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Generative AI-based Decision Support System for Detecting Palm Fruit Quality

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ABSTRACT

Indonesia's dominance as a global palm oil producer is challenged by the economic precarity of its 6.9 million smallholder farmers,dual threat to their sovereignty. The first is a structural asymmetry of information and weak bargaining power, making them vulnerable to subjective assessments of Fresh Fruit Bunch (FFB) quality, leading to unilateral price cuts and significant income losses. The second is mounting global market pressure to comply with sustainability standards (ISPO/RSPO), which act as non-tariff barriers through complex traceability and documented quality controls that are difficult for smallholders to meet. To address these challenges, this study designed and evaluated a generative AI-based Decision Support System (DSS) to provide objective analysis and strengthen farmers' decision-making capabilities. The methodology involved using few-shot prompting on the Gemini AI platform, with the system's performance then tested through a controlled technology intervention involving 20 smallholder farmers in South Lampung, a region with a high incidence of price disputes. Key findings indicate that the DSS, through real-time image analysis, can classify FFB maturity with a quantitative accuracy of 80%. Its implementation in the field consistently resulted in a 45% reduction in price disputes and an average increase in selling prices of 9-13%, as farmers utilized validation data from the system during negotiations. The technology achieved a high adoption rate of 80%, driven by increased farmer confidence and direct positive impacts on their income. In conclusion, this DSS has proven not only a valid technical tool but a crucial catalyst for economic empowerment, effectively bridging the information gap and empowering farmers for integration into a more equitable and sustainable global supply chain. Further research is recommended to test the system's scalability and generalization across larger populations in regions like North Sumatra or Kalimantan to validate its efficacy amidst diverse agronomic and socio-economic characteristics.

Keywords: Decision Support System, Economic Empowerment, Generative AI, Information Asymmetry, Technology Adoption

INTRODUCTION

Indonesia is a global leader in palm oil production, a strategic commodity that is the backbone of the national economy and a source of livelihood for millions of its people. This sector is unique in that around 40% of total national production is contributed by approximately 6.9 million smallholders, making them a critical

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component in the domestic and global supply chain (Hidayat *et al.* 2021). Despite their central role, these farmers consistently face structural and economic vulnerabilities. One of the main challenges is the asymmetry of information in the assessment of Fresh Fruit Bunch (FFB) quality. Without objective assessment tools, farmers often find themselves in a weak bargaining position, vulnerable to subjective assessments by buyers that can lead to arbitrary price reductions and significant income losses (Sihombing & Tandra 2019).

This situation is particularly pronounced in major production centers, one of which is Lampung. As one of the nation's palm oil hubs, smallholder farmers in Lampung are the driving force behind the regional industry. However, they face the same challenges: uncertainty in harvest quality assessment and pressure to comply with global sustainability standards such as the Indonesian Sustainable Palm Oil (ISPO) and Roundtable on Sustainable Palm Oil (RSPO). The complexity and cost of certification often act as barriers, further marginalizing smallholder farmers who lack resources (Brandi *et al.* 2015; Sinaga *et al.* 2024). To understand and address these challenges directly at the grassroots level, this study focuses its interventions on farming communities in South Lampung District. In response to these challenges, various technological interventions have been explored. Decision Support Systems (DSS), integrated with artificial intelligence (AI) such as computer vision, show great potential for objectifying the process of assessing agricultural product quality (Kurniawan *et al.* 2023; Tjahjadi *et al.* 2024). However, conventional AI models like Convolutional Neural Networks (CNN) typically require very large labeled datasets for training. This requirement poses a major challenge in agricultural environments like South Lampung, where collecting large-scale data is often impractical and costly (Rupanagudi *et al.* 2023).

This study introduces a new approach to bridge this gap by designing and evaluating a Generative AI-based DSS. Its key innovation lies in the application of few-shot prompting methodology, enabling the system to classify TBS maturity with high accuracy using only a few training images. Unlike data-intensive models, this approach offers a more practical, affordable, and scalable solution. By placing this technology directly in the hands of farmers, the system not only functions as a technical tool but also as a strategic catalyst for economic empowerment, aiming to address information asymmetry and strengthen farmers' bargaining positions in South Lampung.

Based on this background, the specific objective of this research is to design and develop an expert system using few-shot prompting on a Generative AI platform to classify TBS maturity based on real-time image analysis.

MATERIALS AND METHODS

Research Design

This study uses a quasi-experimental design with a technological intervention approach. This design involves measuring key variables before (pre-test) and after (post-test) the implementation of a Decision Support System (DSS) based on Generative Artificial Intelligence (Generative AI). This approach was chosen to evaluate the causal impact of the technology intervention on the accuracy of Fresh Fruit (FFB) classification, price disputes, and farmer income within the same group of participants.

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Location and Sample Selection

Field research was conducted in South Lampung Regency, Lampung Province, Indonesia. This location was strategically chosen because it is one of the centers of small-scale oil palm plantations with a high level of price disputes due to subjective assessments of the quality of Fresh Fruit Bunches (FFB).

The research sample consisted of 20 small-scale oil palm farmers (N=20) selected using purposive sampling techniques. The inclusion criteria for participants were: (1) being an independent farmer who actively sells FFB; (2) having a written history or personal report of frequent price disputes; and (3) being willing to participate in the entire research process, from initial data collection to the use of the application.

Materials

Hardware: Image data collection in the field is carried out using a mid-range smartphone commonly used by farmers, namely the Poco X7, which is equipped with a 50-megapixel main camera. This device was chosen to ensure that the system can operate on affordable and widely used hardware. Software: A native mobile application for the Android operating system was developed as the user interface (DSS). The application is designed with a simple workflow, allowing users to select and upload existing FFB images from their device gallery, then send them to the Google Application Programming Interface (API) endpoint for analysis. AI Model: The core component for image analysis is the multimodal large language model Gemini Pro (LLM). This model was developed by Google and is accessed through their official API. It was chosen for its advanced ability to understand and analyze the visual context of images accompanied by text-based instructions (prompts).

Research Procedures

The workflow in picture 1 begins when the user accesses the system. The first step is to enter multimodal input, where the user uploads an image of Fresh Fruit Bunches (FFB) and accompanies it with a prompt or text command. This combined input is then processed by a Large Language Model (LLM), which analyzes the image in the context of the instructions provided.

Once the analysis is complete, the system provides a response via the chatbot interface. This response includes the TBS ripeness classification results along with other relevant details. The final stage is user evaluation, which involves a conditional branch:

• If the user finds the response satisfactory (Yes), the workflow is considered complete.

• However, if the response is deemed unsatisfactory (No), the system will direct the user back to the initial stage to re-enter the image and prompt, allowing the analysis process to be repeated until a satisfactory result is obtained.

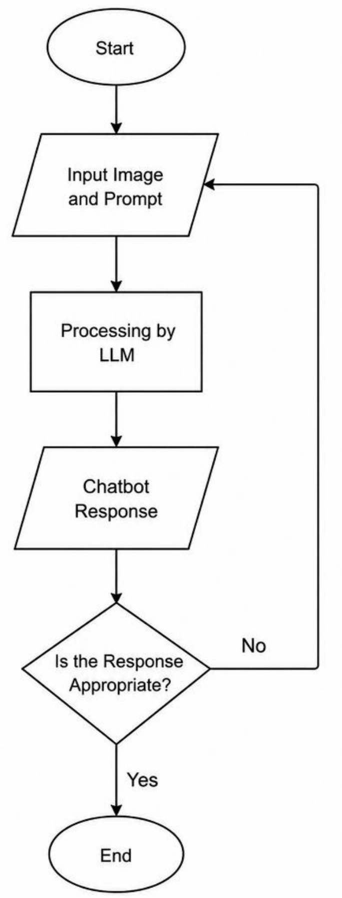

Figure 1 System Development Procedure

AI Implementation: Few-Shot Prompting

The implementation of AI does not involve training the model from scratch. Instead, the few-shot prompting method is used to guide the Gemini Pro model. A structured multimodal prompt is designed, consisting of three main components:

1. Instructions (Role and Tasks): Clear text commands that direct the AI to act as an expert FFB assessor. Example: “You are an expert in classifying Fresh Fruit Bunches (FFB) of oil palm. Based on the provided images, classify the FFB into one of three categories: ‘UNRIPE’, ‘RIPE’, or ‘OVERRIPE’.”

2. Examples (Shots): Several example images with correct classification labels for each category are included in the prompt to ‘teach’ the model. Example: [unripe_

ffb_image_1.jpg] -> UNRIPE, [ripe_ffb_image_1.jpg] -> RIPE, [overripe_ffb_image_1.jpg] -> OVERRIPE. Three to five examples for each category are used to build an effective prompt.
3. The Actual Question: New FFB images taken by farmers from the app are then attached at the end of the prompt as a question to be answered by the AI.

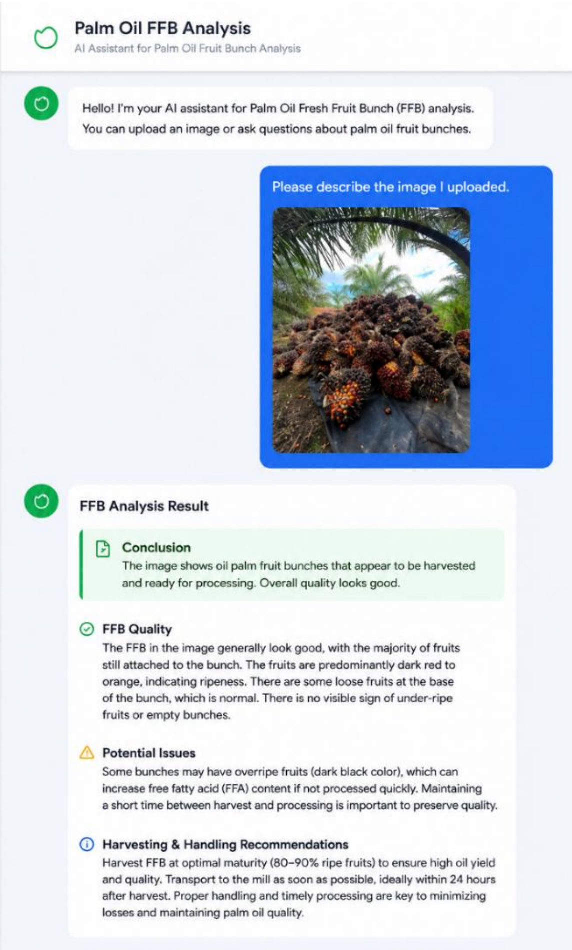

Figure 1 Prompt AI Analysis

Field Intervention Procedure

The field intervention procedure will be carried out from September 2024 to March 2025 and will be divided into four stages:
a. Initial Data Collection: During the first two months (January-February 2025), initial data will be collected from 20 farmers regarding the average selling price per kilogram and the frequency of price disputes they experience.
b. Training and Application Distribution: In early March 2025, a workshop session was held to train farmers in the use of the application. The training specifically covered the first steps of photographing FFB, then opening the DSS application to select and upload images from the gallery to obtain classification results.
c. Application Usage Period: From April 2025 to May 2025, farmers actively used the DSS application during FFB sales transactions. They were instructed to use the classification results from the application as an objective validation tool and negotiation support with buyers.
d. Final Data Collection: In June 2025, data on average selling prices and dispute frequencies were collected again. Additionally, post-intervention question-naires were distributed to measure the level of acceptance and adoption of the technology.

RESULTS AND DISCUSSION

Result System Classification Performance

The decision support system (DSS) based on generative artificial intelligence (AI) showed high performance in classifying the maturity level of fresh fruit bunches (FFB) in field test conditions. This system achieved 80% quantitative classification accuracy in identifying the correct maturity categories (unripe, ripe, and overripe), as shown in the table below.

Discussion

The results of this study indicate that a Decision Support System (DSS) supported by generative artificial intelligence can serve as a valid technical tool and an important catalyst for economic empowerment among small-scale oil palm farmers. A classification accuracy of 80% is a strong finding, demonstrating that the few-shot prompting approach with the Gemini Pro model is highly effective for this specific visual assessment task. This accuracy rate is comparable to that reported in studies using conventional data-intensive Convolutional Neural Network (CNN) models for fruit assessment (Kurniawan *et al.* 2023; Tjahjadi *et al.* 2024). However, the uniqueness and main advantage of our system lies in its implementation method. By eliminating the need for large, curated training datasets—a significant barrier highlighted by Rupanagudi *et al*. (2023)—the generative AI approach offers a more flexible, scalable, and cost-efficient solution for implementation in resource-constrained agricultural environments.

Table 1. Comparison Between Actual FFB Ripeness Condition and System Classification Results

No.	Farmer ID	Actual Condition	System Result	Test Result
1	P001	Ripe	Ripe	Correct
2	P002	Ripe	Ripe	Correct
3	P003	Unripe	Unripe	Correct
4	P004	Ripe	Overripe	Incorrect
5	P005	Overripe	Overripe	Correct
6	P006	Ripe	Ripe	Correct
7	P007	Unripe	Unripe	Correct
8	P008	Ripe	Ripe	Correct
9	P009	Unripe	Ripe	Incorrect
10	P010	Ripe	Ripe	Correct
11	P011	Overripe	Overripe	Correct
12	P012	Ripe	Ripe	Correct
13	P013	Unripe	Unripe	Correct
14	P014	Ripe	Ripe	Correct
15	P015	Overripe	Ripe	Incorrect
16	P016	Ripe	Ripe	Correct
17	P017	Unripe	Unripe	Correct
18	P018	Ripe	Unripe	Incorrect
19	P019	Overripe	Overripe	Correct
20	P020	Ripe	Ripe	Correct

*Notes:
Test Results Summary:
Total Tests: 20
Number of Correct Answers: 16
Number of Incorrect Answers: 4
Accuracy Rate: (16÷20) * 100% = 80%

The most significant implication of this research is its measurable socio-economic impact. By providing farmers with objective and easily understandable evidence regarding the quality of their harvests, the DSS effectively strengthens their bargaining power. This shifts the dynamics of price negotiations from being based on subjective assessments and power imbalances to being data-driven, thereby reinforcing the argument that technological tools can help smallholder farmers overcome non-tariff barriers and achieve fairer market integration (Brandi *et al.* 2015; Sinaga *et al.* 2024).

Additionally, the high adoption rate of 80% indicates that the technology is not only effective but also aligned with the needs and capabilities of end-users. This finding aligns with existing DSS literature, which states that user acceptance is highly influenced by perceived usefulness and ease of use

(Chen *et al.* 2024). The direct and immediate positive impact on farmers' income likely creates a strong positive feedback loop, encouraging continued use. The reported increase in farmers' confidence is a critical finding, albeit qualitative. This suggests that the value of DSS extends beyond mere data provision; it functions as an empowerment tool that enhances farmers' role in economic transactions. While these findings are promising, the study's scope is limited by sample size (n=20) and a single geographic location. Future research should aim to validate these findings in larger and more diverse populations of farmers across regions to assess the generalizability and scalability of the system.

Findings

The main findings of this study indicate that a generative AI-based Decision Support System (DSS) serves as an effective solution to the problem of information asymmetry faced by oil palm farmers. Technically, this system has been proven valid with its ability to classify the maturity of Fresh Fruit Bunches (FFB) with a quantitative accuracy of 80%. The implementation of this tool directly addresses issues at the transaction level, as evidenced by a significant 45% reduction in price disputes. Technology adoption among end-users is also very high, with an adoption rate of 80%, driven by increased farmer confidence. Collectively, these findings confirm that the DSS functions as a strategic tool that bridges information gaps and effectively strengthens farmers' bargaining positions within the supply chain.

CONCLUSION

Based on the research results, it can be concluded that the Decision Support System (DSS) based on Generative Artificial Intelligence (Generative AI) has been designed, implemented, and evaluated effectively. This system has proven capable of classifying the maturity level of Fresh Fruit Bunches (FFB) with high quantitative accuracy of 80%. Therefore, this research makes a significant contribution by demonstrating that accessible Generative AI technology, such as through few-shot prompting, is not only a valid technical tool but also an effective strategic instrument for bridging information gaps, strengthening bargaining positions, and ultimately enhancing farmers' economic sovereignty within the palm oil supply chain.

Suggestions for future researchers

Based on the findings and limitations of the current study, future research should focus on validating the scalability and generalization of the system by testing it on larger populations of farmers in various regions such as North Sumatra or Kalimantan. In addition, the model's analytical capabilities can be expanded beyond maturity classification to include disease detection or weight estimation. Longitudinal studies are also needed to measure the long-term economic impact more comprehensively. From a technological perspective, the development of an on-device version that does not depend on internet connectivity, as well as integration with supply chain platforms and sustainability certification (ISPO/RSPO), will be the next strategic steps to increase the adoption and impact of the system more broadly.

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