

## Sustainability of pepper cultivation in Lampung, Indonesia, with rap-pepper coordination techniques and pepper thresher technology

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**Abstract:** This study evaluates the sustainability of pepper cultivation in Lampung, Indonesia, using the Rap-Pepper multidimensional scaling (MDS) method and pepper threshing technology. Pepper is a strategic commodity, yet its sustainability faces challenges from declining productivity and post-harvest inefficiency. This research employs quantitative and qualitative methods, assessing five dimensions: ecological, economic, social, technological, and institutional. A pepper threshing tool was also designed and tested to improve processing efficiency. Results indicate a sustainability index of 64.95, categorized as "quite sustainable," with technological and institutional dimensions identified as the weakest aspects. The threshing equipment increased harvest efficiency by 40% and reduced seed damage by 15% compared to manual methods. Findings suggest that while technological innovation provides solutions, limited training and institutional support hinder widespread adoption. A significant policy model for increasing the index involves productivity-focused approaches, such as providing disease-resistant seedlings. The study concludes that sustainable development requires active government and private involvement to strengthen farmer capacity through education and incentives. These results serve as a reference for stakeholders to design strategies based on technological innovation and institutional strengthening to enhance productivity and farmer welfare.

**Keywords:** *Cultivation, Pepper thresher technology, Pepper, RAP-Pepper, Sustainability.*

### 1. Introduction

The plantation sub-sector has a strategic role in the national economy, especially in supporting the contribution of the agricultural sector to the Gross Domestic Product (GDP). In 2022, this subsector accounted for 40.12% of the total GDP of the agricultural sector, a figure much higher than the food crops, livestock, and horticulture subsectors. Plantation commodities not only function as the main driver of the local economy but also as a source of the country's foreign exchange through exports [1, 2]. One of the mainstay commodities is pepper (*Piper nigrum*), known globally as the "king of spices." Pepper is an essential ingredient in various industries, from culinary to pharmaceuticals, making it a high-value commodity in the international market. In Indonesia, Lampung has long been a center for black pepper production, which plays a major role in supporting the export of this commodity.

However, pepper productivity in Lampung is still relatively low compared to other regions, such as Bangka Belitung. Statistics show that the average pepper productivity in Lampung only reaches 0.46 tons/ha, while Bangka Belitung can produce up to 1.16 tons/ha. This inequality indicates serious challenges in pepper cultivation and management in Lampung. Additionally, the area of pepper plantations in this province decreased drastically by 24.25% from 2014 to 2020. The main factors causing this decline are land conversion for non-agricultural activities and increased plant disease attacks, such as stem rot and jaundice, which damage pepper plants [3]. This condition raises concerns about the sustainability of pepper cultivation in Lampung, both in terms of productivity and the cultivation area size.

Lampung, despite being a major producer of black pepper in Indonesia, faces significant sustainability challenges. One of the main obstacles is the fluctuating price of pepper in the global market. These fluctuations are influenced by supply and demand dynamics, as well as competition with other pepper-producing countries such as Vietnam, India, and Brazil. This price instability has a direct impact on the income of pepper farmers, who are often in a vulnerable position due to their weak bargaining power [4, 5]. Low pepper productivity is also a significant obstacle. Factors such as traditional cultivation techniques, pest infestation, and the lack of adoption of modern technology have worsened this situation.

The post-harvest process is also a challenge in itself. Most farmers still use traditional methods to harvest and process pepper, including manual threshing. This process is not only time-consuming but also increases the risk of pepper seed damage, thereby reducing the added value that farmers can obtain [6]. On the other hand, the monopsonic pepper marketing system, in which wholesalers or exporters control prices, makes farmers only price takers. This weakens farmers' motivation to increase the productivity and quality of their crops. Therefore, a thorough analysis of the sustainability of pepper cultivation in Lampung is needed to ensure the sector's sustainability amid global challenges.

Sustainability of aquaculture has been a concern in various previous studies. Climate factors in determining pepper productivity, such as rainfall and soil moisture, are significant. These results emphasize the importance of diversifying pepper products to increase added value and reduce risks due to price fluctuations. However, although the contribution of these studies is significant, the approach used is generally limited to certain aspects only, such as ecology or economics [7]. Multidimensional approaches, such as the Rapid Appraisal for Pepper Sustainability (RAP-Pepper), which can evaluate sustainability across ecological, economic, social, technological, and institutional dimensions, are still not widely applied. Especially in Lampung, research integrating multidimensional analysis with post-harvest technology evaluation, like pepper threshing equipment, remains very limited [8]. This creates a significant research gap, especially in addressing sustainability challenges holistically.

This research offers a new approach that integrates multidimensional analysis with technology evaluation to address the sustainability challenges of pepper cultivation in Lampung. The RAP-Pepper approach was used to evaluate sustainability based on five key dimensions, providing a comprehensive picture of current conditions [9]. In addition, this study also evaluates the effectiveness of pepper threshing equipment in improving the efficiency of the post-harvest process. This tool is expected to reduce the time and labor needed, as well as improve the quality of the pepper seeds produced.

The results of this study will not only provide an overview of the level of sustainability of pepper cultivation in Lampung but also strategic recommendations for the development of this sector. With the adoption of efficient and evidence-based technology, this research is expected to increase farmers' incomes, strengthen the institution of pepper cultivation, and open up new market opportunities, both domestically and internationally [10]. The developed sustainability model can also serve as a reference for local governments and other stakeholders in designing policies for the overall revitalization of pepper cultivation. This research aims to have a broad impact, not only at the local level but also nationally. By strengthening the competitiveness of Lampung pepper in the global market, this research contributes to the larger goal of maintaining the sustainability of the plantation subsector as one of the main pillars of the Indonesian economy.

## 2. Materials and Methods

This study uses a combination of quantitative and qualitative approaches to evaluate the sustainability of pepper cultivation in Lampung Province, Indonesia. The focus of this research includes sustainability analysis using the Rapid Appraisal for Pepper Sustainability (RAP-Pepper) technique and evaluation of the effectiveness of pepper threshing equipment as an innovative technology. The research location includes three districts of pepper production centers, namely Tanggamus Regency, East Lampung, and North Lampung. The sample was determined using the purposive sampling method, with a total of 105 respondents (35 respondents per district). The data used includes primary and secondary

data. Primary data were obtained through structured interviews, field observations, and experiments with pepper threshers. Secondary data are taken from official reports, scientific journals, and government statistics related to pepper cultivation in Lampung.

### 2.1. Analysis of the Sustainability of Pepper Cultivation with RAP-Pepper

The RAP-Pepper approach evaluates the sustainability of pepper cultivation across five main dimensions: ecological, economic, social, technological, and institutional. This analysis employs the Multidimensional Scaling (MDS) method to calculate the sustainability index. The index is generally formulated using the Multidimensional Scaling (MDS) method, which is designed for this purpose.

$$SI = \left( \frac{\text{Actual dimension score}}{\text{Maximum dimension score}} \right) \times 100 \quad (1)$$

- SI: Sustainability index
- Actual score of the dimension: the result of calculating the score of each dimension (ecological, economic, social, technological, institutional).
- Dimension maximum score: The maximum possible value achieved on each dimension
- The results of the IK are then categorized into:
  - Unsustainable:  $IK < 50$
  - Fairly sustainable:  $50 \leq IK \leq 75$
  - Highly sustainable:  $IK > 75$

The following is the application of Rap-Pepper coordination techniques through the multidimensional scaling (MDS) method in the pepper cultivation process in Figure 1.



**Figure 1.** Pepper coordination technique through the multidimensional scaling (MDS) method.

### 2.1. Evaluation of the Effectiveness of Pepper Thresher Technology

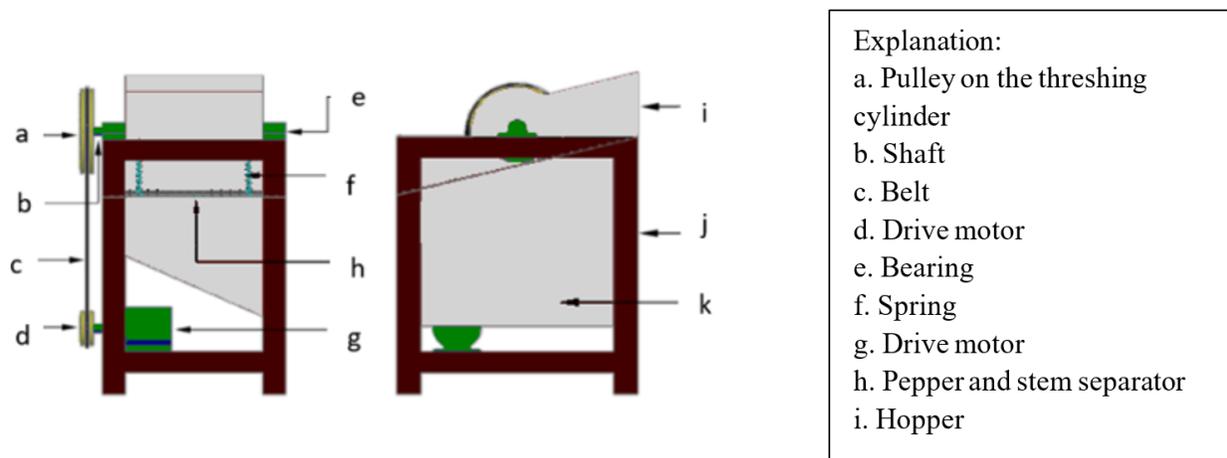
The effectiveness of the pepper threshing tool was tested by comparing harvest time efficiency, pepper seed damage rate, and productivity per labor between manual methods and the pepper thresher. The time efficiency formula used is:

$$E = \frac{P_a}{P_m} \times 100 \quad (2)$$

Where:

- E: Effectiveness (%)
- P<sub>a</sub>: Performance of the threshing machine
- P<sub>m</sub>: Performance using the manual method

The design of the image of the pepper threshing tool used in this study is shown in Figure 2 below:



**Figure 2.**  
Pepper Thresher.

### 3. Results and Discussion

#### 3.1. Analysis of the Sustainability of Pepper Cultivation with RAP-Pepper

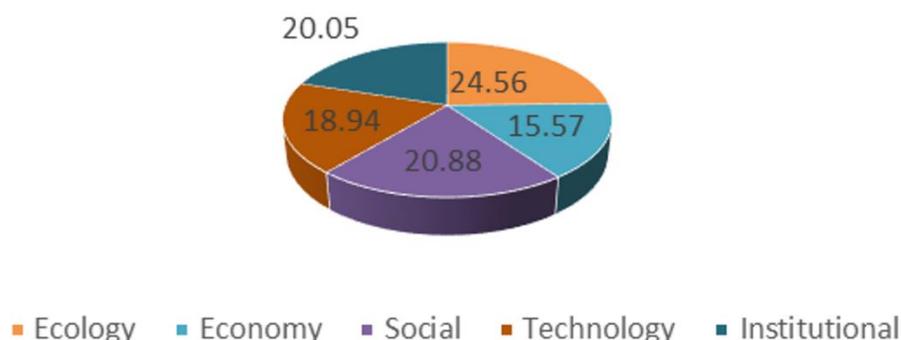
The RAP-Pepper technique, using the Multidimensional Scaling (MDS) method, is a sustainability evaluation approach emphasizing rapid analysis across ecological, economic, social, technological, and institutional dimensions. Its main goal is to understand the relationships among factors affecting pepper cultivation's sustainability and to identify priorities for strategy development [11]. MDS is used to map the complexity of data in two-dimensional spaces, allowing visualization of the level of similarity or difference between locations, groups, or sustainability indicators. By using RAP-Pepper, farmers can more quickly take necessary steps to improve sustainability in the pepper sector. Based on data findings from research on pepper cultivation in Lampung, Indonesia, the following data were found:

**Table 1.**  
RAP-Pepper Sustainability Index.

Dimension	Sustainability Index	Information
Ecology	79.75	Highly Sustainable
Economics	50.57	Fairly Sustainable
Social	67.81	Fairly Sustainable
Technology	61.50	Fairly Sustainable
Institutional	65.12	Fairly Sustainable

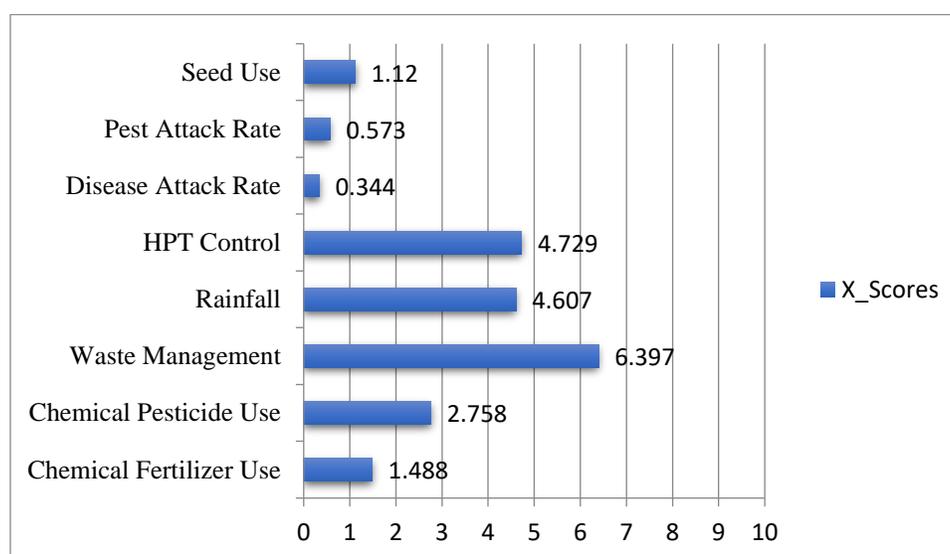
Based on Table 1, the RAP-Pepper sustainability index indicates that pepper cultivation in Lampung, Indonesia, demonstrates varying levels of sustainability across five dimensions. The ecological dimension shows the highest sustainability index (79.75), categorized as highly sustainable, suggesting that environmental conditions and natural resource management strongly support pepper cultivation. The economic dimension records the lowest index value (50.57), classified as **fairly** sustainable, indicating moderate economic viability and highlighting the need for improvements in market access, price stability, and farmers' income. The social dimension achieves an index of 67.81, reflecting fairly sustainable social conditions, including community participation and labor availability.

Similarly, the technology dimension (61.50) and the institutional dimension (65.12) are both categorized as fairly sustainable, suggesting that technological adoption and institutional support exist but remain suboptimal. Overall, these findings imply that while ecological sustainability is well established, strategic interventions are required, particularly in the economic, technological, and institutional dimensions, to enhance the overall sustainability of pepper cultivation. Of the five dimensions, the sustainability composition for each dimension can be seen in the following graph:



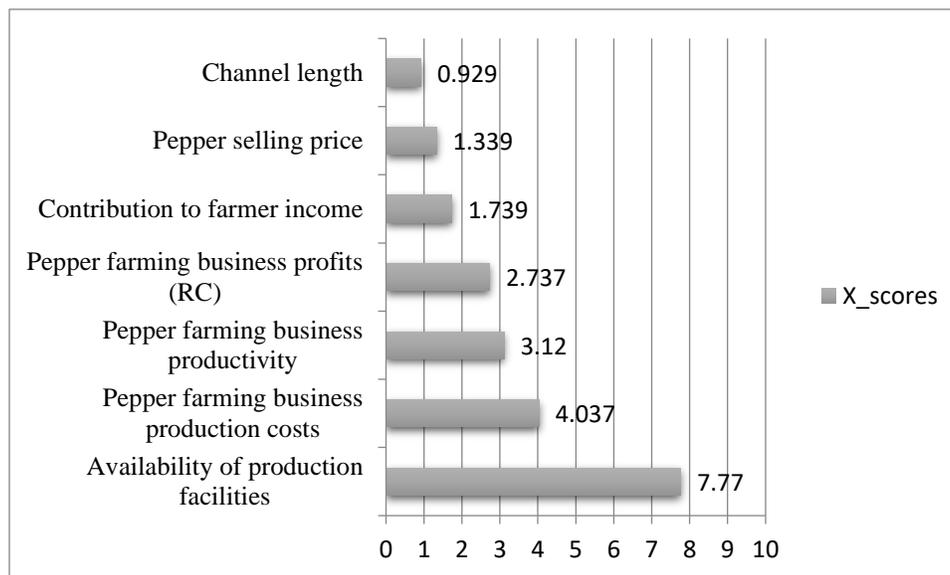
**Figure 3.**  
Distribution of the Dimensions of the Pepper Sustainability Index.

The RAP-Pepper approach was used to evaluate the sustainability of pepper agribusiness based on five main dimensions, namely ecological, economic, social, technological, and institutional. The results of the analysis show that each dimension has a different level of sustainability, with the index score calculated using the Multidimensional Scaling (MDS) method. Based on the results of the evaluation, the ecological dimension has the highest sustainability index, which is 79.75, and is included in the "Highly Sustainable" category. This shows that environmental aspects, such as land sustainability, planting patterns, and soil and water health, have been well maintained. Optimal environmental management is essential in supporting the sustainability of pepper agribusiness, as a healthy ecosystem will ensure pepper productivity in the long term [12, 13]. For more details, please refer to the following image:



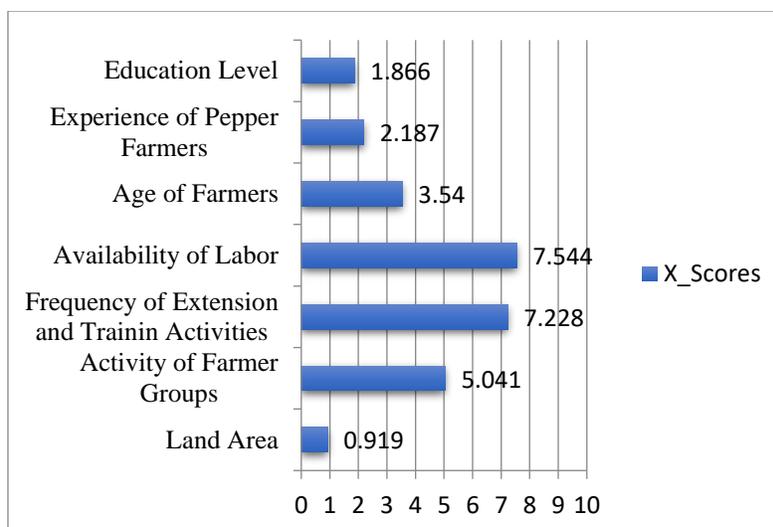
**Figure 4.**  
Sensitive attributes of the ecological dimension of pepper cultivation

On the other hand, the economic dimension has a sustainability index of 50.57, which is in the category of "Fairly Sustainable." These dimensions include indicators such as pepper productivity, selling price in the market, and production costs. Although quite good, there is still room for improvement, especially in improving the cost efficiency and price stability of pepper in the market [14]. The economic dimension is very important because it affects the welfare of farmers and the competitiveness of pepper as a superior commodity. For more details, please refer to the following image:



**Figure 5.**  
Sensitive attributes of the economic dimension of pepper cultivation

The social dimension recorded a sustainability index of 67.81, also in the "Fairly Sustainable" category. This dimension involves community engagement, environmental awareness, and gender equality. This result shows that there is quite good community participation, but it needs to be improved so that the benefits of pepper agribusiness can be felt more evenly. Increasing community engagement programs and environmental awareness campaigns can be a strategic step [15]. Furthermore, the technology dimension has a sustainability index of 61.5, which is also classified as "Fairly Sustainable." This reflects access to technology, training, and the use of modern tools that are quite adequate. However, the development of more innovative technologies and the expansion of access, especially to remote areas, are steps that need to be taken to encourage the efficiency of pepper production. For more details, the supporting factors of the social dimension can be seen in the following graph:



**Figure 6.**  
Sensitive attributes of the social dimension of pepper cultivation.

Finally, the institutional dimension has a sustainability index of 65.12, which is in the "Fairly Sustainable" category. This dimension includes government support, regulation, and market access. These results show that institutions have a significant role in supporting the sustainability of pepper agribusiness. To further improve sustainability, it is necessary to strengthen regulations, policies that favor farmers, and facilitate wider market access. This analysis indicates that pepper cultivation has a fairly good sustainability, with the ecological dimension as the most prominent aspect [14]. However, the economic, technological, and social dimensions still require more attention to achieve a higher level of sustainability. With an integrated approach, the sustainability of pepper agribusiness can continue to improve to ensure business continuity and farmers' welfare.

### 3.2. Evaluation of the Effectiveness of the Pepper Thresher

This study shows that the use of pepper threshing equipment provides a significant increase in efficiency compared to manual methods. Based on the data obtained, the average harvest time using a pepper threshing tool is 12 hours per hectare, faster than the manual method, which requires 20 hours per hectare [15]. Here are the uses of pepper threshers:



**Figure 7.**  
Use of pepper threshing tools.

Based on Figure 7, here are the steps to use the pepper threshing tool with the arrangement of tools as described:

#### 1. Tool Preparation

Make sure all components are properly installed: Check the pulleys on the threshing cylinders, shafts, belts, bearings, springs, drive motors, hoppers, and frames to ensure nothing is loose or

damaged. Connect the drive motor to the power source: Make sure the drive motor can operate stably. Clean the appliance before use: Ensure the hopper, pepper and stalk separator, and pepper outlet are free of dirt or pre-harvest residues.

## 2. Charging Process

Put the harvested pepper stalks into the hopper (i). The hopper serves as the initial place to load the material. Make sure the pepper stalks are inserted gradually to avoid buildup that can interfere with the process.

## 3. Operation

Turn on the drive motor (g and d): The motor will rotate the pulley (a) and shaft (b) through the belt (c), driving the threshing cylinder. The belt is responsible for transferring power from the drive motor to the threshing cylinder. Check the threshing cylinder: This cylinder works to separate the pepper from its stalk through mechanical movement. The spring (f) maintains optimal pressure on the threshing cylinder, ensuring that the pepper stalks are properly processed without damaging the seeds.

## 4. Separation Process

Peppers that have been separated from their stalks will be moved through the pepper and stalk separator (h). This system helps to separate the clean pepper from the rest of the stalk or other material. The cleaned pepper will come out through the pepper outlet (k), while the remaining stalks will be disposed of separately.

## 5. Collection and Settlement

Collect the clean pepper that comes out through the channel (k) and check the quality of the results to ensure there are no stalks still mixed. Turn off the drive motor after the process is complete. Clean the tool: after use, clean the hopper, separator, threshing cylinder, and drain to maintain the tool in good condition.

## 6. Security and Maintenance

**Safety:** Ensure that the operator uses safety gear (gloves, masks, etc.) and maintains a safe distance while the tool is working. **Maintenance:** Perform regular checks on shafts, belts, bearings, and springs to ensure optimal long-term function of the tool.

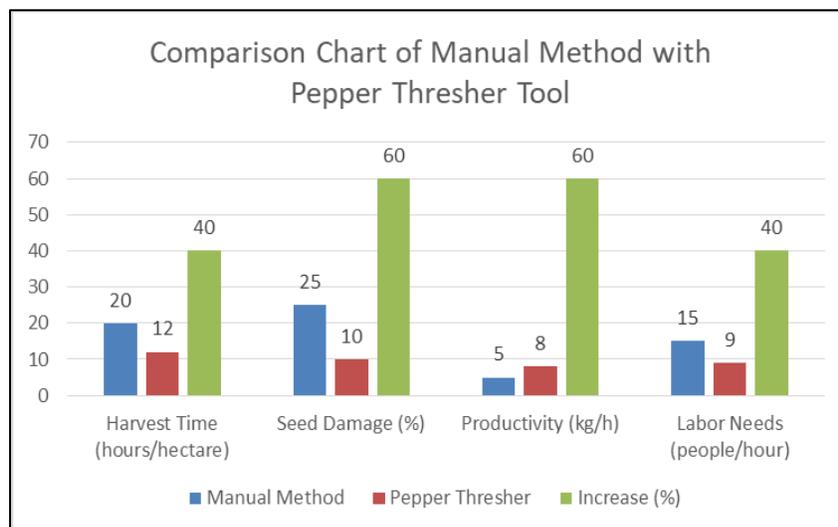
**Table 2.**

Comparison of Manual Methods and Pepper Threshing Tools

Indicators	Manual Method	Pepper Thresher	Increase (%)
Harvest Time (hours/hectare)	20	12	40
Seed Damage (%)	25	10	60
Productivity (kg/h)	5	8	60
Labor Needs (people/hour)	15	9	40

Table 2 presents a comparison between the manual method and the use of a pepper threshing tool based on key operational indicators. The results show that the application of the pepper thresher significantly improves overall processing efficiency. Harvesting time is reduced from 20 hours per hectare using the manual method to 12 hours per hectare when using the threshing tool, representing a 40% reduction in time. Seed damage also decreases substantially, from 25% under manual processing to 10% with the pepper thresher, indicating a 60% improvement in product quality. In terms of productivity, output increases from 5 kg/h to 8 kg/h, reflecting a 60% increase in productivity when the threshing tool is applied. Additionally, labor requirements decline from 15 to 9 people per hour, corresponding to a 40% reduction in labor needs. These findings demonstrate that the use of pepper threshing tools not only enhances efficiency and productivity but also minimizes post-harvest losses and labor dependency, thereby contributing positively to the technological and economic sustainability of pepper cultivation.

The bar diagram below illustrates the comparison between the manual method and the pepper threshing tool based on the main indicators:



**Figure 8.**  
Comparison Chart of Manual Method with Pepper Thresher.

This represents a time efficiency of 40%, as calculated using the following formula:

In addition to time efficiency, pepper threshing tools can significantly reduce pepper seed damage. Data shows that the seed damage rate in the manual method reaches 25%, while threshing tools result in only 10% damage. This reduction is crucial for improving pepper quality, especially to meet export market standards. Regarding productivity, the pepper threshing tool also performs better, with a productivity of 8 kg/hour compared to 5 kg/hour for manual methods. This 60% increase in productivity offers direct benefits to farmers by increasing production capacity, allowing them to boost yields with more efficient use of time and labor.

The use of pepper threshing equipment has a significant impact on efficiency and productivity in the harvesting process. Compared to manual methods, this tool has proven to be superior in various aspects, such as harvest time, seed damage rate, productivity, and labor requirements. One of the main benefits is time efficiency. The manual method requires about 20 hours per hectare to harvest pepper, while the thresher only requires 12 hours per hectare. This 40% reduction in time is very beneficial, especially during the harvest season. Farmers can process more pepper in less time, reducing the risk of damage or quality degradation due to pepper being in the field for too long. With this time efficiency, the crop can be processed or marketed immediately, increasing the profit potential [16].

In addition to time efficiency, pepper threshing tools also reduce the rate of seed damage significantly. In the manual method, the damage rate reaches 25%, while the use of the tool results in about 10% damage. This 60% increase in quality is very important for farmers who want to maintain the quality of their crops. Seed damage often occurs due to uneven pressure or human error in separating the pepper from the stalk. The threshing tool is designed to provide more precise pressure, so that the pepper seeds remain in shape and quality [17]. With high-quality pepper seeds, farmers can sell their crops at more competitive prices in the market.

In terms of productivity, pepper threshing tools provide much more optimal results. If the manual method can only process about 5 kilograms of pepper per hour, the threshing tool can increase productivity by up to 8 kilograms per hour. This 60% increase allows farmers to maximize crop yields simultaneously. Additionally, this higher productivity helps farmers meet market demand more quickly

and efficiently. At a large harvest scale, the ability to process more pepper per hour is crucial in supporting smooth operations and effective time management.

Another advantage of using a pepper threshing device is the reduction in labor requirements. The manual method requires about 15 people per hour to process the pepper, while the threshing tool only requires 9 people per hour. By reducing labor requirements by 40%, farmers can save on high operational costs. This reduction is especially beneficial for farmers who face labor limitations or want to reduce wage costs. Additionally, threshing tools also provide more flexibility in human resource management, as the harvesting process can be carried out by fewer people without reducing productivity.

While pepper threshing offers various advantages, challenges such as the initial investment cost may be a constraint for some farmers [18]. However, this can be overcome with strategies such as collective purchases within farmer groups or equipment rentals. Additionally, training on the use of the tool needs to be provided to ensure optimal use and minimize the risk of damage [19]. Pepper threshing equipment provides an efficient and cost-effective solution for farmers, improving crop quality, productivity, and reducing physical workload. By utilizing this technology, farmers can increase competitiveness in the market, optimize crop yields, and achieve sustainability in their agricultural ventures.

#### 4. Conclusions

This study evaluates the sustainability of pepper cultivation in Lampung, Indonesia, using the Rapid Appraisal for Pepper Sustainability (RAP-Pepper) method, which analyzes five main dimensions: ecological, economic, social, technological, and institutional. Additionally, this study assesses the effectiveness of pepper threshing equipment in improving harvesting efficiency and pepper yield quality. The analysis results show that the sustainability of pepper cultivation in Lampung is categorized as "fairly sustainable," with an average sustainability index value of 64.95. Among the five dimensions analyzed, the ecological dimension has the highest score (79.75), classified as "highly sustainable," indicating that the environmental conditions of pepper cultivation are quite good and sustainable. Conversely, the economic dimension has the lowest score (50.57), revealing ongoing challenges related to productivity, pepper selling prices, and farmers' welfare.

The technological and institutional dimensions are also fairly sustainable but require increased innovation adoption and policy support. One of the efforts to improve the sustainability of pepper cultivation is through the application of pepper threshing technology, which has been proven to increase harvest efficiency by 40% compared to manual methods. This tool is also able to reduce the damage rate of pepper seeds by up to 15%, increase productivity from 5 kg/hour to 8 kg/hour, and reduce labor needs by 40%.

However, the application of this technology is still limited due to the lack of training of farmers and limited access to these tools. To improve the sustainability of pepper cultivation in Lampung, a more integrated approach is needed. Governments and the private sector must play an active role in providing technology training, strengthening institutional regulations, and providing incentives for farmers to adopt agricultural innovations. In addition, policies that encourage increased productivity, such as the assistance of more resistant pepper seeds, have been shown to have a significant impact on the sustainability index. This research provides important insights for policymakers and stakeholders in designing sustainable pepper development strategies.

With a combination of technological innovation, increasing farmers' capacity, and strengthening institutions, pepper cultivation in Lampung can continue to grow, improve farmers' welfare, and strengthen Indonesia's position as one of the main pepper producers in the world.

## Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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