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Farmers and Price Instability Risks: An Adaptation of the Black-Scholes Model in the Agricultural Insurance Premium Mathematics Formulation

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Abstract: This research discusses agricultural insurance, which provides coverage to customers (farmers) for losses caused by falling prices of agricultural commodities. In calculating agricultural insurance premiums, the price component is assumed to follow a Geometric Brownian motion. So that through the $It\hat{o}$ process, a price target can be determined which will be used as a reference to decide whether the customers experience a loss at the harvest time. The Black-Scholes model approach is used to construct the mathematics formula for determining insurance premiums for agricultural commodity prices. The research data includes: (1) commodity price data (red chilies, shallots, and garlics) in the provinces of West Sumatra, Jambi, and Bengkulu, which are then simulated and included in the model building, so that a value for the agricultural insurance premium can be obtained; (2) Survey data to farmers in central agricultural areas in West Sumatra and Jambi to review the farmer's tendency level towards agricultural insurance. As for data analysis, R program is utilized.

***Keywords**: Agricultural insurance, Black-Scholes model, European option, Insurance premium mathematics formulation, $It\hat{o}$ process.*

Introduction

The instability of agricultural commodity prices causes the risk faced by farmers to be even greater. One strategy to deal with such risk is through agricultural insurance (Sumaryanto & Nurmanaf, 2007). This research seeks to minimize the risk through the application of insurance for agricultural commodity prices. In previous studies, researchers have modeled agricultural insurance, which includes insurance price and income but have not paid attention to the variables that make the model applicable (Wendra, 2022). This paper makes further discussion and specifically regarding price insurance, which is developed with the approach of the Black-Scholes model.

The farmers' weakness in minimizing risk is complicated by agricultural commodity price instability, which has had a very fluctuating movement in recent years. This allows the actual price to be far below the expected price, which implies a loss for farmers. If this condition is allowed to continue, it is not impossible for agricultural stability to be interrupted. Therefore, a formal and systematic protection system is needed. In this context, the development of a formal agricultural insurance system, especially for strategic commodities is worth considering. In fact, normatively it needs to be positioned as an integration of a long-term agricultural development strategy.

Empirically, in developed countries such as Canada, the US, Japan, and several European countries, agricultural insurance is growing rapidly and is effective in protecting farmers (World Bank, 2014). In addition, the government policies also greatly affect the price stability of agricultural commodities in many countries (Brooks, 2014; Kath et al, 2019; Li et al, 2018; Vroege et al., 2019) such as Canada (Turvey, 1992), Australia (Potts & Kastelle, 2017), Germany (Petrick & Zier, 2012), Turkey (Demirdogen et al., 2016), Bangladesh (Hill et al, 2019), China (Liang et al, 2019), Japan, and Thailand (Jaijit et al., 2018). Therefore, agricultural insurance is one of the applicable strategies and policies to adapt to price instability.

In Indonesia, the development of agricultural insurance is still very low. It is ironic because the prices of certain agricultural commodities such as red chilies, shallots, and garlics are very volatile. In fact, the Indonesian government through the Ministry of Agriculture has begun to try to analyze the feasibility of implementing an insurance system for agriculture from 1982 to 1985 but has not succeeded (Boer, 2012).

Considering the agricultural commodity prices which are relatively stable in the aforementioned countries, the model applied in these countries may not necessarily work in a different context, such as in Indonesia, where some agricultural commodities experience quite an extreme price volatility. Therefore, this research aims to construct a formula that enables insurance premiums to fit in the context of a volatile market. The model construction using the Black-Scholes model takes into account previous prices to predict prices at harvest time, which is the most important part of calculating premiums.

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Research Methodology

This research consists of two stages. The first stage is literature study obtained from official sources, such as books, scientific journals, and through discussion with experts. In the second stage, a study case using real-world data. The data needed in this study: (1) data on land area and productivity of agricultural commodities from the Central Bureau of Statistics and the Ministry of Agriculture Indonesia, (2) data on agricultural commodity prices from related institutions, and (3) supporting data about the description and paradigm of horticulture farmers toward agricultural insurance.

Next, to answer the questions in the formulation of the problems: (1) The authors studied agricultural literature from books and journals, including papers (Boer, 2012; Nurmanaf, et al., 2007) that eloaborated the development of the implementation of insurance system for agriculture in Indonesia. Agriculture problems in Indonesia are discussed in the LEMHANNAS RI research journal (2013). Other literature (Hassan et al, 2018; Insyafiah and Wardhani, 2014; Saharuddin, 2014; Sianturi and Jetten, 2018) discussed agricultural and shariah insurance. The discussion on the coordination of agricultural insurance premium payments between the central and local governments is included in Yasin (2014). The legal basis for the agriculture insurance implementation in Indonesia is elaborated in Bramantia (2011) and Pasaribu et al (2010). To strengthen and complete the researchers' understanding, a direct interview was conducted with horticulture farmers in the central agriculture area.

To answer question (2), the authors strengthens the theory by studying articles from previous research and the appropriate literature. Furthermore, an analysis on potential variables is carried out in the model building, based on a study of agriculture theory and direct information from farmers.

Before finalizing the model, the authors conducted a literature study and discussion with economic actors and experts to answer question (3). Therefore, the required supporting variables and technical calculations can be acquired.

As for the collected data, the R program is used for data processing and further analysis is performed adjusted to the characteristics of the data obtained.

Results and Discussions

In this paper, a Black-Scholes approach is used to determine agricultural insurance premiums. In 1973, Fischer Black and Myron Scholes made a major breakthrough in option pricing. This option price calculation is known as Black-Scholes model. This model has a great influence on the way how option pricing and hedging are calculated (Bain & Engelhardt, 1992; Bean, 2001; London, 1997; Ross, 2003). This becomes crucial in the financial sector's development (Laksmidewi & Gunawan, 2022).

A Black-Scholes model is the most well-known and generally accepted option pricing model. In deriving the Black-Scholes formula, there are several assumptions:

a. The risk-free interest rate is knowns and constant throughout the coverage period (Anwar, 2022).
b. Agricultural commodity prices and incomes move randomly in continuous time; thus, prices and incomes follow a lognormal distribution, and the variance of return is constant.
c. The type of option is the European-style option, which can only be exercised on the expiration date. In this case, a claim can only be made at harvest time.
d. No transaction fees.

Five variables affect the price of insurance premiums with the Black-Scholes model, i.e., commodity prices, target prices, time until harvest, interest rates, and volatility of commodity price returns (Wang, 2010). Thus, the formula to determine the insurance premiums for agricultural commodity prices is

$$V_P = e^{-rt}[Z_P N(-d_2) - PN(-d_1)] \qquad (3.1)$$

where

$$d_1 = \frac{\ln\left({P_0}/{Z_P}\right) + rt + 0{,}5\sigma_f{}^2 t}{\sigma_f\sqrt{t}}$$

$$d_2 = \frac{\ln\left({P_0}/{Z_P}\right) + rt - 0{,}5\sigma_f{}^2 t}{\sigma_f\sqrt{t}}$$

and V_P is the premium price, P_0 is the commodity price at $t = 0$, Z_P is the target price, t is the time until harvest, r is the interest rate of Bank of Indonesia, $N(x)$ is the cumulative standard normal distribution, and σ_f is the return volatility of commodity prices.

The data used in the simulation in determining the insurance premium of agricultural commodity prices is data on daily prices of red chilies, shallots, and garlics in the provinces of West Sumatera, Jambi, and Bengkulu. The collected data is obtained from daily commodity prices for a full year, from 1st January to 31st December 2020. It is secondary data from the National Strategic Food Price Information Center (PIHPS). According to Figure 3.1, the movement of agricultural commodity prices in 2020, including red chilies, shallots, and garlics, are very fluctuating.

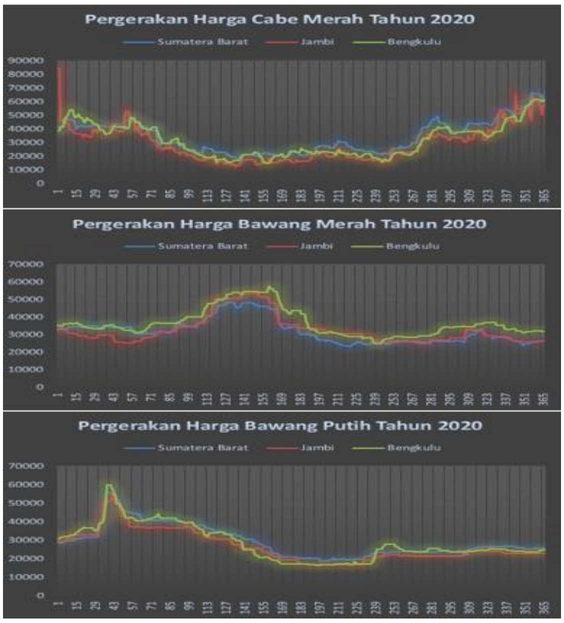

Figure 3.1 The movement of agricultural commodity prices in 2020

Further analysis by examining the distribution pattern of daily commodity price movements, several extreme points of decreasing and increasing in commodity prices are found. Among the extreme points of increase in commodity prices are during the month of Ramadan, ahead of Eid al-Fitr and Eid al-Adha, as well as on days of the month when there are many cultural and religious celebrations for certain regions in Indonesia. Extreme points of decline in commodity prices also often occur both nationally and in certain areas, such as at the beginning of the months of Ramadan and Shawwal. Figure 3.2 shows the map of the distribution of regions in Indonesia that experienced a fairly high price increase before the Eid al-Fitr.

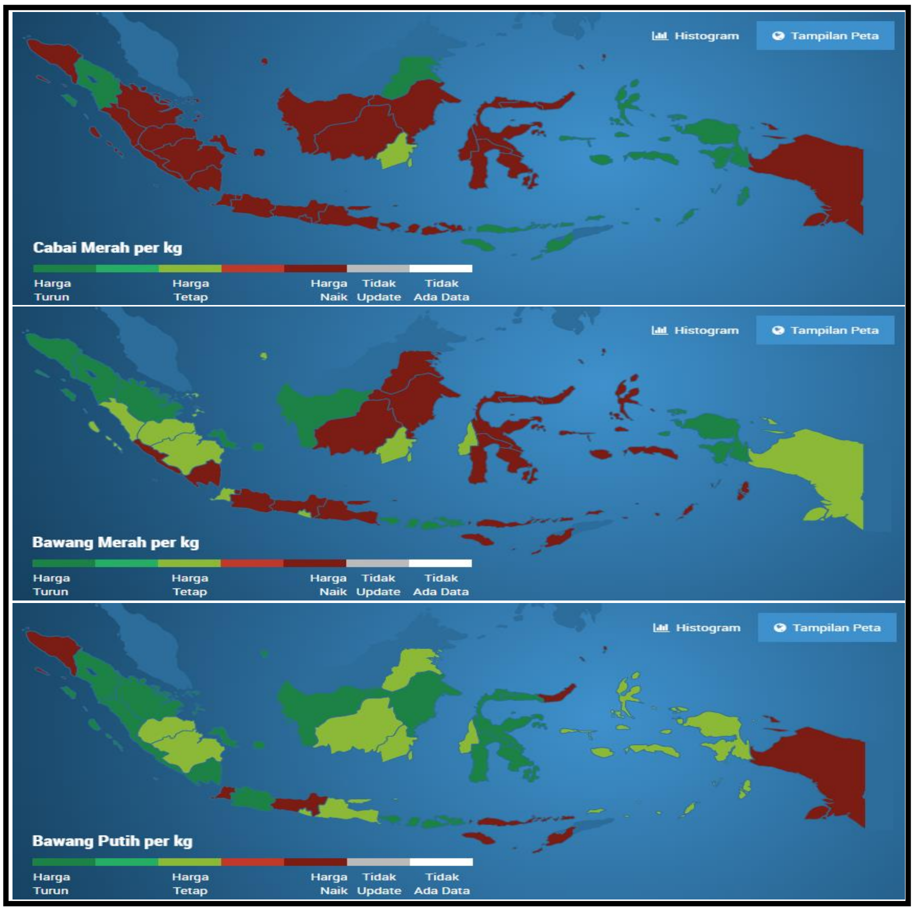

Figure 3.2 Changes in commodity prices on ahead of Eid Al-Fitr 2020

Figure 3.2 indicates that the red chili price experienced an increase in almost all regions in Indonesia, except in North

Sumatera, and parts of eastern Indonesia. The shallot price has increased in most areas of Java, Kalimantan, Sulawesi, and East Nusa Tenggara. The garlic price experienced an increase only in Papua, Aceh, Central Java, and East Nusa Tenggara.

Agricultural Commodities

The agricultural commodity types discuss in this paper are red chilies, shallots, and garlics. These commodities are quite promising agricultural commodities. When commodities are rare, prices can soar higher. However, sometimes it can suffer the farmers because of "breaking promises", meaning that when production is abundant, the price may drop sharply (Anita, 2010).

Several assumptions are made to determine the agricultural insurance premium for red chili, shallot, and garlic plants per hectare for one planting period:

1. Customers purchase the insurance policy on the day of planting.
2. The harvesting time for red chilies is carried out 16 times in one planting period with the first harvest being 90 days after planting. Meanwhile, shallots and garlics are harvested one time, i.e., on the 90th day for shallots, and on the 120th day for garlics.
3. The harvest time interval for red chilies is every four days for two months. Thus, harvesting time is carried out 16 times in one planting period, i.e., on days 90, 94, 98, 102, 106, 110, 114, 118, 122, 126, 130, 134, 138, 142, 146, and 148 after planting.
4. The average production per harvest is determined based on data on the productivity of red chilies, shallots, and garlics in Jambi province in 2017.

Table 3.1 Harvest area and production of agricultural commodities in Jambi Province in 2017

Commodity type	Harvest Area (in hectare)	Production (in quintal)	Productivity (quintal/hectare)	Productivity in one time of planting period (kg/hectare)
Red chili	7,776	399,241	51.34272	160.44600
Shallot	1,465	89,408	61.02935	3051.46750
Garlic	1	20	20	2000

Source: Central Bureau of Statistics and Directorate General of Horticulture

Based on Table 3.1, the total production and the harvest area for red chilies in 2017 are 399,241 quintals and 7.776 hectares, respectively. Thus,

$$1 - year\ production\ per\ hectare = \frac{399,241}{7,776}$$

$$= 51.34272\ quintals$$

Since there are two planting periods in one year, then:

$$Production\ per\ planting\ period = \frac{51.34272}{2}$$

$$= 25.67136\ quintals.$$

Furthermore, with 16 harvesting time in one planting period, then the average production per one-time harvest for 1 hectare of red chilies:

$$Production\ per\ one - time\ harvest = \frac{25.67136}{16}$$

$$= 1.60446\ quintals$$

$$= 160.446\ kg\text{s}.$$

The productivity of shallots and garlics for a one-time planting period can be calculated similarly.

Volatility Value and Expected Profit Rate

Based on daily prices of red chilies, shallots, and garlics in the Provinces of West Sumatera, Jambi, and Bengkulu in the period 1st January to 31st December 2020, the following results are obtained:

1. The average price return of red chilies in the West Sumatera province is 0.001031835 with a standard deviation of 0.03457156. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = 0.001031835$, and the estimated price volatility of red chilies in the West Sumatera province is $\sigma_f = \sigma_p = 0.03457156$.
2. The average price return of shallots in the West Sumatera province is -0.0006233792 with a standard deviation of 0.01948565. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.0006233792$, and the estimated price volatility of shallots in the West Sumatera province is $\sigma_f = \sigma_p = 0.01948565$,
3. The average price return of garlics in the West Sumatera province is -0.0003277418 with a standard deviation of 0.02329292. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.0003277418$, and the estimated price volatility for garlics in the West Sumatera province is $\sigma_f = \sigma_p = 0.02329292$.
4. The average price return of red chilies in the Jambi province is -0.001069649 with a standard

deviation of 0.07297269. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.001069649$, and the estimated price volatility of red chilies is $\sigma_f = \sigma_p = 0.07297269$.

5. The average price return of shallots in the Jambi province is -0.0006078726 with a standard deviation of 0.0213496. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.0006078726$, and the estimated price volatility of shallots in the Jambi province is $\sigma_f = \sigma_p = 0.0213496$.

6. The average price return of garlics in the Jambi province is -0.000697714 with a standard deviation of 0.02289008. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.000697714$, and the estimated price volatility of garlics in the Jambi province is $\sigma_f = \sigma_p = 0.02289008$.

7. The average price return of red chilies in the Bengkulu province is 0.001249752 with a standard deviation of 0.04064126. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = 0.001249752$, and the estimated price volatility of red chilies in the Bengkulu province is $\sigma_f = \sigma_p = 0.04064126$.

8. The average price return of shallots in the Bengkulu province is -0.0002989536 with a standard deviation of 0.01624571. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.0002989536$, and the estimated price volatility of shallots in the Bengkulu province $\sigma_f = \sigma_p = 0.01624571$.

9. The average price return of garlics in the Bengkulu province is -0.0006042264 with a standard deviation of 0.0240701. Thus, the estimate for the expected profit rate is $\alpha_f = \alpha_p = -0.0006042264$, and the estimated price volatility of garlics in the Bengkulu province is $\sigma_f = \sigma_p = 0.0240701$.

Risk-Free Interest Rate

In the calculation of agricultural insurance premiums in this study, the risk-free interest rate used is the Bank Indonesia Certificate interest rate in 2020. According to the website https://www.bps.go.id/indicator/13/379/1/bi-rate.html, the average interest rate in Indonesia is 4.5% (Table 4.2). Thus, the risk-free interest rate $r = 0{,}045$ is used to compute the insurance premium for agricultural commodities prices.

Table 3.2 Bank Indonesia interest rate in 2020

No.	Month	BI Rate
1	January	5.00
2	February	4.75
3	March	4.50
4	April	4.50
5	May	4.50
6	June	4.25
7	July	4.00
8	August	4.00
9	September	4.00
10	October	4.00
11	November	3.75
12	December	3.75
	Average	4.25

Source: Central Bureau of Statistics

Target Prices of Agricultural Commodities

The changes in daily red chili prices are assumed to follow a geometric Brownian motion, so that: $dP = \alpha_f f dt + \sigma_f f dZ_f$. Since $dZ_f = \epsilon_t \sqrt{dt}$, then:

$$dP = \alpha_f f dt + \sigma_f f \epsilon_t \sqrt{dt}. \quad (3.4)$$

Next, to determine the target price at harvest time, a simulation on red chili prices is carried out using the following formula:

$$Target\ Price\ [1+i] = Target\ Price\ [i] + dP\ [i] \quad (3.5)$$

where

i = target price of red chilies on the days after planting ($i = 1$ indicates a price on the first day after planting).

Using the values of α_f and σ_f from each agricultural commodity, as well as the value of the time period $t = {}^{1}/_{365} = 0{,}00274$, the simulation results for the target prices of red chilies, shallots, and garlics in the provinces of West Sumatera, Jambi, and Bengkulu are shown in Table 3.3.

Tabel 3.3 Target Price for Agricultural Commodities

Day$[i]$	**Target Price for Red Chili**		
	West Sumatera	Jambi	Bengkulu
90	61015.16	57334.99	61170.19
94	61016.04	57334.25	61171.14
98	61016.42	57333.82	61171.67
102	61016.00	57334.49	61172.79
106	61016.31	57332.95	61173.31
110	61016.63	57330.76	61173.47
114	61015.75	57331.51	61175.07
118	61016.50	57328.54	61176.17
122	61018.41	57327.60	61177.76
126	61019.84	57327.43	61178.03
130	61019.59	57323.64	61179.67
134	61020.04	57323.67	61180.02
138	61020.42	57322.19	61181.54
142	61022.59	57322.50	61182.41
146	61022.37	57324.29	61183.35
150	61022.55	57322.75	61183.89

Day$[i]$	**Target Price for Shallot**		
	West Sumatera	Jambi	Bengkulu
90	26493.69	26646.54	31746.79

Day$[i]$	**Target Price for Garlic**		
	West Sumatera	Jambi	Bengkulu
120	25647.47	22994.88	24996.45

Calculation of Insurance Premium for Agricultural Commodities

In calculating the insurance premium for agricultural commodity prices with the approach of the Black-Scholes model, some information is required, i.e., the price at planting time (P_0), the target price at harvest time (Z_p), the risk-free interest rate (r), the volatility (σ_f), dan the harvest time (t).

Based on agricultural commodity prices in 2020 in the provinces of West Sumatera, Jambi, and Bengkulu, the estimated prices at planting time (P_0) are obtained as presented in Table 3.4.

Table 3.4 Agriculture commodity prices at planting time

Indicator	Red chili prices (Rp)		
	West Sumatera	Jambi	Bengkulu
P_0	61000	57350	61150

Indicator	Shallot prices (Rp)		
	West Sumatera	Jambi	Bengkulu
P_0	26500	26650	31750

Indicator	Garlic prices (Rp)		
	West Sumatera	Jambi	Bengkulu
P_0	25650	23000	25000

The values of Z_p and t depend on the harvest days. For red chilies, it is carried out on days: 90, 94, 98, 102, 106, 110, 114, 118, 122, 126, 130, 134, 138, 142, 146, and 150 after the planting period, and the harvest time for shallots is carried out on the 90th day after the planting period, while the harvest time for garlics is carried out on the 120th day after the planting period. The value of Z_p is the value of price simulation on the harvest day, and t is the number of days from planting to harvesting divided by the number of days in a year (365 days).

Using equation (3.1), the insurance premium value (V_p) for agricultural commodity prices per kilogram per planting period in each province can be seen in Table 3.5.

Table 3.5 Insurance premium for agricultural commodity prices per kilogram per planting period

Indicator	Red Chili		
	West Sumatera	Jambi	Bengkulu
V_p	2784.357	9517.77	3925.351

Indicator	Shallot		
	West Sumatera	Jambi	Bengkulu
V_p	17.23651	23.38081	11.31668

Indicator	Garlic		
	West Sumatera	Jambi	Bengkulu
V_p	25.56654	21.32832	27.33209

From table 3.5, the insurance premium for agricultural commodity prices per planting period with an area of 1 hectare can be determined. For example, for red chili in the province of West Sumatera is:

$$Insurance\ Premium\ Price = 2784.357 \times 160.44600$$

$$= 446738.9.$$

The premium price above is the premium price for the 100% coverage level. Therefore, by paying an insurance premium for red chili commodity price of $Rp. 446.738{,}9$ at the beginning of planting, farmers will be guaranteed to get coverage during the harvest period with:

$$Benefit = Price\ Difference \times Average\ Production. \quad (3.6)$$

The total benefit received by the customers is the sum of the claim per harvest time. It should be noted that the benefits are paid by the insurance company after the harvest time is over. Using a similar calculation, the insurance premiums for all agricultural commodities per planting period with an area of 1 hectare are summarized in Table 3.6.

Table 3.6 Insurance premiums for agricultural commodities per hectare per planting period

Commodity	Insurance Premium Prices		
	West Sumatera	Jambi	Bengkulu
Red chili	446,738.90	1,527,088	629,806.80
Shallot	52,596.66	71,345.80	34,532.48
Garlic	51,133.07	42,656.64	54m664.19

If farmers (policy holders) only paid 75% of the premium price, in other words, the selected coverage level is 75%. Therefore, the claim that the insurance company should pay to farmers is $0.75 \times Price\ Difference \times Average\ Production$ or 75% of the benefits that should be received.

Conclusion

This study discusses the mathematics formulation of agricultural insurance premiums with the Black-Scholes model approach in an effort to reduce the farmers' risk on agricultural commodity price instability. The price movements of agricultural commodities: red chili, shallot, and garlic are highly fluctuating. An extreme increase usually occurs before the month of Ramadan and religious holidays, and an extreme decrease occurs at the beginning of the month of Ramadan and after religious holidays.

To further maximize the role of insurance companies or the banking sector in Indonesia and to develop an agricultural insurance system, the involvement of Islamic banking needs to be considered for two reasons. First, there is a preference for some people toward Islamic banking; and, second, the very significant development of Islamic banking in recent years. Therefore, in-depth study and further research are necessary so that the agriculture insurance model in this study can be adopted as a sharia agricultural insurance model.

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