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OPTIMIZING REFUGIA PLANTING AREAS AND INCREASING THE FREQUENCY OF PREDATOR SIGHTINGS CAN INCREASE ENVIRONMENTALLY FRIENDLY AND SUSTAINABLE RICE PRODUCTION

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goodness of fit, indicator, predator, production rice, refugia

Abstract
Efforts to increase rice production in Indonesia are crucial due to the country's large population and heavy reliance on rice as a staple food. While chemical pest control has been widely used, it is costly and harmful to the environment. Therefore, alternative eco-friendly approaches, such as utilizing refugia plants and predators, are needed. This study aims to analyze the influence of refugia plants on predator presence and their impact on rice production. The research is conducted in Maleber, Kuningan Regency, West Java, Indonesia. Primary data collection takes place from July to December 2024, with processing in January 2025. This quantitative study employs a survey method with 120 randomly selected farmers who use refugia plants in rice cultivation. Data is analyzed using Structural Equation Modeling (SEM) with AMOS. The findings indicate a complete mediation effect, where refugia plants significantly influence predator presence (0.93), which in turn positively affects rice production (0.97). The most dominant indicator in refugia variables is the embankment area allocated for refugia planting (0.86), while in predator variables, it is the frequency of predator sightings (0.86). These results suggest that environmentally friendly and sustainable rice production can be improved by optimizing embankment areas for refugia planting and enhancing predator populations in rice fields.

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INTRODUCTION

Efforts to increase rice production in Indonesia are significant because of the large and majority population's food, rice. However, efforts to increase the production of paddy face various serious challenges, and one of them is the existence of attack pest plant rice, such as mice, brown planthoppers, chocolate, and borer stem. The Presence of attack pests has caused loss economic and non-economic issues Because of the impact on the decline results in harvest until puso (failure) harvest) (Umakamea et al., 2020). According to the Center for Forecasting Plant Pest Organisms (BBPOPT, 2020), the Ministry of Agriculture Republic of Indonesia reported that attack organisms that bully the main plant in the Rice in Season Rain (MT 2019/2020) in general national reaching 126,588.1 ha. Therefore, efforts to control pests that attack plant rice above to produce paddy can be maintained or increased. (Azhari et al., 2021).

Efforts to overcome attack pests have Been made, especially in a chemical way, namely with the use of pesticides. This method is very effective in the short-term but rated costly high and destructive environments, such as pollution of land and water (Pimentel, 1995), damage to biological diversity (Darimont et al., 2023; Gagic et al., 2016), and resistance pests (Septiani & Aminah, 2021). Therefore, other efforts are required to be assessed as adequate. However, it is a costly, cheaper, and friendly environment, namely, in a biological way, by utilizing refugia plants and the presence of predators.

Refugia is a flowering plant planted on the embankment or around the land area, and it functions as a habitat for predatory pest plants (Habibi & Fuadah, 2021). Therefore, refugia can bring in predators to help reduce population pests in a way that improves the diversity of life in land agriculture (Erdiansyah & Putri, 2017). Predators are organisms that eat, kill, or prey pest plants so that they can control population pest plants in a way experience (Froneman, 2022; Johnson & Belk, 2020; O'Bryan et al., 2018; Ristyadi et al., 2022). The utilization of refuge and predator plants to control the population of pest plant paddy has already been implemented by farmers throughout Indonesia. However, its implementation is Still limited by some farmer pioneers due to A lack of understanding farmer about the benefits of refugia and its low level of socialization by the parties related (Pribadi et al., 2020), including utilization of refugia in the Village Maleber Subdistrict Maleber Regency Kuningan, Province West Java, Republic of Indonesia.

Village Maleber is a rural area on the tall plains (Supendi et al., 2023)and has become one of the centers of rice production. Some farmer pioneers have utilized refugia plants as controller pest garden rice, and some big farmers have not yet implemented it. Based on the survey introduction to June 2024, know that farmers who have not utilized refugia plants due to Not yet understanding the benefits of refugia plants that can control pests and increase the production of rice require adequate socialization so that farmers can utilize refugia in assisting their business. Even though Already There is a number of results study previously raised about benefit refugia and predator plants to increase production rice , including : 1) Sakir & Desinta (2019) explain use of refugia can increase results harvest up to 15.1% compared to land that relies on pesticide chemistry; 2) Ristyadi et al., (Ristyadi et al., 2022), show that using predators as a biological control method can reduce crop losses due to pests while increasing overall production.; 3) Pribadi et al. (Pribadi et al., 2020) show that farmers have started to realize the dangerous application of pesticide chemistry in a way that keeps going continuously and improves understanding of the benefits of refuge plants in rice fields; 4) Pérez-Hedo et al. (2022), predators such as species zoophytophagy can increase production plant tomatoes and peppers; 5) Garcia et al., (2021), some species bird can increase production plants by pressing pest invertebrate plants; 6) Lemaire et al., (2023)predators play a role in increase fertility land and support productivity plant; and 7) O'Bryan et al., (O'Bryan et al., 2018), predators can increase production plants by controlling population pests.

Based on the results of the previous Study, it was known that the method of frequent data analysis used generally is descriptive and analytical regression. However, the method has several weaknesses, such as not being capable of explaining role indicators correctly. Therefore, this study used the Structural Equation Modeling (SEM) method with the help of the Analysis Moment of Structural (AMOS) application, which is assessed more effectively and specifically in explaining role indicators on the variables involved, especially for latent variables. This allows more recommendations to be directed, especially in biological efforts, such as using refugia and predator plants to increase rice production. The difference between this research and the research previously lies in the method of data analysis used, namely the application of SEM AMOS, so the research gap is raised in the form of a methodological gap due to the existence of different method analysis where amos sem method is assessed more well and comprehensive (Miles, 2017).

Based on previous studies, it is known that the commonly used data analysis methods are descriptive and analytical regression, but this method has limitations in explaining the relationship between variables in depth. Therefore, this study has a methodological gap, namely by adopting Structural Equation Modeling (SEM) using AMOS, which is considered more effective in explaining the role of latent variables more specifically and accurately (Mil, 2017). The novelty of this study lies in the use of the SEM-AMOS method to evaluate the effectiveness of refugia and natural predators in increasing rice production more comprehensively than previous approaches.

This study aims to analyze the relationship between the use of refugia and predators on increasing rice production with the SEM-AMOS approach, as well as evaluate the level of understanding and application of refugia by farmers. The benefits of this research include scientific aspects, namely enriching the literature on environmentally friendly pest control methods; economic, namely providing recommendations for pest management strategies that are more cost-effective than the use of chemical pesticides; and practical, namely increasing farmers' awareness of the importance of refugia in reducing the natural pest population. Thus, this research is expected to provide more appropriate policy recommendations in supporting sustainable agriculture and increasing rice production in Indonesia.

RESEARCH METHOD

This study uses a quantitative approach with a survey method to measure the relationship between the variables of the presence of refugia plants, the presence of predators, and rice production. This study aims to analyze the influence of the presence of refugia and predators on rice production in Maleber Village, Maleber District, Kuningan Regency, West Java Province.

This study is explanatory, which aims to explain the causal relationship between the independent variable (the presence of refugia) and the intermediate variable (the presence of predators) to the bound variable (rice production). All three variables are latent, so they are measured through specific indicators using the Likert Scale (5 = strongly agree to 1 = strongly disagree).

The data in this study were collected through two main sources:

1. Primary data was obtained through a survey using a structured questionnaire to 120 farmers who have used or have not used refugia as a pest control method. Sample selection was carried out by the purposive sampling method based on the criteria of farmers who have experience in rice farming systems and understand aspects of pest control.

2. Secondary data is obtained from literature studies, scientific journals, research reports, and official documents from related agencies that discuss the role of refugia and predators in the rice farming system.

Data analysis in this study uses the Structural Equation Modeling (SEM) approach with Analysis of Moment Structures (AMOS) software. This technique was chosen because it is able to test the relationship between latent variables in more depth and provides more accurate analysis results than the usual regression method.

Steps in data analysis include:

1. Likert Scale Transformation – Given that the Likert scale is ordinal, it is converted to an interval scale using the Method of Successive Interval (MSI) to qualify for SEM analysis.
2. Structural Model Testing – Model fit tests are carried out using Chi-Square, RMSEA, SRMR, GFI, AGFI, TLI, CFI, NFI, PNFI indicators to ensure that the model used is valid and can be used as a recommendation.
3. Hypothesis Testing – Hypothesis testing is carried out based on significance values (p-values) with the following criteria:
   a. If the p-value < 0.05, then the null hypothesis (H_0) is rejected, meaning that the presence of refugia and predators has a significant influence on rice production.
   b. If the p-value ≥ 0.05, then the null hypothesis (H_0) is accepted, meaning that the presence of refugia and predators does not have a significant influence on rice production.

RESULTS AND DISCUSSION

Results

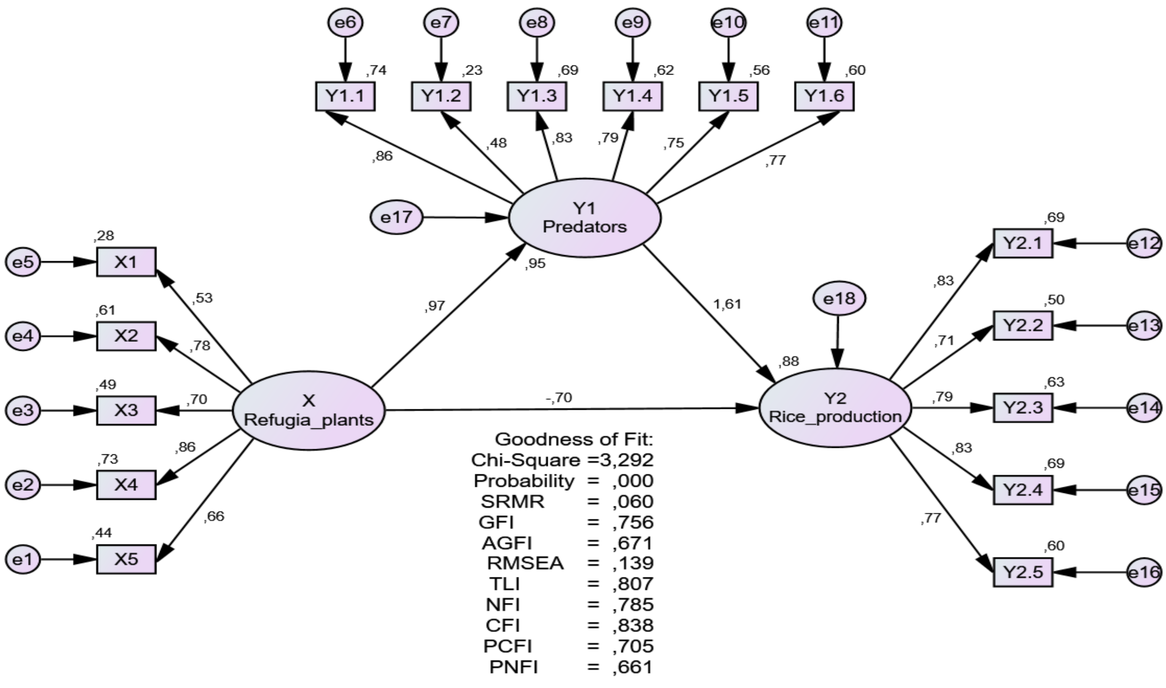

Figure 1. Goodness of fit in the X-Y1_Y2 model

Source: Primary data processed (2025)

Figure 1 shows value indicators in the goodness of fit test model) which can seen in Table 1.

Table 1. Goodness of Fit Indices and Cut-off Value

No	Goodness of Fit Indices	Cut-off value	Observation value	Information
1.	Chi-Square (CMIN/DF)	< 2.00	3,292	No, fit
2.	Probability	> 0.05	0,000	No, fit
3.	RMSEA	< 0.05	0.139	No, fit
4.	SRMR	< 0.08	0.060	Fit
5.	GFI	> 0.90	0.756	No, fit
6.	AGFI	> 0.90	0.671	No, fit
7.	TAG	> 0.90	0.807	No, fit
8.	CFI	> 0.90	0.838	fit
9.	NFI	> 0.90	0.785	No, fit
10.	PNFI	> 0.5	0.661	fit
11.	PCFI	> 0 .5	0.705	fit

Source: (Mulaik et al., 1989; Yanuar et al., 2015) and Primary data processed (Primary data processed, 2025)

Table 1 shows that part of the large (64%) value observation from the AMOS SEM output does not fulfill the mark standard (cut-off value), so this model does not fit. Therefore, a model modification must be made, and its results can be seen in Figure 3.

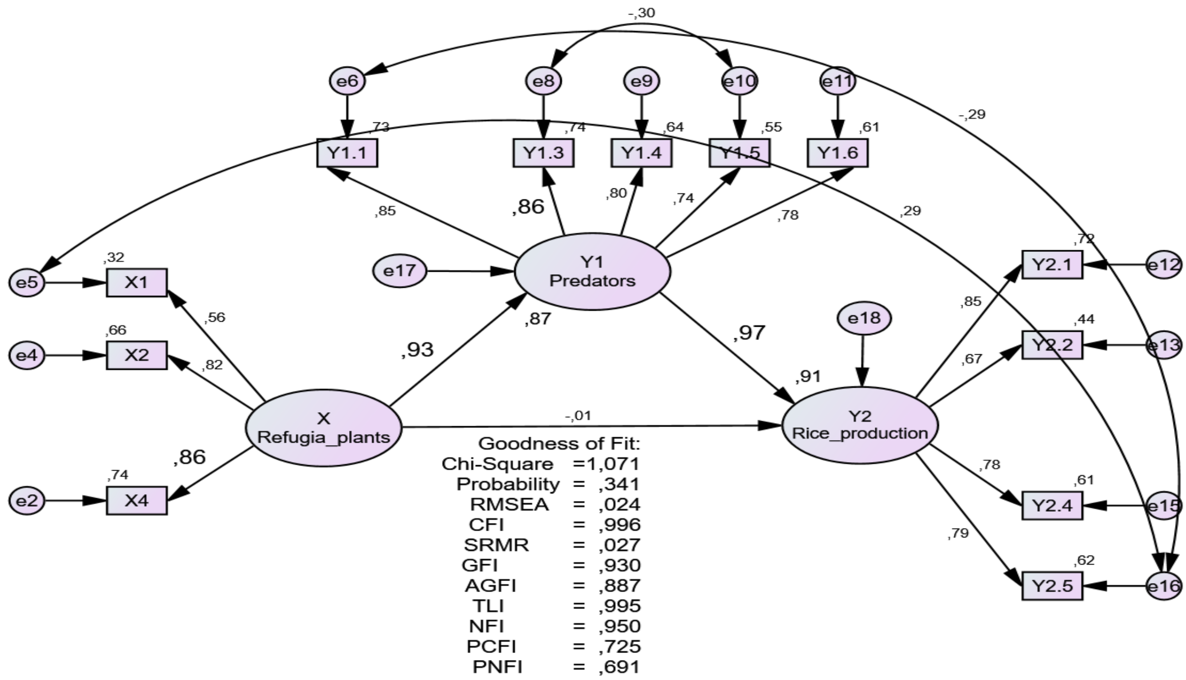

Figure 2. Modification of the X-Y1-Y2 fit model

Source: Primary data processed (Primary data processed, 2025)

Figure 2 shows the resulting structural model. from modification based on goodness of fit, which can be summarized and assessed, as in Table 2.

Table 2. Goodness of Fit Indices and Cut-off Value after Modification

No	Goodness of Fit Indices	Cut-off value	Observation value	Information
1.	Chi-Square (CMIN/DF)	< 2.00	1,071	Fit
2.	Probability	> 0.05	0.341	Fit
3.	RMSEA	< 0.05	0.024	Fit
4.	SRMR	< 0.08	0.027	Fit
5.	GFI	> 0.90	0.930	Fit
6.	AGFI	> 0.90	0.887	Fit
7.	TAG	> 0.90	0.995	Fit
8.	CFI	> 0.90	0.996	Fit
9.	NFI	> 0.90	0.950	Fit
10.	PNFI	> 0.5	0.691	Fit
11.	PCFI	> 0 .5	0.725	Fit

Source : (Mulaik et al., 1989; Yanuar et al., 2015) and Primary data processed (Primary data processed, 2025)

Table 2 shows that all mark observations from the SEM AMOS output have fulfilled the mark standard (100%), so the structural model obtained is fit and can be used for analysis. Hypothesis testing has been carried out to strengthen the existing model fit obtained, and the results can be seen in Table 3.

Table 3. Significance Influence the Presence of predators (X) on rice production (Y)

Influence between variables and reflective indicators			Estimate	SE	Probability*	Information
Y1_Predators	<---	X_Refugia_plants	,889	,087	0.005	Significant
Y2_Rice_production	<---	Y1_Predators	,972	,266	0.011	Significant
Y2_Rice_production	<---	X_Refugia_plants	-,012	,250	0.983	Significant
X4	<---	X_Refugia_plants	1,000			Significant
X2	<---	X_Refugia_plants	,926	,086	0.012	Significant
Y1.3	<---	Y1_Predators	1,008	,082	0.013	Significant
Y1.4	<---	Y1_Predators	,956	,087	0.013	Significant
Y1.5	<---	Y1_Predators	,873	,091	0.028	Significant
Y2.1	<---	Y2_Rice_production	1,000			Significant
Y2.2	<---	Y2_Rice_production	,751	,092	0.007	Significant

Influence between variables and reflective indicators			Estimate	SE	Probability*	Information
Y2.4	<---	Y2_Rice_production	,922	,090	0.007	Significant
Y2.5	<---	Y2_Rice_production	,927	,089	0.009	Significant
X1	<---	X_Refugia_plants	,638	,098	0.012	Significant
Y1.1	<---	Y1_Predators	1,000			Significant
Y1.6	<---	Y1_Predators	,911	,087	0.013	Significant

Source: Primary data processed (Primary data processed, 2025)

- Probability value using bootstrap standard (Alfons et al., 2022)

Table 3 shows that variable X (refugia plants) has a significant and positive on Y1 (predator presence), and variable Y1 has a significant and positive effect on Y2 (rice production). Variable X does not significantly influence variable Y2. Thus, hypotheses 1, 2, and 3 are proposed and accepted. Figure 3 also shows that in variable X, there is an indicator with the most considerable loading factor value, namely 0.86, and located on indicator X4 (area of embankment) rice fields), while the Y1 variable is also the same, namely 0.86 and is located on the Y1.3 indicator (frequency predator sightings). On both indicators, the most dominant in reflecting conditions of variables X and Y1. Therefore, these two indicators will also become the focus of recommendations.

Next to test The 4th hypothesis is that variable X has an influence No direct to the variable Y2 through Y1, then done by using Sobel test (Ramirez & Haas, 2021; Sofia et al., 2023; Wachdijono et al., 2023). The Sobel test method is used to test the significance of the mediating intervening variables between independent and dependent variables (Ghozali, 2011; Hair Jr et al., 2021), a test in this Study. Does the variable Y2 play a role? In a significant way or not, the result of mediating between variables X and Y2 can be seen in Figure 4.

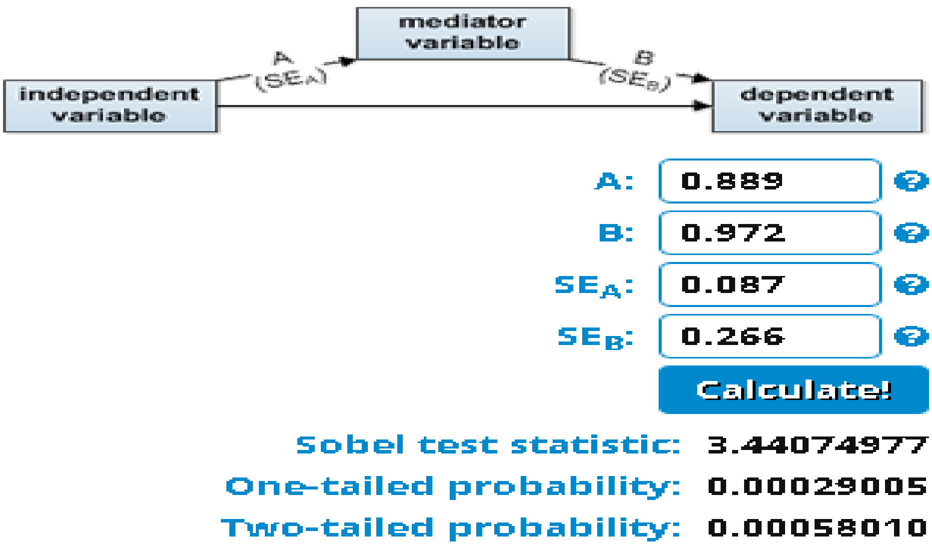

Figure 3. Sobel test for significance intervening variable

Source: Primary data processed (Primary data processed, 2025)

Figure 3 shows the value of one-tailed probability (0.00029) and two-tailed probability 0.00058) < 0.05, so it can concluded that the variable Y1 plays a role in a way significant and positive as an intervening variable. For that reason, it can explain the existence of influence No direct from variable X to Y2 through Y1. The Presence of predators has a real positive effect on rice production and can be accepted. Thus, the hypothesis stating that variable X has an effect Not directly on variable Y2 through variable Y1 **can accepted**.

Discussion

1. **Influence the existence of refugia plants (X) against the existing predators (Y1)**

   The Presence of refugia plants (X) has a significant and positive impact on the Presence of predators (Y1) in the field agriculture Village Maleber Subdistrict Maleber Regency Kuningan. The more substantial plants around the land area agriculture rice, the more predators come to the area. Interest in the refugia plant, according to Septiani & Aminah (Septiani & Aminah, 2021), because refugia plants produce nectar and pollen that become food for predators, so that becomes an interesting thing for predators, especially during periods when pests become prey Not available. Therefore, The existence of refugia plants can function as place protection and microhabitats for predators like spiders, ladybugs, and parasitoids, where these habitats help maintain predator populations, even when the population is currently low (Sakir & Desinta, 2019). Thus , the existence of refugia plants has an impact on reducing pesticide chemistry because predators can control population pests in a way that makes the ecosystem more awake (Habibi & Fuadah, 2021).

   On the other hand, refugia plants have enriched diverse life in land agriculture with an interest in insects and other organisms that play a role in maintaining the ecosystem, which helps create a more stable and healthy environment (Erdiansyah & Putri, 2017). Predators that protect their population with their existing refugia plants have the potential to prey on pest plants, such as leafhoppers, caterpillars, borer stems, and lice leaves, which directly decline population pests in a natural way (Pribadi et al., 2020).

   Remember, the existence of refugia plants in general statistics is a latent variable, and the most dominant indicator to explain the variable's condition is an indicator with the highest loading factor value (Hu & Bentler, 1999). Based on Figure 3, then the highest loading factor value is 0.86 and is located on the X4 indicator (area of the embankment) rice fields), meaning that the indicator is an indicator that must be noted to give recommendations technical to the perpetrator farming rice in order increase the Presence of predators. The X4 indicator shows that the wider the embankment rice fields designated for refugia planting, the more predators there are. As for the technical efforts to expand the embankment area ricefield referred to, among others:

   1) Manage areas or broad embankment rice fields for refugia planting:
      Use part of embankment rice fields that are not used optimally for planting refugia, such as flower knickers, flower the sun, or plant other supporting flowers in a natural predator ecosystem. Next, determine the proportion of the vast embankment rice fields planted with refugia sufficient to support natural predator populations (Froneman, 2022; Mustarin et al., 2023).
   2) Choose the right refugia plants:

Choose easy refugia plants to grow and survive in a conditioned environment, such as flowering fascinating little predatory insects (for example, flowers), footprint virgin, aster, and flowers sun). Besides that, sustainable refugia plants with cycle flowering should be used to support the Presence of predators throughout the season. (Habibi & Fuadah, 2021; Wardana et al., 2017).

3) Promote the importance of using embankment rice fields to plant refugia through training, seminars, or field examples. The steps provide a technical guidebook for planting refugia on embankment rice fields without disturbing rice cultivation. (Dinas Pertanian Kabupaten Buleleng Provinsi Bali, 2024; Ilhamiyah et al., 2020; Muhammad & Nasir, 2022).

2. The influence of predators (Y1) on the production of rice (Y2)

The Presence of predators (Y1) has a real and positive effect on rice production (Y2). This means that the more lots there are of predators, the more rice production will increase in the village Maleber Subdistrict Maleber Regency Kuningan. This is because predators can control population pests by preying on pests and planting paddy naturally, which can reduce damage to plant rice. Enemies - predators (spiders, ladybugs), parasitoids, and pathogens prey pest main plant paddy like leafhopper, borer stems, and lice leaves. Therefore, plant paddy can grow optimally and produce more production increases in quantity and quality. Predators work continuously during the season to ensure that population pests are controlled. Thus, the way to control pests in a way that is natural, more friendly, environmentally, and sustainable compared to controlling pests with pesticide chemistry, which often causes resistance pests in the long term length (Septiani & Aminah, 2021).

On the other hand, the Presence of predators positively impacts efforts to reduce the use of pesticide chemistry, which can reduce the cost of production. However, not only that, but it also improves quality production or results in the harvest of paddy because plants avoid pesticide residue (Pribadi et al., 2020). In this regard, Sakir and Desinta (Sakir & Desinta, 2019) explain that the Presence of predators helps guard the balance of ecosystem agriculture to create optimal conditions for plant rice growth, which can positively impact the stability and sustainability of rice production. This explanation is reinforced in a way concrete by results research-results study previously, such as: 1) Erdiansyah & Putri (Erdiansyah & Putri, 2017) conclude that land agriculture with stable predator populations can increase results harvest up to 15% taller compared to land that relies on pesticide chemistry; 2) Elvina et al., (2023) and Iannella et al., (2021) who concluded application of natural predators influential actual to improvement production and area of crops rice ; 3) Sakir & Desinta (Sakir & Desinta, 2019) which shows existence refugia plants can bring in predators as enemy natural and capable increase results production paddy by 15.1%; 4) Lemaire et al., (Lemaire et al., 2023) that predators play a role in increasing fertility land and recycling repeat nutrition, which is No direct support productivity plant; and 5) Ali et al., (Ali et al., 2019) explain Some predators, such as parasitoids and spiders, increase production paddy.

According to the research results above, the highest loading factor value on variable Y1 is 0.86 and is significantly located on the Y1.3 indicator (frequency) predator sightings). This indicator reflects predator activity in rice planting areas, so the more often predators are seen there, the more predators prey on pest plant rice. Therefore, it can reduce population pests in the field so that plants can grow in the way better than previously. Besides that, it also shows that the most dominant indicator to explain the condition of variable Y1 is Y1.3, which can become the basis for giving recommendations proper technical to farmers to increase production in a more rice-friendly environment and sustainability. There are several effort natural factors related to the Y1.3 indicator, including:

1) Plant refuge plants on the embankment or around the ricefield:

   Planting refugia on embankments or around ricefields can provide a place of residence and resources food for predators that attack pest plant rice. This has the potential to increase the number of predators that come and are seen on land agriculture (Froneman, 2022; Sakir & Desinta, 2019).

2) Do diversify plants (planting) various types of plants):

   Planting various types of plants around the agricultural area can create a more diverse environment that supports diverse life. This can also improve the natural predator population (Buchori et al., 2023).

3) Creating a natural habitat:

   Forming a natural habitat around land agriculture, such as bush, tree big and old, areas watery, swampy, or forest small, can provide place protection and resources food for predators, such as birds, spiders, dragonflies, insects predators, as well as aquatic (González-Chang et al., 2020; van Huis & Oonincx, 2017).

3. The Presence of refugia plants (X) does not directly influence the production of rice (Y2)

The Presence of refugia plants (X) does not influence the direct production of rice (Y2). In statistics, this is because the existence of other possible variables can accept influence directly from the existence variable refugia plants, which then influence the transmitted to production variables rice (Y2). Such conditions allow direct influence and influence No directly so that very open opportunity exists intervening variables in this structural model (Anas et al., 2023; Oktafiani et al., 2023; Prasetyo et al., 2023). The intervening variables mediate or explain the connection or influence between the independent and dependent variables (Ghozali, 2011; Jr. et al., 2017; Voorveld et al., 2018). To determine whether or not there are intervening variables in this model, a Sobel test was carried out, as can be seen in Figure 4 above.

4. The Presence of refugia plants (X) has no direct effect on the production of rice (Y2) through the presence of predators (Y1)

Figure 4 shows that variable Y1 (the Presence of predators) plays a role in a way real as an intervening variable so that it can explain the occurrence influence No direct from variable X to Y2. This means that the improved production of rice (Y2) is not directly influenced by the existence of refugia plants (X). However, the existence of refugia plants (X) affects the Presence of predators (Y1), which then the Presence of predators (Y1) affects in a way real to increase in rice production (Y2). In the rule statistics, this event is included in type mediation full (complete mediation) because the influence directly from variable X is not significant on variable Y2. The entire mediation event above shows that the predator variable (Y1) is an essential element as a " liaison " in explaining the connection between the variable of the existence of refugia (X) and the production of rice (Y2). Without the increase in predators, the influence of refuge plants on paddy production becomes insignificant.

Based on the discussion above, then can deliver that X4 indicator (area of embankment) rice fields) play the most significant role in supporting the successful existence of refugia plants. By ensuring the utilization of embankment ricefield optimally through the steps technically above, the Presence of predators (Y1) can increase, which is marked by the increasing frequency of the appearance of a predator (Y1.3), which eventually will contribute to the improved production of rice (Y2) in the Village Maleber Subdistrict Maleber Regency Kuningan Province West Java, Republic of Indonesia. This finding is expected to become a recommendation technique for farmers of rice and the like throughout the world who want to increase their production in a natural way that is natural, friendly, environmentally, and sustainable.

CONCLUSION

Based on the results and discussion above, we can withdraw the conclusion that the existence of variable refuge plants has an effect directly improves the Presence of predators, and the Presence of predators directly improves the production of rice in the village Maleber Subdistrict Maleber Regency Kuningan, Province West Java, Indonesia. The most dominant indicator in reflecting the variable condition of the existence of predators is the vast area of embankment rice fields, and the variable of predator presence is the frequency of predator sightings. For that, it recommended that the farmers paddy that to increase rice production friendly environmental and sustainable by implementing efforts in technical matters related to the two indicators, namely: 1) optimization of broad embankment rice fields for refugia planting; 2) selection of appropriate refugia plants; 3) socialize importance utilization embankment rice fields for planting refugia; 4) planting refuge plants on the embankment or around rice fields; 5) do diversification plants (planting) various type plants); and 6) creating natural habitats.

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