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Production Risk Analysis in Maize: Comparative Insights from Major Producing Countries

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ABSTRACT

Increasing maize productivity is a strategic step for developing the global agricultural sector. Maize plays an important role as a source of food, feed, industrial raw materials, and energy sources. However, maize production faces internal risks, such as capital availability, management capacity, land ownership, and external risks, such as climate change, pest attacks, and limited agricultural inputs. This study discusses the development of maize production risks in ten major producing countries, including the USA, China, Brazil, Argentina, and Mexico. The study uses secondary data from FAOSTAT from 1961-2021 (61 years). The study uses a qualitative method by analysing maize production trends and risks using the coefficient of variation (CV) analysis. The analysis results show that the USA ranks first as the largest maize producer in the world, followed by China and Brazil, with an increasing trend over the past 61 years. This is related to adopting biotechnology, food production, and precision farming systems. France and the USA have low CV values of 0.36 and 0.40, indicating that the risk of maize production in the two countries is relatively low compared to the other eight countries. Maize stabilization in the USA is supported by implementing irrigation and precision farming models to reduce the impact of drought due to climate variability. On the other hand, Argentina, Ukraine, and Indonesia have high CV values, indicating a high risk of maize production in the three countries. Several factors causing high production risks are climate change in the form of increasing average annual temperatures, attacks of Maize Stunt Disease, political challenges, inaccurate use of fertilizers, low technology adoption, and limited resources.

Keywords: *Production Risk, Maize Productivity, Climate Change, Coefficient of Variation*

1. INTRODUCTION

Increasing the productivity of maize commodities is a strategic step for a country. Based on Mopangga et al [1], Maize is one of the food crop commodities that has the potential to help the development of the agricultural industry. Maize can be used as food, feed, energy sources, and raw materials for large industries [2]. Food and Agriculture Organization of the United Nations (FAO) in 2021, maize became one of the top three export commodities, contributing a significant share of total exports of 67 per cent, with global maize consumption reaching 303.67 million metric tons. The world's leading maize producers, such as China, tend to be included in the category of significant maize exporters. China stands out as a major producer country focusing on domestic demand because maize exports from China are small compared to its production [3].

All agricultural sectors, including maize farming, cannot be separated from uncertainty and risk [4], [5],[6]. Sources that can cause agricultural risks come from internal and external factors [7]. Internal factors are factors that farmers can control, manifested in the form of capital availability, management capacity and land control. Constraints in internal factors are found in Indonesia, one of which, according to research results from Kaban et al. [2] namely, the health of farmers is often disturbed so that it affects the harvest; there is a lack of capital due to the high household expenditure of farmers and low income; and there is the absence of formal financial institutions that can help farmers borrow capital. Furthermore, external factors cannot be controlled because they are beyond the reach of farmers. Risks that often arise in Indonesia include unpredictable weather such as prolonged drought, pests such as insects, diseases, and weeds; limited availability of subsidized seeds; high prices of maize fertilizers and pesticides; and lack of assistance from agricultural extension workers during production [2], [8].

Internal and external production risk factors differ significantly in maize commodities from several maize-producing countries worldwide. In Argentina, the main production risk factor in the last 10 years was caused by extreme drought. Maize for Argentina represents 28% of the country's total exports, thus affecting the balance of payments, accumulation of international reserves, and credit risk [9]. In contrast to Argentina, the decline in agricultural production in Ukraine, including maize, was caused by long-term uncertainty due to the COVID-19 pandemic and the Russia-Ukraine war [10]. Other findings show that maize yields in Brazil increased by between 6.6% and 9.9% per year over the decade. Although agricultural efficiency increased between 2011 and 2020, this was not enough to offset the negative impacts of rainfall changes on yields [11]. Furthermore, maize production in Brazil showed promising results in the first 15 days of the dry season, but after that, productivity dropped significantly [12].

The risk of decreasing maize production must be recognized and managed through risk mitigation strategies. Based on Carter et al [13] found that to reduce the risk of farming in sandy loam soils of Atlantic Canada, the entire crop is cultivated without tillage. The impact of this action is a promising strategy to facilitate rapid maize planting. Dynamic environmental changes and meteorological impacts on agriculture, such as climate change, have a significant impact on maize production declines in China, France and Mexico [14], [15], [16]. The solution to this problem is to find maize seeds that have the potential to increase production, one of which was done by researchers in the US, namely Onyekwelu & Sharda, who found a root proliferation adaptation strategy to increase maize productivity by simulating plants in the future climate change. More profoundly, Li et al. [17] in their research, showed that timely and accurate handling of crop losses would improve risk management of declining maize production. The existence of advanced contracts and cooperation between regions and policies to stabilize the regional agricultural workforce can prevent the risk of declining national maize production as a whole [17]. Perception and attitude towards risk play an important role in agriculture. However, research on risk management is still limited in developing countries [18]. This study focuses on determining the development of maize production risks in ten major maize-producing countries from year to year and determining each country's rice production risk level.

2. LITERATURE REVIEW

2.1 Risk

Risk cannot be separated from uncertainty, and farming activities occur in an environment full of both. According to Frank Knight, possible outcomes and the probability of these outcomes occurring cannot be known in conditions full of uncertainty; on the contrary, in risky conditions, possible outcomes and the probability of risk occurring can be known. However, Debertin considers that the two are related, with risk on the one hand and uncertainty on the other (risk uncertainty continuum). Many events in the agricultural sector are at two different poles between risk and uncertainty; usually, several possibilities that occur can be known, but not all outcomes have probabilities attached to them. Most agricultural activities fall midway the risk uncertainty continuum [19].

The qualitative definition of risk is as a complete description of the likelihood of an undesirable consequence arising from an action, followed by an indication of its similarity and urgency. However, this definition is considered not to offer clear criteria for making decisions about accepting risk, so six alternatives were created in defining risk, namely: (1) risk is the possibility of loss; (2) risk is a measure of (reasonable) loss; (3) risk is the expected loss; (4) risk is the variance of the probability distribution of the utilities possessed by all possible consequences; (5) risk is a semi-variant of the utility distribution referred to in point 4; (6) risk is a linear function of the expected value and the variance of the distribution of possible consequences [20].

2.2 *Risk and Uncertainty in Agricultural Production*

The main sources of risk and uncertainty can be grouped from the agricultural producer's point of view. First, there is something that can be broadly defined as production uncertainty: in agriculture, the quantity and quality of output that will be produced from a number of inputs is generally not known with certainty; the stochastic production function proves this. This uncertainty is a result of the fact that uncontrollable elements, such as weather, play a fundamental role in agricultural production. The impact of these uncontrollable factors is increased because time also plays an important role in agricultural production because the long production process is regulated by the biological processes underlying plant production and animal growth. Despite similarities in other production activities, we can say that uncertainty is agricultural production's main characteristic[21].

Production risks in maize vary in each region, as do the factors that influence them. In Bonto Majannang Village, Bantaeng Regency, the risk of maize production is low, and the factors causing the risk include weather and climate in the high category and plant pests and diseases the low category [22]. Meanwhile, in Landak Regency, farmers who cultivate maize in smaller land areas have a higher production risk. Furthermore, the risk of maize production is influenced by the number of labor [23].

3. METHODS

This research is a quantitative study that uses data from the 10 largest maize producing countries in the world, namely Argentina, Brazil, Canada, China, France, India, Mexico, Ukraine and the United States. These countries were chosen because they have a large contribution to world maize availability. The data used is maize production data for each country from 1961 to 2021 (61 years) obtained from FAOSTAT. The first objective of this research is to determine annual trends and the level of maize production risk in each producing country. Production risk is calculated using the Coefficient of Variation (CV) which shows the comparison between production variability relative to the population average, the formula is as follows:

$$CV = \frac{\sigma}{\mu} \qquad (1)$$

Where CV is the coefficient of variation, σ is the standard deviation of maize production and μ is the average production. In determining the level of risk, the higher the CV value, the higher the production risk, and vice versa, a low CV value indicates a low level of production risk. Production risk trends in each country will be shown using a line chart, which is shown by the average CV value for each country per year from 1961-2021. Meanwhile, the production risk for each maize producing country is calculated using the average production and average standard deviation of maize production for 61 years and will be displayed using a bar chart

4. RESULTS AND DISCUSSION

Major producing countries support maize production in the world. The major maize producing countries worldwide include Argentina, Brazil, Canada, China, France, India, Indonesia, Mexico, Ukraine, and the United States of America (USA). The American continent ranks first as the most significant maize-producing continent. Some of the largest maize-producing countries in the American continent are the United States of America, Argentina, Brazil, Mexico, and Canada. Most areas in the American continent have a climate that supports maize growth. The warm climate and little rain in summer, especially in the Midwest of the United States, are ideal for maize growth. According to [24], the USA supplies around 35% of total global maize production, making it a leader in the world maize industry. In addition, other countries such as China, Brazil, Argentina, and Mexico contribute significantly to maize production, with each having policies and programs supporting increasing agricultural yields [24]. Description of maize production statistics in major producing countries is presented in Table 1.

Table 1. Description of Maize Production Statistics in 10 Maize Major Producing Countries

Countries	Maize Production (tons)		
	Average	Minimum	Maximum
Argentina	16.966.431	4.360.000	60.525.805
Brazil	37.010.871	9.036.237	109.420.717
Canada	7.266.575	741.912	14.538.878
China	112.101.532	16.286.265	277.415.553
France	11.391.361	1.866.560	18.343.320
India	12.409.053	4.312.000	33.729.540
Indonesia	9.545.590	2.254.380	30.253.938
Mexico	15.978.942	6.246.106	28.250.160
Ukraine	14.667.011	1.539.400	42.109.850
USA	222.610.907	88.504.000	412.262.180

Source: Processed Secondary Data, FAOSTAT (2024)

Brazil ranks third as a contributor to maize producers worldwide with an average production 1961 2022 of 37,010,871 tons. The highest production occurred in 2022 with 109,420,717 tons, while the lowest production occurred in 1961 with 9,036,237 tons. Maize production in Brazil has experienced fluctuating growth, both positive and negative. In terms of average growth, maize production in Brazil has experienced an average growth of 5.39% annually. An increase in the area of maize harvest supports the increase in maize production in Brazil. Brazil's maize harvest area ranks third in the world in 2022, at 21,037,669 ha, which has increased from the previous year by 10.81%. The area of maize harvest in Brazil has experienced an average annual growth of 2.11%. In terms of productivity, Brazil has a maize productivity of 5.20 tons per hectare in 2022. Brazil is considered to have a high average annual growth in maize productivity, namely 2.96% per year.

Argentina ranks fourth as a maize producer in the world, with an average maize production of 16,966,431 tons. Minimum production occurred in 1963 with a production of 4,360,000 tons, while the highest production occurred in 2021 with a production of 60,525,805 tons. Maize production in Argentina has a fairly high average growth rate every year, reaching 7.85% per year. The availability of maize farming land supports the increase in maize production in Argentina. The area of maize harvest in Argentina ranks fifth in the world in 2022. In 2022, the area of maize harvest in Argentina was 8,768,441 Ha. This harvest area is far behind the maize harvest area in Brazil. The difference in the area of maize harvest in Argentina and Brazil reaches 58.32%. However, the area of Argentina's harvest has an average positive growth rate every year, which is 2.96%. This high production growth is supported by high productivity. Maize productivity in Argentina in 2022 was 6.73 tons per hectare. This value is higher than the maize productivity of Brazil and China. Maize productivity in Argentina has grown by 3.74% annually. This increase is influenced by the area of harvest and the use of modern agricultural technology and more efficient superior varieties. Research shows that the use of transgenic varieties in countries such as Brazil and Argentina has also contributed to increased maize yields, although there are challenges related to costs and adoption in areas with subsistence farming systems [25].

The fifth-largest producer in the world is Mexico. The average maize production in Mexico over the past 61 years is 15,978,942 tons. The highest production occurred in 2018 with a production of 28,250,160 tons, while the lowest production occurred in 1961, with 6,246,106 tons. The average growth in maize production in Mexico is 3.22%. One factor contributing to the increase in maize production is the adoption of genetically modified maize varieties. Research shows that using better maize seeds and efficient irrigation techniques have increased yields in several Mexican states, including Sinaloa, a major maize producer [24]In addition, government support programs, such as the Programa de Apoyos Directos al Campo (PROCAMPO), have played an important role in increasing the competitiveness and productivity of agricultural production in Mexico, especially in the period 1989-1994, where significant production increases occurred [26]. However, pressures from climate change, such as drought and rising temperatures, may threaten future maize yields [27]

India ranks second in Asia as a major maize producer or seventh in the world. The average maize production in India is 12,409,053 tons with the lowest production occurring in 1961 at 4,312,000 tons, while the largest maize production occurred in 2022 with a production of 33,729,540 tons. The average growth in maize production in India reaches 4.47% annually. The high production is supported by the area of maize harvest in India. The area of maize harvest in India ranks fourth in the world after Brazil, with an area of harvest in 2022 of 9,957,950 hectares. The area of harvest in India has experienced positive growth with an average of 1.37% per year. Although it ranks fourth in terms of area of harvest, India only ranks seventh in terms of production. In terms of productivity, maize productivity in India in 2022 was only 3.38%. This value is relatively low compared to previous countries. The low maize productivity in India can be attributed to several factors, including the use of suboptimal agricultural technology and differences in the varieties used. Countries such as the United States, Brazil, and Argentina have successfully increased their maize productivity by adopting GMO varieties that yield higher yields than conventional varieties [25]On the other hand, India still relies on local varieties that may not be as efficient as genetically modified varieties. This suggests that to increase productivity, India needs to consider adopting modern agricultural technologies and superior varieties [28]; [25]

France ranks second in Europe as a major producer of maize or eighth in the world. The average maize production in France is 11,391,361 tons. The lowest production occurred in 1962 with a production of 1,866,560 tons, while the largest production occurred in 2014 with a production of 18,343,320 tons. Maize productivity in France in 2022 was 7.47 tons/hectare with an average of 6.95 tons/hectare. This value is quite large when compared to Argentina, Brazil, and China. The high productivity of maize in France contributes to the high production of maize, although the area of maize land in France in 2022 was only 1,456,090 ha. One method to improve the sustainability of agriculture in France and reduce degradation is the cropping system, which is dominated by maize plants [29]. Maize plants can grow in spring, summer, and autumn and are considered potential seasons for maize plants [30]

Indonesia ranks ninth as the world's leading maize producer or third in Asia. As an agricultural country, Indonesia is able to produce 23,564,000 tons of maize in 2022. The average maize production in Indonesia is 9,545,590 tons. The lowest production occurred in 1972 at 2,254,380 tons. While the highest production occurred in 2018 at 30,253,938 tons. Most of the maize production areas in Indonesia are in East Java Province [31]Indonesia has achieved self-sufficiency in recent years but its sustainability cannot be predicted due to population growth, diet changes, and agricultural land conversion [32]. The tenth maize producer in the world is Canada. Canada ranks third in Europe as a maize producer in the world. The average maize production in Canada is 7,266,575 tons. The lowest maize production occurred in 1961 with a production of 741,912 tons. Meanwhile, the largest production occurred in 2021, producing 14,610,792 tons.

The development of maize production in the world's major producing countries has been increasing from 1961 to 2022. The development of maize production in 10 major producing countries can be seen in Figure 1. The data shows that global maize production continues to increase significantly, especially in countries such as the United States (USA), China, and Brazil, major global producers. This trend illustrates the success of agricultural technology as well as the challenges faced in sustainable food production amid climate change and increasing global demand. The United States remains the leader in global maize production, with an increase from 50 million tons in 1961 to more than 400 million tons in 2021. This can be attributed to the adoption of biotechnology, mechanization, and precision farming systems. The adoption of biotechnology has played a significant role in increasing maize yields. The development of hybrid maize varieties, which began in 1926, has contributed greatly to productivity. Maize hybrids show increased vigor and higher yields compared to traditional varieties [33]Agricultural mechanization also contributes to efficiency and productivity in maize production. With the use of modern machines, farmers can plant, maintain, and harvest maize faster and more efficiently. This not only reduces labor costs but also improves the timeliness of the farming process, which is very important for optimal results [34]

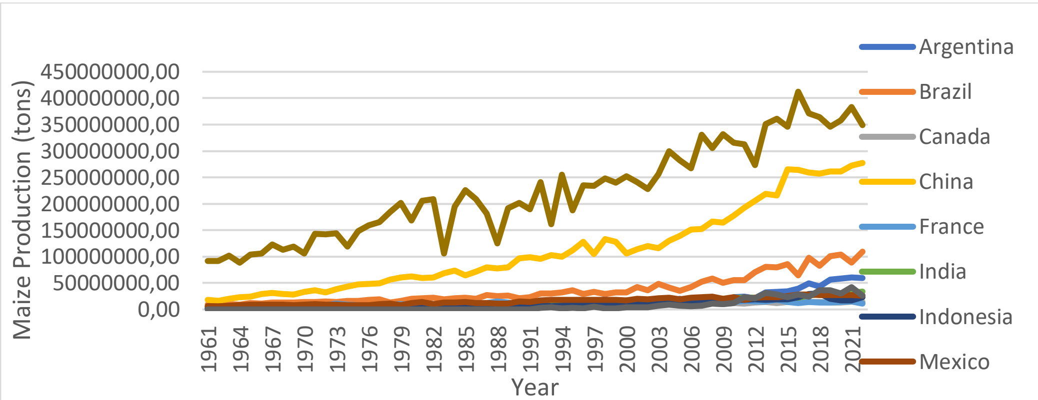

Figure 1. Production Trend of Maize Major Producing Countries in 1961-2022

Source: FAOSTAT (2024)

China has rapidly increased maize production, especially since the economic reforms in the late 1970s. Production increased from less than 50 million tons to more than 250 million tons in 2021, reflecting the success of agrarian reforms that boosted agricultural productivity to meet large domestic demand. The increase in maize consumption in China is closely related to population growth and rising incomes, which drive demand for food and animal feed products [35]. However, China still faces challenges, especially related to climate change, which may affect maize production in the future. Studies have shown that the intensity and frequency of extreme weather events, such as high temperatures and droughts, are increasing and may negatively impact maize yields [36].

Nevertheless, the potential for growth in maize production in China remains high, with a significant yield gap indicating that there is room for further productivity improvements [37].

Maize production in Brazil and Argentina also shows a significant upward trend. Both countries are major players in the world maize export market. The main factors driving this production growth are the expansion of agricultural land in tropical and subtropical regions and the use of maize varieties that are resistant to extreme environmental conditions [38]. The use of modern agricultural technologies, including the use of improved maize varieties and more efficient farming techniques, is also an important factor in increasing maize production in both countries. In this context, improved varietal management, use of agrochemicals, and better irrigation have contributed to increased maize yields in Mexico, which could indicate similar practices in Brazil and Argentina [26]

Countries such as Mexico, Ukraine, and India have shown more stable growth than other major countries. Although their total contribution to global maize production is smaller, their role is important in meeting domestic and regional needs. In Mexico, challenges faced in maize production include climate change, pandemics, and conflicts, which affect maize production and distribution systems [26]In this context, Mexico has sought to increase maize production through programs such as PROCAMPO and MasAgro, which aim to improve agricultural productivity and sustainability [24]. In Ukraine, although its contribution to global maize production is smaller, the country has great potential in the agricultural sector due to its fertile soils and developed agricultural practices. Ukraine is known as one of the largest maize producers in Europe, and its growth in this sector has shown significant stability. India has also shown stable growth in maize production, thanks to the adaptation of new varieties and improved agricultural techniques. The country has great potential to increase maize production, known as the “queen of grains” due to its ability to grow in a wide range of agro-climatic conditions [28]

The graph in Figure 2 shows maize production's coefficient of variation (CV) in major producing countries. The coefficient of variation is a measure used to describe the relative degree of variation in production in a dataset, expressed as a percentage of the mean. Higher CV values indicate greater instability or volatility in production, while lower values indicate greater stability. The coefficient of variation value for maize production in 10 major producing countries can be seen in Figure 2.

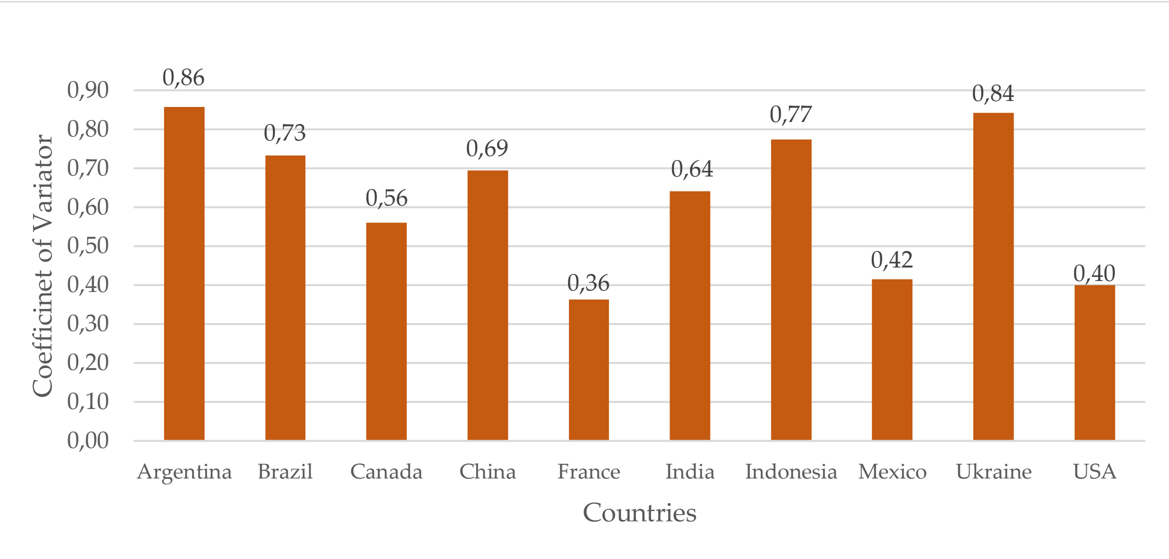

Figure 2. Coefficient of Variation of Maize Major Producing Countries in 1961-2022

Source: Processed Secondary Data (2024)

The graph shows that Argentina has the highest CV value of 0.86, indicating a very significant level of maize production instability. As one of the main maize exporters, production instability in Argentina can have a major impact on the international maize market. Research shows that uncertainty in maize production can exacerbate commodity price volatility in the global market. For example, [39]noted that declining international commodity prices can exacerbate volatility in production growth rates, reducing long-term growth and increasing the risk of a balance of payments crisis. Furthermore, climate change can significantly affect maize production, which in turn can affect the availability of maize in the international market [39]. [40] found that Maize Stunt Disease can cause significant yield reductions, this disease not only reduces yields but can also affect the quality of maize produced, which is very important for the export market.

Meanwhile, Ukraine also showed a high CV value of 0.84, which can be attributed to political and economic instability, as well as the impact of climate change. These factors are often major challenges for countries that depend on maize exports as a major commodity. Ukraine’s agricultural sector plays a significant role in the national economy, contributing a large share to GDP and employment. However, political challenges such as the Russian military invasion and policy uncertainty have undermined the resilience of this sector [41]. On the other hand, [42] highlighted that climate change is exacerbating Ukraine’s agricultural instability. An increase in annual average temperature of 1.2°C during 1990–2020, coupled with changes in uneven rainfall patterns, has led to increased incidence of droughts and floods. This has directly impacted the production of major crops such as maize and wheat, which are major export commodities.

In contrast, countries such as France and the United States have relatively low CVs, at 0.36 and 0.40, respectively. This indicates a high level of maize production stability, most likely due to the application of advanced agricultural technology, supportive government policies, and adequate agricultural infrastructure. According to [43] the stability of maize yields in the United States is highly dependent on the application of irrigation and precision farming models that can reduce the impact of drought by 10–27%. This reflects the effectiveness of modern technology in reducing the risk of crop loss due to extreme climate variability. [44] highlighted that technological innovations based on climate models also support the United States' ability to maintain stable maize production. Climate simulations allow predictions of the impact of climate risks on maize production, which aids decision-making in agricultural risk management. This is reinforced by the findings of [45] which show that France and the United States adopted high-performance maize hybrids that provide higher yields and are resistant to various environmental stresses, including high temperatures and water shortages.

Indonesia has a CV of 0.77 in maize production, indicating a high level of variability compared to other countries. The high CV indicates significant challenges the agricultural sector faces, especially in maize production. [46] explain that risk factors such as pest attacks, inappropriate use of fertilizers, and climate change are the main causes of the decline in the quality and quantity of maize production. In this context, pest attacks have the highest risk probability of 9.63% and the impact of losses reaches IDR 562,102 per hectare. [47] also revealed that the income risk of dry maize farmers in East Nusa Tenggara is largely due to high labor costs and lack of adoption of modern technology. The use of modern technology such as superior seeds and the right fertilizer dosage is identified as the main strategy to increase land productivity and reduce risk. [48] added that the risk of maize production is higher for farmers with land areas of less than 1 hectare, with a coefficient of variation of 0.18, compared to farmers with larger land areas (0.086). This shows that small farmers are more vulnerable to variations in production results due to resource constraints.

CONCLUSION

Agricultural policies, climate conditions, and the adoption of innovative agricultural technologies greatly influence global maize production. The USA, China, and Brazil are among the top three countries contributing to global maize production, with an increasing trend over the past 61 years. Argentina, Ukraine, and Indonesia have high production risks. Disease attacks, global climate change, low technology adoption, and resource constraints are factors causing high production risks. On the other hand, the USA and France have low maize production risks due to the application of advanced agricultural technologies, such as climate model-based technological innovation and biotechnology, supportive agricultural policies, and adequate agricultural infrastructure. Major producing countries, especially in the Americas, have great potential to increase maize production through appropriate strategies that are responsive to existing challenges, including climate change and growing market needs.

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