoted in developing regions due to their simplicity and low cost, previous studies lack systematic experimental comparisons that quantify their performance relative to electronic systems in terms of stability, efficiency, and product quality. This gap limits mill operators' ability to make evidence-based decisions. To address this limitation, controlled experiments were conducted to assess grain flow stability, throughput rate, flour quality consistency, and maintenance requirements for both systems. The results showed that the electronic grain flow balancer achieved superior flow stability, reducing grain flow fluctuations by approximately 18-22% compared to the mechanical balancer. In addition, the electronic system improved throughput efficiency by about 10-15% and provided more consistent flour quality, as indicated by reduced variability in moisture content and extraction rate. While the non-electronic balancer demonstrated advantages in lower initial cost (≈30% reduction) and simpler maintenance requirements, it exhibited greater flow variability and lower control accuracy during extended operation. These findings indicate that electronic balancers offer higher operational efficiency and process control. In contrast, non-electronic balancers remain a viable low-cost alternative for small-scale mills operating under severe infrastructure constraints. Overall, this study provides quantitative experimental evidence to clarify the trade-offs between electronic and non-electronic grain flow balancers, supporting more informed technology selection for flour mills in Iraq and similar developing regions.

Keywords: Flour mill, Grain flow balancer, Green manufacturing, Moisture measurement, Wheat processing.

1. Introduction

Wheat is one of the most essential cereal crops worldwide, serving as a cornerstone of global food security and a primary raw material for flour-based products. Beyond its nutritional value, wheat plays a strategic role in ensuring stable food supply chains, particularly in developing countries where population growth and dietary demand continue to rise. The quality and economic value of wheat-based products, however, depend strongly on milling performance, especially on the control of bran separation and flour extraction efficiency. Excessive bran incorporation can negatively affect bread volume, texture, and consumer acceptance, while controlled reintegration of fine bran has gained importance due to increasing demand for whole-grain and high-fiber products [1].

Grain milling, particularly wheat milling, has a long and critical history. The modern milling process includes sequential stages such as cleaning, conditioning, grinding, and sifting to achieve the desired flour characteristics. Wheat remains the primary grain processed in most flour mills, although cereals like corn, oats, and barley are also milled for specific applications [2, 3]. Each wheat kernel comprises bran, germ, and endosperm, each responding differently to mechanical forces. Thus, conditioning wheat by adjusting moisture content (typically 15-15.5% for soft wheat and 16–16.5% for hard wheat) is necessary to soften the endosperm, toughen the bran, and improve separation and sifting efficiency [4].

Modern flour milling is a complex, multi-stage industrial process that involves cleaning, conditioning, grinding, sifting, and blending. Each wheat kernel consists of bran, germ, and endosperm, which exhibit different mechanical responses during milling. Consequently, precise conditioning, typically at moisture levels of 15%-15.5% for soft wheat and 16%-16.5% for hard wheat, is required to enhance endosperm friability, strengthen bran elasticity, and improve separation efficiency. Inadequate control of these parameters often leads to unstable flour quality, higher energy consumption, and increased material losses [5].

Further analysis using 3D contour plots showed that closer plate distances and higher speeds increased throughput to 400 kg/h, but at a higher energy cost. In contrast, wider plate distances and lower speeds reduced energy consumption to 6 kWh while lowering throughput to 225 kg/h. An optimal balance allowed 90% flour fineness and a protein content of 14.5% [6]. Validation experiments confirmed these results, reporting a 15% increase in throughput and a 10% reduction in energy use compared to non-optimized settings [7].

Complementing this work, Bassey et al. [8] conducted a comparative analysis of hammer and disk mills for yam flour processing. Their study underscored trade-offs between particle size, energy consumption, and scalability. Hammer mills, which operate through impact forces, deliver finer flour at the cost of higher energy input. In contrast, disk mills, which rely on shear forces, were more limited in terms of feed rate and industrial scalability. Although the focus was on yams, the authors emphasized that the findings applied more broadly to cereal milling, especially in settings that use locally fabricated equipment without standardized performance data.

Further reinforcing the value of localized engineering solutions, Desta and Oumer [9] designed and evaluated a hammer mill fabricated from affordable and locally sourced materials for processing maize, wheat, sorghum, and barley into fish feed.

The system demonstrated high efficiency, achieving crushing rates between 90-95% with throughput ranging from 65-78 kg/h at 1,800 rpm and 3,000 W.

Using Statistix 8.0 software, researchers found consistent performance across various sieve sizes of 1 to 3 mm, with the coefficient of variation remaining below 7%. The machine achieved optimal performance when the grain moisture content was maintained at 13%, underscoring its practical suitability for feed production in resource-constrained regions.

Other studies also emphasize the importance of controlling milling parameters. Jet milling, for example, has proven capable of producing ultrafine flour while minimizing starch damage. Feed rate was shown to be the most influential factor affecting both particle size and energy consumption [10]. Similarly, optimized roller settings and the reintegration of fine bran can push extraction rates to 92%, though such adjustments may negatively impact dough rheology and must be carefully managed [1].

Modern mills often incorporate real-time weighing systems to ensure material input/output balance and maintain product quality. In addition, operational efficiency can be improved through standardized measurement practices and the use of metric units, which also facilitate international consistency [11]. These improvements are particularly important in developing regions, where automation is often constrained by limited infrastructure or budgets [12].

Amid these technical advancements, grain flow balancing remains a core component of mill operation. The grain flow balancer, typically positioned under raw or conditioned wheat silos, plays a critical role in regulating and measuring the quantity of grain discharged into the system. Accurate flow control directly affects upstream processes, such as cleaning and moistening.

However, in many mills, such as the Al-Dora flour mill, shown in Fig. 1, the mechanical grain flow balancer has become increasingly unreliable due to outdated technology and a lack of spare parts [13]. These deficiencies result in inconsistent flour and bran yields, higher production costs, and the inability to monitor flow volumes in real time, thereby impairing inventory control and production planning.

Fig. 1. Al-Dora mill.

To overcome these challenges, adopting a non-electronic grain flow balancer has emerged as a practical and cost-effective solution. Unlike complex electronic systems, the non-electronic design is inexpensive to manufacture, easy to maintain, and well-suited to manual monitoring systems. It provides consistent, real-time data to more accurately estimate flour and bran output, which in turn, supports more effective production forecasting, logistics, and inventory control [14]. As such, grain flow balancing is not merely a technical detail but a strategic component of optimizing milling efficiency, reducing operational overhead, and reinforcing national food production resilience.

Recent studies have explored alternative approaches for grain flow regulation in resource-constrained environments, emphasizing robustness, simplicity, and low maintenance requirements. Non-electronic, mechanically driven balancing systems have been proposed as cost-effective solutions when electronic sensors and software-based controls are impractical. While such systems offer advantages in terms of affordability and ease of maintenance, there remains a lack of recent experimental studies that quantitatively compare electronic and non-electronic grain flow balancers under real industrial operating conditions, particularly in the context of flour mills in developing countries.

Existing literature often addresses milling optimization or machine design independently, without systematically evaluating trade-offs among control accuracy, operational stability, maintenance requirements, and the economic feasibility of different grain flow balancing technologies. This gap motivates the present study.

The objective of this research is to experimentally evaluate and compare the performance of electronic and non-electronic grain flow balancers in an operational Iraqi flour mill. The study focuses on grain flow stability, throughput efficiency, flour quality consistency, and maintenance characteristics under real production conditions. Unlike prior works that emphasize design or simulation, this study provides practical, data-driven insights into the suitability of each system for industrial deployment in regions with infrastructural limitations. The balancers themselves were not replaced. Only the moisture content measurement unit was changed from the traditional manual method to the developed electronic measurement device, while the existing grain flow balancers remained in operation.

2. Research Method

The grain flow balance unit is designed to quantitatively assess wheat throughput by calculating both the instantaneous flow rate and the cumulative discharged quantity while dynamically regulating the air-seal mechanism. Operators can monitor and adjust flow parameters either locally through control panels or centrally via supervisory control units. System outputs are displayed in absolute units (kg/h) and relative percentages (%), enabling precise mass-balance control across milling sections [15].

This section presents a classification of grain flow balancing systems, distinguishing conventional mechanical balancers from electronic load cell-based implementations. Modern systems utilize strain-gauge load cells in place of balance beam-spring assemblies to achieve higher measurement accuracy and dynamic response. The electronic grain flow balancer determines the mass flow indirectly by sensing the force exerted on a deflection plate. The resulting electrical signal is processed by a control unit, which performs continuous real-time feedback regulation to compensate for deviations from the predefined set point flow rate [16, 17].

The Automated Flow Balancer maintains consistent throughput irrespective of grain moisture or density fluctuations. Throughput parameters can be configured either locally at the control unit or remotely via analogue/serial interfaces. Proper installation necessitates positioning beneath continuously supplied storage bins. Initial nominal throughput is established during commissioning, with subsequent operational adjustments possible. The system enables synchronized percentage-based control across multiple units, ensuring coordinated operation.

During flow interruptions, such as temporary bin depletion, the system automatically opens the discharge slide and activates limit switches and optional alarm systems. Operation modes include manual and remote control. Although the system does not utilize electric motors for actuation, it requires oil-free compressed air at approximately 0.5 bar, with an average consumption of 150 L/h per unit. Throughput verification is performed using timed grain collection and mass measurement, a procedure essential for calibration and performance validation when integrated into centralized control systems [18], as shown in Figs. 2 and 3.

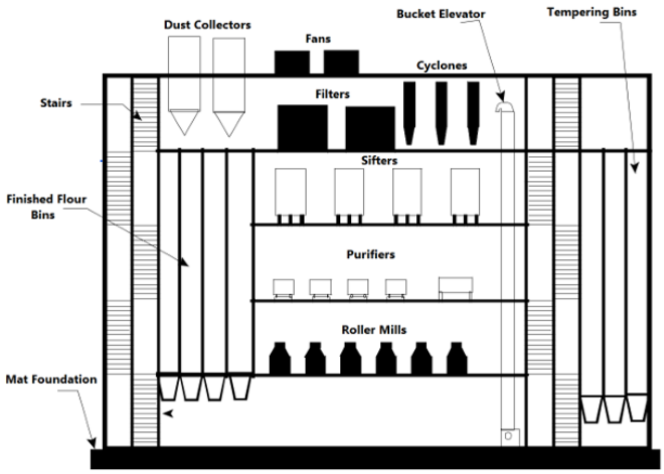
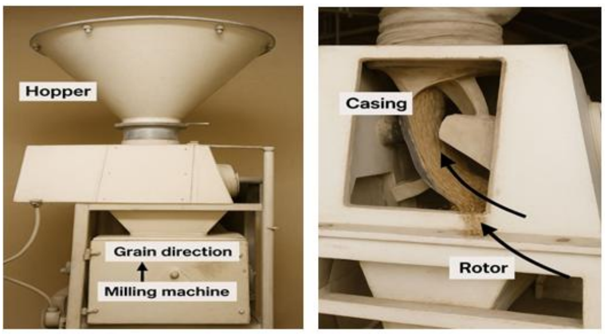


Fig. 2. Flour milling process diagram (19).



a. Flow balancer b. Balancer in operation

Fig. 3. Old flow balancer in operation.

2.1. Wheat milling preparation

The process of preparing wheat for milling involves several stages to ensure that the wheat is properly cleaned, treated, and mixed before milling to achieve the desired flour quality. The following is a breakdown of the stages:

Wheat Mixing stage: This step is done before cleaning and involves blending different types of wheat. The purpose is to achieve the desired flour specifications, which might not be possible with only one variety of wheat. For example, mixing strong wheat with common wheat helps achieve the desired protein content and other characteristics of the final product. Wheat mixing also serves to reduce the cost of the mixture, as some varieties may be cheaper than others.

Cleaning stage: After mixing, the wheat undergoes a cleaning process to remove impurities such as dust, dirt, and foreign materials. This ensures that only the wheat grains are processed.

Water Treatment stage: In some cases, water treatment is applied after mixing or storage to help condition the wheat, improving the milling process and the final flour quality. This treatment ensures that the wheat absorbs the right amount of moisture, making it easier to mill.

Ventilation stage: Proper ventilation is essential in storage and treatment areas to keep wheat dry and free of mould or spoilage. It helps maintain the wheat's quality until it is ready for milling.

2.2. Mixing devices

Measuring Volume Mixing Devices: These are simple devices consisting of cylinders with pockets and graduated valves. They work by measuring the volume of wheat and mixing similar types or varieties based on their hectolitre weight. These devices are used for wheat types with similar characteristics, making them a cost-effective and straightforward option for mixing.

Flow Balancers: These are more advanced devices designed to control the flow of wheat and maintain a balanced mixture. They are often used for precise control when mixing different types of wheat with varying characteristics.

This process ensures that the wheat is of uniform quality and meets the specifications for the desired flour, while remaining cost-effective.

The device was experimentally deployed beneath one of the raw wheat silos at the Dora Mill and integrated with a suitable balancing power supply. The system was operated under real industrial milling conditions, during which energy-related signals were continuously acquired. The experimental methodology was designed to assess how balancing accuracy influences process control capability, particularly in regulating flour and bran flow rates in accordance with the production requirements of the Ministry of Trade.

From a methodological perspective, improved balancing precision was considered a key control variable affecting material distribution consistency, loss minimization, and maintenance planning efficiency. In addition to primary operational parameters-such as wheat feed rate, water addition rate, and ambient humidity-the experimental framework explicitly accounted for wheat material properties that significantly affect milling performance. These properties included grain size distribution, initial moisture content, kernel hardness, and impurity level. Variations in these characteristics were treated as influential input parameters due to their impact on flow stability, conditioning Behavior, grinding resistance, and flour extraction potential.

Consequently, system performance was evaluated as a function of the interaction between balancer type (mechanical or electronic), operational conditions, and wheat material properties. Measurements were recorded at multiple time intervals during normal milling operation to capture process variability. A comparative methodological analysis was then conducted by applying identical operating conditions to both mechanical and electronic balancing systems.

3. Results and Discussion

This section presents the experimental results obtained from the practical evaluation of the grain flow balancing system under real milling conditions at the Dora Mill. The recorded data reflect the system's behaviour during continuous operation and highlight the impact of balancing accuracy on flow regulation and production stability. The results are analysed through a comparative assessment between mechanical and electronic balancers, considering the influence of operational parameters and wheat material properties on overall milling performance. Figure 4 compares the wheat flow rates (kg/h) obtained using electronic and mechanical balancers between 8:30 AM and 12:00 PM.

The electronic balancer achieved an average wheat flow rate of 12.52 kg/h, compared to 11.95 kg/h for the mechanical balancer, representing an overall improvement of approximately 4.77% in wheat throughput. The mechanical balancer demonstrated stable operation, confirming its suitability for environments that require simplicity and robustness. However, the electronic balancer provided higher accuracy and better responsiveness to flow variations resulting from changes in wheat properties, such as moisture content and grain uniformity. This enhanced control contributes to improved coordination between cleaning and grinding units, reducing process variability and improving overall production efficiency.

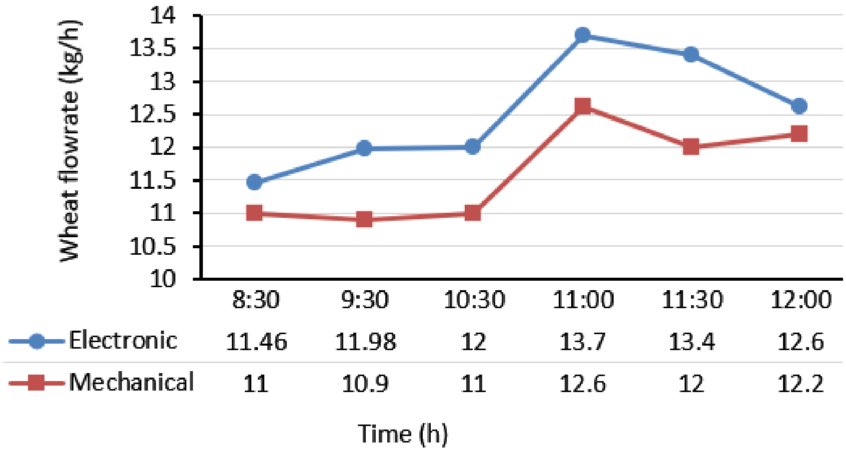


Fig. 4. Wheat flow over time on May 12, 2024.

Figure 5 presents the water flow rates (L/h) used for wheat tempering from 9:00 AM to 12:30 PM under both mechanical and electronic control systems. Precise control of water addition is essential, as it directly affects grain conditioning, milling performance, and flour quality. The electronic system exhibited superior accuracy and flexibility, particularly during changes in processing demand or grain characteristics. In contrast, the mechanical system provided stable and acceptable performance under steady conditions. This comparison highlights that while mechanical systems remain cost-effective and reliable for standard operations, electronically controlled tempering systems offer greater adaptability, resulting in more uniform moisture distribution, reduced conditioning errors, and enhanced milling efficiency.

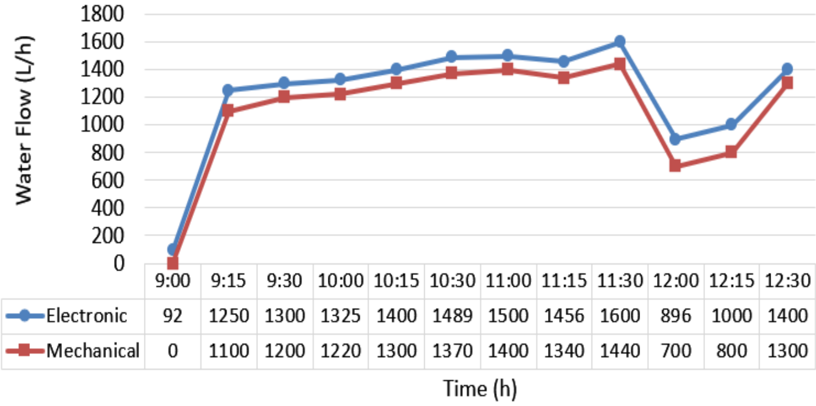


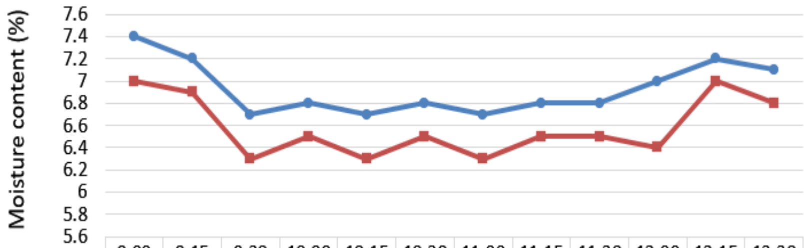
Fig. 5. Water quantities over time (March 12, 2024).

Figure 6 illustrates the moisture content (%) of conditioned wheat over time. Moisture content is a key determinant of flour quality and milling efficiency, with deviations within ±0.5% considered acceptable in industrial practice. The mechanical balancer demonstrated adequate performance in maintaining moisture levels within this tolerance range, supporting its viability as a practical solution for facilities with limited access to advanced electronic infrastructure.

However, inaccuracies observed in the older mechanical grain flow balancer are mainly due to mechanical wear and component aging. Repairing such systems often involves high costs and long delays due to the need for imported spare parts. In contrast, the electronic system enables performance evaluation through electrical energy monitoring, allowing for more accurate efficiency assessment and potential energy optimization.

Although the electronic balancer showed higher short-term efficiency, accuracy, and responsiveness, the mechanical balancer retains advantages in terms of durability, simplicity, and long-term operational reliability. This explains the apparent contradiction between the statements made in the Abstract and Introduction and the experimental results. The electronic system is superior in terms of technical performance.

In contrast, the non-electronic system remains attractive from an economic and maintenance standpoint. It should be noted that the presented results are based on data collected over a single operational day. While sufficient for preliminary performance comparison, a one-day dataset does not fully capture daily variations in wheat properties, environmental conditions, and operational loads. Extended testing over multiple days would provide a more reliable statistical evaluation and strengthen the validity of the conclusions.



	9:00	9:15	9:30	10:00	10:15	10:30	11:00	11:15	11:30	12:00	12:15	12:30
Electronic	7.4	7.2	6.7	6.8	6.7	6.8	6.7	6.8	6.8	7	7.2	7.1
Mechanical	7	6.9	6.3	6.5	6.3	6.5	6.3	6.5	6.5	6.4	7	6.8

Time (h)

Fig. 6. Humidity over time (December 23, 2023).

4. Conclusions

This study evaluated the performance of an electronic moisture measurement device used in wheat conditioning and milling operations and compared its behaviour with that of the conventional manual moisture assessment method. The experimental results indicate that the electronic system achieves superior measurement accuracy, improved repeatability, and more uniform water distribution during the conditioning stage. These characteristics enable tighter control of critical conditioning parameters and reduce variability associated with operator-dependent manual adjustments.

The findings further demonstrate that implementing a two-stage water addition strategy, enabled by real-time moisture monitoring, increased flour extraction rate by approximately 6.5%, reflecting enhanced milling efficiency. Improvements in flour quality were also observed, including increased flour brightness and a reduction in ash content to 0.17%, indicating improved endosperm separation and more stable conditioning conditions.

These performance improvements are directly attributable to the device's capability to continuously monitor wheat moisture content and automatically regulate water addition during operation. In contrast, the traditional manual method relies on periodic sampling, manual calibration, and operator intervention, which introduces delays and measurement inconsistencies. It should be noted that the conclusions of this study are based on short-term experimental operation.

Further investigations are recommended to evaluate long-term system reliability, maintenance requirements, and energy consumption to assess the overall economic feasibility of large-scale industrial implementation. Nevertheless, the developed electronic moisture measurement device represents a technically sound and practical advancement for modern wheat milling facilities aiming to improve efficiency, process stability, and product quality under controlled operating conditions.

Nomenclatures

MC	Moisture content of wheat, %
T	Temperature, °C
t	Time, h or sec
$\dot{V}$	Water volumetric flow rate, L/h
$\dot{W}$	Wheat mass flow rate, kg/h
Greek Symbols	
η	System efficiency, %

References

1. Alhendi, A.S.; Ahmed, Z.A.; Hussein, M.S.; and Abed, S.A. (2021). Large scale industry mill: Effect of extraction rate of flour on the dough rheological properties. *Food Research*, 5(4), 80-85.
2. Owens, G. (2003). Mill Efficiency. *World Grain*, 20-22.
3. Posner, E.S.; and Hibbs, A.N. (2005). *Wheat flour milling*. In Kulp, K.; and Shewry, P.R. (Eds.), *Wheat*: *Chemistry and technology*. AACC International, Inc., 233-264.
4. Dendy, D.A.V.; and Dobraszczyk, B.J. (2001). *Cereals and cereal products*: *Chemistry and technology*. Aspen Publishers Inc., 140-172.
5. Saroja, P.E.; Muthugounder, P.; Shanmugam, S.; and Dhairiyasamy, R. (2024). Enhancing flour quality and milling efficiency: Experimental study on bullet plate type flour grinding machine. *Matéria* (*Rio de Janeiro*), 29(3), e20240331.
6. Ye, J.; Zhu, P.; and Luo, J. (2023). Optimization of rapid-repair material ratio and performance analysis based on orthogonal test. *Matéria* (*Rio de Janeiro*), 28(2), e20230079.
7. Venugopal, R.; Muthusamy, N.; Natarajan, B.; and Govindan, V. (2023). Statistical optimization of fibre reinforced polymer concrete made with recycled plastic aggregates by central composite design. *Matéria* (*Rio de Janeiro*), 28(3), e20230182.
8. Bassey, J.B.; Odesola, I.F.; and Olawuyi, J.A. (2022). A comparative technique for performance evaluation of hammer mill and disk mill in yam flour processing. *World Journal of Engineering and Technology*, 10(03), 613-625.
9. Desta, M.A.; and Oumer, A. (2022). Design and performance evaluation of grain feed grinding machine. *Turkish Journal of Agricultural Engineering Research*, 3(2), 231-244.
10. Protonotariou, S.; Ritzoulis, C.; and Mandala, I. (2021). Jet milling conditions impact on wheat flour particle size. *Journal of Food Engineering*, 294, 110418.
11. Fang, C.; and Campbell, G.M. (2000). Effect of measurement method and moisture content on wheat kernel density measurement. *Food and Bioproducts Processing*, 78(4), 179-186.

12. Wrigley, C.W. (2010). Equivalence between metric and U.S. Units for the grain industry. *Cereal Foods World*, 55(1), 32-34.
13. Abdel-Wahab, M.K.; El-Shazly, M.A.; Afifi, M.K.; and El-Maghawry, H.A.M. (2007). Effect of some operational factors on the efficiency of wheat milling processes. *Misr Journal of Agricultural Engineering*, 24(4), 688-698.
14. Donnelly, B.J.; and Ponte, J.G. (2000). *Pasta*: *Raw materials and processing*. In Kulp, K. (Ed.), *Handbook of cereal science and technology*. CRC Press.
15. Okonigene, R.E.; and Omondaigbe, C. (2009). Electrical energy consumption pattern of flour mill in Nigeria. *The Pacific Journal of Science and Technology*, 10(2), 514-519.
16. Arafa, G.K.; and Abd El-Rahmam, A.A. (2017). Prediction of moisture content of grains during the re-wetting process for milling. *Misr Journal of Agricultural Engineering*, 34(1), 385-402.
17. Bühler Group. Moisture control unit: MYFD / MOZG. Retrieved May 5, 2025, from https://www.buhlergroup.com/global/en/products/moisture_controlunit.html
18. Kis, P.B.; Mihálykó, C.S.; and Lakatos, B.G. (2005). Optimising design of continuous grinding mill-classifier systems. *Chemical Engineering and Processing*: *Process Intensification*, 44(2), 273-277.
19. Williams, G.D.; and Rosentrater, K.A. (2007). Design considerations for the construction and operation of flour milling facilities. Part I: Planning, structural, and life safety considerations. *Proceedings of American Society of Agricultural and Biological Engineers* (*ASAE*) *Annual Meeting, June* 17-20, *Minneapolis*, *Minnesota*, *the USA.*