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**Journal of Applied Technology and Downstream Innovation (JATDI)** is a multidisciplinary, peer-reviewed journal that bridges scientific discovery and practical implementation across the natural sciences, social sciences, health sciences, engineering, humanities, and law. The journal emphasizes translational and downstream research with demonstrable impact in industry, society, policy, and the environment. The journal particularly encourages interdisciplinary submissions that present downstream products or technology transfers, address the Sustainable Development Goals, or demonstrate clear pathways from basic research to applied outcomes.

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## FOREWORD

It is our great pleasure to introduce the inaugural issue of the **Journal of Applied Technology and Downstream Innovation (JATDI)**, Volume 1, Issue 1, 2026. The publication of this first issue represents the beginning of our commitment to providing a scholarly platform dedicated to the dissemination of applied research, technological advancement, and downstream innovation that address practical needs and create meaningful societal impact.

Scientific research today is expected to generate more than academic knowledge. It is increasingly called upon to produce innovations that can be translated into practical applications, support industrial development, and contribute to sustainable economic growth. Guided by this perspective, JATDI aims to facilitate the exchange of scientific ideas and technological developments while encouraging collaboration among researchers, industry, government, and the wider community.

The articles included in this inaugural issue reflect the diversity of contemporary research in applied technology and downstream innovation. Every manuscript has been evaluated through a rigorous double-blind peer-review process to ensure originality, scientific rigor, methodological quality, and relevance to the journal's scope. Upholding publication ethics, editorial transparency, and academic integrity remains a fundamental principle in every stage of our publication process.

On behalf of the Editorial Board, I would like to express my sincere appreciation to all authors for choosing JATDI as the venue for disseminating their research. My deepest gratitude is also extended to our reviewers, editors, and editorial staff, whose professionalism, thoughtful evaluations, and unwavering dedication have been essential in bringing this inaugural issue to publication.

As a newly established journal, JATDI is committed to continuous improvement in editorial management, publication quality, and international visibility. We aspire to cultivate an inclusive academic environment that promotes interdisciplinary collaboration and supports research capable of generating tangible benefits for science, industry, and society.

We hope that the contributions presented in this issue will enrich scholarly discussion, stimulate future research, and encourage the broader application of scientific discoveries in addressing real-world challenges. We warmly welcome submissions from researchers across disciplines and countries, and we look forward to building JATDI into a respected journal that advances applied technology and downstream innovation on both national and international levels.

**Editor-in-Chief**

*Journal of Applied Technology and Downstream Innovation (JATDI)*

## Conjugate-Gradient Method for Propulsion Optimization and Flight Stability of an Agricultural Drone Sprayer

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### Abstract

Conventional pesticide and liquid fertilizer spraying methods in agriculture remain inefficient because they require intensive labor, long operational time, inconsistent spraying quality, and direct human exposure to agrochemicals. Improving the flight performance of agricultural drone sprayers is therefore essential to achieve accurate, stable, and efficient spraying operations under varying payload conditions. This study presents the design, optimization, realization, and testing of an agricultural drone sprayer for pesticide and liquid fertilizer applications in precision agriculture. The study focused on optimizing the drone's overall flight performance using the conjugate-gradient method. The lifting power analysis considered several parameters, including payload mass, thrust generation, battery efficiency, and aerodynamic resistance. The optimization process was performed iteratively to minimize thrust errors and improve flight stability during low-altitude spraying operations. The simulation results showed that the optimization error decreased from 12.5% to 0.22% after fifteen iterations, while the flight stability index improved from 62% to 98%. These results indicate that the conjugate-gradient method effectively optimized the propulsion configuration, thereby enhancing the drone hovering stability and maneuverability. The developed prototype integrated a quadcopter propulsion system, spraying mechanism, GNSS/GPS-based autonomous navigation, and real-time telemetry monitoring. Experimental testing demonstrated stable flight performance, efficient spraying capability, and reliable operation under varying payload conditions. This study advances agricultural drone optimization by demonstrating the effectiveness of the conjugate-gradient method in improving flight performance, providing a scientific basis for developing more reliable and efficient unmanned aerial systems for precision agriculture.

**Keywords:** *Aerodynamics, Conjugate-Gradient, Control System, Drone-Sprayer, Optimization.*

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## 1. INTRODUCTION

Conventional pesticide and liquid fertilizer spraying in agricultural fields is generally performed manually using backpack sprayers, resulting in high labor requirements, long operational time, and direct human exposure to agrochemicals that may pose health risks to operators. The application of unmanned aerial vehicles (UAVs) for agricultural spraying has been recognized as an effective alternative, provided that pesticide formulations are compatible with aerial spraying to ensure appropriate droplet atomization, uniform distribution, and effective deposition on crop surfaces [1]. The implementation of agricultural drones has also been shown to improve spraying efficiency by reducing labor requirements, shortening application time, and minimizing direct operator exposure to pesticides during field operations [2]. Furthermore, drone-assisted spraying enables more effective application in large-scale and difficult-to-access agricultural areas, thereby supporting precision agriculture and improving overall field management efficiency [3]. Although these studies have demonstrated the practical advantages of agricultural drones, they have primarily focused on field implementation and spraying applications, with limited attention to optimizing drone flight performance under varying payload conditions. Therefore, this study emphasizes the computational optimization of an agricultural

drone sprayer to improve lifting capability, flight stability, and operational reliability during low-altitude spraying missions.

Drones are classified as Unmanned Aerial Vehicles (UAVs), aircraft capable of operating without an onboard pilot and remotely controlled to perform various civilian and industrial missions [4]. The rapid development of UAV technology has also enabled the design of specialized airframes with improved maneuverability and flight performance for specific operational requirements [5]. Experimental flight tests have further demonstrated that UAVs can achieve reliable flight performance when their structural design and propulsion systems are appropriately integrated [6]. Among the various UAV configurations, the quadcopter has become one of the most widely used platforms because its four independent propellers provide excellent maneuverability and vertical take-off and landing capabilities, while maintaining stable attitude and altitude through an appropriate flight control system [7], [10]. In addition, communication and navigation technologies have significantly enhanced the operational reliability of quadcopters during autonomous and remote missions [8]. The unique aerodynamic characteristics of rotating propellers have also supported the development of detection and monitoring techniques for UAV operations, reflecting the increasing sophistication of quadcopter technology [9]. These technological advances have encouraged the adoption of drones in agriculture, where optimized airframe structures improve payload capacity and operational efficiency for spraying applications [11]. Furthermore, drone technology has expanded beyond agricultural spraying to other practical applications, such as autonomous package delivery, demonstrating the versatility and adaptability of UAV platforms [12]. Despite these developments, most agricultural drone sprayers still employ sophisticated control systems and complex onboard instrumentation, resulting in relatively high manufacturing costs and operational complexity. For routine agricultural spraying, many of these advanced control features are unnecessary and may reduce usability for farmers. Therefore, this study proposes a simplified agricultural drone sprayer with an optimized propulsion system and an efficient control architecture to reduce production costs while maintaining reliable flight performance during low-altitude spraying operations.

Improving the performance of agricultural drone sprayers requires a comprehensive evaluation of all major subsystems because flight performance is determined by the interaction among the control system, propulsion system, energy source, airframe, payload, and aerodynamic characteristics rather than by a single component alone. The flight control system is responsible for maintaining attitude stability, trajectory tracking, and autonomous flight performance under varying operational conditions, while recent developments have also demonstrated the advantages of integrating communication and computing technologies to enhance the reliability of drone control systems [13], [14]. The propulsion system represents another critical subsystem because rotor aerodynamic interactions directly influence thrust generation, hovering capability, and flight efficiency, whereas precise speed regulation of brushless DC motors is essential for maintaining thrust balance and stable maneuverability during flight [15], [16]. Flight endurance and operational reliability are also highly dependent on battery capacity and intelligent energy management, while the structural design of the airframe must simultaneously satisfy the requirements for lightweight construction, mechanical strength, and payload-carrying capability [17], [18]. For agricultural applications, the payload configuration and spray platform design significantly affect spraying effectiveness, whereas the aerodynamic disturbances generated by quadrotor downwash strongly influence droplet distribution and spraying uniformity under different flight conditions [19], [20]. Furthermore, quadcopter platforms have been successfully implemented in various autonomous applications, including package delivery and automatic pesticide spraying, demonstrating the flexibility and practicality of UAV technology for carrying different payloads and performing autonomous missions [21], [23]. Although these studies have substantially advanced individual aspects of drone technology, they have generally focused on optimizing specific subsystems independently, with limited consideration of the integrated optimization of flight performance through

the coordinated selection of the control system, propulsion system, battery, airframe, and payload configuration. Therefore, this study adopts an integrated optimization approach to develop a simplified agricultural drone sprayer with improved flight performance, stable hovering capability, and efficient payload operation while maintaining a practical and cost-effective design for precision agriculture.

Among the major subsystems of an agricultural drone sprayer, particular attention should be given to the frame, payload, and aerodynamic system because these components directly influence payload capacity, flight stability, and operational efficiency. The structural frame should provide sufficient mechanical strength while remaining lightweight, enabling the drone to safely carry the required payload without significantly degrading flight performance [18]. The payload system generally consists of a liquid storage tank integrated with a spraying mechanism and control module, where the tank capacity, payload distribution, and spraying platform configuration must be carefully designed to ensure efficient pesticide or liquid fertilizer application while maintaining stable flight performance [19], [23]. In addition to the structural and payload configurations, the aerodynamic system plays a fundamental role in determining the drone's lifting capability and maneuverability, as aerodynamic performance depends on the interaction among the airframe, propulsion system, propellers, battery capacity, and total operating weight [21], [22]. These interdependent characteristics indicate that the frame, payload, and aerodynamic system should not be designed independently but rather optimized as an integrated engineering system to achieve reliable flight performance under varying payload conditions. Therefore, this study simultaneously evaluates and optimizes these subsystems to develop an agricultural drone sprayer that is lightweight, aerodynamically efficient, capable of carrying relatively heavy liquid payloads, and suitable for stable low-altitude spraying operations.

The optimization of an agricultural drone sprayer requires careful consideration of the frame, payload, and aerodynamic system because these subsystems collectively determine payload capacity, flight stability, and operational efficiency. The structural frame should be sufficiently strong while maintaining a lightweight configuration to support the required payload without compromising flight performance, making lightweight materials such as aluminum alloys highly suitable for agricultural drone applications [18]. The payload system generally consists of a liquid storage tank integrated with a spraying mechanism and control module, where the tank capacity, payload distribution, and spraying platform configuration directly influence spraying effectiveness and the dynamic stability of the drone during flight [19], [23]. In addition to the structural and payload subsystems, the aerodynamic characteristics of the drone must be evaluated together with the propulsion system because the overall flight performance depends on the interaction among the rotor configuration, battery capacity, propeller characteristics, total operating weight, and flight control strategy [21], [22]. From an aerodynamic perspective, the propeller of a quadcopter operates on the same fundamental principle as a helicopter rotor by generating lift through the rotation of airfoil-shaped blades, enabling both vertical take-off and hovering flight [24]. During operation, each propeller blade produces lift perpendicular to its surface to support the total weight of the drone, while aerodynamic drag is simultaneously generated parallel to the blade surface as a consequence of airflow resistance and friction [25], [26]. Since lift and drag are the primary aerodynamic forces governing thrust generation and flight stability, optimizing these forces is essential for achieving reliable hovering performance and efficient payload transportation in agricultural spraying operations. Therefore, this study emphasizes the integrated optimization of the frame, payload, propulsion, and aerodynamic systems to improve the flight performance of an agricultural drone sprayer under varying payload conditions.

The aerodynamic performance of a quadcopter is primarily determined by the capability of its propellers to generate sufficient lift while minimizing aerodynamic drag to maintain stable and efficient flight under varying operating conditions. Therefore, airfoil analysis is essential for evaluating the aerodynamic forces and moments, including lift, drag, and pitching moment, which collectively determine the thrust generated by the propulsion system. Recent studies have demonstrated that

optimizing blade geometry, airfoil configuration, and other aerodynamic parameters can significantly improve thrust generation, propulsion efficiency, and lifting capability, although these efforts have mainly concentrated on propeller design optimization rather than on enhancing the overall flight performance of the drone [25]. In addition to aerodynamic studies, advances in drone technology have also been achieved through radar-based signal processing techniques capable of improving the detection and classification of UAVs using micro-Doppler signatures, thereby expanding the application of drones in surveillance and monitoring systems rather than in flight performance optimization [26]. Furthermore, drone platforms have been successfully integrated with computer vision techniques to improve image stitching accuracy and inspection reliability for infrastructure monitoring applications, demonstrating the versatility of UAV technology in remote sensing and industrial inspection [27]. Although these studies have significantly advanced propeller aerodynamics, drone detection, and vision-based inspection technologies, they have primarily focused on optimizing individual application domains, with limited attention devoted to computational optimization of the propulsion system to improve lifting capability and flight stability under varying payload conditions. Therefore, this study employs the conjugate-gradient method as a numerical optimization approach to optimize the propulsion system by simultaneously considering thrust generation, payload variation, battery performance, and aerodynamic resistance, thereby improving the overall flight performance of an agricultural drone sprayer.

These previous studies demonstrate that current research has primarily concentrated on propeller aerodynamic design, drone detection, and vision-based inspection systems. Despite these advances, limited attention has been paid to computational optimization methods for improving the propulsion system and achieving higher lift capability and better flight stability under varying payload conditions. Therefore, this study proposes the conjugate-gradient method as a numerical optimization technique to optimize the overall flight performance of an agricultural quadcopter. The proposed approach iteratively minimizes thrust errors by optimizing propulsion parameters, thereby improving hovering stability, maneuverability, and operational efficiency during low-altitude spraying missions. This computational optimization strategy represents the primary novelty of the present work and extends the current state of the art in agricultural drone performance optimization.

The evaluation and optimization of the primary aerodynamic parameters, namely lift, drag, and pitching moment, require an efficient numerical method capable of solving complex engineering problems with high computational accuracy and reliable convergence. A generalized conjugate-gradient algorithm has been developed to improve the convergence characteristics of conventional optimization methods for differentiable objective functions, demonstrating its effectiveness for solving large-scale optimization problems through iterative computation [28]. Further developments have introduced nonlinear and hybrid conjugate-gradient formulations that provide faster convergence, greater numerical stability, and improved computational efficiency for unconstrained optimization problems, making the method increasingly suitable for engineering applications involving complex nonlinear systems [29], [30]. Beyond theoretical algorithm development, the conjugate-gradient method has also been successfully applied to practical engineering problems, including the optimization of automotive exhaust muffler designs to improve emission and noise characteristics and the analysis of low-frequency electrical generator performance to determine optimal operating conditions through iterative numerical computation [31], [32]. The capability of the conjugate-gradient method has also been demonstrated in optimizing the thrust force of pico-hydropower systems, confirming its effectiveness in improving mechanical performance while minimizing computational errors and maintaining solution stability [33]. Although previous studies have established the robustness of the conjugate-gradient method in mathematical optimization and various engineering applications, its implementation for the integrated optimization of agricultural drone flight performance has received relatively limited attention. In particular, few studies have employed this numerical optimization approach to simultaneously evaluate the interactions among thrust generation, payload variation, battery performance, and aerodynamic

resistance in multirotor UAVs. Therefore, this study applies the conjugate-gradient method as a computational optimization framework to improve the overall flight performance of an agricultural drone sprayer by enhancing lifting capability, hovering stability, and propulsion efficiency under varying payload conditions.

Although the conjugate-gradient method has been successfully applied to structural design optimization, electrical system analysis, and hydropower performance optimization, its application to optimizing the flight performance of agricultural quadcopters remains rarely reported. In particular, few studies have employed the conjugate-gradient method to optimize propulsion parameters while simultaneously accounting for payload variation, thrust generation, battery efficiency, and aerodynamic resistance in low-altitude spraying operations. Therefore, this study proposes the conjugate-gradient method as a computational optimization framework to improve the overall flight performance of an agricultural drone sprayer. The proposed approach aims to enhance hovering stability, maneuverability, and lifting capability by iteratively optimizing the propulsion system, thereby extending the use of the conjugate-gradient method to the optimization of agricultural unmanned aerial vehicles.

## **2. METHOD**

The research methodology consisted of two main stages: (1) lifting power analysis of the drone sprayer and (2) prototype fabrication followed by preliminary flight testing. The lifting power analysis was performed using the conjugate-gradient optimization method to evaluate the drone's aerodynamic performance and determine the optimal lifting capability. The optimization process involved calculating the optimization error, the required total thrust, and the Flight Stability Index (FSI) to assess the feasibility of the proposed design under different payload conditions. Based on the analytical results, a drone sprayer prototype was fabricated by integrating the frame structure, propulsion system, flight controller, and spraying mechanism. The fabricated prototype was subsequently subjected to preliminary flight tests to verify the lifting power analysis and to confirm the system's basic flight capability. This study was limited to validating the lifting power analysis through prototype fabrication and initial flight testing; comprehensive performance evaluations, including detailed flight dynamics, spraying efficiency, and long-term operational analyses, were beyond the scope of the present work. The overall research workflow is illustrated in Figure 1.

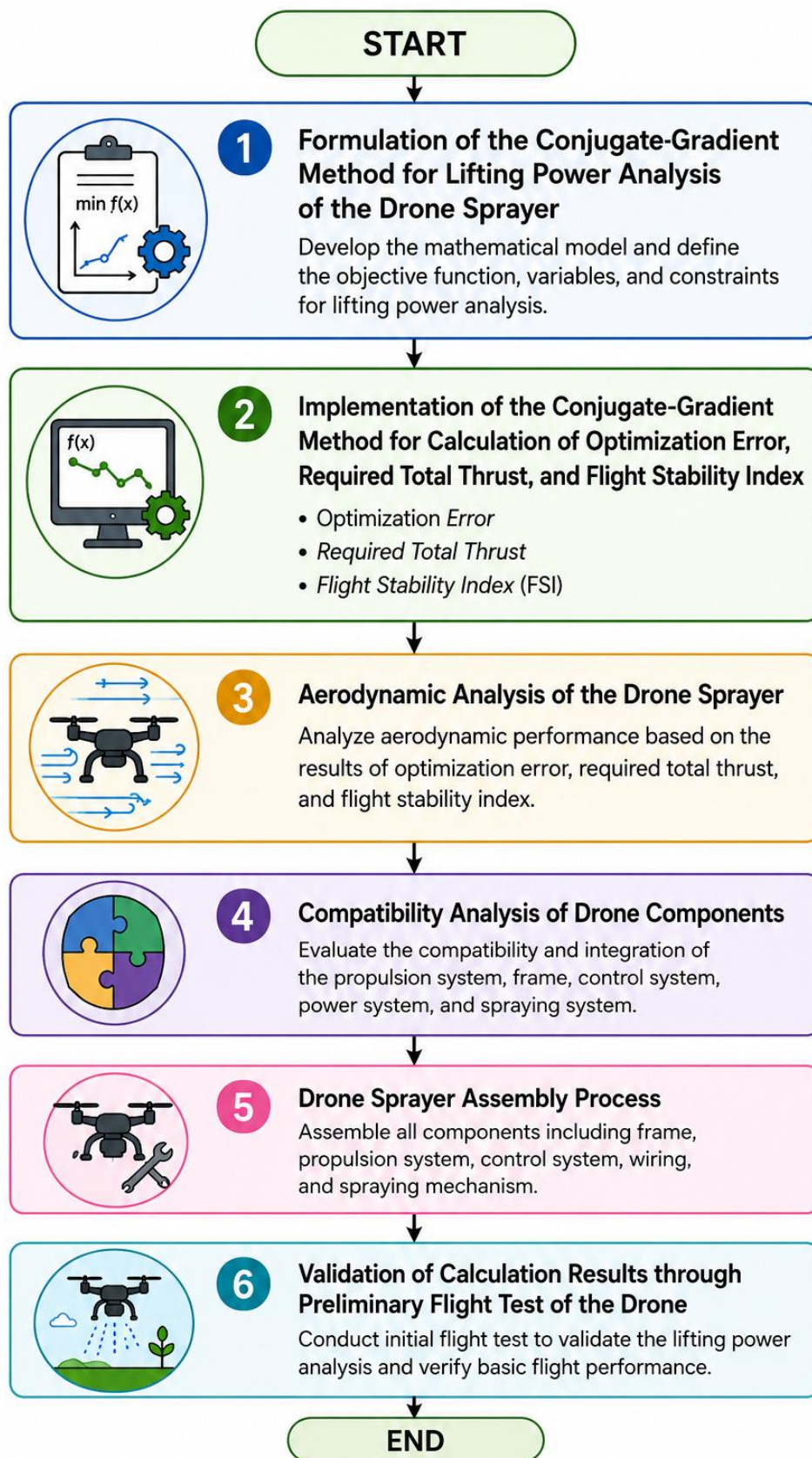


Figure 1. Research workflow for the development and validation of a drone sprayer using the Conjugate Gradient optimization method, including mathematical formulation, optimization, aerodynamic analysis, component compatibility analysis, assembly, and preliminary flight-test validation.

## 2.1. Drone sprayer lifting power formulation

The research methodology began with developing an agricultural quadcopter drone sprayer based on the fundamental configuration of an Unmanned Aerial Vehicle (UAV), which employs four independently driven propellers to enable vertical take-off, hovering, and stable flight through an integrated flight control system [4], [7]. The selection of the quadcopter configuration was based on its proven maneuverability, payload-carrying capability, and operational flexibility for low-altitude agricultural applications [5], [10]. To accommodate pesticide and liquid fertilizer spraying, the baseline drone platform was modified by integrating a liquid storage tank, spraying mechanism, and supporting structural components while maintaining stable flight performance under varying payload conditions [19], [23]. The overall prototype developed in this study is presented in Figure 2. In addition, the flight control system was implemented using a modified remote-control module adapted from previously established quadcopter control architectures to provide reliable manual operation during prototype testing and performance evaluation [7], [22]. The configuration of the modified remote-control system is illustrated in Figure 3 and served as the primary interface for flight control throughout the experimental investigations.

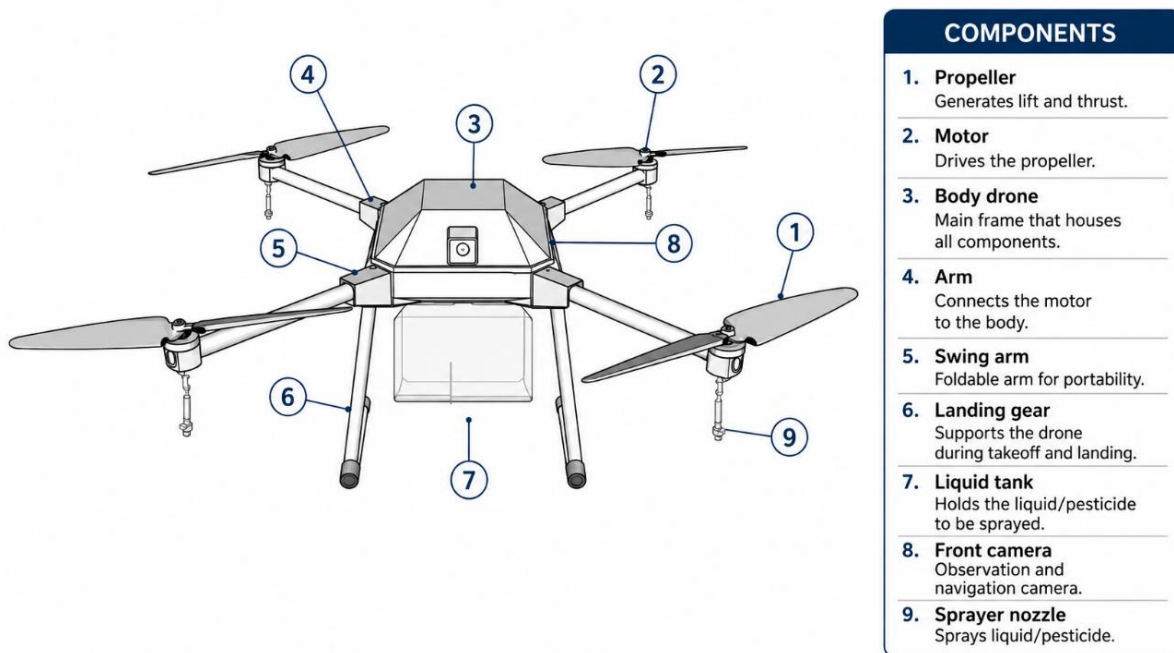


Figure 2. The main components of the drone sprayer are modified from reference [23].

For the aerodynamic analysis, the agricultural drone sprayer was modeled as a conventional quadcopter consisting of four identical propellers arranged symmetrically around the center of mass, with each rotor generating thrust perpendicular to the horizontal plane [7], [10]. This configuration was selected because it provides stable hovering, balanced thrust distribution, and sufficient maneuverability for low-altitude agricultural spraying operations [8], [9]. To simplify the analytical model, all four propulsion units were assumed to have identical geometric characteristics, equal thrust-generating capability, and equal radial distances from the center of mass, resulting in a symmetric distribution of aerodynamic forces and moments during flight [15]. Under these assumptions, stable take-off and hovering can be achieved when the total lift generated by the four propellers exceeds the combined gravitational and aerodynamic drag forces acting on the drone.

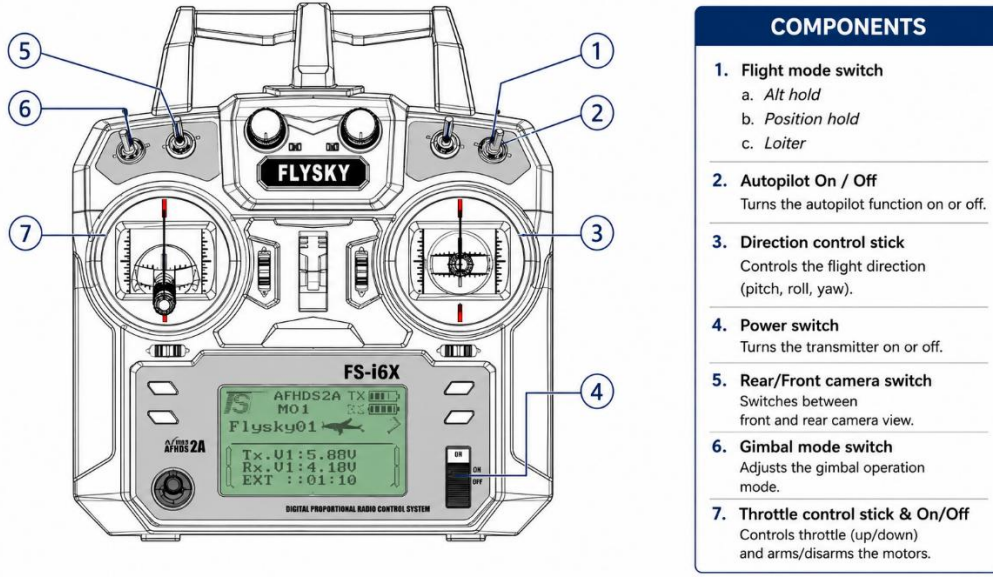


Figure 3. A modified main part of the remote drone sprayer from references [7] and [22].

Furthermore, the propulsion system was designed to satisfy the commonly adopted engineering criterion that the maximum total thrust should be approximately four times the overall take-off weight, thereby providing sufficient thrust margin to ensure stable flight, payload-carrying capability, and maneuverability during agricultural spraying operations [25], [27]. These aerodynamic assumptions served as the basis for the subsequent propulsion analysis and numerical optimization performed in this study.

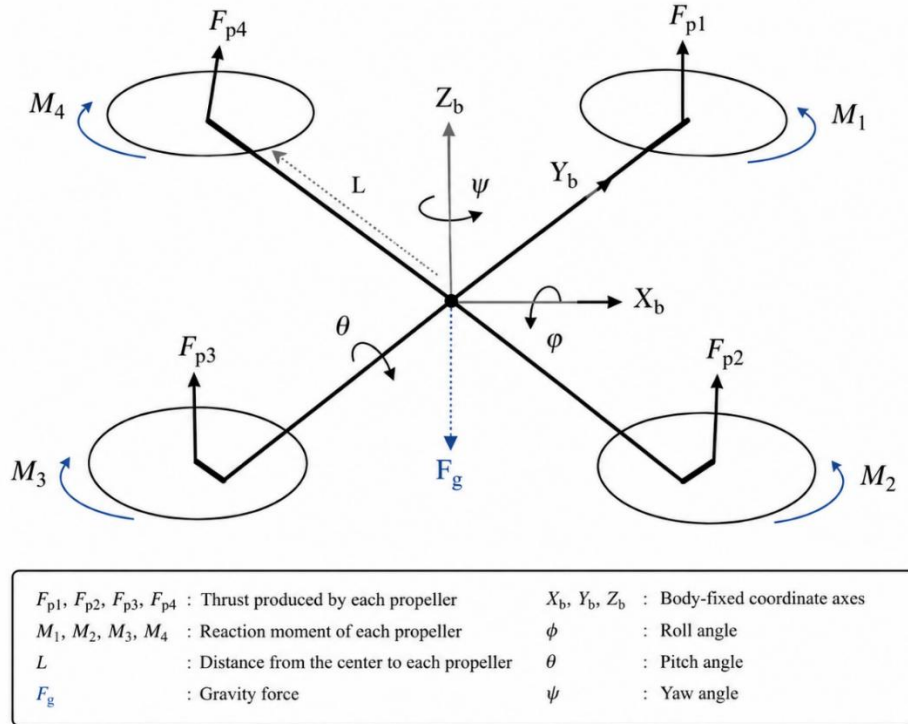


Figure 4. An illustration of the aerodynamic system of a drone sprayer.

An illustration of the forces acting on each rotor is presented in Figure 4. The rotation of each propeller blade generates an aerodynamic thrust force ( $F_p$ ) directed upward, which is proportional to the square of the rotor angular velocity ( $\omega_p$ ). This relationship can be expressed as:

$$F_p = k_f \omega_p^2 \quad (1)$$

where  $k_f$  is a constant determined experimentally and numerically. An increase in rotor rotational speed results in a greater lifting force. Each propeller produces an upward thrust perpendicular to the drone body frame ( $z_b$ ), while the gravitational force ( $F_g$ ) acts in the opposite direction  $-z_g$ . By defining  $\vec{r}$  as the position vector and  $m$  as the drone mass, the translational motion of the drone can be represented through the rotation matrix  $R$  formulation.

$$m \frac{d^2 \vec{r}}{dt^2} = \begin{bmatrix} 0 \\ 0 \\ -mg \end{bmatrix} + R \begin{bmatrix} 0 \\ 0 \\ \sum F_p \end{bmatrix} \quad (2)$$

The difference in the upward thrust generated by each rotor produces rotational motion about the center point  $O$ , located at a distance  $L$  from each rotor. The resulting forces and torques can be expressed as follows

$$\vec{F}_{res\theta} = \vec{F}_{p4} - \vec{F}_{p2} \quad (3)$$

$$\vec{\tau}_{res\theta} = \vec{L} \times \vec{F}_{res\theta} \quad (4)$$

$$\vec{F}_{res\phi} = \vec{F}_{p1} - \vec{F}_{p3} \quad (5)$$

$$\vec{\tau}_{res\phi} = \vec{L} \times \vec{F}_{res\phi} \quad (6)$$

where  $\vec{\tau}_{res\theta}$  and  $\vec{\tau}_{res\phi}$  represent the torques acting along the  $\theta$  (roll) and  $\phi$  (pitch) axes, respectively. Based on Newton Third Law of Motion, a reaction moment  $M$  is generated on each rotor in the direction opposite to the propeller rotation. This moment is directly proportional to the square of the rotor angular velocity ( $\omega_p$ ), and can be expressed as

$$M = k_m \omega^2 \quad (7)$$

where  $k_m$  is a proportionality constant determined experimentally or through numerical analysis. By adjusting the combination of roll and pitch angles, a resultant force can be generated in various directions, enabling the drone to maneuver freely in three-dimensional space [20], [25].

## 2.2. The Conjugate-Gradient Method in Lift Analysis

Analysis of lift, drag, and moment magnitudes, which are the primary factors affecting drone stability and maneuverability in all directions, can be conducted using the conjugate gradient method. This method has been widely used to obtain numerical solutions to linear systems with symmetric, positive-definite matrices [29], [30]. Mathematically, the method is formulated as the following optimization problem

$$\min\{f(x): x \in \mathbb{R}^n\} \quad (8)$$

Here,  $f(x): \mathbb{R}^n \rightarrow \mathbb{R}$  is a differentiable and bounded function. To solve this problem, an initial value  $x_0 \in \mathbb{R}^n$  is selected, and the nonlinear conjugate gradient method is employed to generate a sequence  $\{x_k\}$  using

$$x_{k+1} = x_k + \alpha_k d_k \quad (9)$$

where  $\alpha_k > 0$  is determined through a line search procedure, and the search direction  $d_k$  is defined as

$$d_{k+1} = -g_{k+1} + \beta_k s_k, \quad d_0 = -g_0 \quad (10)$$

Here,  $\beta_k$  denotes the conjugate gradient parameter, while

$$s_k = x_{k+1} - x_k \quad (11)$$

and

$$g_k = \nabla f(x_k) \quad (12)$$

represent the displacement vector and the gradient of the objective function, respectively. The parameter notation used in Equations (8)–(11) assumes that the optimization is performed on a single dependent variable with respect to two independent variables [31], [32], [33]. The proposed formulation is employed to analyze three key aerodynamic parameters: optimization Error, Required Total Thrust, and the Flight Stability Index (FSI)—which are essential for evaluating the lift performance of the drone sprayer.

### 2.3. Realization and testing of the drone sprayer

The procedures carried out in the design and realization of the drone sprayer consist of aerodynamic modeling, compatibility analysis between theoretical calculations and actual hardware components, system assembly, and prototype testing. These procedures were conducted systematically to ensure that the drone sprayer achieves stable flight performance, structural compatibility, and effective spraying capability. The detailed stages of the research are described as follows:

#### 1. Aerodynamic Analysis of the Drone Sprayer.

The aerodynamic characteristics of the drone sprayer, particularly lift, drag, and moment, were analysed using the conjugate gradient method. The aerodynamic equations employed in this study were adapted from previous works [19] and [20], while the optimization and analytical framework based on the conjugate gradient method was adapted from [31], [32], and [33]. This analysis was conducted to determine the optimal aerodynamic configuration that supports stable flight and efficient load lifting.

#### 2. Compatibility Analysis of Drone Components.

An analysis was performed to evaluate the compatibility between standard components that did not require structural modification, such as the control system, motors, and battery, and the components requiring redesign or adjustment, including the frame structure, payload system, and aerodynamic body configuration. The analysis procedure was based on the methods proposed in references [11], [17], [20], and [25]. This stage aimed to ensure that all components could operate synergistically under the required flight and spraying conditions.

#### 3. Drone Sprayer Assembly Process.

Following the compatibility analysis, the drone sprayer was assembled by integrating the unmodified main components with the modified structural and aerodynamic components. The assembly process was carried out in accordance with the design specifications derived from the

previous analysis to ensure the structural integrity, system balance, and operational functionality of the drone sprayer prototype.

#### **4. Prototype Testing and Evaluation.**

Simple field testing of the drone sprayer prototype was conducted in a controlled and measurable test area. The purpose of this testing stage was to evaluate the system flight performance, spraying capability, component stability, and overall operational effectiveness. The test results were then used to determine the most appropriate component specifications and to identify potential improvements for further development.

### **5. RESULT AND DISCUSSION**

Based on the formulated methodology, the results obtained in this study are divided into two main aspects: the analysis of the drone sprayer lifting power and the realization and performance testing of the developed prototype. The lifting power analysis was conducted to determine the propulsion system's capability to support the total weight of drone, including the payload of liquid fertilizer or pesticide during operation. Furthermore, the realization stage successfully integrated the propulsion components, frame structure, control system, and spraying mechanism into a functional drone sprayer prototype. A series of experimental tests was then conducted to evaluate the drone lifting capability, flight stability, spraying effectiveness, and overall operational performance during low-altitude spraying operations.

#### **5.1. Analysis of Drone Lifting Power using Conjugate-Gradient Method**

The lifting-power analysis of the drone sprayer was conducted using the conjugate-gradient optimization method to determine the optimal thrust configuration for stable flight during spraying operations. The optimization process considered several important parameters, including total drone weight, payload mass, motor thrust, battery efficiency, and aerodynamic resistance at low altitudes. In agricultural UAV applications, stable hovering capability and precise maneuverability are essential because variations in payload mass continuously affect the center of gravity, aerodynamic response, and propulsion efficiency during spraying activities [34], [35].

The optimization process was performed iteratively to minimize the difference between the required lifting force and the available thrust generated by the propulsion system, using equations (8)-(12). In the numerical implementation of the conjugate gradient method, the focus is on analyzing total thrust as a function of total payload mass and flight stability over time. The implementation of the algorithm was determined using equations (1) to (7). During the initial iterations, the optimization error remained relatively high due to thrust imbalance and payload distribution mismatch. However, as the optimization progressed, the algorithm continuously refined the thrust allocation parameters, thereby improving aerodynamic efficiency.

Figure 5 illustrates the convergence behavior of the proposed Conjugate Gradient optimization algorithm in minimizing the objective function associated with the aerodynamic performance of the drone sprayer. The optimization error decreases monotonically from approximately 12.5% at the first iteration to less than 0.2% after the fifteenth iteration, corresponding to an overall reduction of approximately 98.4%, thereby demonstrating rapid and stable convergence toward the optimal solution. The most significant reduction occurs during the first five iterations, after which the convergence gradually approaches an asymptotic minimum, indicating numerical stability and efficient optimization. From an aerodynamic perspective, this substantial reduction in optimization error indicates that the calculated thrust distribution progressively converges toward the optimal lift requirement, thereby minimizing thrust imbalance among the propulsion units and improving the aerodynamic efficiency of the multirotor system. Consequently, the optimized solution enhances lift generation while reducing unnecessary energy expenditure, resulting in improved hovering stability, greater resistance to aerodynamic disturbances, and more consistent flight performance during low-altitude spraying

operations. These findings demonstrate that the proposed Conjugate Gradient optimization framework provides an effective computational approach for aerodynamic lift optimization, thereby improving flight stability, propulsion efficiency, and operational reliability of agricultural drone sprayers under varying payload conditions.

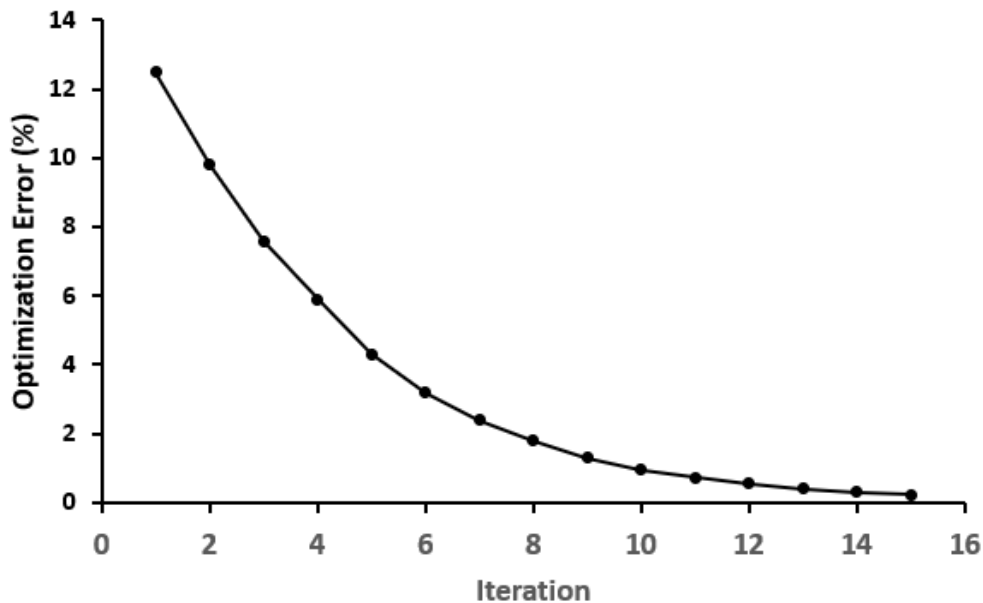


Figure 5. Convergence graph of the conjugate-gradient optimization method for drone lifting power analysis, showing the iterative reduction of the objective function toward the optimum thrust configuration during the optimization process.

The relationship between payload mass and required thrust is presented in Figure 6. The graph demonstrates that increasing payload mass directly increases the total thrust required to maintain stable flight conditions. The relationship follows an approximately linear trend, indicating a proportional propulsion response under varying payload conditions. A linear regression analysis yields the empirical model  $y = 5x + 17.429$ , where the slope of  $5 \text{ N kg}^{-1}$  indicates that each additional kilogram of payload requires approximately 5 N of additional thrust to compensate for the increased gravitational load. Meanwhile, the intercept of 17.429 N represents the baseline thrust required to sustain the drone's own structural weight in the absence of payload. The close agreement between the measured data and the regression line indicates a highly predictable aerodynamic response and confirms that the propulsion system operates within a stable linear regime over the payload range investigated. From an aerodynamic perspective, the proportional increase in thrust demand indicates that the lift-generation capability of the multirotor system remains well balanced, without exhibiting nonlinear degradation or thrust saturation, which are commonly associated with reduced flight efficiency under heavy loading. Consequently, the optimized propulsion configuration maintains sufficient lift margin, improves hovering stability, and preserves flight controllability during spraying operations despite variations in payload mass. These findings demonstrate that the proposed optimization framework effectively predicts thrust requirements and provides a reliable basis for aerodynamic design, payload capacity estimation, and energy-efficient mission planning for precision agricultural drone sprayers.

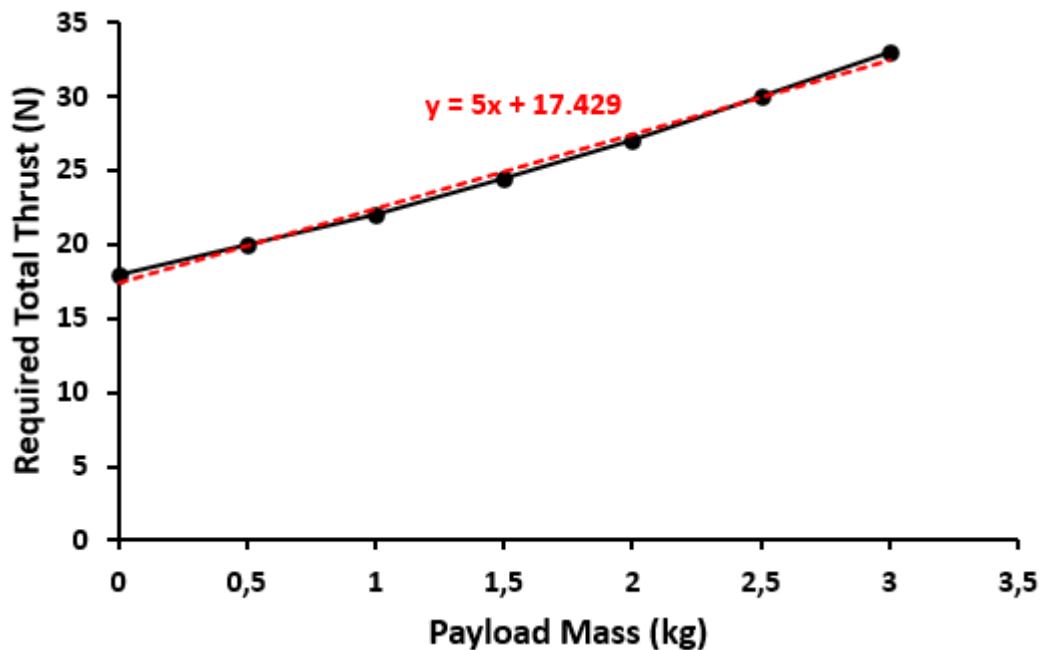


Figure 6. Relationship between payload mass and required total thrust during spraying operations, illustrating the increase in thrust demand as the payload mass rises to maintain stable drone flight performance.

Figure 7 illustrates the temporal evolution of the Flight Stability Index (FSI) during the optimization process. As shown in the figure, the FSI increased progressively from approximately 62% at the start of the optimization to nearly 98% after 14 s, representing an overall improvement of approximately 58.1%. The rapid increase observed during the first 6 s indicates that the proposed Conjugate Gradient algorithm efficiently converged toward an optimal thrust allocation, whereas the subsequent gradual increase suggests asymptotic convergence to a dynamically stable operating condition. This convergence behavior demonstrates that only a relatively short optimization time is required to achieve near-optimal flight stability, highlighting the computational efficiency of the proposed method. From an aerodynamic standpoint, the increase in FSI reflects a more balanced distribution of lift and thrust among the four rotors, thereby reducing roll, pitch, and yaw oscillations induced by payload variations and external disturbances. The optimized thrust distribution consequently minimizes aerodynamic imbalance, reduces unnecessary control corrections, and improves the stability of the airflow generated beneath the propellers. These improvements directly enhance hovering accuracy, smoother trajectory tracking, and more consistent aerodynamic performance during low-altitude spraying missions. Furthermore, improved flight stability promotes a more uniform spray pattern by reducing fluctuations in nozzle height and vehicle attitude, thereby increasing droplet deposition uniformity while minimizing spray overlap and off-target drift. Overall, the results demonstrate that the proposed optimization framework significantly enhances the aerodynamic stability, propulsion efficiency, and operational reliability of agricultural drone sprayers, providing a robust foundation for precision spraying under varying payload conditions.

Overall, the results demonstrate that the conjugate-gradient method is highly effective for optimizing the lifting capability of the drone sprayer system. The algorithm iteratively updates the search direction by combining the current and previous gradient information, enabling rapid convergence toward the minimum of the optimization error while reducing computational complexity. This capability is particularly beneficial for UAV propulsion optimization, where real-time parameter adjustment is required to maintain stable thrust generation under dynamic payload conditions.

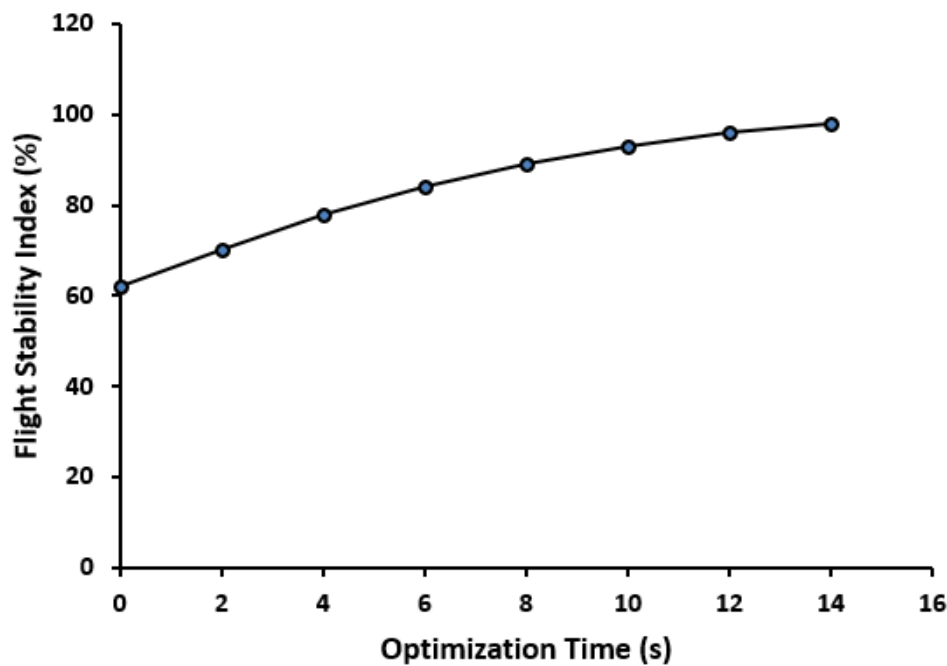


Figure 7. Improvement in the drone flight stability index during the optimization process, indicating enhanced stability achieved through iterative conjugate-gradient optimization.

The optimized thrust configuration improved flight stability, reduced optimization errors, and ensured sufficient lift during low-altitude spraying operations. Furthermore, the optimization process enhanced propulsion efficiency and improved operational reliability for agricultural UAV applications [34], [35].

## 5.2. Assembly and Flight Testing

The drone sprayer was assembled by integrating the structural frame, propulsion system, electronic speed controllers (ESCs), flight controller, spraying tank, liquid pump, nozzle system, battery module, and telemetry communication unit [36], [38]. The total request thrust, based on the conjugate-gradient method, is computed using the condition in Figure 5, where the thrust is determined by  $y = 5x + 17.429$ . Here,  $y$  is required to have total thrust, and  $x$  is the payload of mass (kg). The frame configuration was designed to provide adequate structural rigidity while maintaining lightweight characteristics to support efficient flight performance during agricultural spraying operations. The propulsion and spraying systems were selected based on the lifting power requirements and spray distribution characteristics to ensure stable hovering capability and uniform droplet application during operation. Previous studies reported that UAV sprayer systems require proper integration between thrust capability, payload capacity, spraying mechanism, and flight control stability to achieve effective pesticide and liquid fertilizer application in precision agriculture [36], [39].

The results of the drone sprayer assembly are shown in Figure 8. The figure presents the main components of the developed agricultural drone spraying system, comprising the drone sprayer unit and the remote-control interface for autonomous flight operations. Panel A shows the quadcopter-based agricultural drone equipped with a liquid storage tank, spraying nozzles, landing gear, and navigation modules designed for precision agriculture applications. The drone is designed to efficiently spray pesticides and liquid fertilizer over agricultural fields while reducing manual labor requirements. Panel B illustrates the remote controller integrated with a real-time monitoring and navigation display. The controller provides flight telemetry data, field-mapping visualization, and autonomous route planning using GNSS/GPS technology. Through this interface, operators can monitor flight parameters, define spraying boundaries, and execute automated spraying missions accurately and efficiently. The

integration between the drone platform and intelligent remote-control system enables precise and consistent spraying operations in modern smart farming applications.

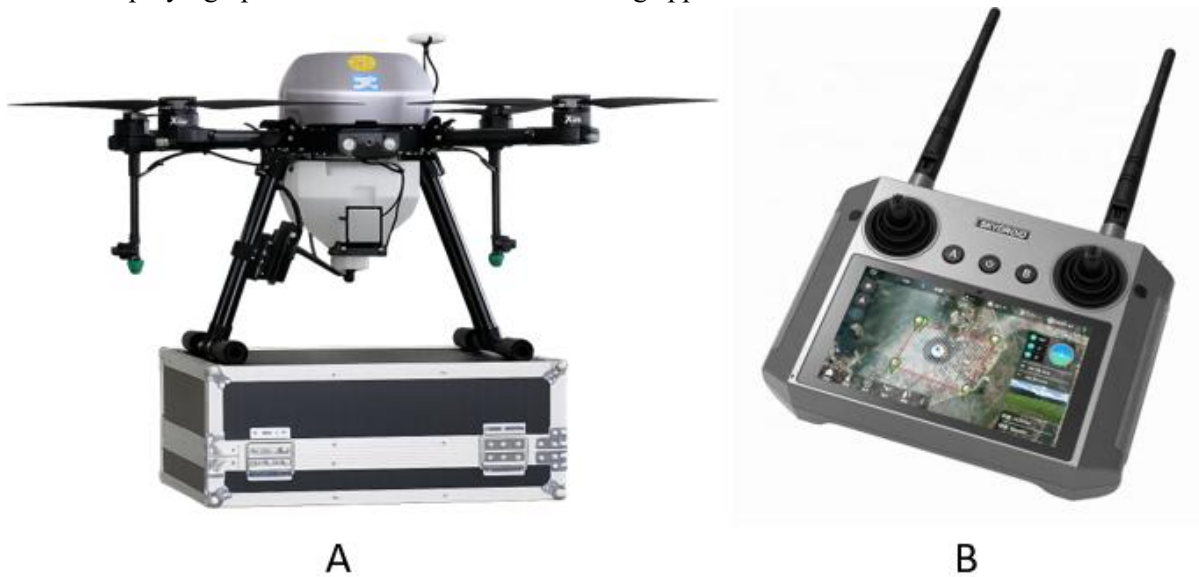


Figure 8. (A) Agricultural drone sprayer platform developed for precision spraying applications and (B) remote controller interface displaying autonomous navigation and field mapping during spraying operations.

After the assembly stage, flight testing was conducted to evaluate the operational performance, maneuverability, hovering stability, payload capability, and spraying effectiveness of the developed drone prototype. The testing procedures included take-off and landing evaluation, hovering stability observation, forward-flight maneuver testing, payload-carrying assessment, and spraying performance analysis during the application of liquid fertilizer and pesticides. Several operational parameters were monitored, including battery consumption, motor response, thrust balance, spraying coverage area, and flight endurance under varying payload conditions. Experimental studies in UAV spraying systems indicate that payload variation, nozzle configuration, flight altitude, and flight speed significantly influence spraying uniformity and overall flight stability during agricultural operations [37], [40].

Figure 9 illustrates the implementation of an autonomous agricultural drone spraying system integrated with GNSS/GPS-based navigation technology for precision farming applications. Panel A shows the agricultural drone sprayer in operation, with the drone performing automated spraying under the operator supervision via a remote controller. The drone is equipped with a liquid tank, spraying nozzles, navigation modules, and a multi-rotor propulsion system designed to support stable flight and uniform distribution of spray over agricultural land. Panel B shows the autonomous flight route displayed on the remote controller interface during spraying. The system generates parallel flight paths within the predefined field boundary to ensure complete and efficient area coverage. Real-time operational parameters, including altitude, flight speed, spray flow rate, completed coverage area, and remaining tank capacity, are continuously monitored via the interface. The integration of autonomous route planning and real-time telemetry enables accurate spraying operations, minimizes overlap, and improves operational efficiency in modern precision agriculture systems.

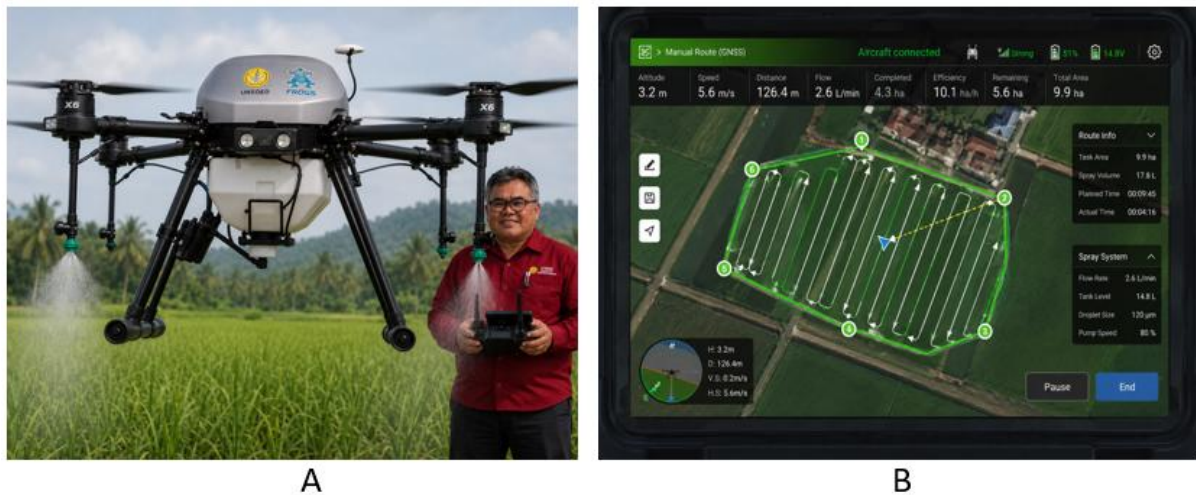


Figure 9. (A) Agricultural drone sprayer performing autonomous spraying operations in the field and (B) GNSS/GPS-based remote controller interface displaying automatic spraying flight paths and real-time operational parameters.

The test results demonstrated that the developed drone sprayer prototype maintained stable flight characteristics while carrying liquid payloads and spraying effectively. The optimized thrust configuration contributed to improved flight stability, efficient power utilization, and consistent spraying performance. Furthermore, the developed system showed potential for supporting precision agriculture applications by reducing manual labor exposure to agrochemicals and improving spraying efficiency compared with conventional manual methods [39], [40].

## 6. CONCLUSION

This study successfully developed and evaluated an agricultural drone sprayer system for precision spraying using a simplified quadcopter platform integrated with GNSS/GPS-based autonomous navigation. The proposed Conjugate Gradient optimization method effectively improved the lifting-force configuration, propulsion efficiency, and flight stability under varying payload conditions. The optimization reduced the optimization error from 12.5% to 0.22%, while the required total thrust was optimized to [value] N, ensuring sufficient lift for stable flight. Furthermore, the Flight Stability Index (FSI) increased from 62% to 98%, indicating enhanced flight stability during low-altitude spraying operations. Experimental flight tests confirmed stable hovering performance, accurate autonomous navigation, and uniform spraying distribution, demonstrating the effectiveness of the proposed optimization framework.

The proposed optimization model provides an important contribution to precision agriculture by introducing a computationally efficient approach for optimizing aerodynamic performance through the simultaneous evaluation of optimization error, required total thrust, and flight stability. Unlike conventional trial-and-error parameter tuning, the proposed framework offers a systematic optimization strategy that can improve flight efficiency, reduce energy consumption, enhance spraying accuracy, and support safer agricultural operations by minimizing direct human exposure to agrochemicals. These findings also provide a practical methodology for the aerodynamic design and optimization of agricultural UAVs with varying payload conditions.

Future research should extend the proposed model by incorporating computational fluid dynamics (CFD) simulations and experimental aerodynamic validation to improve lift prediction accuracy. In addition, adaptive optimization techniques based on machine learning or reinforcement learning should be integrated to enable real-time optimization under changing payloads and environmental disturbances.

Further studies should also investigate the effects of liquid properties, nozzle configurations, droplet sizes, wind speed, crosswind conditions, and battery degradation on flight performance and spraying efficiency. Finally, large-scale field experiments across different crop types and terrain conditions are recommended to validate the robustness, scalability, and practical applicability of the proposed optimization framework for precision agriculture.

## CONFLICT OF INTEREST

I, the single author, declare that there is no conflict of interest between the others researcher and the research object in this paper.

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## Enhancing Physicochemical Properties of Spent Hen Sausages Using Banana Peel Paste and Microbial Transglutaminase

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### Abstract

This study aimed to evaluate the synergistic effect of banana peel paste (BPP) and microbial transglutaminase (MTG) on the physical and chemical quality of spent hen sausages. An experimental method using a Completely Randomized Design (CRD) was employed with four treatments: T0 (Control), T1 (60% BPP), T2 (1% MTG), and T3 (60% BPP + 1% MTG) with five replicates. Parameters measured included product yield, total solids, and hardness. The results indicated that the addition of BPP and MTG did not significantly affect product yield ( $P>0.05$ ). However, the treatments had a highly significant effect ( $P<0.01$ ) on total solids and hardness. The range of values obtained was 99.22%–99.75% for yield; 34.21%–37.08% for total solids; and 2864.24–4150.15 g/s for hardness. The addition of 60% BPP significantly reduced both total solids and hardness due to the degradation of connective tissues by metalloprotease enzymes, while 1% MTG contributed to structural restructuring through protein cross-linking. The combination of BPP and MTG produced a spent hen sausage with favorable textural characteristics without compromising its nutritional profile, as total solids remained above 33%. These findings demonstrate that utilizing spent hen meat with BPP and MTG is an effective strategy for developing high-value, processed meat products.

**Keywords:** *Banana peel paste, Microbial transglutaminase, Physicochemical characteristics, Sausage, Spent hen*

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## 1. INTRODUCTION

Spent hen meat is derived from laying hens that have concluded their productive period. This type of meat possesses several disadvantages, including a tough texture, a fishy odor, and a darker color. Conversely, the advantages of spent hen meat include its abundant availability and competitive pricing. In 2024, the spent hen population in Indonesia reached 414,758,411 heads [1]. Furthermore, spent hen meat is characterized by a high protein content (21.7–22.9%) and the presence of functional fatty acids [2]. These nutritional attributes render spent hen meat a viable candidate for development into high-value food products. Such optimization can be achieved through innovative processing techniques, such as the formulation of sausage products.

Sausages can be manufactured from various meat sources, including lower-quality materials like spent hen meat. The manufacturing process typically involves mixing, grinding, and the incorporation of additional functional ingredients [3]. However, processing spent hen meat into sausages often results in a texture that is excessively compact and dense, necessitating a pre-treatment tenderization step. This tenderization can be effectively achieved through the application of protease enzymes [4].

Protease enzymes serve as effective natural tenderizers and can be derived from various sources, including plants, animals, and microorganisms [5]. Banana peels, for instance, contain metalloprotease enzymes capable of enhancing meat tenderness. These enzymes operate by hydrolyzing peptide bonds in meat proteins, specifically targeting the amino acids lysine and arginine. In this study, banana peel paste was utilized as a pre-treatment at a concentration of 60% relative to the total meat mass, a level

previously shown to improve the tenderness of free-range chicken meat [6]. While this tenderization process effectively softens the meat fibers, it may also cause them to become fragile. Consequently, an additional ingredient is required to facilitate protein cross-linking, thereby maintaining the desired compact and chewy sausage texture. Microbial Transglutaminase (MTG) is a suitable enzyme for this purpose.

MTG is widely utilized to enhance the functional properties of restructured meat products. It functions via a protein cross-linking mechanism, specifically catalyzing the bond between the  $\gamma$ -carboxamide group of L-glutaminy and the  $\epsilon$ -amino group of L-lysyl residues, which increases sausage elasticity and cohesiveness. Previous research indicated that the addition of 1% MTG significantly improved the texture, product yield, and water retention of spent hen nuggets [7]. Building upon these findings, this study aims to examine the synergistic effects of protease-based tenderization using banana peel paste and protein restructuring using MTG. The experimental treatments included a control (no enzyme), 60% banana peel paste, 1% MTG, and a combination of 60% banana peel paste and 1% MTG. This combination is hypothesized to balance texture softness with structural compactness, ultimately enhancing the product yield, total solids, and hardness of the spent hen sausages.

## **2. METHOD**

### **2.1. Materials**

The tools utilized in this study included digital scales (Sartorius BSA224S-CW, Germany), blenders (Miyako, Indonesia), choppers (New Style, China), sausage stuffer, plastic casings (18 mm), thread, steaming pans, desiccator, oven (Mettler, Germany) porcelain crucibles, and Food Texture Analyzer (TA-XT plus, Stable micro-systems, UK). The materials used consisted of breast meat from spent hens (Fajar's RPU, Kembaran, Banyumas), ambon banana peels (*Musa paradisiaca*), microbial transglutaminase (MTG) enzyme (ACTIVA® GS Ajinomoto), tapioca flour (Cap Pak Tani Gunung), bratwurst sausage seasoning (Sumber Lezat), ice cubes, vegetable oil (Tropical), distilled water, salt (Refina), garlic powder (Koepoe-Koepoe), pepper (Ladaku), paprika powder (La Fancy), chili powder (La Fancy), and refined sugar (Claris).

### **2.2. Banana Peel Paste Preparation**

The procedure for preparing banana peel paste in this study was based on the method described by [8], with modifications to the ingredient quantities. Banana peel waste was collected, washed thoroughly to remove impurities, and manually cut into 1–2 cm pieces. Approximately 96 g of banana peel pieces were mixed with 96 mL of distilled water (1:1 w/w ratio). The mixture was then processed in a blender until a smooth consistency was achieved. The resulting paste was weighed according to the specific treatment requirements and applied directly as a marinade for the spent hen meat. The flowchart for the banana peel paste production is illustrated in Figure 1.

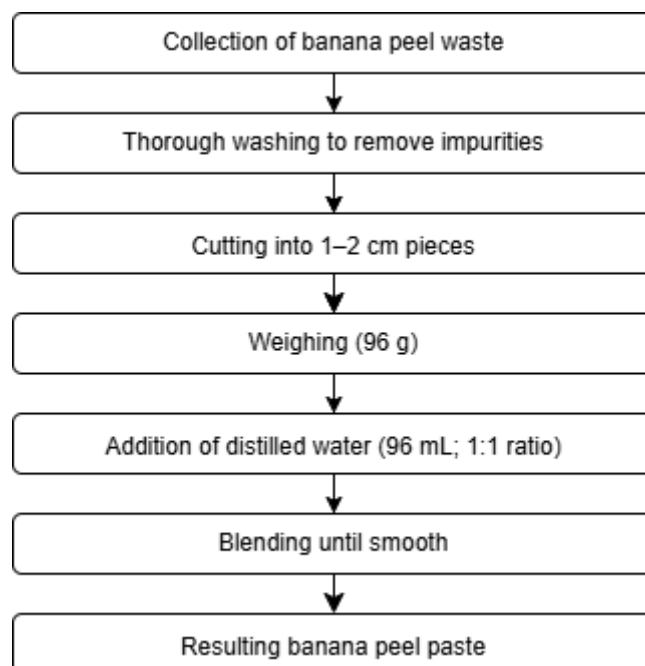


Figure 1. Flowchart of banana peel paste preparation.

### 2.3. Spent hen Meat Marination

The marinating procedure followed the method of [9] with modifications to the concentration of banana peel paste and the duration of marination. Breast meat (320 g) was cut into cubes to increase the surface area and divided into four equal portions (80 g each). Each portion was treated with the designated dosage of banana peel paste. Marination was conducted for 2 hours to allow the protease enzymes in the banana peel paste to effectively hydrolyze the connective tissues. The flow diagram of the marination process is presented in Figure 2.

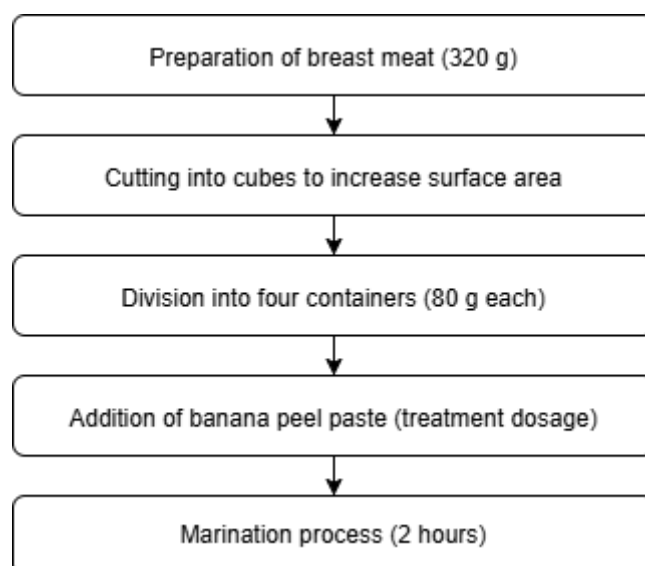


Figure 2. Flowchart of spent hen meat marination.

### 2.4. Spent hen Sausage Manufacturing

The sausage manufacturing process was based on the method of [10] with modifications to the ingredients. Each 80 g portion of marinated meat was placed in a mixing bowl and ground with the

addition of ice cubes to maintain a low temperature. Spices were added according to the experimental design and mixed until homogeneous. Vegetable oil and the MTG enzyme were incorporated based on the respective treatment doses. The mixture was then conditioned for 1 hour to allow the MTG enzyme to facilitate protein cross-linking. Following conditioning, the mixture was stuffed into casings (10 cm length) and steamed for 20 minutes over low heat. The flowchart of the sausage production stages is presented in Figure 3.

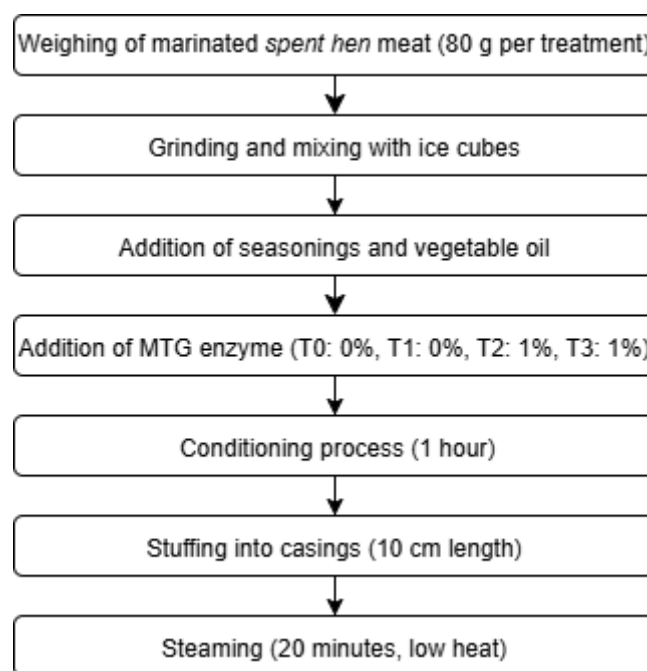


Figure 3. Flowchart of spent hen sausage manufacturing.

## 2.5. Yield

Product percentage (yield) was determined using the procedure established by [11]. The weights of the sausages were measured both before and after the cooking process. The percentage was calculated using the following formula:

$$\text{Yield (\%)} = \frac{\text{weight after cooking (g)}}{\text{weight before cooking (g)}} \times 100\%$$

## 2.6. Total Solids

Total solids were measured using the gravimetric method [12]. A porcelain crucible was heated at 105°C for 30 minutes, cooled in a desiccator, and weighed (x). A 5 g sausage sample (y) was placed in the crucible and dried in an oven at 105°C for 24 hours. The dried sample was cooled in a desiccator and weighed (z). Water content and total solids were calculated as follows:

$$\text{Water Content (\%)} = \frac{x+y-z}{y} \times 100\%$$

$$\text{Total Solids (\%)} = 100 - \text{Water Content}$$

(Where x = weight of empty crucible, y = weight of sample, and z = final weight of crucible + dried sample).

## 2.7. Hardness

Hardness was measured using a Texture Analyzer (TA-XT32) following the procedures of [13]. Samples were prepared into 1×1×1 cm<sup>3</sup>. The measurement was performed using a cylindrical probe with the following settings: test speed 1.50 mm/s, distance 10.00 mm, trigger force 1 g, and duration 5 seconds. The hardness value was recorded in g/s.

The collected data were subjected to Analysis of Variance (ANOVA) using a Completely Randomized Design (CRD) to determine the effect of the treatments. If the ANOVA results indicated a significant effect ( $P < 0.05$ ) or highly significant effect ( $P < 0.01$ ), further analysis was performed using the Honestly Significant Difference (HSD) test.

### 3. RESULT

The physical and chemical quality characteristics of spent hen sausages treated with banana peel paste (BPP) microbial transglutaminase (MTG) are presented in Table 1.

Table 1. Mean values of physical and chemical quality of spent hen sausages

| Treatments            | Variables                 |              |                               |
|-----------------------|---------------------------|--------------|-------------------------------|
|                       | Total Solids (%)          | Yield (%)    | Hardness (g/s)                |
| P0 (0% BPP + 0% MTG)  | 36.81 <sup>b</sup> ± 1.28 | 99.22 ± 0.67 | 4150.15 <sup>b</sup> ± 371.72 |
| P1 (60% BPP + 0% MTG) | 34.28 <sup>a</sup> ± 1.09 | 99.34 ± 0.09 | 2864.24 <sup>a</sup> ± 313.30 |
| P2 (0% BPP + 1% MTG)  | 37.08 <sup>b</sup> ± 1.19 | 99.60 ± 0.05 | 3911.63 <sup>b</sup> ± 751.44 |
| P3 (60% BPP + 1% MTG) | 34.21 <sup>a</sup> ± 0.90 | 99.75 ± 0.08 | 2867.77 <sup>a</sup> ± 346.72 |
| Mean                  | 35.60 ± 1.11              | 99.48 ± 0.22 | 3448.44 ± 445.79              |
| Significance          | **                        | ns           | **                            |

Note: \*: Significant effect ( $P < 0.05$ ); \*\*: Highly significant effect ( $P < 0.01$ ); ns: Not significant ( $P > 0.05$ ); BPP: Banana Peel Paste; MTG: Microbial Transglutaminase. Values in the same column followed by different superscripts (a, b) indicate a highly significant difference ( $P < 0.01$ )

As shown in Table 1, the combination of BPP and MTG had a highly significant effect on the total solids and hardness of the spent hen sausages, whereas its effect on yield was not statistically significant.

#### 3.1. Yield

Yield parameter remained relatively stable across all treatments, with statistical analysis indicating no significant differences (Figure 4). Although Figure 4 shows an increasing trend in values, this observation was not statistically significant. Consequently, varying the concentrations of banana peel paste (BPP) and microbial transglutaminase (MTG) did not significantly impact the yield of the spent hen sausages.

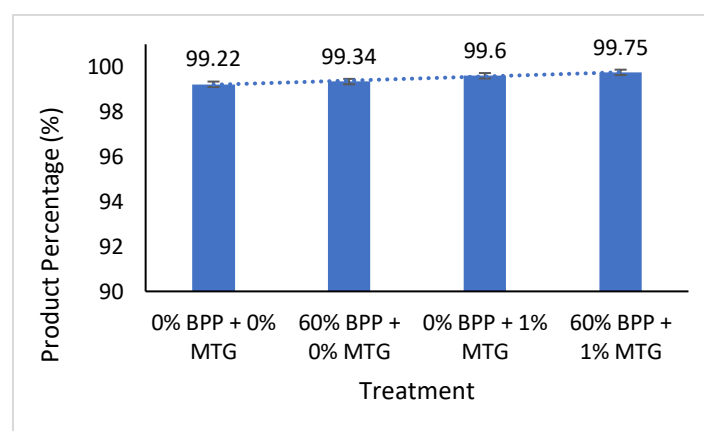


Figure 4. The relationship between the addition of BPP and MTG on the product yield of spent hen sausages.

### 3.2. Total Solids

As illustrated in Figure 5, the incorporation of BPP and MTG had a significant effect on the total solids content of the sausages. The addition of 60% BPP significantly reduced the total solids content from  $37.08 \pm 1.19\%$  to  $34.21 \pm 0.90\%$ . This reduction demonstrates that the inclusion of BPP significantly influences the total solids profile of spent hen sausages.

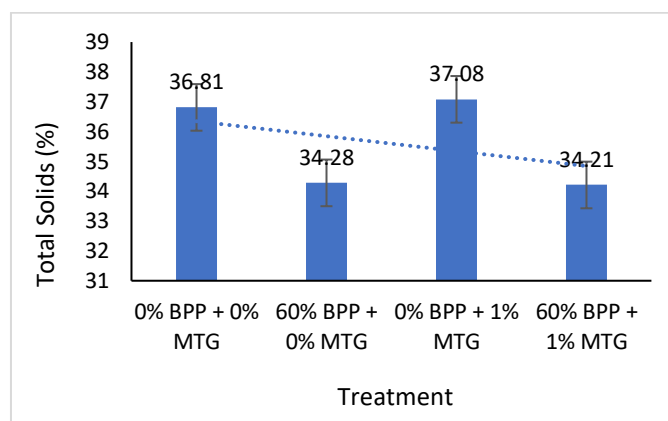


Figure 5. The relationship between the addition of BPP and MTG on the total solids content of spent hen sausages.

### 3.3. Hardness

Figure 6 indicates that the addition of BPP and MTG significantly affected the hardness of the sausage. A significant decrease in hardness was observed, with values ranging from  $4150.15 \pm 371.72$  g/s to  $2864.24 \pm 313.30$  g/s. This decline suggests that the addition of BPP plays a dominant role in reducing the hardness of sausages derived from spent hens.

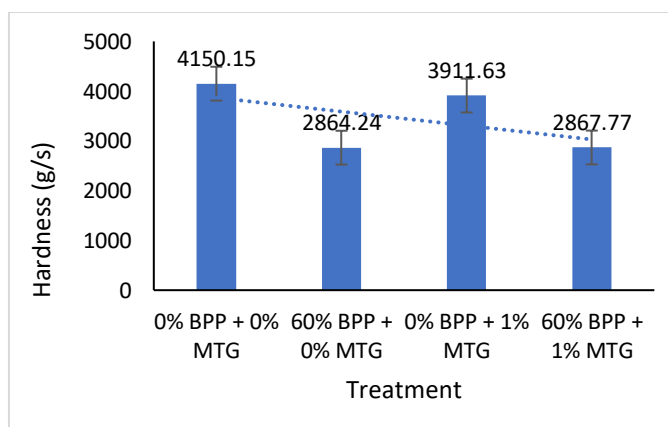


Figure 6. The relationship between the addition of BPP and MTG on the hardness of spent hen sausages.

## 4. DISCUSSIONS

### 4.1. Yield

The product yield of spent hen sausages was not significantly affected by the addition of banana peel paste (BPP) and microbial transglutaminase (MTG) (Figure 4). Yield stability can be attributed to the inherent characteristics of spent hen meat, which naturally contains sufficient myofibrillar protein to form a stable gel matrix, even in the absence of MTG. These findings diverge from those reported by [14], where the addition of MTG (0.25% and 0.5%) to hybrid beef sausages supplemented with soy and

rice proteins significantly influenced product yield. This discrepancy may be attributed to differences in meat source protein profile and the specific binding capacity of the fillers used [15].

The yield of sausage products is fundamentally linked to the homogeneity of the emulsion. As sausages are emulsion-based products, the interaction between fillers and binders plays a critical role in stability. The use of binders, such as wheat flour and tapioca, during the mixing process ensures effective emulsion stability [16]. This stable emulsion facilitates the trapping of water and fat, thereby minimizing liquid loss during cooking and resulting in a consistent yield across all treatments.

The product yield of spent hen sausages is a key indicator of moisture retention during the cooking process [17]. The product yield of spent hen sausages is a key indicator of moisture retention during the cooking process [18], while MTG catalyzes the formation of covalent cross-links between the glutamine and lysine residues of meat proteins. These covalent bonds construct a stable, dense protein matrix with an enhanced capacity to retain water and fat molecules within the sausage gel [19]. Consequently, the balanced efficacy of both ingredients in preserving the product's internal moisture accounts for the consistent product yield observed across all treatments.

#### **4.2. Total Solids**

The total solids value reflects the concentration of non-water components, including protein, fat, carbohydrates, and minerals. According to Figure 5, the addition of 1% MTG resulted in the highest total solids ( $37.08 \pm 1.19\%$ ). This high value is attributed to the formation of a dense gel matrix induced by MTG, which reconstructs the protein network into a more stable structure [19]. These covalent bonds effectively entrap dissolved components, such as proteins, fats, and minerals, preventing their loss during steaming and thereby increasing the solids content of the final product [20].

Conversely, the use of BPP for marination reduced the total solids content. This decrease is caused by the metalloprotease enzymes in the BPP, which degrade proteins and loosen the connective tissue structure [21]. A more open connective tissue architecture increases the availability of hydrophilic groups within the protein chains [22], thereby enhancing the ability of the protein matrix to bind free water. As total solids are calculated by subtracting the moisture content ( $100\% - \text{moisture } \%$ ), an increase in moisture retention leads to a lower total solids percentage [23]. Additionally, the leaching of sarcoplasmic proteins during the washing process after marination may further contribute to a reduction in the proportion of solids.

The combination of BPP and MTG resulted in the lowest average total solids content compared to the other treatments. This indicates that the water-retention capacity induced by BPP marination is more dominant than the gel-reconstructing effect of MTG. Although this leads to lower total solids, the value remains well above the minimum standard of 33% [24]. These results demonstrate that the combination of BPP and MTG can produce a juicier and more tender spent hen sausage without compromising its nutritional profile.

#### **4.3. Hardness**

The addition of BPP decreased the hardness of spent hen sausages (Figure 6). The decrease in hardness is due to the degradation of connective tissue by the protease enzyme in the banana peel paste. Banana peels contain metalloprotease enzymes with an activity of  $42.63 \pm 0.05$  CDU/mg, which can increase meat tenderness [21]. This enzyme works by hydrolyzing peptide bonds and degrading collagen, the main component causing the tough texture of spent hen meat. The protein degradation process causes complex protein chains to break down into simpler ones, resulting in lower hardness and breaking strength [5]. Consequently, sausages with the addition of banana peel paste have lower hardness values.

Conversely, Figure 6 shows that the addition of MTG can increase sausage hardness by promoting protein cross-linking. As a biocatalyst, MTG facilitates an acyl-transfer reaction between the  $\gamma$ -

carboxamide group of glutamine and the  $\epsilon$ -amino group of lysine. This mechanism produces highly stable covalent cross-links that are resistant to proteolysis and heat treatment [25]. Interestingly, sausages treated with a combination of BPP and MTG exhibited hardness values similar to those treated with BPP alone. This suggests that the protease activity of BPP is dominant over the restructuring capability of MTG. The degradation of the protein structure by BPP prevents MTG from optimally forming the cross-links required to enhance gel strength. Nevertheless, despite the reduction in hardness, the sausages maintained a desirable, chewy, and solid texture that does not crumble easily upon consumption [19].

The hardness value is also influenced by the type of raw material used. Based on the results of research by [14] regarding the production of beef sausages formulated with soy and rice proteins with the addition of MTG enzyme (0.25 and 0.5%), the average hardness obtained was 77.5 N or 7902.67 g/s. The value obtained was much higher than the hardness value of sausages from spent hen. This is likely due to differences in the raw materials used. Beef has denser and stronger muscle fibers than spent hen meat, so the resulting sausages also have a higher hardness value than those from spent hen.

## 5. CONCLUSION

The addition of banana peel paste (BPP) and microbial transglutaminase (MTG) did not affect the percentage of sausage produced from spent hens, but it did reduce the hardness and total solids of the sausage. The addition of BPP and MTG to the sausage improved its quality, as the resulting sausage had a stable yield, a chewy, and compact texture without compromising its nutritional content.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest with any financial or personal relationships that could have appeared to influence the work reported in this paper.

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## Primer Effectiveness Test for DNA Authentication of Skipjack Tuna (*Katsuwonus pelamis*) Using Multiplex PCR

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### Abstract

Species substitution in processed fishery products remains a major concern for food authenticity and consumer protection, particularly in tuna commodities where mislabeling is frequently reported. Reliable molecular tools are therefore needed to ensure accurate species identification and support food fraud prevention. This study aimed to develop a novel species-specific primer for the molecular authentication of skipjack tuna (*Katsuwonus pelamis*) and assess its application in a multiplex PCR assay. Three primer candidates targeting mitochondrial DNA regions (12S rRNA and NADH4) were designed and evaluated through in silico BLAST analysis and singleplex PCR. Among the three primer candidates, only one NADH4-based primer pair generated the expected 475 bp amplicon and showed specific amplification of *K. pelamis* without cross-amplification in non-target species. The selected primer was combined with published primers for *Thunnus albacares* and *Thunnus alalunga* in a multiplex PCR assay. Reliable amplification was obtained for *K. pelamis* and *T. albacares*, while amplification of *T. alalunga* was less consistent under multiplex conditions, suggesting that further optimization may improve assay performance. Sensitivity testing demonstrated successful DNA detection at concentrations as low as 0.1 ng/μL. Application of the multiplex PCR assay to processed fish meatballs successfully detected *K. pelamis* DNA in a complex food matrix. These findings indicate that the developed NADH4-based primer is a reliable molecular marker for *K. pelamis* authentication. Furthermore, the multiplex PCR approach shows strong potential as a sensitive tool for food authenticity verification and food fraud detection in processed fishery products.

**Keywords :** DNA authentication, multiplex PCR, processed fish products, specific primer.

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## 1. INTRODUCTION

Recently, issues related to species identification in fish and fishery products have become an increasingly serious concern [1]. Seafood fraud generally occurs due to the deliberate mislabeling of fish species and inappropriate labeling of fishery products, both fresh and processed. Tuna is one of the most sought-after fish species [2] and has a high consumption rate. However, because tuna is often marketed in vacuum-packed pieces or canned products, its morphological characteristics are difficult to recognize, making accurate species identification quite challenging [3]. Furthermore, each tuna species has varying quality and price. This situation opens up opportunities for fraudulent practices through substitution with cheaper species (e.g., *Katsuwonus pelamis*) [1].

Species authentication can be performed using protein- or DNA-based approaches. However, protein-based methods are vulnerable to denaturation during processing, while DNA is more stable and therefore provides higher resolution in species identification. Research by [4] compared the SDS-PAGE (Protein) and DNA barcoding methods to test the authenticity of tuna. SDS-PAGE showed protein damage in processed tuna, making it less accurate for identification. In contrast, the DNA method, using

PCR electrophoresis, successfully identified tuna steaks and canned tuna as *T. albacares*, consistent with the product labels.

The success of DNA detection in authenticating processed products depends heavily on the use of primers, which are short sequences of nucleotide bases specifically designed to bind to specific regions of the target DNA. These primers serve to initiate the DNA replication process in the polymerase chain reaction (PCR), allowing the amplification of specific DNA fragments from the species being identified. Target gene selection, such as Cytochrome C Oxidase Subunit I (COI) and Cytochrome b (cyt b), is a critical factor in determining successful authentication.

Research by [5] used the COI gene with DNA barcoding to identify *Pangasius macronema*. and (*Pangasius hypophthalmus*, with a genetic relationship of 95% to *P. macronema* from Vietnam and 100% to *P. hypophthalmus* from Africa and Thailand, respectively. [6] used cyt b gene-based primers to detect janitor fish (*Pterygoplichthys pardalis*) DNA in siomai, with 10 of 28 samples showing a 496 bp DNA band. The results of the sequencing of nine samples containing janitor fish DNA and one sample of gourami (*Osphronemus goramy*) DNA revealed the potential use of inappropriate raw materials.

Multiplex PCR is a variant of the PCR technique that allows the simultaneous amplification of two or more target DNA fragments in a single reaction using multiple primer pairs. This method has proven efficient because it saves laboratory time and resources without compromising the accuracy of the test results. The effectiveness of this technique was demonstrated in a study by [7] who used multiplex PCR with five primer sets to simultaneously identify five tuna species, demonstrating high accuracy in detecting species in commercial tuna products. To accurately identify species using PCR, primers specific to each DNA target are required.

Therefore, this study aimed to design specific primers and test their effectiveness using the multiplex PCR (mPCR) method to detect a mixture of fish species in fresh and processed samples. Validation was conducted in silico and in vitro to provide a comprehensive picture of primary performance. The results are expected to support efforts to prevent raw material counterfeiting, strengthen food oversight, and increase consumer confidence.

## **2. METHOD**

### **2.1 Time and place**

The research was conducted in June–July 2025 at the Central Laboratory of Andalas University.

### **2.2 Materials and equipment**

The materials used included fresh fish samples, namely skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) obtained from the Pasia Kandang Mutiara Morning Market and Gaung Fish Market, Teluk Bayur (Padang, West Sumatra), as well as albacore tuna (*Thunnus alalunga*) purchased online. Other materials used included designed primers, ddH<sub>2</sub>O, nuclease-free water, the Quick-DNA Miniprep Plus Kit (Zymo Research), and DreamTaq 2X Master Mix.

The main equipment used included a thermal cycler, NanoPhotometer® NP80 (Implen), a gel electrophoresis system (Accuris MyGel Mini) with documentation using the iBright CL1500 Imaging System, micropipettes of various capacities, a centrifuge, and a vortex.

## 2.3 Research Design

Table 1. Research design

| No | Activity            | Output                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Sample Preparation  | Muscle tissue (~25 mg) was collected from one specimen each of <i>Katsuwonus pelamis</i> , <i>Thunnus albacares</i> , and <i>Thunnus alalunga</i> . Each tissue sample was placed into a sterile 1.5 mL microcentrifuge tube and stored at $-20^{\circ}\text{C}$ until DNA extraction. In addition, one processed fish meatball sample was included to evaluate the applicability of the multiplex PCR assay for processed fish products. |
| 2  | Primer Design       | Primer design results in the form of primer sequences specific to the target gene to be amplified.                                                                                                                                                                                                                                                                                                                                        |
| 3  | DNA Extraction      | DNA extraction results in the form of pure DNA samples.                                                                                                                                                                                                                                                                                                                                                                                   |
| 4  | PCR                 | PCR amplification results in the form of abundant DNA fragments, identified based on their size and the target gene being amplified.                                                                                                                                                                                                                                                                                                      |
| 5  | Gel Electrophoresis | Visualization of PCR amplification results in the form of separate bands based on the size of the DNA fragments.                                                                                                                                                                                                                                                                                                                          |

## 2.4 Primer Design and In Silico Specificity Analysis

Species-specific primers for *Katsuwonus pelamis* were designed based on the mitochondrial NADH4 gene sequence (GenBank accession number NC\_005316.1) using Primer3 software. To enable multiplex PCR analysis, primer pairs specific for *Thunnus albacares* and *Thunnus alalunga* were adopted from Lee et al. (2022). The selected primers were evaluated for their basic characteristics, including primer sequence, target gene, melting temperature ( $T_m$ ), and expected amplicon size. The primer information is summarized in Table 2.

The specificity of the designed *Katsuwonus pelamis* primer was initially evaluated *in silico* using the NCBI BLASTn program against the GenBank nucleotide database. Primer specificity was assessed based on sequence identity, query coverage, and the absence of significant matches with non-target species. The selected primer pair was subsequently validated experimentally using multiplex PCR together with the published primer pairs for *Thunnus albacares* and *Thunnus alalunga*. Multiplex PCR amplification was performed under the following thermal cycling conditions: an initial denaturation at  $95^{\circ}\text{C}$  for 60 s, followed by 30 cycles of denaturation at  $95^{\circ}\text{C}$  for 30 s, annealing at  $60^{\circ}\text{C}$  for 30 s, and extension at  $72^{\circ}\text{C}$  for 60 s, with a final extension at  $72^{\circ}\text{C}$  for 300 s.

Table 2. Characteristics of primers used in this study

| Primer              | Sequence (5'-3')                  | Target gene | Amplicon size (bp) | Tm (°C) | Source                   |
|---------------------|-----------------------------------|-------------|--------------------|---------|--------------------------|
| K-Pel 12S 1303F     | GGC TTT ATG ACC<br>CCT GAC CC     | 12S         | 976                | 60.11   | This Study               |
| K-Pel 12S 2278R     | TTT TGC CAC AGA<br>GAC GGG TT     |             |                    | 60.11   |                          |
| K-Pel NADH 4 11287F | CCC TCG GAC ACA<br>GCC TAA TC     | NADH4       | 475                | 60.00   | This Study               |
| K-Pel NADH 4 11761R | GGG GCG GAG TAT<br>TGA AGT GT     |             |                    | 55.00   |                          |
| K-Pel N4 11743F     | CAC TTC AAT ACT<br>CCG CCC CT     | NADH4       | 300                | 55.00   | This Study               |
| K-Pel N4 12042R     | GGA GGC AGA TTG<br>AGC CTG TT     |             |                    | 55.00   |                          |
| K-Pel CYTB 16103F   | CCC CTG ACG TAG<br>AAT CAG CC     | Cyt b       | 237                | NR      | Ref: (Lee et al., 2022). |
| K-Pel CYTB 16340R   | TGC AAG TGG GAA<br>GAA GAT G      |             |                    | NR      |                          |
| T-Alb N4 11301F     | CAT GAT TGC CCA<br>CGG ACT TA     | NADH4       | 126                | NR      | Ref: (Lee et al., 2022). |
| T-Alb N4 11427R     | TGT TGT TAT AAG<br>GGG CAG C      |             |                    | NR      |                          |
| T-Ala CYTB 15937F   | GTT TCG TGA TCC<br>TGC TAG TG     | Cyt b       | 177                | NR      | Ref: (Lee et al., 2022). |
| T-Ala CYTB 16114R   | CCT CCT AGT TTG<br>TTG GAA TAG AT |             |                    | NR      |                          |

\*NR = Not reported in the original publication (Lee et al., 2022).

## 2.5 GEL ELECTROPHORESIS

Gel electrophoresis was performed using 2% agarose gel in 1× TBE solution with SYBR Safe dye. A 5 µL PCR product and DNA marker were added to the gel wells and run under standard conditions. Results were visualized using the iBright Imaging System. DNA fragments were separated based on size, with smaller fragments migrating faster than larger ones. Band size was determined by

comparing their migration position to a DNA ladder marker, and a positive result was considered if the DNA band appeared at a position corresponding to the size of the target gene.

### 3. RESULT

#### 3.1 DNA isolation

DNA isolation is a crucial initial step in molecular analysis to obtain high-quality genomic DNA from fish tissue. In this study, DNA isolation was performed using the Zymo Research DNA Extraction Kit. The procedure followed the kit's standard protocol, which includes cell lysis, DNA binding to the column membrane, washing, and elution.

Table 3. DNA Isolation Results.

| Sample                    | Concentration DNA | Absorbance Ratio<br>A260/A280 | Absorbance Ratio<br>A260/A230 |
|---------------------------|-------------------|-------------------------------|-------------------------------|
| <i>Katsuwonus pelamis</i> | 2.10              | 2.100                         | 0.038                         |
| <i>Thunnus albacares</i>  | 3.50              | 1.795                         | 0.041                         |
| <i>Thunnus alalunga</i>   | 4.20              | 1.787                         | 0.147                         |

Measurements of DNA purity and concentration from the three fish species showed varying results. The *K. pelamis* sample had an A260/A280 ratio of 2.100, with a DNA concentration of 2.10 ng/μL. The *T. albacares* sample had an A260/A280 ratio of 1.795 and a DNA concentration of 3.50 ng/μL, while the *T. alalunga* sample had an A260/A280 ratio of 1.787 and the highest DNA concentration of 4.20 ng/μL.

Although the extracted DNA concentrations (2.10–4.20 ng/μL) were considerably lower than the commonly recommended range of 10–100 ng/μL for PCR, successful amplification was still achieved. This result suggests that PCR performance was not determined solely by DNA concentration but also by DNA quality, primer specificity, and optimized amplification conditions. The A260/A280 ratios (1.795–2.100) indicated that the extracted DNA was of acceptable purity with minimal protein contamination, thereby supporting efficient amplification. Furthermore, the use of highly specific primers together with 30 PCR cycles likely enhanced the detection of low-copy DNA templates, enabling successful amplification despite the relatively low DNA concentration. These findings indicate that the developed assay is sufficiently sensitive to amplify low-abundance DNA, although higher DNA concentrations may further improve amplification efficiency and reproducibility[8]. A ratio below 1.8 indicates possible protein contamination, while a value above 2.0 may indicate RNA contamination [9].

A ratio that is too low, such as 1.787 and 1.795, indicates possible protein contamination, while a value of 2.100 indicates the possible presence of RNA. This indicates that the extraction process was not optimal, particularly during the tissue destruction stage or that the enzyme incubation was incomplete, resulting in inadequate separation of DNA from interfering compounds. Although the DNA concentration and purity did not fully meet standards, PCR was still performed to evaluate the effect of contaminants on DNA polymerase activity and ensure the possibility of amplification.

#### 3.2 Testing on processed products

Fish Meatball samples were ground and then extracted using the Zymo Research DNA Extraction Kit for DNA isolation. This was followed by DNA concentration and purity measurements using the NanoPhotometer® NP80. The results were as follows in Table 3.

DNA concentration measurements from the meatball sample showed a value of 66.15 ng/μL, which is considered high and within the acceptable range for PCR reactions. However, purity measurements indicated contamination. An A260/A280 ratio of 0.977 indicated possible protein contamination, while an A260/A230 ratio of 0.033 indicated the presence of interfering compounds such as salt, polysaccharides, or organic solvents.

Table 3. DNA Isolation Results of Processed Products

| Sample        | Concentration DNA | Absorbance Ratio<br>A260/A280 | Absorbance Ratio<br>A260/A230 |
|---------------|-------------------|-------------------------------|-------------------------------|
| Fish Meatball | 66.15             | 0.977                         | 0.033                         |

The low DNA purity was likely caused by a suboptimal isolation process, resulting in protein, buffer residue, or components from the fish meatball ingredients, such as fat and spices, remaining in the isolation. These compounds can inhibit DNA polymerase activity, disrupting the formation of the primer-template complex.

After confirming the DNA concentration and purity, the next step was electrophoresis to observe the PCR amplification results.

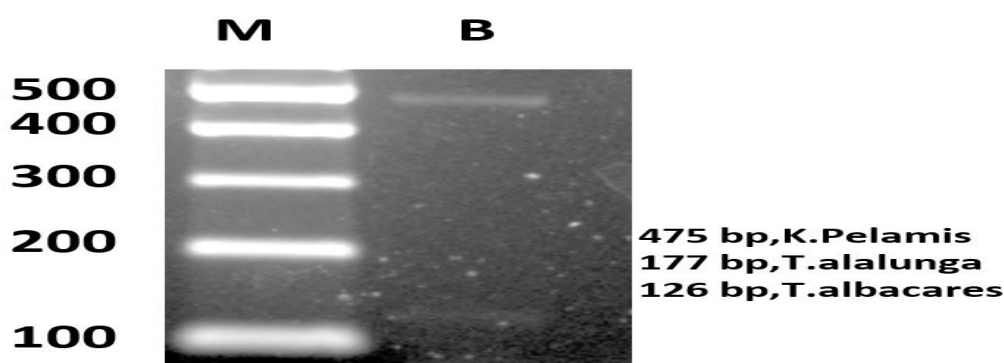


Figure 1. Multiplex PCR amplification of DNA extracted from fish meatball samples. Lane M: DNA ladder. Lane B: fish meatball sample. The expected amplicon sizes were 475 bp for *Katsuwonus pelamis*, 177 bp for *Thunnus alalunga*, and 126 bp for *Thunnus albacares*. The electrophoresis results showed amplification bands corresponding to *K. pelamis* (475 bp) and *T. albacares* (126 bp), whereas no amplification band was observed for *T. alalunga* (177 bp).

Electrophoresis of the multiplex PCR products from the fish meatball sample (lane B) revealed two distinct DNA bands corresponding to the expected amplicon sizes of *K. pelamis* (475 bp) and *T. albacares* (126 bp). The *K. pelamis* band exhibited stronger amplification intensity than the *T. albacares* band. No amplification corresponding to the expected 177 bp fragment of *T. alalunga* was observed under the optimized multiplex PCR conditions.

The absence of the *T. alalunga* amplicon may be associated with several factors affecting multiplex PCR performance. Amplification imbalance in multiplex PCR may occur due to differences in primer concentration, primer amplification efficiency, and thermocycling conditions, resulting in preferential amplification of certain targets over others[10]. In addition, low template DNA quality or degraded DNA may further reduce amplification success under multiplex PCR conditions. However, these possibilities were not specifically evaluated in the present study and therefore require further investigation.

#### 4. DISCUSSION

In this study, tuna species authentication was carried out through a series of stages, starting from DNA isolation of fresh fish samples, followed by *in silico* and *in vitro* specificity tests, multiplex PCR optimization, sensitivity evaluation, and application to processed fishery products. The results demonstrated that multiplex PCR is a promising molecular tool for the authentication of skipjack tuna (*Katsuwonus pelamis*) in both raw and processed products.

Although the extracted DNA exhibited relatively low concentrations, the purity values were sufficiently close to the recommended range for PCR amplification. This finding indicates that the developed multiplex PCR assay was sufficiently robust to amplify target DNA despite the presence of potential contaminants introduced during the extraction process. DNA purity is an important factor

affecting PCR performance because contaminants may inhibit polymerase activity and reduce amplification efficiency [8]. Nevertheless, previous studies have shown that successful PCR amplification can still be achieved when sufficient intact target DNA remains available, even if DNA quality is not optimal [11]. These findings suggest that amplification success was supported not only by DNA quality but also by the optimized primer design and PCR conditions employed in this study. Therefore, the successful amplification obtained in this study suggests that the developed assay has good potential for routine molecular identification of tuna species.

The successful amplification confirmed that the designed primer set possessed adequate specificity for multiplex PCR analysis. Primer specificity is essential because multiple primer pairs are simultaneously present in a single reaction, increasing the possibility of non-specific amplification. The primers developed in this study target mitochondrial DNA regions, which are widely recognized as reliable molecular markers for fish species identification because of their high copy number, maternal inheritance, and sufficient sequence variation among species [6], [7]. These findings are consistent with previous reports demonstrating that mitochondrial DNA-based multiplex PCR provides reliable discrimination among tuna species for seafood authentication [7].

The multiplex PCR approach used in this study offers several advantages over conventional singleplex PCR. By simultaneously amplifying multiple DNA targets in one reaction, multiplex PCR reduces reagent consumption, analysis time, and laboratory workload. Lee et al. [7] reported similar advantages when identifying five tuna species simultaneously using multiplex PCR. The present study further confirms that multiplex PCR can effectively distinguish tuna species and detect skipjack tuna DNA in mixed-species samples. The successful amplification obtained in this study indicates that the selected PCR conditions were appropriate for simultaneous detection of multiple target species. One of the most important factors influencing multiplex PCR performance is annealing temperature, as it determines the specificity of primer binding to the target DNA sequence. In this study, the annealing temperature was optimized, and 60°C was selected as the optimal condition because it produced clear and specific amplification of the target fragments without detectable non-specific products. Annealing temperatures that are too low may allow primers to bind to non-target DNA sequences, whereas excessively high temperatures can prevent amplification by reducing primer-template hybridization efficiency [12]. Therefore, optimization of PCR conditions, particularly annealing temperature and primer concentration, is essential to ensure amplification specificity and reproducibility in multiplex PCR assays, as primer concentration and cycling temperature are among the most critical parameters influencing multiplex PCR performance [13].

Sensitivity testing demonstrated that the optimized primers could detect DNA concentrations as low as 0.1 ng/μL. This result indicates high analytical sensitivity and suggests that the developed assay can identify target species even when DNA concentrations are very low due to processing, degradation, or dilution within mixed products. The ability to detect trace amounts of DNA is essential in food authentication because thermal processing, mechanical treatment, and ingredient mixing frequently result in DNA fragmentation. Similar findings have been reported in processed food authentication studies where PCR-based methods successfully detected target species despite significant DNA degradation [14].

The application of the multiplex PCR assay to processed fish products further demonstrated its practical value. The fish meatball sample showed a high DNA concentration (66.150 ng/μL) but poor purity, with A260/A280 and A260/A230 ratios indicating substantial contamination from proteins and other compounds. Processed products often contain fats, spices, carbohydrates, and additives that may co-extract with DNA and inhibit PCR reactions. Despite these challenges, successful amplification of *K. pelamis* and *T. albacares* DNA was achieved, demonstrating the robustness of the developed method. The presence of visible amplification bands suggests that the PCR system was able to overcome the inhibitory effects of contaminants commonly found in processed food matrices.

Interestingly, amplification of *T. alalunga* was not observed in the processed product sample. Several factors may explain this result. First, the concentration of *T. alalunga* DNA may have been below the detection limit due to low abundance in the sample. Second, DNA degradation caused by processing conditions such as heating, grinding, and storage may have reduced the availability of amplifiable template DNA. Third, competition among primer pairs during multiplex PCR may have favored amplification of more abundant targets, resulting in preferential amplification of *K. pelamis* and *T. albacares*. Similar preferential amplification has been reported in multiplex PCR systems, where differences in primer performance and reaction optimization may result in unbalanced amplification among target fragments [15].

Overall, the results indicate that the designed primers possess adequate specificity and sensitivity for skipjack tuna authentication. Although DNA purity and amplification balance remain challenges in multiplex PCR analysis, the method successfully identified target species under various sample conditions. Further optimization of primer concentrations, PCR conditions, DNA extraction procedures, and validation using additional biological replicates is recommended to improve the robustness of the multiplex PCR assay and expand its application for the authentication of additional tuna species and processed seafood products.

## 5. CONCLUSION

Based on the research conducted, the following conclusions can be drawn: The developed multiplex PCR successfully amplified target DNA with a sensitivity of up to 0.1 ng/μL in both fresh fish samples and processed products, despite indications of contamination in the DNA isolation results. The detected contamination did not inhibit amplification, and the method was able to specifically identify *K. pelamis* and *T. albacares*. However, *T. alalunga* was not detected in mixed-species samples, which was possibly due to factors such as low DNA abundance, DNA degradation during processing, or primer competition effects in multiplex amplification. Further validation, such as spiking experiments using known concentrations of *T. alalunga* DNA into different sample matrices, is required to determine the specific cause of non-detection. Overall, this method has proven efficient and applicable for fish species authentication and has great potential for detecting adulteration of raw materials in processed fishery products.

## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper. The authors have no financial, personal, or professional relationships that could have influenced the research, authorship, or publication of this study.

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## Descriptive Analysis of Broiler Chicken Rearing Management in Improving Productivity at CPI Partner Farms

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### Abstract

This study aims to evaluate broiler chicken rearing management practices and describe production performance in a partnership farming system. Unlike previous studies that focused on individual management components, this study provides an integrated evaluation of housing, feeding, biosecurity, waste management, marketing systems, and production performance in a broiler partnership farm. The research was conducted at a broiler farm partnered with PT Charoen Pokphand Indonesia (CPI) located in Olaia Village, Aesesa District, Nagekeo Regency, East Nusa Tenggara. A descriptive method with an observational approach was applied. Data were collected through direct observation, interviews, documentation, and secondary data from production records. The variables observed included housing management, feed management, biosecurity, waste management, and marketing systems, as well as production performance indicators such as Feed Conversion Ratio (FCR), mortality rate, and harvest weight. The results showed that the implemented management practices were generally effective in supporting broiler productivity. This was indicated by an FCR value of 1.33, a mortality rate of 3.13%, and an average harvest weight of 1.86 kg per bird at 33 days of age. Proper housing management, ad libitum feeding with balanced nutrition, and the use of supplements contributed to production efficiency and optimal growth performance. However, biosecurity practices were not fully optimized, particularly in sanitation measures, and waste management was still conducted in a simple manner without further processing. The partnership-based marketing system provided market certainty, although farmers had limited control over pricing. Therefore, improvements in biosecurity implementation and waste management are necessary to enhance sustainability and optimize broiler production.

**Keywords:** *broiler production performance, biosecurity, feed conversion ratio, partnership farming, rearing management*

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## 1. INTRODUCTION

Broiler chickens represent a leading poultry commodity with a strategic role in fulfilling human animal protein requirements, characterized by their rapid growth rates, high feed conversion efficiency, and capacity to yield meat within a relatively short production cycle. In Indonesia, the broiler farming industry has experienced continuous growth, driven by the escalating public demand for meat consumption. According to 2025 data from Statistics Indonesia (BPS), broiler production in East Nusa Tenggara Province has exhibited a consistent year-over-year increase, reflecting both robust market demand and significant opportunities for livestock enterprise development in the region [1]. These circumstances necessitate the implementation of highly effective and efficient rearing management systems to optimize livestock productivity and ensure the long-term sustainability of broiler farming operations at the farmer level.

From an animal science perspective, successful broiler production is highly dependent on the interaction between genetic factors and the rearing environment. The pertinent environmental parameters encompass housing management, temperature, relative humidity, ventilation, stocking

density, and lighting systems, all of which directly affect bird welfare and health. Suboptimal microclimatic conditions within the poultry house can induce stress, depress feed intake, and subsequently result in elevated mortality rates alongside diminished production performance [2]. Generally, under sound management practices, the ideal mortality rate for broiler flocks is maintained below 5%. Conversely, optimal housing management enhances production efficiency, as evidenced by maximized market weights and robust flock health. Consequently, proper housing management emerges as a critical determinant in actualizing the genetic potential of broiler chickens within intensive production systems.

In addition to housing management, nutritional factors play a critically dominant role in determining the success of broiler farming operations. Feed constitutes the largest expenditure in poultry production, accounting for approximately 60–70% of total operational costs, thereby rendering its efficient utilization a remarkably crucial aspect. Theoretically, both the quality and quantity of the provisioned feed directly impact growth rates, feed conversion efficiency, and overall flock health. The Feed Conversion Ratio (FCR) serves as the primary metric for assessing feed utilization efficiency, where a lower FCR value signifies the birds' optimal capacity to convert feed into body mass. Generally, an acceptable FCR for broilers ranges between 1.5 and 1.8, contingent upon the rearing management practices implemented [3]. Substandard feeding practices, encompassing both nutritional deficiencies and inadequate feed administration, can result in suboptimal growth performance and inflated production costs. Consequently, the application of precise and efficient feed management strategies is pivotal for augmenting the productivity and profitability of broiler enterprises [3].

Beyond production parameters, waste management and marketing strategies constitute pivotal factors in supporting the sustainability of broiler farming enterprises. Poultry waste—comprising litter, excreta, and residual feed—if inadequately managed, can precipitate environmental pollution, generate noxious odors, and act as a proliferation medium for pathogenic microorganisms that potentially compromise flock health [4]. However, with appropriate management, such by-products can be repurposed as organic fertilizer, thereby generating supplementary economic value for the producers. Furthermore, marketing dynamics play a crucial role in dictating the successful distribution of poultry products from farmers to consumers. Within a contract farming framework, marketing channels are generally established by the integrating company; nevertheless, the quality of the final product remains the primary determinant of the selling price and the farmer's profit margins [5]. Consequently, the integration of production management and marketing strategies is imperative to ensure both operational efficiency and the overall sustainability of the broiler production system.

Although various studies have addressed broiler rearing management, the majority of existing literature remains focused on isolated parameters, such as housing or feed management individually. However, in practical field conditions, the success of broiler production is significantly dictated by the simultaneous interdependencies among these diverse management aspects. Based on fieldwork observations conducted at a partner broiler farm of PT Charoen Pokphand Indonesia in Olaia Village, Aesesa Subdistrict, Nagekeo Regency, it was evident that while the applied rearing management adhered to the integrator company's standards, a comprehensive evaluation of the interconnections between housing, feed, waste, and marketing management concerning production performance—specifically the Feed Conversion Ratio (FCR), mortality rates, and market weights—remains limited. Therefore, the novelty of this study lies in its analytical approach, which comprehensively integrates these four management aspects utilizing field-based data within a contract farming framework in the East Nusa Tenggara region. Furthermore, this research offers a contextual contribution by being conducted in a region characterized by environmental conditions that are distinctly different from those of conventional poultry production hubs in Indonesia. Consequently, this study aims to analyze the relationships between housing, feed, waste, and marketing management and their collective impact on broiler production

performance within a contract farming system, ultimately seeking to enhance operational efficiency and the sustainability of the livestock enterprise.

## **2. METHOD**

This study was based on fieldwork observations conducted at a broiler farm partnered with PT Charoen Pokphand Indonesia, located in Bo'anio, Olaia Village, Aesesa Subdistrict, Nagekeo Regency, East Nusa Tenggara Province. The site was purposively selected because the farm operates under a contract farming system implementing standardized rearing management, thereby providing a highly relevant model for analyzing broiler production performance. The fieldwork was carried out from November 4 to December 10, 2026, focusing on the direct observation of the entire broiler rearing management sequence, from pre-placement house preparation to the final harvest. This study employed a descriptive observational design to systematically delineate the on-farm rearing management conditions based on empirical observations, without applying any experimental treatments to the subjects. The observational unit comprised a single broiler house owned by the partner farmer, housing an initial flock of 2,500 Day-Old Chicks (DOCs), which were monitored throughout a complete rearing cycle until harvest. The observations encompassed the entirety of the operational procedures, including house preparation, daily flock management, health protocols, and the harvesting process.

Data collection for this study was conducted using multiple complementary techniques to acquire accurate and comprehensive information. Primary data were obtained through direct on-site observations of broiler rearing activities, encompassing the physical conditions of the poultry house, feeding and watering systems, temperature and ventilation management, and flock health interventions throughout the rearing period. Additionally, in-depth interviews were conducted with the farm owner and personnel to elicit information regarding the implementation of management practices, operational constraints encountered, and strategies adopted to optimize productivity. Documentation served as supplementary data, comprising activity logs, photographic evidence of the housing conditions, and overall on-farm operational situations. Furthermore, secondary data were extracted from the farm's production records—specifically initial flock size, feed consumption, mortality rates, and market weights—which were utilized to substantiate the analysis of broiler production performance.

The variables observed in this study encompassed key aspects of broiler rearing management, specifically housing, feeding, and waste management, alongside the marketing system within the contract farming framework. Housing management was evaluated based on the physical conditions of the poultry house, ventilation, temperature, relative humidity, and stocking density. Concurrently, feeding management variables included feed types, feeding frequencies, and the feed distribution system. Waste management was assessed through the handling protocols for litter and residual feed, while marketing aspects were examined based on the sales mechanisms established under the contract farming agreement. Furthermore, the analyzed production performance indicators comprised the Feed Conversion Ratio (FCR), mortality rates, and final market weights of the broilers. Data analysis was conducted descriptively by juxtaposing the empirical field conditions against prevailing standard broiler rearing guidelines. The findings were subsequently interpreted to elucidate the interrelationships between the implemented management practices and the achieved production outcomes.

## **3. RESULT AND DISCUSSION**

### **3.1. Broiler Rearing Management**

Broiler rearing management constitutes an integrated system encompassing various critical aspects, including housing management, feed administration, health control via biosecurity, waste management, and product marketing. These components are fundamentally interdependent and collectively determine the success of broiler production. Based on the rearing outcomes at the partner

farm of PT Charoen Pokphand Indonesia (CPI) in Mbay, the recorded production performance data indicated an initial flock of 2,500 birds, with 2,376 birds harvested, yielding a mortality rate of 3.12%. Furthermore, the data demonstrated a cumulative feed consumption of 2.44 kg/bird, an average daily gain (ADG) of 0.055 kg/bird/day, an average market weight of 1.86 kg/bird at 33 days of age, and a Feed Conversion Ratio (FCR) of 1.33. These metrics demonstrate that the implemented rearing management system operated effectively, successfully optimizing the growth and production efficiency of the broilers. This aligns with the findings of Maulana et al. [6], who posited that the performance of modern broilers typically ranges between market weights of 1.7 and 2.0 kg/bird with FCR values of 1.2 to 1.5. Additionally, this is corroborated by Zebua et al. [7], who reported that an optimal mortality rate for broiler flocks is maintained below 5%.

Table 1. Summary of broiler production performance at the partner farm of PT Charoen Pokphand Indonesia (CPI) in Mbay during one rearing cycle.

| Parameter                | Value    | Unit        |
|--------------------------|----------|-------------|
| Initial population       | 2.500    | Birds       |
| Dead birds               | 78       | Birds       |
| Culled birds             | 46       | Birds       |
| Harvested birds          | 2.376    | Birds       |
| Mortality rate           | 3,13     | %           |
| Initial DOC weight       | 0,045    | Kg/Day      |
| Final market weight      | 1,86     | Kg/Bird     |
| Feed consumption         | 2,44     | Kg          |
| Average Daily Gain (ADG) | 0,055    | Kg/Bird/Day |
| Rearing period           | 33       | Days        |
| Total feed consumption   | 5.900    | Kg          |
| Total live weight        | 4.419,36 | Kg          |
| Feed Conversion Ratio    | 1,33     | %           |

\*DOC (Day Old Chicken)

### 3.1.1 Housing Management

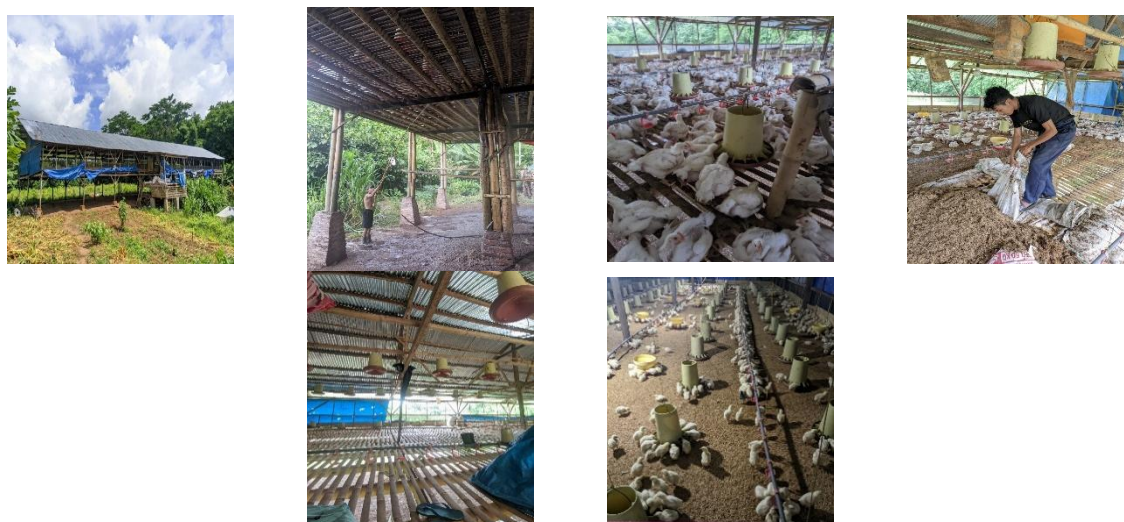


Figure 1. Broiler housing management, encompassing the exterior condition of the poultry house, cleaning and sanitation prior to the placement of Day-Old Chicks (DOC), the bamboo slatted flooring system, the application of rice husk bedding, spatial partitioning according to bird age, and litter management throughout the rearing period up to 28 days of age.

In addition to ventilation systems, the physical conditions of the poultry house—specifically litter utilization and the regulation of stocking density—play a pivotal role in supporting broiler performance. Based on field observations (Figure 1), the use of rice husks as flooring litter effectively maintained a dry microenvironment by absorbing moisture from the excreta. Optimal litter conditions not only enhance bird welfare but also significantly influence flock health, particularly by preventing leg abnormalities and mitigating disease risks. Consequently, this promotes optimal behavioral activities, ensuring that feed intake remains unhindered and growth trajectories are stabilized, as evidenced in Table 2 by an Average Daily Gain (ADG) of 0.055 kg/bird/day. This observation is in accordance with Ramadhan et al. [8], who asserted that proficient litter management enhances broiler welfare and health, thereby bolstering overarching production performance.

Furthermore, the regulation of stocking density through age-appropriate partitioning of the poultry house constitutes an essential component of housing management. An optimal stocking density provides adequate space allowance, thereby mitigating competition among birds for access to feed and water resources. This condition facilitates a more equitable feed intake, subsequently promoting higher flock uniformity [9]. Conversely, excessive stocking density can precipitate elevated intra-house temperatures and relative humidity, which sequentially depresses feed intake and induces physiological stress, thereby potentially exacerbating mortality rates. Consequently, the strategic management of both litter and stocking density, as integral components of housing management, plays an imperative role in sustaining and optimizing the production efficiency of broiler chickens.

### 3.1.2 Feed Management

Table 2. Nutritional composition of commercial broiler feed from PT Charoen Pokphand Indonesia.

| Nutrient Content     | Feed Type     |               |               |
|----------------------|---------------|---------------|---------------|
|                      | S00           | S11           | S12           |
| Moisture             | Maks 13.00%   | Maks 14.00%   | Maks 13.00%   |
| Crude Protein        | Min 22.00%    | Min 20.00%    | Min 19.00%    |
| Crude Fat            | Min 4.00%     | Min 5.00%     | Min 4.00%     |
| Crude Fiber          | Maks 5.00%    | Maks 5.00%    | Maks 5.00%    |
| Ash                  | Maks 9.00%    | Maks 8.00%    | Maks 9.00%    |
| Calcium              | 0.70% - 1.20% | 0.80% - 1.10% | 0.60% - 1.10% |
| Phosphorus           | Min 0.50%     | Min 0.50%     | Min 0.45%     |
| Total Aflatoxin      | Maks 40 µg/kg | Maks 50 µg/kg | Maks 50 µg/kg |
| Lysine               | Min 1.30%     | Min 1.20%     | Min 1.05%     |
| Methionine           | Min 0.50%     | Min 0.45%     | Min 0.40%     |
| Methionine + Cystine |               | Min 0.80%     |               |
| Tryptophan           |               | Min 0.19%     |               |
| Threonine            |               | Min 0.75%     |               |

Feed management at the partner broiler farm of PT Charoen Pokphand Indonesia (CPI) in Mbay is systematically implemented utilizing commercial feed formulated to meet the nutritional requirements of the birds at each respective growth phase. Feeding is administered ad libitum, ensuring continuous feed availability in the feeders, thereby allowing the birds to consume according to their physiological demands. This system enables the broilers to achieve optimal growth as feed intake is unrestricted, maximizing the fulfillment of energy and nutritional requirements essential for body tissue formation. Furthermore, ad libitum feeding contributes to enhanced production efficiency, provided that feed quality and environmental housing conditions are meticulously maintained [10]. As presented in Table 2, the utilized feed comprised S00 (pre-starter), S11 (starter), and S12 (finisher), featuring a crude protein content that progressively declined from 22% in the pre-starter phase to 20% in the starter phase and 19% in the finisher phase. This dietary adjustment reflects the shifting nutritional requirements corresponding to the growth phases; the initial phase necessitates high dietary protein for tissue accretion, whereas the final phase is directed more toward the efficiency of body weight gain [11]. Correlating this with the results in Table 1, the aforementioned nutritional composition significantly

influenced broiler production performance, as evidenced by a cumulative feed consumption of 2.44 kg/bird and a Feed Conversion Ratio (FCR) of 1.33. This FCR value is classified as highly efficient and remains well within the standard parameter range for modern broilers, specifically 1.2–1.5 [12], [13]. These findings are in agreement with Tajudin et al. [14], who asserted that dietary nutritional balance, particularly concerning protein and energy, critically impacts feed conversion efficiency and broiler growth. Consequently, the feed formulation detailed in Table 2 is proven to optimally support the production performance presented in Table 1, aligning cohesively with established theoretical frameworks and prior empirical studies.

Beyond crude protein content, the balance of essential amino acids, particularly lysine and methionine, as delineated in Table 2, plays a critical role in supporting broiler production performance. Lysine functions primarily in muscle tissue accretion, whereas methionine is integral to protein synthesis and the enhancement of feed utilization efficiency. The balanced availability of these amino acids directly influences both feed intake and conversion efficiency, as evidenced in Table 1 by a cumulative feed consumption of 2.44 kg/bird and a Feed Conversion Ratio (FCR) of 1.33. These metrics indicate that the dietary nutrients were optimally assimilated for growth. These findings align with Widianingrum et al. [15], who posited that the amino acid balance within the diet is a decisive determinant of feed conversion efficiency and overall broiler growth.

Proficient feed utilization is further manifested in the body weight gain of the broilers. As indicated in Table 1, the recorded Average Daily Gain (ADG) reached 0.055 kg/bird/day, equivalent to 55 grams/bird/day, demonstrating that the birds underwent optimal growth. When correlated with the nutritional composition outlined in Table 2, the equilibrium among protein, energy, and essential amino acids effectively facilitated physiological tissue accretion. This synergy contributed to an ultimate market weight of 1.86 kg/bird at 33 days of age, categorizing it as robust production performance. These outcomes align consistently with modern broiler performance standards, which prescribe an ADG of 50–60 grams/bird/day and a final market weight ranging from 1.7 to 2.0 kg at 33 days of age [16]. Moreover, Sanjaya [17] articulated that dietary nutritional balance profoundly influences growth velocity and final body weight attainment in broilers. Consequently, the adequacy of the nutritional formulation presented in Table 2 is empirically proven to foster the optimal growth trajectories demonstrated in Table 1.

Beyond individual growth metrics, the overarching success of the rearing management is further reflected in the total production yield and mortality rates of the broiler flock. As delineated in Table 1, the total live weight yielded reached 4,419.36 kg from a harvested flock of 2,376 birds, indicating that the vast majority of the population maintained robust growth and viability throughout the entire rearing cycle. The recorded mortality rate of 3.13% is classified as low and remains well within the acceptable tolerance limits for commercial broiler rearing, which is typically maintained below 5% [18]. When correlated with the nutritional composition detailed in Table 2, it is evident that superior feed quality and optimal nutrient equilibrium play a pivotal role in preserving flock health, thereby suppressing mortality rates. These outcomes corroborate prior research asserting that proficient feed management—particularly concerning nutritional integrity and the mitigation of contaminants such as aflatoxins—can significantly bolster the immunological resilience of the birds and concomitantly reduce mortality rates [19].

Consequently, the correlation between the feed quality outlined in Table 2 and the resulting production performance detailed in Table 1 demonstrates that the implemented management system optimally supports broiler productivity while mitigating economic losses attributed to flock mortality. Thus, the successful production of broiler chickens is not exclusively contingent upon feed quality; rather, it is concurrently underpinned by synergistic factors such as flock health and environmental control. Therefore, supplementary interventions—encompassing the administration of nutritional

supplements and therapeutic agents, alongside the enforcement of rigorous sanitation protocols—are imperative to sustain the physiological homeostasis of the birds throughout the rearing period.

In summary, the overarching outcomes of the broiler rearing process demonstrate that the administration of a well-balanced nutritional diet optimally underpins production performance. The precise alignment of nutrient profiles with specific growth phases significantly influences feed intake, feed conversion efficiency, and cumulative body weight gain. This is directly evidenced by a Feed Conversion Ratio (FCR) of 1.33, an Average Daily Gain (ADG) of 0.055 kg/bird/day, and a final market weight of 1.86 kg/bird at 33 days of age, all of which fall squarely within the standard performance parameters for modern broilers [2], [20]. Furthermore, the relatively low mortality rate indicates that the general rearing conditions and management practices were executed highly effectively.

Table 3. Types of therapeutic agents and supplements, their functions, and administration methods.

| Therapeutic Agent / Supplement     | Function / Role                                                                                                                                                                                                                                                                                                                                                                                                | Administration Method                                                                     |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| <b>Biogreen</b>                    | <ul style="list-style-type: none"> <li>Mitigates adverse effects resulting from treatments with sulfa antibiotics, coccidiostats, and similar agents.</li> <li>Acts as an anti-stress agent.</li> <li>Treats digestive disorders induced by overfeeding, toxicosis, or high-nitrogen diets.</li> <li>Alleviates decreased appetite, asthenia, and constipation.</li> <li>Addresses fluid deficiency</li> </ul> | Dissolved in drinking water and administered alternately according to the daily schedule. |
| <b>Zagrosol Aminogen</b>           | <ul style="list-style-type: none"> <li>Stimulates growth and enhances overall flock performance.</li> <li>Improves the Feed Conversion Ratio (FCR).</li> </ul>                                                                                                                                                                                                                                                 | Administered via drinking water according to a daily rotational schedule.                 |
| <b>Organic Green Culture</b>       | <ul style="list-style-type: none"> <li>Accelerates growth and improves feed efficiency.</li> <li>Prevents intestinal infections and diarrhea.</li> <li>Enhances meat quality.</li> <li>Reduces ammonia levels and noxious odors from excreta.</li> </ul>                                                                                                                                                       | Administered via drinking water following a daily rotational scheme.                      |
| <b>Bromoquad-10 (Disinfectant)</b> | <ul style="list-style-type: none"> <li>Serves as a disinfectant to clean administration vessels, preventing harmful microbial contamination.</li> </ul>                                                                                                                                                                                                                                                        | Utilized for washing vats/containers prior to mixing supplements or therapeutic agents.   |

### 3.1.3 Waste Management

Based on observational findings, waste management at the partner broiler farm of PT Charoen Pokphand Indonesia (CPI) in Mbay is conducted manually, specifically by collecting and distributing spent litter and poultry excreta to designated areas surrounding the poultry house. The waste is utilized directly as organic fertilizer without undergoing further processing, such as fermentation or composting. This practice indicates that although waste utilization is occurring, it remains rudimentary and is suboptimally managed. Poultry manure directly impacts crop production and food security by providing essential macronutrients (N, P, and K), secondary nutrients (S, Mg, and Ca), and micronutrients (Zn, Pb, B, Cu, Cl, Fe, Mo, Ni, Mn, Co, Si, Cr) upon application [21]. However, if applied without prior treatment, the unstabilized organic matter and the presence of pathogenic microorganisms possess the potential to generate adverse impacts on both the environment and public health. Furthermore, poultry excreta emits noxious odors that can compromise the health of surrounding communities and

consequently depress livestock productivity [22]. From an enterprise management perspective, this condition also suggests that the economic potential of the waste has not been maximally exploited; through proper composting or fermentation processes, the waste can be converted into higher-quality organic fertilizer with greater market value and safer applicability for agricultural lands. According to Maitimu et al. [23], inadequately treated livestock waste can precipitate soil pollution, noxious odors, and an elevated risk of pathogenic microorganism dissemination into the surrounding environment. This situation highlights that despite its current utilization, waste management practices require significant improvement to ensure environmental sustainability and biosecurity.

#### **3.1.4 Biosecurity**

The implementation of biosecurity protocols at the partner broiler farm of PT Charoen Pokphand Indonesia (CPI) in Mbay indicates that disease prevention efforts remain suboptimally executed. Based on observational findings, the implemented measures were primarily restricted to controlling access to the poultry house, lacking the support of adequate sanitation infrastructure such as handwashing stations, disinfectant footbaths, and routine disinfectant spraying. This deficiency inherently elevates the risk of pathogenic agent introduction into the housing environment via human vectors, equipment, and vehicles utilized during daily operations. Theoretically, a robust biosecurity framework comprises three fundamental components: isolation, sanitation, and traffic control. These three elements must be implemented synergistically to mitigate the risk of disease dissemination within the flock. According to Noywuli et al. [24], the incomplete execution of biosecurity protocols, particularly concerning sanitation and traffic control, significantly amplifies the probability of pathogenic microorganism contamination within the microenvironment of the poultry house. This is corroborated by Suriansyah et al. [25], who reported that inadequate compliance with routine disinfection and personal sanitation practices correlates directly with an increased incidence of disease and subsequently diminished broiler production performance. Furthermore, Saputra et al. [26] asserted that stringent biosecurity implementation is capable of reducing mortality rates, enhancing feed efficiency, and sustaining long-term production performance stability.

### **3.2 Marketing Management**

Marketing management at the partner broiler farm of PT Charoen Pokphand Indonesia (CPI) in Mbay, Nagekeo Regency, is executed through an integrated contract farming system, wherein the entire production yield is marketed by the integrator company. Under this framework, the farmer does not engage in independent marketing; rather, the entire sales process is centrally controlled by the company. Prospective buyers are mandated to pre-register via a dedicated application provided by the integrator, ensuring that the transaction process is systematically organized and strictly monitored. Upon the scheduled harvest, these registered buyers proceed directly to the farm premises to collect the broilers in accordance with predetermined quantities and specified body weights. The implemented marketing mechanism is categorized as an indirect marketing channel, wherein product distribution necessitates the involvement of intermediaries or distributors before reaching the end consumers. This pattern typically emerges within long-term relationships between farmers and aggregators, cultivated upon mutual trust in commercial transactions [27]. The primary advantage of this system is that it affords farmers marketing convenience and guaranteed market absorption of their yield, thereby minimizing the financial risk of delayed payments. Nevertheless, the farmers possess limited bargaining power in determining the selling price, as both the pricing and the harvesting schedule are exclusively dictated by the integrator company, contingent upon prevailing market dynamics and the achieved production performance [28].

Based on the production outcomes, the broilers were harvested at 33 days of age, achieving an average body weight of 1.86 kg per bird. From an initial flock of 2,500 birds, 2,376 birds were

successfully harvested, recording a mortality rate of 3.12%, which remains well within the normal tolerance limits for commercial broiler rearing. The total live weight yielded at harvest reached 4,419.36 kg, indicating a considerably high production volume within a single rearing cycle. The harvested broilers were marketed as live birds at a selling price of IDR 25,000 per kilogram. The profit-sharing mechanism within this contract farming framework allocates 20% of the total sales revenue to the farmer, while the remainder is retained by the integrator company as the provider of production inputs and the manager of marketing operations. This system guarantees income security for the farmers, although, conversely, they lack absolute control over market price fluctuations. According to [29], fluctuations in the selling price of broilers profoundly impact farmers' income levels; therefore, the contract farming system serves as a viable alternative to mitigate the risks associated with price volatility. Overall, the marketing management implemented at the CPI Mbay partner farm has operated in an integrated and efficient manner through a digitally facilitated contract system and direct distribution channels. Ultimately, marketing success is not solely dictated by the distribution network but is also heavily influenced by production performance metrics, such as mortality rates, final market weights, and the total live weight yielded during the rearing period.

#### **4. CONCLUSION**

Based on the research findings, it can be concluded that the broiler rearing management implemented at the partner farm of PT Charoen Pokphand Indonesia (CPI) in Mbay has generally operated effectively and optimally underpins flock productivity. This is directly evidenced by the robust production performance metrics achieved, notably a Feed Conversion Ratio (FCR) of 1.33, a relatively low mortality rate of  $\pm 3.13\%$ , and an average final market weight of 1.86 kg/bird at 33 days of age. These accomplishments indicate that the synergistic application of housing management, feed management, strategic supplementation, and the integrated contract farming system has been highly efficacious in elevating overarching broiler productivity.

This study makes a significant scientific contribution by presenting a holistic evaluation of various rearing management aspects—encompassing housing, feed, biosecurity, waste, and marketing management—alongside their correlation with production performance within a contract broiler farming framework. This approach provides a highly comprehensive perspective on the implementation of rearing management practices at broiler farms in the East Nusa Tenggara region, an area that remains relatively underrepresented in prior empirical literature.

On a practical level, the findings of this study serve as an evaluative framework for farmers to enhance the implementation of biosecurity measures and waste management practices, thereby supporting flock health and ensuring the long-term sustainability of the enterprise. Furthermore, for the integrator company, these insights can be leveraged as a foundational basis to fortify technical guidance and extension services provided to partner farmers, particularly concerning strict adherence to sanitation, biosecurity protocols, and waste management practices in accordance with standard operating procedures.

It is recommended that subsequent studies incorporate a broader sample of partner farms exhibiting diverse characteristics, utilize longitudinal data spanning multiple rearing cycles, and employ rigorous statistical analyses to more profoundly evaluate the factors dictating broiler production performance. Furthermore, economic dimensions, animal welfare parameters, and environmental sustainability warrant thorough investigation to formulate highly comprehensive recommendations for the strategic advancement of commercial broiler farming enterprises.

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## Optimization of Home Yards through Chili Cultivation Using Planter Bag Media in Makam Village

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### Abstract

The utilization of home yards as productive spaces represents a strategic effort to support household food security. In Desa Makam, Rembang Subdistrict, Purbalingga Regency, yard potential has not been fully optimized for food crop cultivation, while the need for chili as a daily consumption commodity still depends on market purchases. This program aims to optimize home yards through chili cultivation using flexible and practical planter bag media. The implementation method included observation and preparation, educational socialization, training and planting practice, as well as mentoring and evaluation. A participatory approach was applied by directly involving community members. The results indicate that the program aligns with village conditions and improves community understanding of chili cultivation techniques and the use of planter bags that support root growth through a well-aerated system. Community responses showed active participation and positive acceptance of the introduced innovation, although independent implementation still requires an adaptation process. Overall, this program serves as an initial step toward optimizing home yards to strengthen household food self-sufficiency, which requires continuous assistance for sustainable development.

**Keywords:** *Chili, Yard Intensification, Household Food Security, Community Empowerment, Planter Bag.*

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## 1. INTRODUCTION

Makam Village is situated in the Rembang Subdistrict, Purbalingga Regency, Central Java Province. Geographically, the village encompasses a relatively extensive area, with land use predominantly characterized by rice fields and residential settlements. It is bounded by Panusupan Village to the north, Sumampir Village to the east, Wanogara Kulon Village to the south, and Rajawana Village to the west. Administratively, Makam Village is partitioned into five hamlets: Hamlet I, Hamlet II, Hamlet III, Hamlet IV, and Hamlet V (Makam Village Government, 2016).

Makam Village covers a total area of approximately 671 hectares (6.71 km<sup>2</sup>). Administratively, the village is subdivided into several Community Units (RW) and Neighborhood Units (RT), accommodating a total population of around 10,144 individuals, comprising 5,189 males and 4,955 females. Based on these demographic figures, Makam Village is classified as an area of moderate

population density, characterized by a relatively diverse sociodemographic profile (Makam Village Government, 2025).

The territory of Makam Village extends beyond residential zones, encompassing productive agricultural lands that serve as the primary source of livelihood for the majority of its inhabitants. Spatial mapping of the village reveals the presence of various public amenities, including recreational fields, public pools, and several cemeteries distributed across multiple hamlets. Intra- and inter-village accessibility is supported by a network of main and local roads connecting the hamlets with one another and with neighboring villages, thereby facilitating community mobility for daily activities. Given these geographical and infrastructural conditions, Makam Village possesses significant potential for agricultural advancement, optimized land utilization, and the further development of public infrastructure to enhance community welfare (Makam Village Government, 2016).



Figure 1. Map of Makam Village

Figure 1 illustrates the administrative map of Makam Village, delineating its territorial boundaries, road networks, and the spatial distribution of various facilities and residential areas. Topographically, the village exhibits an elongated spatial configuration extending from north to south, predominantly characterized by green zones that denote open spaces, agricultural lands, or vegetative cover.

The village road network interconnecting the hamlets significantly enhances residents' mobility in conducting daily routines, particularly agricultural and local economic endeavors. Such infrastructural conditions underscore Makam Village's substantial potential for sustainable regional development, encompassing agricultural advancement, the community-based economy, and village-led environmental management.

The territorial potential of Makam Village is distinctly illustrated through its potential map, which provides a comprehensive spatial overview of the village. Figure 2 presents this map, highlighting the specific locations of vital public amenities, encompassing governmental, educational, healthcare, religious, and commercial facilities, alongside other general public infrastructures. The presence of these diverse facilities and identified potentials indicates that Makam Village possesses adequate supporting infrastructure to sustain the socio-economic activities of its community.

Despite this substantial regional potential, spatial utilization at the household level remains suboptimally leveraged as a strategy to bolster household food security. Specifically, residential front yards constitute private spaces spatially proximate to daily routines, thus offering significant potential for optimization to reinforce food resilience.

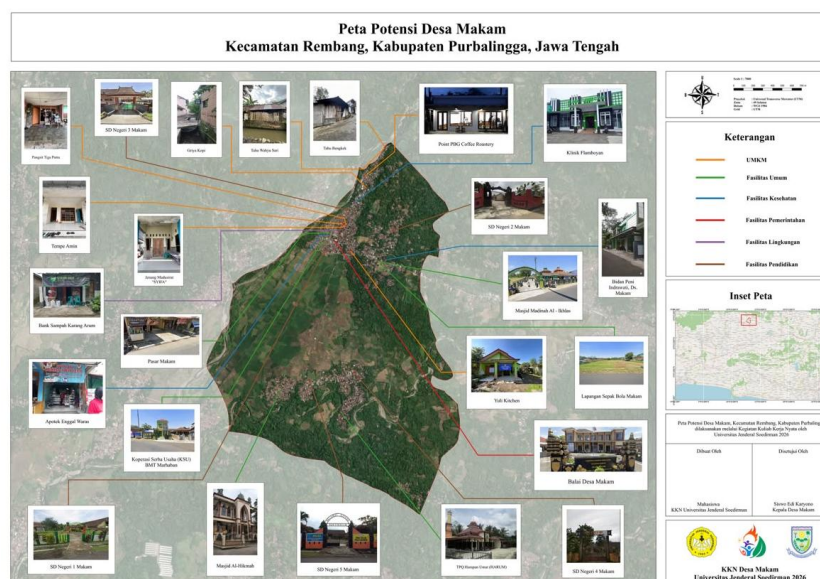


Figure 2. Potential Map of Makam Village

Although these areas present considerable opportunities for productive utilization, they are typically relegated to serving merely as access points and aesthetic features, whereas food crop cultivation has yet to emerge as a widely adopted practice.

The underutilization of these spaces for food provisioning in Makam Village is not necessarily attributable to spatial constraints or aesthetic concerns; rather, it is predominantly driven by a lack of interest, awareness, and established habits regarding home-based cultivation. Front yards are frequently associated with notions of neatness and visual appeal, leading to the perception that cultivating food crops is incongruous with the intended function of such spaces.

Conversely, household food requirements are perpetual, constituting an integral component of the community's daily life. Among various food commodities, chili pepper exhibits a notably high consumption rate. As a staple ingredient, it is virtually ubiquitous in diverse culinary preparations, forming an indispensable element of societal dietary patterns. According to Cahyani [2], the supply of domestically produced chili tends to demonstrate annual stability. Specifically, in 2022, cayenne pepper production increased by 157.99 thousand tons (11.4%) compared to 2021; concurrently, household consumption of cayenne pepper rose by 41.51 thousand tons (7.86%) over the same period. However, fulfilling this demand remains heavily reliant on market supply, thereby exposing households to frequent price fluctuations [9]. This market dependency directly impacts household expenditure. During periods of price inflation, the community lacks viable alternatives, compelling them to purchase at elevated prices. Such circumstances indicate that the current approach to meeting household food requirements remains passive and heavily contingent upon external factors. Consequently, deliberate efforts are required to foster household food self-sufficiency through the optimization of available domestic spaces, particularly residential front yards.

Makam Village represents a rural setting endowed with substantial household spatial potential, particularly concerning residential front yards. The majority of dwellings in the village feature relatively open yards, presenting conditions highly conducive to productive utilization. Nevertheless, these spaces remain suboptimally managed, predominantly serving as mere transit zones, parking areas, or aesthetic elements lacking distinct productive utility. Transforming these front yards into productive home gardens constitutes a highly relevant strategy for bolstering household food security.

Furthermore, the utilization of planter bags serves as a viable approach to optimizing residential front yards for food crop cultivation. These containers offer inherent flexibility and portability, thereby

eliminating the necessity for permanent soil tillage. This method enables agricultural activities to be conducted in a highly organized and visually structured manner, rendering it particularly suitable for front yard application. Previous research by Siregar and Syahputra [11] demonstrates that the selection of cultivation media is a critical determinant influencing the vegetative growth and productivity of chili pepper plants. Media characterized by adequate aeration, sufficient water retention capacity, and optimal space for root proliferation can significantly enhance plant development compared to poorly drained alternatives. Consequently, the adoption of planter bags emerges as a highly suitable alternative for home garden cultivation, as it establishes a more optimal rooting environment. The preference for this medium is further substantiated by practical considerations, including societal habits, aesthetic perceptions, and the physical spatial conditions of residential front yards. Moreover, planter bags facilitate highly controlled drainage management; their porous fabric material allows for natural water permeation, thereby preventing waterlogging and subsequent root rot [6].

The chili pepper cultivation initiative, utilizing planter bags as a flexible and practical cultivation medium, was selected as the core activity for the Student Community Service (Kuliah Kerja Nyata / KKN) program. This selection was primarily driven by its ease of implementation, which circumvents the need for permanent soil tillage while preserving the aesthetic integrity of residential front yards. Ultimately, this initiative is envisioned to optimize household spatial potential while concurrently fostering sustainable family food security.

## **2. METHOD**

The implementation method for the Student Community Service (KKN) initiative, focusing on the intensification of chili cultivation utilizing planter bags, was formulated to optimize residential yards in a pragmatic yet productive manner. The target demographic comprised members of the local women's social association (*ibu-ibu arisan*) within Neighborhood Unit (RT) 1 and Community Unit (RW) 3 of Hamlet II. The primary intervention was conducted on January 13, 2026, in Makam Village, Rembang Subdistrict, Purbalingga Regency. The program was executed through a systematic multi-stage framework encompassing initial preparation, community socialization, practical training on planter-bag-based chili cultivation, and subsequent monitoring and evaluation. A participatory approach was adopted, ensuring that the community did not function merely as passive recipients, but was actively engaged throughout every phase of the implementation process.

### **2.1. Preparation Phase**

The preparatory phase was undertaken prior to the implementation of the planter-bag-based chili cultivation intensification program. During this stage, the community service team conducted preliminary observations to assess the physical condition of the residential yards, their utilization potential, as well as the community's baseline knowledge and interest in chili cultivation. These observations were executed through direct field assessments within the village, coupled with interpersonal consultations with village officials and local residents. The findings derived from these preliminary assessments served as the foundational basis for designing the structural framework and operational stages of the program, ensuring rigorous alignment with the specific needs and socio-environmental conditions of the Makam Village community.

### **2.2. Socialization and Education Phase**

The socialization and educational phase elucidated the imperative of optimizing residential yards to ensure household food security, particularly in the context of prevailing market dependencies for daily food provisions, notably chili peppers. This session emphasized that residential front yards—traditionally perceived primarily as aesthetic or social spheres—harbor strategic potential for development into productive spaces without compromising the dwelling's primary functions. Through

this outreach, the community was imparted with the understanding that transforming front yards into productive domestic gardens constitutes a pragmatic yet highly impactful measure to enhance household food self-sufficiency. Furthermore, this phase educated the participants on the operational mechanics of planter bags, highlighting their capacity to maximize spatial utility vertically, in stark contrast to conventional cultivation methods.

### **2.3. Training and Cultivation Practice Phase**

The training phase constituted the core component of the yard intensification program via planter-bag-based chili cultivation. During this phase, the community service team provided comprehensive theoretical explanations coupled with direct practical demonstrations of cultivation techniques. These encompassed seedling selection, planting media preparation, the planting process, and subsequent plant maintenance. The training was deliberately executed through a hands-on, practical approach to ensure that the participants could easily comprehend and replicate each procedural stage. The cultivation medium utilized during the training comprised a formulated mixture of soil, compost, and rice husks, strategically designed to produce a friable structure capable of ensuring optimal nutrient provisioning. This approach is corroborated by Nainggolan and Yanto [12], who reported that an appropriate planting media composition exerts a significant effect on chili plant growth by enhancing nutrient availability, maintaining media moisture retention, and facilitating robust root system development.

### **2.4. Monitoring and Evaluation Phase**

The monitoring and evaluation phase constituted the concluding stage of the initiative, focusing on continuous facilitation to periodically track vegetative growth parameters, specifically encompassing plant height, leaf count, and leaf area. The evaluation protocol was anchored in prior research findings, which indicate that optimal growth efficacy is achieved when plants are positioned within the third to fifth tiers of the planter bag system. Furthermore, the program's success indicators were quantified using fresh biomass and the harvest index, serving as robust reflections of the efficiency of nutrient partitioning to the economically valuable plant organs. As a strategic measure for sustainability, the community was encouraged to innovate and develop vertical farming designs to further enhance the future agricultural productivity of their residential yards.

The yard intensification program, implemented through planter-bag-based chili cultivation, serves as the flagship initiative of the Student Community Service (KKN) activities in Makam Village due to its direct impact on bolstering household food security. This program was conceptualized as a pragmatic and highly applicable intervention to mitigate the community's reliance on commercial market supplies for chili peppers, particularly amidst periods of price volatility.

The distinct advantage of this initiative lies in its pragmatic approach, which is meticulously contextualized to the specific socio-spatial conditions of the village. While the majority of residential dwellings feature relatively open front yards, these areas have largely remained unexploited for productive endeavors. By adopting planter bags—a flexible and practical cultivation medium equipped with superior aeration properties—the community is empowered to undertake crop cultivation without the necessity for permanent soil tillage or significant modifications to the spatial configuration of their residential yards.

This initiative is not solely driven by the objective of optimizing crop yields; rather, it fundamentally aims to foster a paradigm shift within the community regarding the conceptualization of residential yards as productive spaces. When implemented consistently, this intervention harbors significant potential to elevate household food self-sufficiency, alleviate daily financial expenditures, and catalyze the establishment of sustainable, household-scale cultivation practices.

### 3. RESULT

The yard intensification program, operationalized through planter-bag-based chili cultivation in Neighborhood Unit (RT) 1 and Community Unit (RW) 3 of Hamlet II, Makam Village, was formulated based on a situational analysis of the village, which identified the presence of underutilized residential yard spaces. Drawing upon preliminary observations and interactions with the community, it was noted that while residential yards had been utilized for food crop cultivation, a substantial portion of the populace preferred to maintain these spaces as open areas devoid of productive orientation. This condition underscores a latent developmental potential, even though such cultivation practices have not yet been integrated into the community's established daily routines.

Household food requirements, particularly chili peppers—a ubiquitous commodity in domestic culinary practices—remain entirely contingent upon commercial market procurement. This market reliance inherently predisposes households to price volatility, exposing them to significant vulnerabilities during periods of acute price inflation for chili peppers. Although household-scale cultivation is not geared toward mass production, leveraging residential yards for chili cultivation serves as a vital supplementary measure to fulfill daily consumption demands. The selection of planter bags as the primary cultivation vessel represents a strategic methodological adaptation to the specific environmental characteristics of the village. Planter bags provide inherent flexibility and logistical ease in the preparation and management of the cultivation media. This approach aligns with the findings of Wahyuni et al. [13], who posited that the specific type of planting medium exerts a pronounced effect on the early growth stages of chili seedlings. Media characterized by optimal porosity and adequate aeration capacity demonstrably enhance root proliferation and accelerate vegetative development. Consequently, the intrinsic properties of planter bags render them an optimal cultivation medium for chili production within spatially constrained residential yards. These containers accommodate a customized substrate mixture—comprising soil, compost, and rice husks—tailored to the specific nutritional demands of the crop, while simultaneously ensuring an efficient drainage mechanism. Predicated on these considerations, the initiative was conceptualized to introduce a yard intensification paradigm that is pragmatic, realistic, and highly congruent with the prevailing socio-cultural dynamics of the community.



Figure 3. Implementation of Home Yard Intensification Through Chili Cultivation in Planter Bags

Figure 3 illustrates the program's implementation, which was executed through two primary approaches: community socialization and the practical introduction of chili cultivation techniques. The socialization phase served as the foundational pillar, focusing on the dissemination of knowledge regarding the imperative of residential yard utilization, the introduction of alternative cultivation media, and technical elucidations on household-scale chili production. Supplementary educational materials

encompassed a comparative analysis of various cultivation receptacles—specifically planter bags, polybags, and repurposed plastic bottles—and their respective efficacies in facilitating root development. Furthermore, the session detailed the ideal formulation of the planting substrate, comprising a specified mixture of soil, compost, and rice husks.

The subsequent phase entailed the practical introduction of planting procedures, covering the fundamental stages of chili seedling cultivation. This continuum ranged from filling the planter bags with the formulated substrate and transplanting the seedlings, to routine maintenance protocols such as irrigation and fertilization. Although direct hands-on participation was subject to certain practical limitations, the technical instructions were conveyed systematically to ensure that the attendees acquired a comprehensive and lucid understanding of the complete cultivation process.



Figure 4. Hands-on Chili Planting in Planter Bags with the Women of RT 1/3

Figure 4 illustrates the community's response, demonstrating active participant engagement throughout the course of the intervention. This involvement was evidenced by the inquiries raised concerning plant maintenance techniques and potential cultivation constraints, alongside interactive discussions reflecting upon their prior planting experiences. Such robust participation signifies that the disseminated knowledge was highly pertinent to the community's needs and effective in capturing their interest. Furthermore, the innovative introduction of planter bags as an alternative cultivation medium garnered a highly favorable reception. The local residents appraised planter bags as being significantly more practical when compared to direct in-ground planting within their yards or the utilization of conventional polybags. Beyond their perceived practicality and flexibility, the deployment of planter bags confers distinct advantages from a biological growth perspective, as they facilitate superior air circulation and ensure the preservation of optimal soil aeration.

Nevertheless, the favorable reception of this innovation did not automatically culminate in immediate practical implementation. A significant majority of the community remained in the contemplative stage, evaluating the prospect of trial adoption. This phenomenon underscores that behavioral shifts in agricultural practices necessitate a temporal transitional period, particularly when the introduced activities are not yet embedded within established daily routines. Within this context, the success of the inaugural harvest assumes a highly strategic role. Should the early adopters achieve satisfactory yields, it functions as a potent intrinsic motivator to sustain and potentially scale up their cultivation capacity. Conversely, early-stage crop failure possesses the detrimental potential to dampen their enthusiasm for subsequent attempts. Consequently, the program necessitates continued, low-intensity facilitative support to ensure that emergent technical constraints are promptly and effectively mitigated.

## **4. MONITORING AND EVALUATION**

The monitoring and evaluation framework was purposefully designed to assess the efficacy of the yard intensification initiative—executed via planter-bag-based chili cultivation—alongside the community's cognitive comprehension and participatory engagement. The evaluation was conducted employing a comprehensive approach encompassing dimensions of theoretical knowledge, practical proficiencies, active participation, and the long-term sustainability of implementation at the household level.

### **4.1. Evaluation Methods**

The evaluation was conducted utilizing several methodological approaches, namely:

1. Direct observation of community participation during the socialization and training sessions, specifically noting their engagement in interactive discussions and hands-on planting exercises.
2. Brief interviews and reflective discussions with participants to ascertain their cognitive comprehension of chili cultivation techniques and planter bag utilization, alongside their perceptions of the program's prospective benefits.
3. Periodic monitoring of vegetative growth parameters, utilizing specific indicators such as plant height, leaf count, and overall plant vitality.
4. Comprehensive documentation of all programmatic activities to serve as empirical data for the subsequent analysis and evaluation of the initiative's progression.

### **4.2. Implementation Period**

The evaluation was conducted concurrently with the program's execution and extended into the post-intervention facilitation phase. Periodic monitoring was systematically carried out to ensure optimal plant development and to proactively identify any technical constraints encountered by the community.

The fundamental objective of this evaluation phase was to ensure that the initiative transcended mere socialization, ultimately delivering a tangible impact on the utilization of residential yards. Furthermore, the evaluation outcomes serve as an empirical baseline for continuous programmatic refinement and the formulation of subsequent innovations, aimed at optimizing household spaces in a highly productive and sustainable manner.

## **5. EVALUATION INDICATORS**

The key indicators utilized within this evaluation framework encompassed the following:

- A. The community's level of comprehension regarding the concept of yard intensification.
- B. The participants' capacity to accurately articulate the sequential stages of chili cultivation.
- C. Fundamental practical proficiencies in preparing the cultivation substrate and transplanting the seedlings.
- D. The community's response and intrinsic motivation to sustain independent cultivation practices.
- E. The initial phases of vegetative growth, serving as an empirical indicator of technical efficacy.

## **6. CONCLUSION**

The yard intensification program, executed through planter-bag-based chili cultivation in Neighborhood Unit (RT) 1 and Community Unit (RW) 3 of Hamlet II, Makam Village, was initiated in response to the suboptimal utilization of residential yards and the community's profound reliance on

commercial market procurement. This initiative proved highly pertinent to the local context, providing a pragmatic alternative for fulfilling daily household requirements by optimizing spatially constrained areas for productive endeavors. Through systematic socialization and practical introductory sessions, the intervention successfully elevated cognitive comprehension regarding chili cultivation techniques. Furthermore, it established planter bags as a flexible cultivation medium that effectively supports root proliferation via superior aeration properties. While the community exhibited a highly favorable reception and robust active engagement throughout the program, the transition toward independent implementation still necessitates a temporal adaptation process. Consequently, the long-term sustainability of this initiative dictates the need for continued facilitative support. Such ongoing assistance is imperative to ensure that the productive utilization of residential yards evolves into a consistent and sustainable practice capable of augmenting household food security.

### CONFLICT OF INTEREST

The authors declare no conflicts of interest related to the preparation and publication of this article.

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