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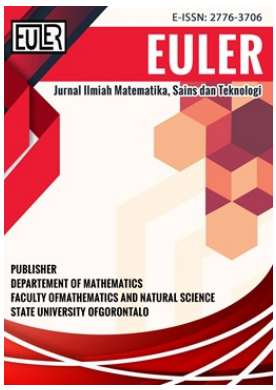
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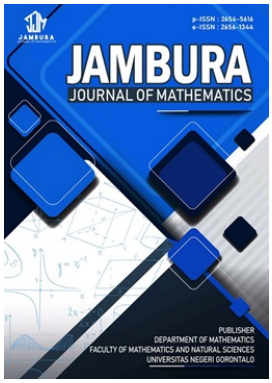


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Research Article

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Development and Evaluation of an Arduino-Based Paddy Drying Machine Using Quality Function Deployment

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ABSTRACT. *Conventional sun drying of paddy is highly dependent on environmental conditions and requires continuous supervision during the drying process. This study aimed to develop an Arduino-based paddy drying machine using Quality Function Deployment (QFD) to translate user requirements into technical characteristics, evaluate the functional responses of the control system under different light and rainfall conditions, and compare relative mass reduction across several stirring configurations. The study employed a product development approach followed by experimental testing. User requirements were identified through a questionnaire administered to 30 farmers and translated into technical characteristics using QFD. The developed prototype integrated an Arduino Uno, a light sensor, a rain sensor, an automatic roof mechanism, and a stirring mechanism. Functional testing was conducted under four combinations of light and rainfall conditions, while six stirring configurations were evaluated descriptively based on absolute mass change and relative mass reduction. The results showed that the actual responses of the roof and stirring mechanisms were consistent with the designed control logic under all four tested conditions. Relative mass reduction across the six configurations ranged from 4.62% to 7.14%, with the double plate–single harrow (DP–SH) configuration producing the highest observed value of 7.14%. These findings establish initial functional conformity under the tested conditions and identify DP–SH as the configuration with the highest observed relative mass reduction. However, drying efficiency and long-term operational reliability were not established.*

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1. Introduction

Rice is one of the major food commodities that requires appropriate postharvest handling to maintain product quality during storage and processing. Drying is a critical stage of postharvest handling because freshly harvested paddy generally contains relatively high moisture content, which must be reduced to a safe level for storage. Inadequate drying may lead to quality deterioration, microbial growth, discoloration, and reduced milling quality. In many agricultural areas, paddy drying is still commonly performed using direct sunlight because of its simplicity and relatively low operating cost. However, conventional sun drying is highly dependent on weather conditions, requires sufficient drying space, and demands continuous monitoring and handling throughout the drying process [1, 2].

Various drying technologies have been developed to address the limitations of conventional sun drying. Jha and Tripathy [1] investigated the optimization of process parameters and heat and mass transfer during simulated solar drying of paddy, while [2] examined an inflatable solar dryer using CFD-Simulink modeling. In contrast, Leilayi et al. [3] focused on the design and performance evaluation of a solar drum dryer equipped with a perforated drum, emphasizing the role of mechanical configuration in the drying process. Ying and Spang [4] reviewed

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existing paddy drying technologies from the perspective of energy consumption. These studies address different aspects of drying technology, including process optimization, dryer design, mechanical configuration, and energy utilization. However, these approaches do not directly establish how user requirements can be integrated with environmental-condition-based automatic control and stirring-configuration assessment within a single prototype development process.

The application of sensors and microcontrollers has further supported the development of automated paddy drying systems. Kusumawardani et al. [5] developed an Arduino Uno-based paddy dryer, while Nebrida [6] investigated an Arduino-driven rice grain dryer for postharvest management. Meanwhile, Syaifurrahman et al. [7] developed an Internet of Things-based system for monitoring temperature and moisture content in a paddy drying machine. These studies illustrate different applications of electronic control and monitoring in drying systems. In comparison, Sukmawati et al. [8] developed an Arduino-based automatic drying prototype for rice husks, demonstrating the application of automatic control to agricultural drying operations. Although these studies support the feasibility of sensor-based automation, the specific integration of user-oriented design requirements, light- and rain-responsive roof control, and comparative assessment of stirring configurations remains insufficiently addressed by the cited studies.

In addition to automatic control, incorporating user requirements into machine development is important to ensure that the resulting design addresses practical operating needs. Quality Function Deployment (QFD) provides a structured approach for translating user requirements into technical characteristics. Huang et al. [9] reviewed developments and improvements in QFD methodologies, while Setianah et al. [10] examined the application of QFD in manufacturing. These studies demonstrate the relevance of QFD as a framework for connecting customer requirements with technical design decisions. However, they do not specifically examine its application to the development of a paddy drying machine integrating automatic environmental control and alternative stirring configurations. Therefore, applying QFD in the present study provides a systematic basis for relating farmer requirements to the technical characteristics implemented in the developed prototype.

Based on the reviewed literature, previous studies have addressed paddy drying through process optimization, dryer configuration, energy considerations, and sensor-based automation, while QFD research has provided approaches for translating user needs into technical characteristics. Nevertheless, the integration of these aspects within a user-oriented paddy dryer development process has received limited attention in the cited studies. The present study addresses this gap by combining QFD-based identification of technical characteristics, Arduino-based control of roof and stirring mechanisms in response to light and rainfall conditions, and experimental evaluation involving two aspects: the conformity of actual actuator responses with the designed control logic under different environmental conditions, and the descriptive comparison of absolute mass change and relative mass reduction across six stirring configurations. The contribution of this study lies in the integration of these design and evaluation components rather than the introduction of a new sensor technology or the demonstration of improved drying efficiency.

Therefore, this study aims to develop an Arduino-based paddy drying machine using Quality Function Deployment to translate farmer requirements into technical characteristics for machine design. It further aims to evaluate the functional responses of the automatic roof and stirring mechanisms under four combinations of light and rainfall conditions and to compare six stirring configurations based on absolute mass change and relative mass reduction.

The performance comparison is limited to the observed changes in paddy mass and is not intended to establish differences in moisture-content reduction or drying efficiency.

2. Methods

2.1. Research Design and Stages

This study employed a product development approach followed by experimental testing to develop and evaluate an Arduino-based paddy drying machine using Quality Function Deployment (QFD). The research was conducted in Donomulyo, Malang Regency, East Java Province, Indonesia, from January to August 2026. The research process consisted of five main stages: (1) user requirements identification and QFD analysis, (2) machine design and development, (3) prototype fabrication, (4) functional testing of the automatic control system, and (5) performance testing based on paddy mass changes across different stirring configurations. The overall research procedure is illustrated in Figure 1.

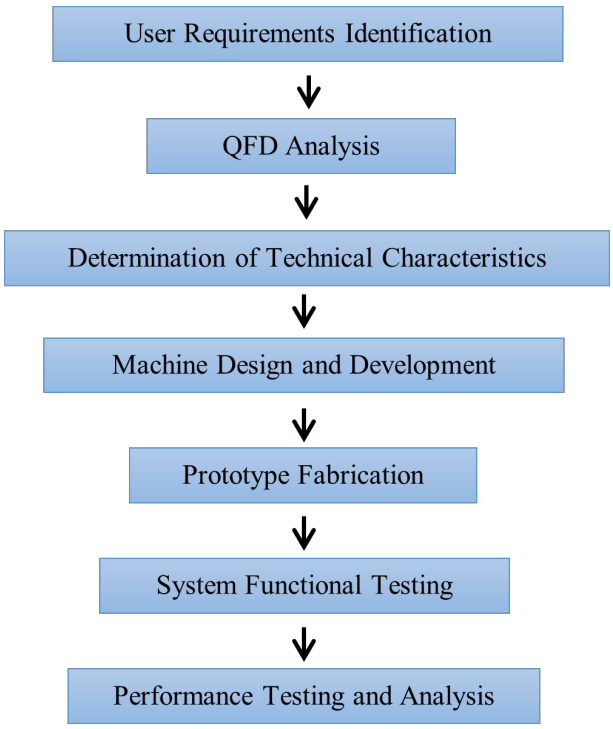


Figure 1. Research Stages

In the first stage, user requirements were identified through a questionnaire administered to 30 farmers as prospective users of the machine. These requirements were translated into technical characteristics through QFD analysis, providing a basis for subsequent design decisions [11–13]. In the second stage, the identified technical characteristics were used to design the machine structure, automatic control system, roof mechanism, and stirring mechanism. The third stage involved fabricating and assembling the prototype according to the developed design, including the integration of an Arduino Uno, light and rain sensors, and the corresponding actuators.

In the fourth stage, functional testing was conducted to evaluate whether the actual responses of the roof and stirring mechanisms conformed to the designed control logic under four combinations of light and rainfall conditions. In the final stage, performance testing was conducted to compare six stirring configurations based on absolute mass change and relative mass reduction of paddy. The results were analyzed descriptively to assess the func-

tional operation of the prototype and the observed differences in mass reduction among the tested configurations. These evaluations were limited to functional responses and observed mass changes and were not intended to establish drying efficiency or long-term operational reliability.

2.2. User Requirements Identification and QFD Analysis

User requirements were identified through a questionnaire administered to 30 farmers in Donomulyo, Malang Regency, East Java Province, Indonesia. Respondents were selected using purposive sampling based on their direct involvement in paddy farming, experience in paddy drying activities, and availability during the study period. The sample was intended to obtain preliminary information on the operational needs and expected characteristics of the proposed drying machine rather than to provide statistically representative estimates of the broader farmer population. Seven user requirement attributes were identified, as presented in Table 1.

Table 1. User requirement attributes for the development of the paddy drying machine.

Code	User requirement
U1	The machine is easy to move
U2	The machine is affordable
U3	The machine is multifunctional
U4	The machine is lightweight
U5	The machine is easy and convenient to operate
U6	The machine is easy to maintain
U7	Spare parts are readily available

The user requirements presented in Table 1 were subsequently translated into technical characteristics using Quality Function Deployment (QFD). A qualitative relationship-mapping approach was employed to identify the relationships between user requirements (WHATs) and technical characteristics (HOWs) based on their functional relevance and engineering feasibility. These relationships were organized in a QFD matrix to guide machine design decisions. The analysis focused on identifying relevant technical characteristics rather than calculating quantitative importance ratings or technical priority rankings.

2.3. Machine Design and Development

The results of the QFD analysis were used as the basis for designing and developing the Arduino-based paddy drying machine. The prototype consisted of a drying chamber, an automatic roof mechanism, a control panel, a stirring mechanism, and an Arduino Uno-based control system. A rain sensor and a light sensor were integrated to detect environmental conditions, while a DC motor and an AC motor were used to operate the roof and stirring mechanisms, respectively. The main technical specifications of the developed prototype are presented in Table 2.

The control system was designed to operate according to the signals received from the rain and light sensors. Under bright conditions without rainfall, the Arduino Uno activated the roof-opening mechanism and the stirring motor. When rainfall was detected or the light conditions did not satisfy the programmed criteria, the roof was directed to the closed position and the stirring mechanism was deactivated. The sensor threshold settings used to distinguish these environmental conditions are specified in Table 2. The integration of the sensors, controller, actuators, and mechanical components is illustrated in Figure 2.

Table 2. Technical specifications of the Arduino-based paddy drying machine.

Component or parameter	Technical specification
Main controller	Arduino Uno R3
Machine dimensions (L × W × H)	1500 × 1000 × 1200 mm
Drying chamber capacity	10 kg of paddy per batch
Construction materials	Mild steel frame; galvanized steel drying chamber
Rain sensor	Resistive rain detection module with analog output
Light sensor	Light-dependent resistor (LDR) module with analog output
Light detection threshold	ADC value of 600 (10-bit scale, 0–1023)
Rain detection threshold	ADC value of 500 (10-bit scale, 0–1023)
Roof actuator	12 V DC geared motor, 30 W
Stirring motor	AC motor, 1/4 HP
Stirring drive	Gearbox, approximately 31 rpm
Electrical power supply	220 V AC mains and regulated 12 V DC supply
Stirring mechanism	Interchangeable plate and harrow configurations; working width of 800 mm

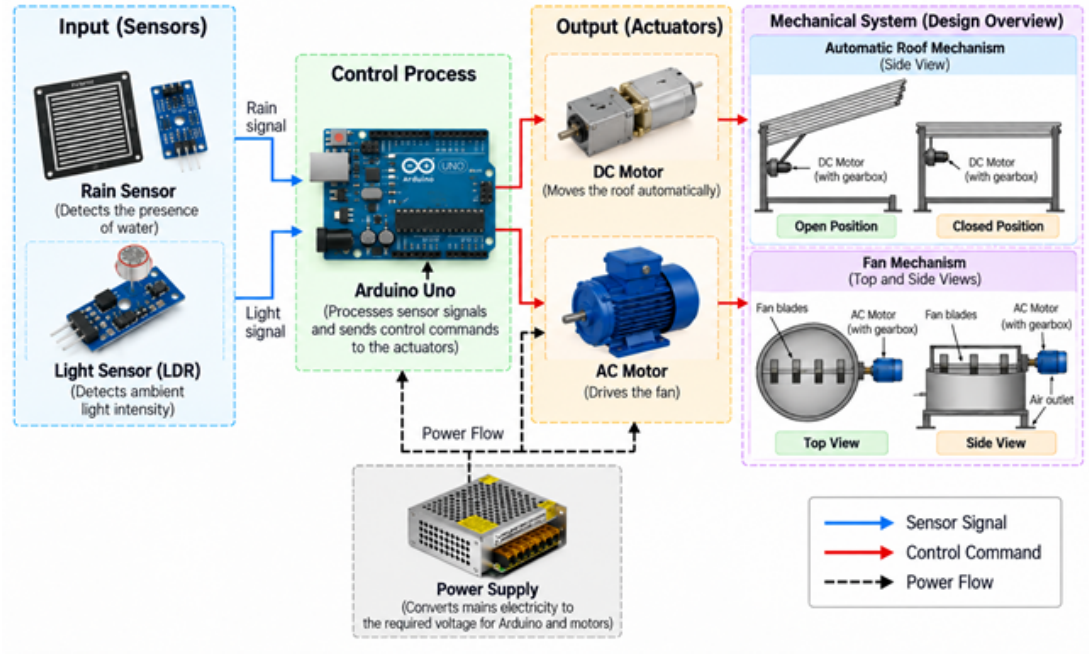


Figure 2. System architecture of the paddy drying machine.

2.4. System Functional Testing

Functional testing was conducted to evaluate whether the automatic control system operated according to the predefined control logic under four combinations of environmental conditions: bright with rain, bright without rain, dark without rain, and dark with rain. The environmental conditions were classified based on the light and rain sensor readings using the programmed threshold settings described in Section 2.3. The system responses were evaluated based on the observed roof position controlled by the DC motor and the operating status of the stirring mechanism driven by the AC motor.

Each environmental condition was tested once, with an observation duration of five minutes per scenario. The environmental conditions were simulated by exposing the light sensor to a light source to represent bright conditions and covering the sensor to represent dark conditions. Rainfall was simulated by applying water to the rain sensor surface, while the absence of rainfall was represented by keeping the sensor surface dry. During each test, the sensor readings and corresponding actuator responses were observed to determine whether the system operated according to the predefined control logic. The expected responses for

the four testing scenarios are presented in Table 3.

Table 3. Functional testing scenarios of the system.

Light condition	Rain condition	Designed roof position	Designed stirring mechanism status
Bright	Rain	Closed	Inactive
Bright	No rain	Open	Active
Dark	No rain	Closed	Inactive
Dark	Rain	Closed	Inactive

The observed system responses were descriptively compared with the expected responses presented in Table 3. Functional conformity was determined based on whether the observed roof position and stirring mechanism status matched the predefined operating conditions. Since each environmental condition was tested only once, the evaluation was limited to the observed conformity of the system responses under the four tested scenarios and did not establish response consistency across repeated operations or long-term operational reliability.

2.5. Performance Testing and Analysis

Performance testing was conducted to evaluate changes in paddy mass across six stirring configurations of the developed prototype. The stirring mechanism was driven by a 1/4 HP AC motor connected to a gearbox, producing a rotational speed of approximately 31 rpm. Paddy samples of the same variety were used throughout the experiments to reduce variation in sample characteristics. The six configurations were tested sequentially within a four-hour period from 11:00 a.m. to 3:00 p.m., with each configuration tested once for 40 minutes, including the measurement of initial and final paddy masses. The same testing procedure was applied to all configurations to support a preliminary descriptive comparison of the observed mass changes.

The absolute mass change was calculated as

$$\Delta m = m_i - m_f \tag{1}$$

where Δm is the absolute mass change, m_i is the initial mass, and m_f is the final mass. Because the initial mass was not identical across all configurations, performance was also compared using the relative mass reduction percentage, calculated as

$$R_m = m_i - m_f / m_i \times 100 \tag{2}$$

where R_m is the relative mass reduction percentage. Both indicators were used to describe the observed mass changes across the six stirring configurations.

The results were analyzed descriptively to identify the configuration showing the greatest observed relative mass reduction. The initial and final moisture contents were not directly measured, and the comparability of environmental conditions across configurations could not be fully established. Furthermore, each configuration was tested only once without independent experimental replication, limiting the assessment of experimental variability. Therefore, the findings were interpreted as a preliminary evaluation based on observed mass changes rather than evidence that differences in stirring configuration caused differences in drying efficiency.

3. Results and Discussion

3.1. User Requirements and Technical Characteristics

The identification of user requirements resulted in seven attributes representing the expected characteristics of the proposed paddy drying machine, as presented in Table 1. These requirements were translated into six technical characteristics using a qualitative Quality Function Deployment (QFD) approach. The relationships between user requirements (WHATs) and technical characteristics (HOWs) are presented in Table 4.

Table 4. Relationship matrix between user requirements and technical characteristics

Code	User requirements (WHATs)	Machine construction	Material and component selection	Automatic control system	Roof mechanism	Stirring mechanism	Component accessibility
U1	The machine is easy to move	•	•				
U2	The machine is affordable	•	•				
U3	The machine is multifunctional			•	•	•	
U4	The machine is lightweight	•	•				
U5	The machine is easy and convenient to operate			•	•	•	
U6	The machine is easy to maintain	•	•				•
U7	Spare parts are readily available		•	•			•

Note: The symbol • indicates an identified functional relationship between a user requirement and a technical characteristic. An empty cell indicates that no direct relationship was identified. The symbols do not represent numerical relationship strengths or technical priority scores.

The relationship matrix was developed by examining the functional relevance of each technical characteristic to the corresponding user requirement. A relationship was indicated when a technical characteristic was considered directly relevant to fulfilling a particular user requirement, whereas an empty cell indicated that no direct relationship was identified. The matrix was used to support design decisions rather than to calculate quantitative technical priorities.

The mapping in Table 4 illustrates the qualitative relationships between user requirements (WHATs) and technical characteristics (HOWs) considered in the machine development. Portability, affordability, and lightweight design were associated with machine construction and material and component selection. Ease of maintenance was related to these characteristics as well as component accessibility, while spare-part availability was associated with material and component selection, the automatic control system, and component accessibility. Meanwhile, multifunctionality and ease of operation were primarily associated with the automatic control system, roof mechanism, and stirring mechanism. These findings indicate that individual technical characteristics can address multiple user requirements, providing a qualitative basis for integrating the mechanical and control components into the developed prototype.

Compared with the QFD-based agricultural sprayer design reported by Muttalib et al. [14], the present application focuses on a paddy drying machine and traces user requirements to a combination of structural, control, roof, and stirring components. The contribution at

this stage is the documented linkage between seven user requirements and six technical characteristics, rather than a demonstrated quantitative ranking of competing engineering solutions. The qualitative relationship matrix therefore supports design traceability but does not establish the relative importance of individual requirements.

The translation of user requirements into technical characteristics is consistent with the QFD principle, in which user requirements serve as the basis for determining technical requirements and product-development decisions [11–15]. In QFD, the relationship between user requirements and technical characteristics provides a structured framework for maintaining a user-oriented design throughout the product-development process.

The resulting technical characteristics were subsequently used as the basis for determining the elements implemented in the machine design. Thus, the translation of user requirements through QFD can be traced to the technical implementations adopted in the development of the machine. The implementation of each technical characteristic is presented in Table 5.

Table 5. Technical characteristics and their implementation in the machine design

Technical characteristics (HOWs)	Design implementation	Function in the system
Machine construction	Frame and drying chamber	Supports the machine structure and drying process
Material and component selection	Construction materials and system components	Supports construction requirements and the use of system components
Automatic control system	Arduino Uno, rain sensor, and light sensor	Detects environmental conditions and processes the control logic
Roof mechanism	DC motor-driven roof	Opens and closes the drying chamber according to light and rainfall conditions
Stirring mechanism	AC motor-driven stirrer	Assists paddy movement during the drying process
Component accessibility	Arrangement of control and mechanical components	Facilitates component inspection and maintenance

The implementation presented in Table 5 shows that the multifunctionality requirement was primarily translated through the integration of drying, protection against changing environmental conditions, and stirring functions. Meanwhile, the requirement for ease and convenience of operation was mainly addressed through an automatic control system integrating the rain sensor, light sensor, Arduino Uno, and drive motors. This integration indicates that the technical characteristics derived through QFD were not implemented independently but function as mutually supporting elements within the machine design.

Overall, the QFD results demonstrate the relationship among user requirements, technical characteristics, and their implementation in the machine design. These technical characteristics were subsequently used as the basis for developing the Arduino-based paddy drying machine.

3.2. Machine Design and Development Results

The technical characteristics obtained from the QFD stage were subsequently implemented in the design and development of the Arduino-based paddy drying machine. The resulting machine design and developed prototype are presented in Figure 3 and 4.

The design shown in Figure 3 illustrates the arrangement of the main components, including the roof, control panel, DC motor, light sensor, rain sensor, stirring mechanism, drying chamber, AC motor, and frame. The overall machine dimensions are 1,500 mm in length,

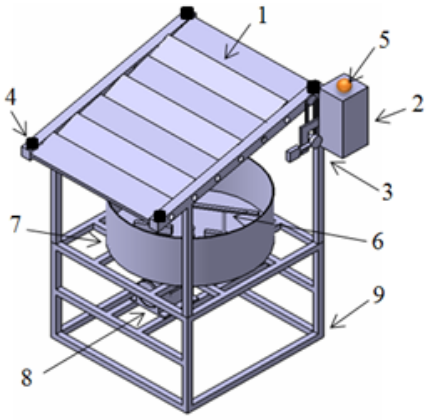


Figure 3. Design of the Arduino-based paddy drying machine



Figure 4. Prototype of the Arduino-based paddy drying machine

1,000 mm in width, and 1,200 mm in height, as specified in Table 2. These components were subsequently integrated into the developed prototype, as shown in Figure 4. The frame and drying chamber constitute the main structural components of the machine, while the roof and stirring mechanism serve as the mechanical components supporting the drying process.

In comparison with Arduino-based paddy drying approaches reported by [5] and [6], the present prototype uses light and rain inputs specifically to coordinate roof positioning and stirring operation. Whereas these earlier studies provide examples of sensor-assisted drying control, the contribution evaluated here is the integration of user-requirement mapping with environmental response and alternative stirring arrangements. This comparison concerns design emphasis and evaluation scope; it does not demonstrate that the present prototype achieves better drying performance than the cited systems.

The control system integrates the light and rain sensors as inputs to the Arduino Uno. The DC motor is used to drive the roof mechanism, while the AC motor drives the stirring mechanism. The integration of the mechanical components and control system resulted in a prototype designed to adjust the operation of the roof and stirring mechanisms according to

environmental conditions based on the predetermined control logic.

The integration of microcontrollers, sensors, and actuators in paddy drying systems has also been implemented in previous studies as part of the development of automated drying systems [16–19]. These studies have demonstrated that information obtained from sensors can be used as input to a control system to regulate dryer components according to detected conditions. In the present study, this concept was implemented by integrating light and rain sensors with the roof and stirring mechanisms within a single prototype.

The prototype development results demonstrate that the technical characteristics established during the QFD stage could be implemented in the machine design through the integration of the construction, roof mechanism, stirring mechanism, and automatic control system. After the mechanical components and control system were integrated, functional testing was conducted to evaluate the consistency of the system responses with the specified light and rainfall conditions.

3.3. System Functional Testing Results

The functional testing results showed that the observed roof positions and stirring mechanism operating states matched the predefined control logic under all four combinations of light and rainfall conditions, as presented in Table 6. These observations indicate that the system produced the intended mechanical responses in each tested scenario.

Table 6. System functional testing results under different light and rainfall conditions

Light condition	Rain condition	Designed response	Actual response	Conformity
Bright	Rain	Roof closed; stirrer inactive	Roof closed; stirrer inactive	Conforming
Bright	No rain	Roof open; stirrer active	Roof open; stirrer active	Conforming
Dark	No rain	Roof closed; stirrer inactive	Roof closed; stirrer inactive	Conforming
Dark	Rain	Roof closed; stirrer inactive	Roof closed; stirrer inactive	Conforming

As shown in Table 6, the roof opened and the stirring mechanism operated under bright conditions without rainfall. When rainfall was detected or the light conditions were insufficient, the roof remained closed and the stirring mechanism was inactive. The observed roof positions reflected the operation of the DC motor-driven roof mechanism, while the stirring mechanism operating states reflected the response of the AC motor. These findings demonstrate the initial functional conformity of the integrated sensor-based control system under the tested environmental conditions.

Compared with previous microcontroller-based paddy drying studies [17–20], including approaches involving fuzzy-based automation [19, 20], the present system focuses on controlling roof positioning and stirring operation in response to light and rainfall conditions rather than regulating drying-process variables. However, because each scenario was tested only once, the findings do not establish response consistency across repeated operations or long-term system reliability. Response time, switching thresholds, and actual grain protection were not quantitatively evaluated.

3.4. Performance Testing and Analysis Results

The performance of six stirring configurations was evaluated descriptively based on initial mass (m_i), final mass (m_f), absolute mass change (Δm), and relative mass reduction (R_m).

Relative mass reduction was used to express the observed mass change as a percentage of the initial mass, allowing descriptive comparisons among configurations with different initial sample masses. Each configuration was tested once using the same paddy variety, with a 40-minute testing period that included initial and final weighing. The results are presented in Table 7.

Table 7. Performance testing results based on stirring configuration

Stirring configuration	Initial mass, m_i (kg)	Final mass, m_f (kg)	Δm (kg)	R_m (%)
Single plate-double plate (SP-DP)	6.5	6.1	0.4	6.15
Single plate-single plate (SP-SP)	6.5	6.2	0.3	4.62
Single plate-double harrow (SP-DH)	7.0	6.6	0.4	5.71
Double plate-single harrow (DP-SH)	7.0	6.5	0.5	7.14
Double plate-double harrow (DP-DH)	6.5	6.2	0.3	4.62
Single plate-single harrow (SP-SH)	6.5	6.2	0.3	4.62

As shown in Table 7, relative mass reduction ranged from 4.62% to 7.14%, with the double plate–single harrow (DP–SH) configuration exhibiting the highest observed value of 7.14%. However, each configuration was tested only once, and the tests were conducted sequentially between 11:00 a.m. and 3:00 p.m. Consequently, possible variations in environmental conditions and initial moisture content could have influenced the observed differences. These differences cannot be attributed solely to the stirring configurations, and no statistical inference regarding differences among configurations was performed.

Relative mass reduction was used as a descriptive indicator of changes in paddy mass rather than a direct measure of moisture-content reduction or drying efficiency. Although expressing mass change relative to initial mass facilitates comparisons across samples of different masses, it does not account for differences in initial moisture content or other factors affecting mass loss. Therefore, the DP–SH configuration can only be identified as producing the highest observed relative mass reduction under the tested conditions, not as having superior drying efficiency.

Previous studies have investigated grain drying using different experimental and analytical approaches. Leilayi et al. [3] examined a solar drum dryer, while Delele et al. [21] and Liu et al. [22] investigated drying behavior through computational modeling. Studies on grain movement and mixing have also highlighted the relevance of material movement to drying-process conditions [21–24]. In contrast, the present study provides a preliminary descriptive comparison of six physical stirring arrangements based on before-and-after mass measurements. Direct comparisons of drying efficiency with these studies are inappropriate because the measured outcomes and experimental conditions differ. Further research should include replicated trials, controlled environmental conditions, direct measurements of initial and final paddy moisture content, drying rate, and energy consumption to provide a more comprehensive evaluation of drying performance.

4. Conclusion

This study developed an Arduino-based paddy drying machine prototype using a qualitative Quality Function Deployment (QFD) approach to translate seven user requirements into six technical characteristics. Functional testing demonstrated that the roof and stirring mechanisms responded according to the predefined control logic under all four tested combinations of light and rainfall conditions. Performance testing of six stirring configurations showed

relative paddy mass reductions ranging from 4.62% to 7.14%, with the double plate–single harrow (DP–SH) configuration producing the highest observed value of 7.14%. However, these results represent preliminary observations because each configuration was tested only once and the initial and final paddy moisture contents were not directly measured. Therefore, the findings establish initial functional conformity and identify the configuration with the greatest observed relative mass reduction, without demonstrating superior drying efficiency.

Declaration of Artificial Intelligence (AI) Use. The authors used artificial intelligence (AI) tools to assist with language editing and improving the clarity of the manuscript. All AI-assisted content was carefully reviewed and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript.

Author Contributions. **Shafiq Nurdin**: Conceptualization, Methodology, Formal Analysis, Investigation, Writing—Original Draft. **Riski Nur Istiqomah Dinnullah**: Data Curation, Formal Analysis, Writing—Review and Editing. **Arianti Kusumawardhani**: Methodology, Validation, Formal Analysis, Validation. **Hisbullah Maulana**: Validation, Investigation, Data Curation, Writing—Review and Editing.

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