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Review Article

Exploring Ginger as Botanical Pesticides for Sustainable Maize Protection, Economic Growth, and Landscape Planning Strategies for Maize in North Sumatra, Indonesia

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Abstract

Maize production in Indonesia faces a significant challenge from the emerging threat of Spodoptera frugiperda, leading to heavy reliance on chemical control methods. Unfortunately, this results in high residue levels, impacting human health and the environment. Addressing this, ginger emerges as a botanical insecticide, presenting a solution to mitigate these negative consequences. Evaluating the botanical insecticide industry's export and import values reveals its potential contribution to economic growth, enhancing national income and societal prosperity. This article addresses the maize armyworm problem through ginger-derived botanical pesticides, evaluating economic benefits and exploring the feasibility of ginger-based formulations, considering economic factors and landscape planning. The systematic review, following the PRISMA-P methodology, ensures a transparent analysis of scientific production in four stages: identification, screening, feasibility assessment, and inclusion. Recent research highlights ginger's efficacy in pest management, emphasizing ecological benefits and sustainable practices. Ginger-based botanical pesticides support environmental sustainability and offer positive economic potential. A holistic maize farming approach in North Sumatra forms the foundation for productive and eco-friendly agriculture. Training in pest management is crucial for maximizing economic benefits and ensuring sustainable ginger-based botanical pesticide application. The amalgamation of scientific research and ginger-based practices offers a model for effective, economical, and sustainable farming.
Keywords: Insecticide; fall armyworm; FAW; secondary metabolites; *spodoptera frugiperda*

1. INTRODUCTION

Maize (*Zea mays* L.) stands as a vital staple alongside rice and wheat, serving as a key source of carbohydrates (Food and Agricultural Organization, 2018; Erenstein et al., 2022). Belonging to the Gramineae family, maize thrives in diverse tropical environments and finds application in an array of whole and processed products (Paliwal et al., 2000; Siyuan et al., 2018). These include popmaize, polenta, tortillas, porridge, cereals, bread, maize flour, fast food, as well as extruded and refined snacks. Syrups and food sweeteners also derive from this versatile grain (Serna-Saldivar, 2010a). In developing nations, maize assumes a fundamental role as a primary food crop. Conversely, in developed countries, its primary use is as animal feed, accounting for over 85% of imports. This trend aligns with an escalating demand for wheat flour and animal feed (Food and Agricultural Organization, 2018). The Food and Agricultural Organization (2018) underscores a global upswing in maize production, emphasizing increased production value and productivity.

The United States, as the leading global maize producer, contributes a substantial 34.52% to world production surpassing 1 billion metric tons with a harvested area nearing 200 million hectares. China secures its position as the second-largest producer, while Indonesia ranks eighth with a 2.19% contribution (Sandhu et al., 2020). Maize plays a pivotal role in the agricultural and economic development initiatives of Indonesia, meeting the escalating demands spurred by population growth and the expanding needs of the food processing industry (Riantin et al., 2021). According to the Central Statistics Agency (2022), the national average maize productivity stood at 57.09 ku/ha in 2017, accompanied by a revenue-to-cost ratio of 0.41 (Table 1). Notably, provinces such as West Sumatra, Jambi, South Sumatra, Bengkulu, Lampung, West Java, Central Java, Banten, NTB, and North Sumatra achieved maize productivity exceeding 60 ku/ha.

Table 1. National Production Value and Production Costs per Planting Season in 2017

Description	Value of Zea (000 IDR)
Production (selling price)	14.385,53
Production Cost	10.197,14
Revenue to Cost	4.188,39
Ratio Revenue to Cost	0,41

Source: BPS (2019).

Despite North Sumatra's maize productivity surpassing the national average, recent reports indicate a concerning trend. The production volume in North Sumatra has seen a decline from 1,965,444 tons in 2020 to 1,724,398 tons in 2021, as reported by BPS Nort Sumatra (2022). This decline poses a significant challenge in meeting the growing needs of the community, as highlighted by Muhammad Zaka et al. (2019). The inability of maize plants to achieve optimal production exacerbates this issue. The Food Security and Livestock Service Office of North Sumatra Province (2019) underscores a rising demand for maize as a staple (Table 2). Such an increase in demand, without a corresponding boost in production, has repercussions on both food availability and market prices. Over the past five years, North Sumatra has witnessed a surge in food prices, including maize, according to the Food Security and Animal Husbandry of North Sumatra Province (2019). The National Food Agency (2023) sheds light on the discrepancy in maize prices in North Sumatra, reporting levels exceeding the national average by up to 3.65% in 2023 (Table 3). This price hike is attributed to diminished production and escalating costs triggered by a surge in attacks by *S. frugiperda*. The escalating threat to maize availability in North Sumatra necessitates urgent attention to reverse the declining production trend.

Table 2. The state of food availability in North Sumatra Province from 2013 to 2017 (tons).

Description	Year				
	2013	**2014**	**2015**	**2016**	**2017**
Availability	885.285	1.025.808	1.138.246	35.783	103.702
Needs	25.646	67.031	25.646	21.743	25.949
Surplus	859.640	958.776	1.112.600	14.040	77.752

Source: The Food Security and Livestock Service Office of North Sumatra Province (2019).

One of the primary challenges in maize cultivation is the infestation of the maize armyworm pest, *S. frugiperda* J.E. Smith (Lepidoptera: Noctuidae) (De Groote et al., 2020). *S. frugiperda*, belonging to the Noctuidae family, represents the most diverse group within Lepidoptera and encompasses the highest number of species in agricultural ecosystems (Caccia et al., 2014). This invasive pest, also known as the FAW, has emerged as a significant threat to maize in Indonesia (Herlinda et al., 2022). It stands out for its unparalleled intensity of attacks and severe impact on maize plants compared to other pests. Originating from America, *S. frugiperda* has rapidly spread to various countries worldwide. In early 2019, the pest was first detected on maize plants in the Sumatra region (Ministry of Agriculture, 2019). This pest is capable of causing extensive damage to maize plants, affecting leaves, stems, cobs, and growing points, leading to the failure of shoot or young leaf formation. Larval infestation is characterized by distinctive scrap marks, resembling coarse powder or sawdust, found on the leaf surfaces or around the tops of leaves. Notably, this pest exhibits a high degree of mobility, enabling it to swiftly spread to different regions in Indonesia (Nonci et al., 2019).

A burgeoning population of *S. frugiperda*, coupled with a conducive environment, amplifies the threat to maize plants. High levels of infestation can result in yield losses ranging from 10-20% (BBOPT, 2020). Trisyono et al. (2019) go further to indicate that *S. frugiperda* larvae have the potential to cause up to 100% damage to young maize. Disturbingly, reports from Sri Lanka reveal that 20% of the 40,000 hectares of maize crops suffered damage from *S. frugiperda*. China, being the largest maize producer in Asia, faces a similar predicament due to the onslaught of this pest. The impact extends globally, with notable losses reported in various regions. Ghana experienced an average crop loss of 45% due to UGJ, while Zambia recorded a 40% loss (Day et al., 2017). Kenya faced losses of 924,000 tonnes (34%) in 2017 and 883,000 tonnes (32%) in 2018 (De Groote et al., 2020). Indonesia, in particular, confronts a staggering potential loss of up to 94% (Meilin, 2020). Although economic losses in Asian countries remain unreported, estimates of the economic damage caused by *S. frugiperda* in Africa range from US$ 1-3 billion (FAO, 2023).

Table 3. The prices for dry shelled maize in North Sumatra Province and nationally for the year 2022-2023

Site	Price (IDR)					
	Producer		Grocery		Retail	
	2022	2023	2022	2023	2022	2023
North of Sumatera	4.750	4.260	11.590	12.460	12.470	12.470
Nasional	4.590	4.110	11.440	12.190	12.320	12.320
Disparities (%)	3,49	3,65	1,31	2,21	1,22	1,22

Farmers traditionally resort to using synthetic pesticides for controlling *S. frugiperda,* but the application of these chemicals has been associated with new challenges for both human health and the environment. These issues include the unintended harm to beneficial insects, particularly natural enemies (Perrin et al., 2021), environmental pollution, the emergence of resistant pest species, the proliferation of secondary pests, resurgence, disruption of ecosystem balance, and broader societal impacts (Piechowicz et al., 2021; Shearer et al., 2021). A promising strategy to mitigate the reliance on chemical pesticides involves the adoption of novel insecticides, specifically semi-chemicals derived from plants, commonly known as botanical insecticides (Muhammad Zaka et al., 2019). The use of botanical insecticides is praised for its minimal disruption to ecosystems during pest control (Saleem et al., 2021). Leveraging plants as botanical pesticides presents an alternative solution to curbing the usage of synthetic pesticides (Palla et al., 2020). Plants that serve as bioinsecticides typically contain bioactive compounds such as cyanides, terpenoids, phenylpropanes, alkaloids, acetogenins, essential oils, flavonoids, steroids, and tannins (Miranti and Fatiqin, 2018). Various plant families are reported to harbor bioactive compounds with insecticidal properties, including *Myrtaceae, Lauraceae, Rutaceae*, *Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Piperaceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, Sapotaceae, and Zingiberaceae* (Ahmad et al., 2017;

Gakuubi et al., 2016; Jnaid et al., 2016). The *Zingiberaceae* family, particularly the ginger plant (*Zingiber officinale* R.), has been reported to possess insecticidal properties (Lengai et al., 2019).

In addressing the challenges posed by the *S. frugiperda* insect in maize cultivation, agricultural landscape planning emerges as a strategic key. Several technologies are known to serve as strategies in controlling the *S. frugiperda* pest in maize cultivation, such as the implementation of plant diversification by planting insect-repelling crops around maize fields, thus reducing insect pressure. Mixed planting patterns, like incorporating certain shrubs or flowers, can provide diversity and aid in controlling the population of insect pests. Furthermore, periodic crop rotation can be an effective preventive measure, hindering the development of the *S. frugiperda* population. Efficient management of water resources is also crucial, given that these insects tend to breed more successfully in high humidity conditions. Additionally, the utilization of natural predators, such as birds of prey or predatory insects, can help maintain the balance of the agricultural ecosystem. Subsequently, the use of botanical insecticides that assist in controlling *S. frugiperda* also becomes a key factor in agricultural landscape planning. The technology of using botanical insecticides, derived from plants such as ginger (*Zingiber officinale R*.), emerges as an effective strategy in controlling *S. frugiperda*. Botanical insecticides, with bioactive compounds such as alkaloids, tannins, saponins, flavonoids, essential oils, and triterpenoids, has been proven to provide anti-insect effects such as repellence, antifeedance, toxicity, growth retardation, chemosterilization, and attraction.

Studies, such as those conducted by Muthomi et al. (2017), demonstrate the effectiveness of ginger in significantly reducing populations of whiteflies and thrips, resulting in a 50% increase in bean plant (*Phaseolus vulgaris*) production. Qatrinida et al. (2021) confirm the potential of ginger as a natural larvicide against *Aedes albopictus* mosquitoes, achieving death rates of up to 100% at an 8% concentration. Ginger essential oil, containing α-caryophyllene, exhibits toxicity and repellency against the tobacco beetle *Lasioderma serrimaizee* (Hikal et al., 2017). Moreover, combining ginger with extracts from other plants can enhance the effectiveness of the insecticide. Qari et al. (2017) demonstrate DNA damage in *R. dominica* pests after treatment with essential oils from *Z. officinale*, *Citrus aurantium*, *Eruca sativa*, and *Origanum majorana*. Ginger and cubeb fruit essential oils also show antifeedant activity against Tribolium castaneum and *Sitophilus oryzae* pests (Chaubey, 2012a, 2012b). The efficacy of ginger also extends to combating armyworm pests on maize plants. Afnan et al. (2018) show that feeding *Spodoptera litura* with 100% ginger extract results in a 100% antifeedant effect with a 20% mortality rate. Rustam et al. (2018) report an 80% mortality rate in *S. litura* with a 0.75% concentration of ginger rhizome extract and an LT50 of 33.00 hours. Specific bioactive content, such as 8-shogaol in ginger, induces mortality in *S. frugiperda* larvae, with an LD50 of 7.68 and 3.96 µg/larvae at 24 and 48 hours post-treatment (Keosaeng et al., 2022). This results in an extended larval duration, reduced larval weight, decreased fecundity, Consumption index (CI), Relative growth rate (RGR), and Digestibility (AD) (Firake and Behere, 2020), along with increased activity of cysteine protease enzymes (Afnan et al., 2018).

In addition to the direct benefits in pest control, the use of ginger as a botanical insecticide offers significant economic potential for farmers and the agricultural sector as a whole. The pesticidal properties of ginger can be utilized in various ways to manage pests and diseases, especially in terms of cost-effectiveness. Cultivating and processing ginger as a botanical insecticide provides a straightforward and economical alternative to synthetic chemicals. With high demand for ginger as a marketable crop in various regions, its by-products can be efficiently used for insecticide formulations. The widespread cultivation of ginger worldwide makes it easily accessible to local farmers, reducing dependence on expensive synthetic chemical pesticide imports. This not only aids in local economic growth but also contributes to the sustainability of rural economies. Furthermore, the use of ginger-based pesticides offers a safer option for farmers, farmworkers, and consumers, given its lower toxicity to humans and non-target organisms. This safety aspect can result in cost savings related to healthcare and safety measures. Moreover, cultivating ginger for use as a botanical insecticide allows farmers to diversify their income streams. They can sell the ginger crop for culinary and medicinal purposes while utilizing by-products for pesticide creation. From a macroeconomic standpoint, regions with significant ginger cultivation potential can process excess ginger into botanical pesticides for export, thereby increasing foreign exchange earnings for the producing country. This represents a noteworthy macroeconomic advantage derived from the abundance of ginger crops. Thus, agricultural landscape planning that leverages the strategy of using botanical insecticides, especially ginger, can have a positive impact not only on pest control but also on economic and agricultural sustainability.

In this article, the authors aim to address the maize armyworm pest *S. frugiperda* by exploring the utilization of botanical pesticides derived from ginger (*Z. officinale R*). Additionally, the study delves into the potential incorporation of ginger's active ingredient as a botanical pesticide within the pesticide industry. The primary objective of the research is to assess the effectiveness of ginger-derived botanical pesticides in managing *S. frugiperda* infestations in maize cultivation, along with evaluating potential economic benefits for farmers. Simultaneously, the study investigates the feasibility of integrating ginger-based formulations into the pesticide industry, considering economic aspects and landscape planning. The author begins by providing an insightful overview of ginger as a botanical insecticide, covering key elements such as (1) Maize (*Zea mays*), (2) maize armyworm (*S. frugiperda*), (3) ginger (*Z. officinale*) as a botanical insecticide, and (4) the pesticide industry. This article is anticipated to serve as a valuable reference for future agricultural practices, specifically concerning the use of ginger as an alternative for plant protection. Moreover, the study addresses the potential development of ginger in the pesticide industry, aligning with health-conscious consumer demands. The overarching aim is to contribute to agricultural sustainability, emphasizing both economic viability and landscape planning as integral components of the proposed strategies.

2. METHODS

The review employed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) methodology. The initial phase involved identifying articles across diverse Scopus. The search utilized the keywords: ginger, maize, and *Spodoptera frugiperda*. Subsequently, the selection process comprised evaluating article titles for relevance to the sub-topics of the research discussion. This method has been widely used to evaluate various academic disciplines, including business, arts, earth sciences, and environmental sciences. The study utilized the PRISMA methodology, consisting of four stages to ensure an objective, clear, and transparent analysis of scientific production. The stages include identification, screening, feasibility assessment, and inclusion (Punnakitikashem and Hallinger 2019) (Figure 1.)

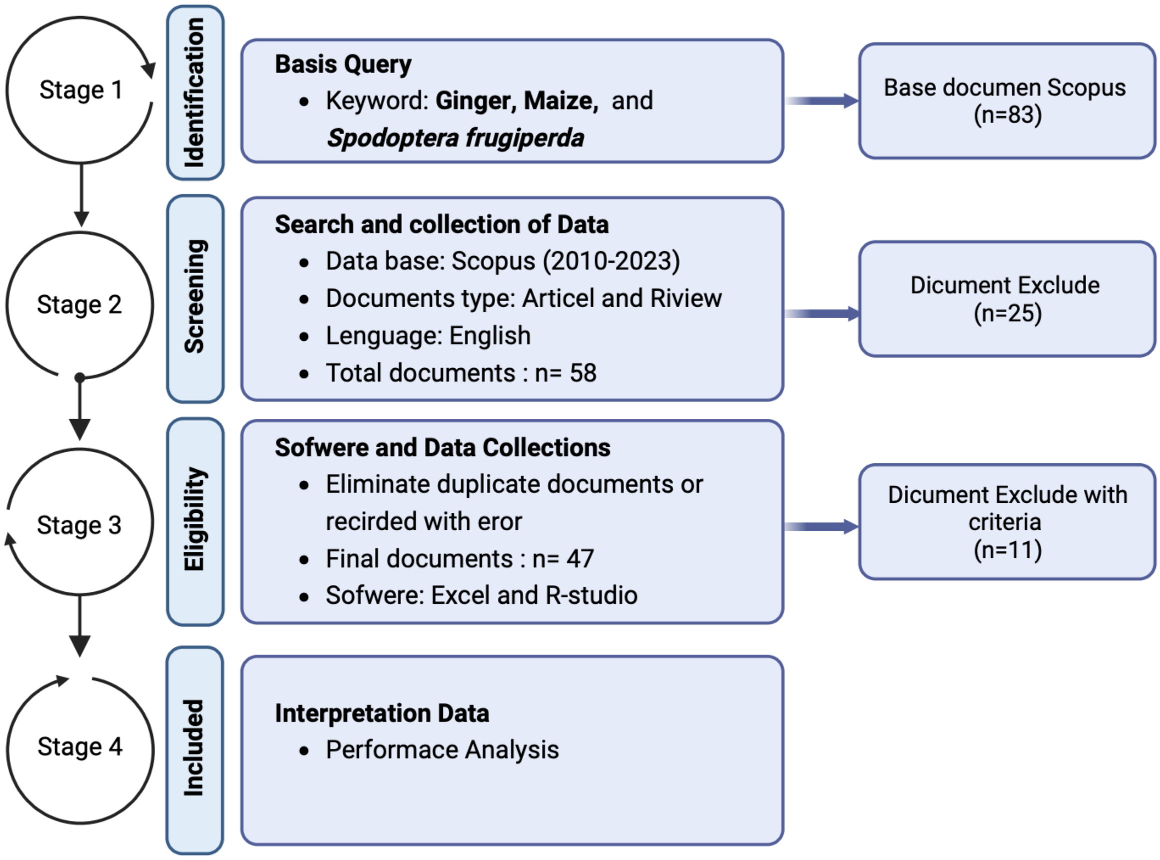

Figure 1. Diagram inspired by the PRISMA statement illustrating the four phases of the research methodology.

3. RESULTS AND DISCUSSION

3.1. Performance Analysis

The process of examining the extent of issues related to the use of ginger as a botanical insecticide on maize plants to control *Spodoptera frugiperda* pests was analyzed in the Scopus database over the last 13 years. The number of publications discussing ginger as a botanical insecticide amounted to 47 publications, and some frequently occurring keywords can be observed in Figure 2.

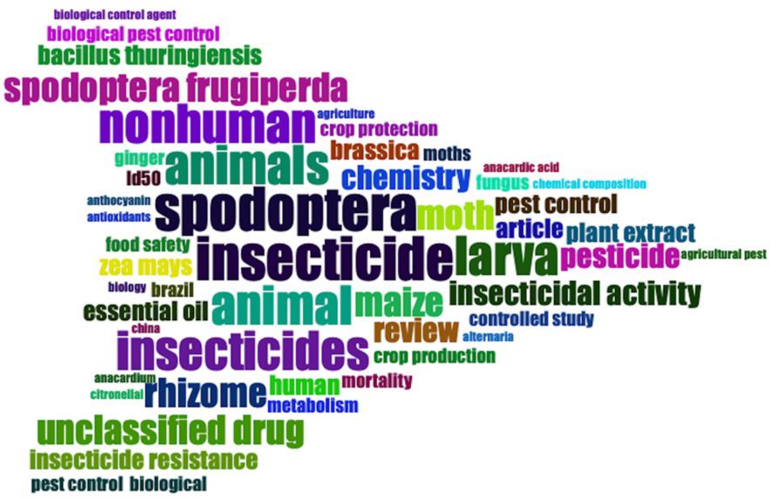

Figure 2. The frequency of the most commonly appearing words in the Scopus database keywords: ginger, maize, and *Spodoptera frugiperda* over the last 13 years.

The analysis of data exported from the Scopus database over the past decade sheds light on the extensive exploration of ginger's role as a botanical insecticide for managing Spodoptera frugiperda pests on maize plants. With 47 publications dedicated to this subject, the frequency of various terms provides valuable insights. Notably, terms such as "insecticide" and "spodoptera" occurring nine times each signify a considerable emphasis on understanding the insecticidal properties concerning the target pest. The inclusion of terms like "animal," "animals," "larva," and "nonhuman" suggests a broader ecological consideration, highlighting the potential impacts on diverse organisms. The repetition of "maize" and "moth" reflects a specific focus on maize plants and their associated pests. Scientific exploration is evident through terms like "chemistry" and "essential oil," emphasizing the chemical composition, possibly related to ginger extracts. Furthermore, the repeated occurrence of terms like "biological pest control" and "plant extract" suggests a keen interest in natural and botanical approaches to pest management. The terms "pesticide" and "pest control" underscore a broader consideration of various strategies for pest management in agriculture. Microbial agents, represented by "bacillus thuringiensis" and "fungus," indicate a potential avenue for pest control research.

The recurrent appearance of "ginger" and "zea mays" highlights the direct relevance of the study to the subject matter. Additionally, terms like "insecticide resistance" and "metabolism" signify an investigation into potential challenges at the molecular level. The presence of terms like "biological control agent" and "agricultural pest" emphasizes an interest in biological agents for managing pests in agricultural settings. Safety considerations are evident through the repetition of terms such as "food safety" and "LD50," reflecting a concern for the safety aspects and lethal dose levels of ginger-based insecticides. Finally, the prevalence of terms like "review" and "article" indicates a substantial contribution of scholarly works and comprehensive reviews on the subject. In summary, the frequency analysis reveals a multifaceted exploration of ginger's potential as a botanical insecticide, encompassing ecological, chemical, and biological dimensions in the context of controlling Spodoptera frugiperda on maize plants. The current research trends based on the database used over the past five years are depicted in Figure 3. The top 10 papers with the highest citation counts over the past 13 years can be observed in Table 4.

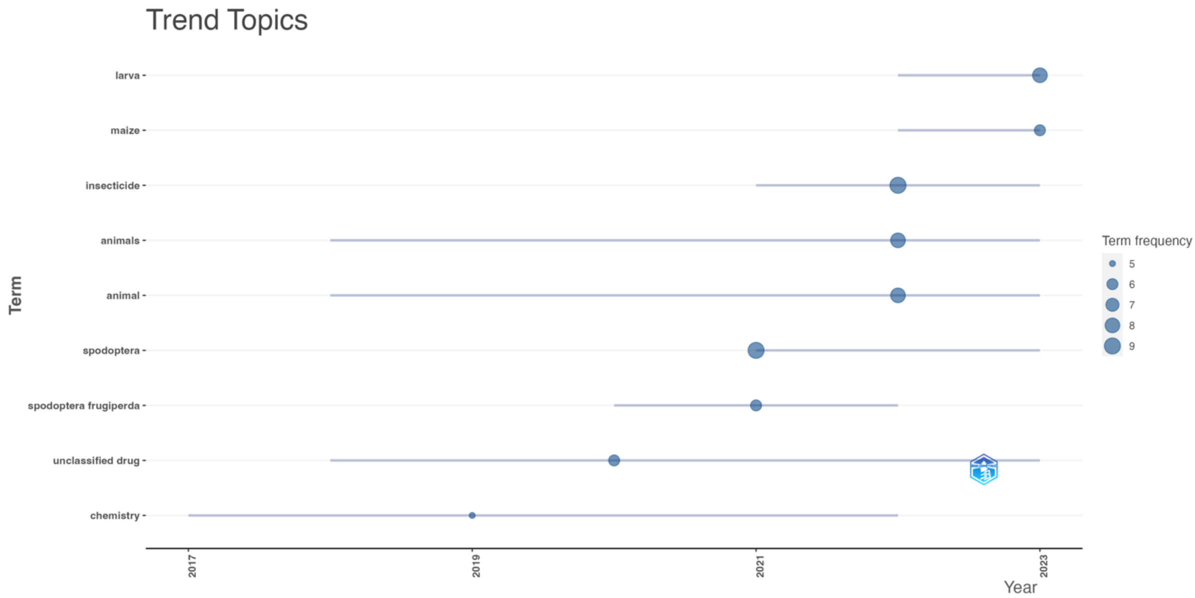

Figure 3. Illustrates the research trends over the past five years concerning control method against *Spodoptera frugiperda* in maize crops.

Table 4. Documents most cited during 2010 – 2023. R = rank; TC = total citations; ACI = annual citation index

R	Autors	Title	TC	ACI
1	(Gruber-Dorninger *et al.*, 2017)	Emerging Mycotoxins: Beyond Traditionally Determined Food Contaminants	228	32.57
2	(Walia *et al.*, 2017)	Phytochemical biopesticides: some recent developments	72	10.29
3	(Hadi and Hussein, 2016)	Antimicrobial Activity and spectral chemical analysis of methanolic leaves extract of Adiantum Capillus-Veneris using GC-MS and FT-IR spectroscopy	54	6.75
4	(Lu *et al.*, 2019)	Paecilomyces variotii extracts (ZNC) enhance plant immunity and promote plant growth	50	10.00
5	(Kenis *et al.*, 2023)	Invasiveness, biology, ecology, and management of the fall armyworm, Spodoptera frugiperda	49	49.00
6	(Krinski *et al.*, 2014)	Insecticidal potential of the Annonaceae family plants	46	4.60
7	(Ngegba *et al.*, 2022)	Use of Botanical Pesticides in Agriculture as an Alternative to Synthetic Pesticides	37	18.50
8	(De Souza Tavares *et al.*, 2016)	Turmeric powder and its derivatives from Curcuma longa rhizomes: Insecticidal effects on cabbage looper and the role of synergists	33	4.13
9	(Dolores Ibáñez and Blázquez, 2019)	Ginger and Turmeric Essential Oils for Weed Control and Food Crop Protection	22	4.40
10	(Otim *et al.*, 2021)	Parasitoid Distribution and Parasitism of the Fall Armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae) in Different Maize Producing Regions of Uganda	21	7.00

Table 4 is organized based on the total citations (TC) received by each document. The most cited document, a meta-analysis conducted by (Gruber-Dorninger et al., 2017), received a substantial 228 citations. This work focuses on emerging mycotoxins, highlighting the health risks posed by fungal spoilage in agricultural products. Aflatoxins, known for their high toxicity, are identified as a severe threat. The paper emphasizes the advancements in analytical methods, particularly LC-MS, enabling the detection of various compounds in food and feed samples. Moving on, the study by Walia et al.,

(2017) delves into the realm of phytochemical biopesticides, discussing their challenges and potential. It notes that while synthetic pesticides are more persistent and effective, phytochemical pesticides are biodegradable but face challenges such as reduced persistence and shelf life. Standardization is hindered by variations in chemical profiles due to various factors. The paper stresses the interdisciplinary expertise required for developing phytochemical biopesticides and the importance of rigorous testing for safety before commercial use.

Furthermore (Hadi and Hussein, 2016) explores the antimicrobial activity of the methanolic extract of Adiantum Capillus-Veneris leaves. GC-MS and FT-IR spectroscopy are employed for spectral chemical analysis, identifying 31 secondary metabolites with potential applications in antibiotic, antioxidant, anti-inflammatory, anticancer, and pharmaceutical industries. The extract is highlighted for its significance as a food resource, addressing human health malnutrition and holding promise as potent drugs for treating obesity. In addition (Lu et al., 2019) investigates the plant immunity-enhancing properties of Paecilomyces variotii extracts (ZNC). The study demonstrates that ZNC promotes plant growth by inducing gene expression related to auxin biosynthesis, regulating nitrogen and phosphorus absorption. Additionally, ZNC enhances defense responses through the salicylic acid biosynthesis pathway, contributing to its potential in crop growth and disease protection.

Additionally, (Kenis et al., 2023) sheds light on the fall armyworm (FAW), advocating for a better understanding of its ecology and management. The call for sustainable Integrated Pest Management (IPM) strategies tailored to specific regions and the consideration of biological control methods reflect the urgency of developing environmentally friendly alternatives to conventional approaches. (Krinski et al., 2014) brings attention to the insecticidal potential of plants from the Annonaceae family. While recognizing their bioactivity, the review emphasizes the need for further research to explore the insecticidal potential of additional Annonaceae species against unstudied insect pests, contributing to sustainable development in agriculture. Furthermore, (Ngegba et al., 2022) advocates for the use of botanical pesticides in agriculture, highlighting their renewable nature and environmental safety. The acknowledgment of challenges in precision and standardization underscores the need for collaborative efforts and regulatory support to ensure the feasibility and affordability of botanical pesticides. De Souza Tavares et al., (2016) contributes insights into the insecticidal effects of turmeric powder and its derivatives on cabbage looper larvae. The identification of ar-turmerone as a promising insecticide, enhanced by the addition of piperonyl butoxide (PBO), introduces a potential alternative for IPM against cabbage looper larvae.

Moreover, (Dolores Ibáñez and Blázquez, 2019) discusses the potential use of ginger and turmeric essential oils in weed control. The proposal of ginger essential oil as a pre-emergent bioherbicide and turmeric essential oil for post-emergent use showcases the versatility of natural products in managing weed populations. Lastly, (Otim et al., 2021) delves into parasitoid distribution and parasitism of the fall armyworm in different maize-producing regions of Uganda. The identification of at least 13 species of parasitoids attacking FAW highlights the potential for biological control strategies. The emphasis on understanding tritrophic interactions and ecological factors underscores the complexity of managing FAW populations. A few of these investigations create two distinct research clusters, as illustrated more prominently in Figure 4.

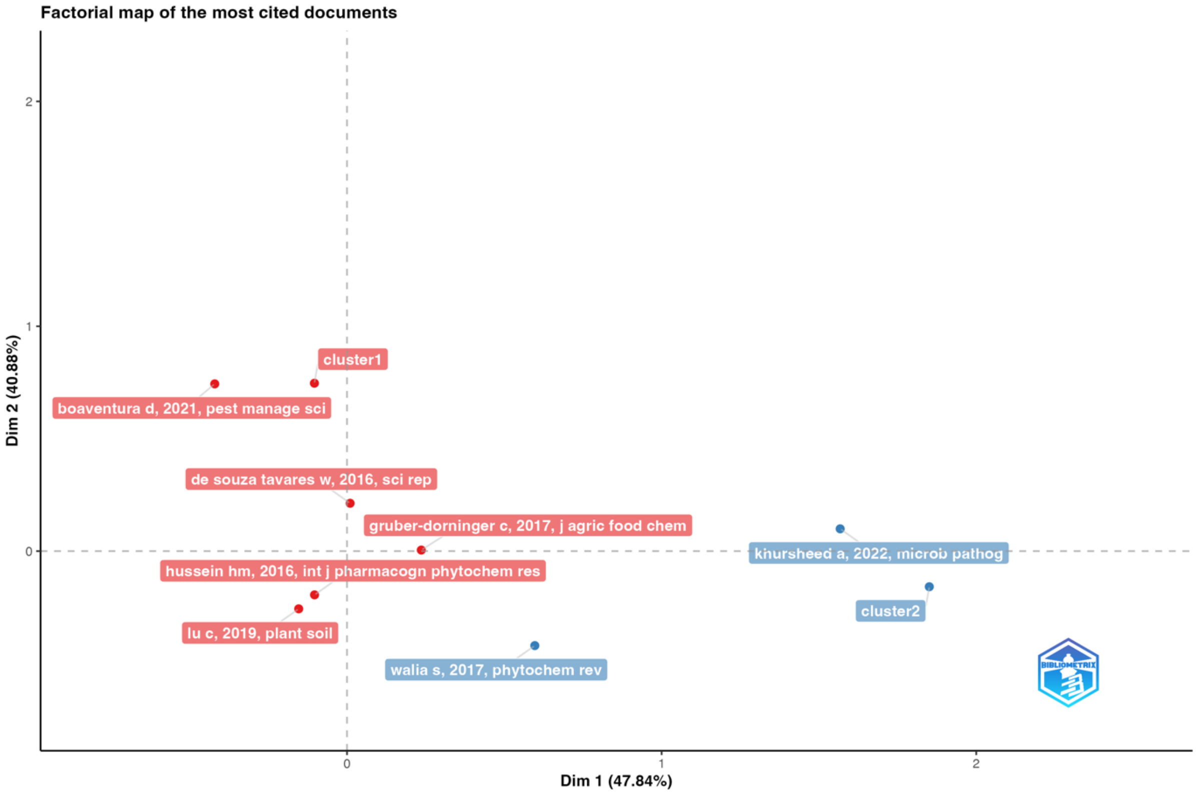

Figure 4. Visualization representing the most cited document through a factorial map.

The interaction patterns among the top 10 most cited articles form two main clusters. In the first cluster (red), the research predominantly revolves around mycotoxins, antimicrobial activity, plant immunity enhancement, pest control, and weed management utilizing natural products. Meanwhile, the second cluster (blue) is centred on phytochemical biopesticides, specifically exploring the insecticidal potential of plants from the Annonaceae family. Challenges related to shelf life, standardization, and safety are the primary focus of this cluster. Based on this understanding, the author grouped various interconnected topics related to ginger as a botanical insecticide on maize plants to control *Spodoptera frugiperda* using the conceptual structure map generated th rough the MCA (Multiple Correspondence Analysis) method (Figure 5).

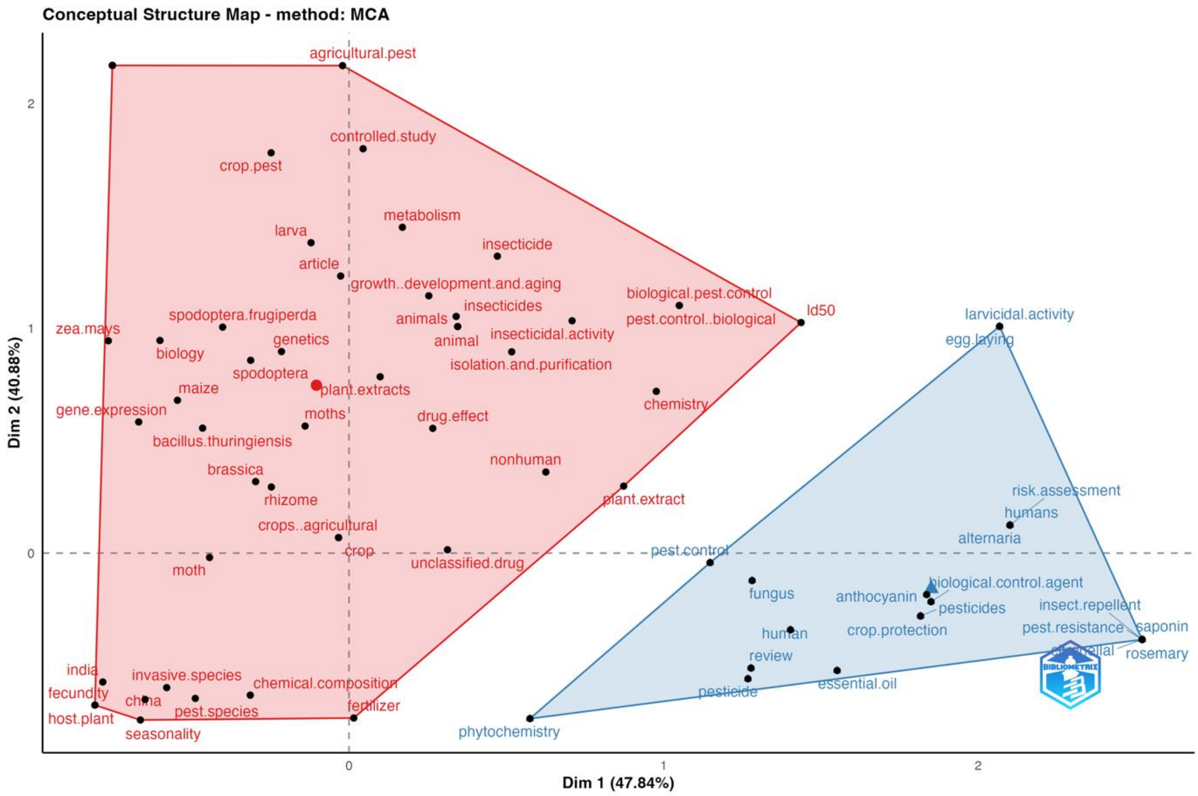

Figure 5. Conceptual Structure based on Multiple Correspondence Analysis (MCA) Method

Employing Multiple Correspondence Analysis (MCA), a statistical methodology illuminating intricate relationships among categorical variables, this research clusters keywords associated with the nitrogen cycle. MCA visually represents data, revealing two clusters: the red cluster (encompassing "insecticide," "spodoptera," "larva," "maize," and "plant extracts") focuses on conventional aspects of insecticides and plant protection, utilizing plant extracts. In contrast, the blue cluster (involving "pesticide," "review," "essential oil," "human," and "pest control") associates more with insecticide resistance, biological control, and human impact. MCA yields profound insights into structural keyword relationships, directing attention to topics with similar implications. Clustering, color-coded for interpretation, distinguishes conventional insecticide and plant protection focus from broader topics including biological aspects and natural substances like essential oils. Recent MCA discussions suggest addressing *Spodoptera frugiperda* with technologies like biological control, botanical pesticides (e.g., ginger extracts), and various essential oils.

3.2. **North Sumatra Maize *(Zea mays*)**

North Sumatra Province, situated close to the equator in Indonesia, predominantly engages in the cultivation of tropical maize. The production value of maize in this region is significantly influenced by weather and climate conditions, crucial components of the ecosystem supporting life. According to the Tile Survey report (2021), 89.59% of maize plantings in North Sumatra remain unaffected by climate change, indicating the region's favorable climate for maize growth (Table 5). Climate factors, including rainfall, temperature and humidity play a substantial role in determining the potential for maize production and crop yields (Cahyaningtyas, 2019). Tropical maize being unsuitable for flooded conditions, thrives in an environment with an ideal rainfall ranging from 85-200 mm/month or 807-1200 mm/year. The optimal temperature and humidity conditions are reported to be 21-28ºC and 80-90%, respectively. These conditions significantly impact critical physiological processes in maize, such as leaf initiation, shoot growth, root growth, and vulnerable phenological phases like pollination to tassel appearance, anthesis, and grain filling (Sanchez et al., 2014). According to Garcı´a-Lara and Serna-Saldivar (2019), the optimal temperature varies at each stage of maize development, as outlined (Table 5).

Table 5. Differential Temperature for Processes and Development Phases Relevant to Maize Development

Process	Temperature (average) (ºC)			*N*
	T_{min}	T_{opt}	T_{max}	
Developmental phase				
Lethal	-1.8±1.9	-	46.0±2.9	14
Flower Initiation	7.3±3.0	31.1±1.7	41.3±1.9	24
Shoot Growth	10.9±1.5	31.1±0.8	38.9±2.8	10
Root Growth	12.6±1.5	26.3±1.8	40.1±3.6	11
Phenological Phase				
Pollination	10.0±2.2	29.3±2.5	40.2±2.1	7
Rumbai Initiation	9.3±2.7	28.3±3.8	39.2±0.6	27
Anthesis	7.7±0.5	30.5±2.5	37.3±1.3	10
Grain Filling	8.0±2.0	26.4±2.1	36.0±1.4	11
Plant Growth	6.2±.1.1	30.8±1.6	42.0±3.3	29

[a] **Temperature:** (T_{min}: T minimal), (T_{opt},: T optimal), (T_{max}, T max), (n: Total)

Source: Modified from Garcı´a-Lara and Serna-Saldivar (2019)

The BMKG North Sumatra (2021) report indicates that the average rainfall in North Sumatra is 212 mm/month, accompanied by an average temperature 27.38ºC and humidity 85.57%. Dispite the rainfall in North Sumatra being above the ideal conditions for tropical maize, the favorable temperature and humidity contribute to productivity values surpassing the national average. According to Mirzaei et al., (2023) air humidity significantly impacts maize productivity as it is interconnected with soil moisture quantity, soil texture, and atmospheric conditions (temperature, solar radiation, wind, and humidity). As per the BPS North Sumatra (2021) report, maize cultivation in North Sumatra predominantly occurs in non-paddy fields, accounting for 92.01% of the total (Table 6). Non-paddy fields encompass various types of agricultural land, excluding paddy fields, such as moorland/gardens, fields/farms, community plantations, community forestry, ponds/recesses/ponds, pens/pastures for grazing/animal feed, temporarily uncultivated land, and other non-paddy agricultural areas (BPS, 2022). These non-paddy fields are reported to possess more favorable soil properties for maize cultivation. The BPS report (2021) highlights that maize grown in non-paddy fields generally exhibits higher productivity compared to maize planted in paddy fields, which are more susceptible to drought. Mirzaei et al. (2023) assert that maize plants can thrive in nearly all soil types, but optimal growth is observed in fertile, loose soil with abundant nutrients and humus, coupled with good aeration and drainage.

In North Sumatra, maize is commonly intercropped with legumes such as peanuts and soybeans. Peanuts are known to have the capability to fix nitrogen (N) from the air, thereby reducing N competition and lessening the need for additional N from synthetic fertilizers (Javanmard et al., 2020). Despite the positive impact of intercropping on N fixation, monoculture cultivation appears to be more prevalent in North Sumatra (Table 6) and is reported to be more effective than intercropping (Anwar et al., 2021). This is evident in the productivity data from the North Sumatra report (2022), BPS, which indicates that maize plants cultivated in monoculture exhibit higher average productivity compared to intercropping, reaching 59.59 ku/ha. This could be attributed to the fact that the primary pest of maize, especially *S. frugiperda*, is polyphagous and has a broad range of hosts, providing alternative hosts when intercropped. Montezano et al. (2018) reported that the *S. frugiperda* pest has 353 species of host plants from 76 families, including legumes. According to Javanmard et al. (2020), maize can be cultivated in both monoculture and intercropping patterns. Monoculture involves planting a single type of plant in one plot of land during the planting period, while intercropping is a planting pattern where two or more types of plants are grown in the same area of planting land at the same or nearly the same time. Maize crops are commonly intercropped with wheat, barley, soybean, sorghum, alfalfa, cloves, and grasses (Farnham et al., 2003; Brummer, 2006).

BPS North Sumatra (2022) reports that maize production in North Sumatra is predominantly in the form of dry shelled maize, leading to the harvesting process taking place during the harvest season, typically 80-100 days after planting. Harvesting is preferably conducted in sunny conditions to avoid high moisture content in maize (Mirzaei et al., 2023). The harvesting of maize is initiated upon reaching physiological maturity or a specific level of maturity, depending on the intended use (Becerra-Sanches and Taylor, 2021). Maize meant for early consumption can be harvested around 68-70 days of age, while dry shelled maize is generally harvested at an average age of 80-100 days after planting (Purwono and Purnamawati, 2007). In general, the readiness of maize for harvest can be determined by observing the color change in the leaves and stems of the plant, which begin to turn yellow and brown at a moisture content of 35-40%.

According to BPS North Sumatra (2021), the availability of maize harvesting tools for farmers is still limited, accounting for only 2.32%. Consequently, the maize harvesting process is primarily manual (Table 5). The conventional harvesting process involves the use of sickles, with two methods: harvesting maize on cobs with husks and harvesting maize on cobs without husks. In the former, maize with a high-water content (30-40%) is cut at the base and immediately separated from the husks. For the latter, maize with lower water content (17-20%) is detached from the husks and directly collected without the need for cutting the maize stalks (Adiputra, 2020). Subsequently, the drying process is employed to reduce the water content of the maize. Harvesting maize can be performed conventionally or with the aid of machinery (Becerra-Sanches and Taylor, 2021). The tools and machines employed in maize harvesting encompass sickles (conventional) and maize harvesters (modern). In addition to saving time and energy, modern harvesters reportedly contribute to a reduction in harvesting costs by up to 60%.

Table 6. Percentage of Maize Households Based on Cultivation in North Sumatra 2021

Description	Percentage (%)
Land Type	
a. Land is not paddy fields	92,01
b. Paddy fields	07,09
Planting Pattern	
a. Monoculture	90,71
b. Polyculture	09,29
Machinery	
a. Harvesting tools	02,32
b. Others	08,58
c. Not accepted	89,29

Climate Change Impacts	
a. Effected	10,41
b. Not effected	89,59

Source: BPS North Sumatra (2022).

North Sumatra plays a significant role as a producer of flat maize, serving as a crucial raw material for the animal feed industry and various other maize-derived products. The prevalent form of maize production in the region is in the shape of dry shells (BPS, 2022). In terms of national maize productivity, North Sumatra Province ranks fifth highest, underscoring its substantial contribution (Table 7). The maize drying process in North Sumatra involves multiple stages, including the drying of maize cobs in the field (both with and without husks) (Mukkun et al., 2018) and shelled maize. Drying methods encompass conventional techniques, such as direct sunlight exposure, and modern approaches utilizing specialized drying equipment like bed dryers, recirculation batch dryers, and continuous mix flow dryers (Lestari and Kurniawan, 2021). Drying maize in the form of husk-free cobs is continued until the maize achieves a moisture content of 17-18%, while shelled maize is dried until it reaches a moisture content of 14-15%. Subsequently, the shelling process is executed to separate maize kernels from the cobs, which can be done conventionally (by human power) or mechanically (using a shelling machine) (Lestari and Kurniawan, 2021). Traditional methods of shelling involve manual techniques like the use of a club, scoured, swiveling iron sheller, and serrated iron sheller. Mechanical shelling, employing a maize sheller, is reported to enhance seed quality by reducing the percentage of damaged or defective seeds and minimizing impurities compared to conventional methods (Mukkun et al., 2018).

Table 7. Average Maize Productivity by national, provincial and district/city level in North Sumatra in 2021.

Cluster	Average Productivity (ku/ha)		
	Subround I	**Subround II**	**Subround III**
National	53,30	57,39	62,17
North of Sumatra	58,29	64,45	63,15
Highest	73,32 (Langkat)	86,05 (Pematang Siantar)	76,88 (South Tapanuli)
Lowest	29,05 (North Padang Lawas)	49,92 (Serdang Berdagai)	30,77 (Central Tapanuli)

Source: BPS Nort Sumatra (2021).

Maize Armyworm Insect Pest The species *Spodoptera frugiperda*

The maize armyworm, *S. frugiperda,* commonly known as the FAW, has emerged as a significant threat to maize plantations in present-day Indonesia. Originally native to the tropical regions spanning the United States to Argentina, *S. frugiperda* undergoes complete metamorphosis, encompassing eggs, larvae, pupae, and imago stages. The eggs are typically laid in clusters on the undersides of leaves, and in high populations, they may extend to the tops of leaves or nearby vegetation. An adult female can produce 900 – 1200 eggs during its life cycle, with an egg period lasting 2 – 3 days (Hutasoit et al., 2020). Upon hatching, 1st instar larvae disperse to find shelter and consume various plant parts (Nonci et al., 2019). *S. frugiperda* larvae progress through 6 instar stages, changing color from pale to greenish and eventually darkening or turning brown. The larval development time spans approximately 12-20 days, with adult larvae reaching sizes between 30 and 40 mm. The 4th to 6th instars are characterized by inverted Y-shaped letters on the head and four black dots forming a square on the penultimate segment, each point adorned with short hair (CABI and FAO, 2019).

Pupae form in the soil, typically at a depth of 2-8 cm, or occasionally on maize cobs. In challenging soil conditions, larvae aggregate plant leaf residues to create pupae above the soil surface (Capinera, 2017). Pupa development takes around 8-9 days (CABL, 2019). Male moths exhibit brown and grey forewings with white triangular patches, while females have brownish-gray front wings. Moths have a lifespan of 21 days (Capinera, 2017). *S. frugiperda* infestations can lead to significant damage to leaves, stems, cobs, and growing points of maize plants, impeding shoot and young leaf formation. Signs of larval attacks include coarse powder resembling sawdust, present on leaves or around their tips (Nonci et al., 2019). BPS (2021) reported a high percentage (83.31%) of OPT attacks on maize plantations in North Sumatra. This pest has caused substantial economic losses for farmers, reducing income by up to 26% and increasing pesticide costs by up to 71% (Buchori, 2020). Farmers in North Sumatra predominantly resort to chemical means (78.95%) for pest control (BPS Nort Sumatra, 2021). Control efforts encompass agronomic, mechanical, biological, and chemical methods. The high reliance on pesticides in North Sumatra is attributed to farmers' limited understanding of the negative impacts of synthetic pesticides and a lack of information on environmentally friendly alternative controls (BPS Nort Sumate, 2021). The percentage of membership in farmer groups in North Sumatra is not yet maximal, standing at 68.70% (Table 8). These groups serve as learning platforms for members to enhance their knowledge and skills in environmentally friendly pest control, contributing to the increased productivity of healthy maize (Mariyono et al., 2022).

Table 8. Percentage of Maize Households Based on OPT Control Efforts and Membership of Farmer Groups in North Sumatra 2021

Description	Percentage (%)
Control Efforts	
a. a. Agronomy	16,03
b. b. Mechanical	2,63
c. c. Biological	2,39
d. d. Chemical	78,95
Farmer Group Membership	
a. a. Member	68,70
b. b. Not a Member	31,30

Source: BPS North Sumatra (2022).

3.3. Ginger (*Zingiber officinale* R.)

Indonesia boasts an array of medicinal plants, each harboring diverse active compounds, among which ginger (*Zingiber officinale* R.) stands out. Ginger is a medicinal powerhouse, enriched with bioactive components, including volatile oil components (sesquiterpenes and monoterpenes) and non-volatile oil (oleoresin) (Suadnyani and Sudarmaja, 2016). According to the Central Bureau of Statistics (2021), ginger ranks as the biopharmaceutical product with the highest production value in Indonesia. In North Sumatra, ginger claims the second-highest position among biopharmaceutical products in Indonesia, following South Sulawesi, with Toba Samosir district leading in production (Table 9). Despite a notable 30% decrease in national and North Sumatra Province growth percentages, ginger production remains at the forefront (Siregar et al., 2022).

Table 9. Production Value and Harvested Area of Ginger Plants Based on National/Provincial/Regency Values

Ginger	Production (kg)	Area (m^2)
National	221.713.138,33	103.427.754
South Sulawesi Province	27.903.618,67	15 183 356
North Sumatra Province	20.751.594,33	11.299.794
Toba Samosir	1.423.027,50	1 220 797

Source: BPS (2021).

Ginger is recognized for containing valuable bioactive secondary metabolites crucial in the control of insect pests (Zhang et al., 2022). Secondary metabolites, derived from plants, offer an excellent alternative to synthetic or chemical pesticides (Hikal et al., 2017). Ginger produces bioactive ingredients such as essential oils (zingiberene, curcumin, geraniol, citronyl acetate, terpineol, linalool, borneol, neral, and geranial), phenols, flavonoids, and organic acids (malic, citric, and tartaric acids). These components exhibit diverse properties, including antiviral, anti-inflammatory, anti-stomach, antioxidant, antibacterial, antidiarrheal, antispasmodic, astringent, hepatoprotective, cyclooxygenase inhibitor, antiulcer, fungicidal, and insecticidal (anti-insect) activities (Figure 2) (Kate and Sutar, 2020). Various extraction techniques can be employed to obtain active plant constituents (Table 9) (Zhang et al., 2018). The insecticidal effects of ginger involve essential oils, alkaloids, flavonoids, triterpenoids, tannins, and saponins, serving as repellents, antifeedants, toxicants, growth retardants, chemosterilants, and attractants (Hikal et al., 2017).

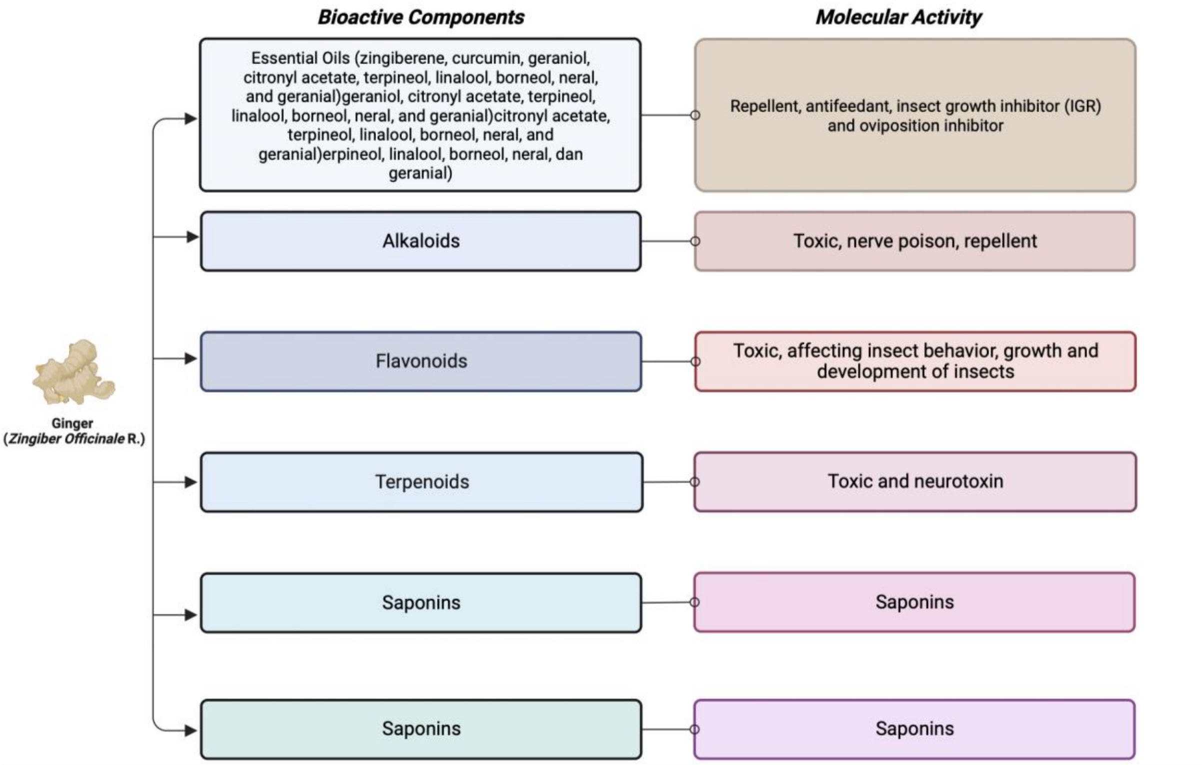

Figure 5. Bioactive Activity and Molecular Mechanisms of Ginger (*Zingiber officinale* R.) (Jaffar and Lu, 2022; Thawadeh et al., 2019; Liu et al., 2022; Scalerandi et al., 2018; Rahayu and Mairawita, 2018).

Essential oils, volatile and odorless fractions extracted from aromatic plants, play a crucial role in managing insect pests and mites (Feroz, 2020; Manh et al., 2020). Ginger's essential oils, including zingiberene, curcumin, geraniol, citronyl acetate, terpineol, linalool, borneol, neral, and geranial, exhibit insecticidal properties (Ivanovic et al., 2021). Ginger essential oil has been reported to cause mortality (45%) and repellency (61%) in Culex theileri (Madreseh-Ghahfarokhi et al., 2018). Additionally, it shows acaricidal and repellent activities of 39% and 62%, respectively, against the pest Rhipicephalus bursa (Madreseh-Ghahfarokhi et al., 2019). The essential oil content of ginger induces mortality in S. *frugiperda* larvae, affecting various parameters such as larval weight, fecundity, consumption index (CI), relative growth rate (RGR), and digestibility (AD) of larvae (Keosaeng et al., 2022) and acts as a repellent to maizecob borers (Ukeh et al., 2010).

Alkaloids, a group of natural compounds integral to insecticides, exert insecticidal effects at low concentrations and pose toxicity to vertebrates (Thawabteh et al., 2019). Their mechanism of action typically involves influencing acetylcholine receptors in the nervous system or the membrane of sodium channels in nerves (Thawabteh et al., 2019). These compounds, prevalent in plants such as those from the *Berberidaceae, Fabaceae, Solanaceae, Zingiberaceae, and Ranunculaceae families,* are employed as insect repellents (Bekele, 2018). Notably, ginger's alkaloids have been reported to induce up to 95% mortality in FAW larvae within 72 hours of treatment (Sisay et al., 2019). Flavonoids play a pivotal role in plant defense against plant-eating insects and herbivores, influencing insect behavior, growth, and development (Simmonds, 2003). Found in plants like ginger, flavonoids exhibit insecticidal activity by inhibiting mating in Drosophila melanogaster and repelling adult whiteflies (*Bemisia tabaci*) (Jerome and Nancy, 2018; Zhang et al., 2004). Additionally, they contribute to controlling populations of pests like the alfalfa leafcutter wasp and demonstrate insecticidal efficacy against stored grain pests (Ong et al., 2020; Ahmad et al., 2018).

Table 10. Methods of Extraction of Plant Materials

Method	Solvent	Temperature	Pressure	Time	Volume of Organic Solvent Consumed	Polarity of Natural Products Extracted
Maceration	Water, Aqueous and Non-Aqueous Solvents	Room Temperature	Atmospheric	Long	Large	Dependent on Extracting Solvent
Percolation	Water, Aqueous and Non-Aqueous Solvents	Room Temperature, Occasionally Under Heat	Atmospheric	Long	Large	Dependent on Extracting Solvent
Decoction	Water	Under Heat	Atmospheric	Moderate	None	Polar Compounds
Refux Extraction	Aqueous and NonAqueous Solvents	Under Heat	Atmospheric	Moderate	Moderate	Dependent on Extracting Solvent
Soxhlet Extraction	Organic Solvents	Under Heat	Atmospheric	Long	Moderate	Dependent on Extracting Solvent
Pressurized Liquid Extraction	Water, Aqueous and Non-Aqueous Solvents	Under Heat	High	Short	Small	Dependent on Extracting Solvent
Supercritical Fuid Extraction	Supercritical Fuid (Usually S-CO2), Sometimes With Modifer	Near Room Temperature	High	Short	None or Small	Nonpolar to Moderate Polar Compounds

Ultrasound Assisted Extraction	Water, Aqueous and Non-Aqueous Solvents	Room Temperature, or Under Heat	Atmospheric	Short	Moderate	Dependent on Extracting Solvent
Microwave Assisted Extraction	Water, Aqueous and Non-Aqueous Solvents	Room Temperature	Atmospheric	Short	None or Moderate	Dependent on Extracting Solvent
Pulsed Electric Feld Extraction	Water, Aqueous and Non-Aqueous Solvents	Room Temperature, or Under Heat	Atmospheric	Short	Moderate	Dependent on Extracting Solvent
Enzyme Assisted Extraction	Water, Aqueous and Non-Aqueous Solvents	Room Temperature, or Heated After Enzyme Treatment	Atmospheric	Moderat e	Moderate	Dependent on Extracting Solvent
Hydro Distillation and Steam Distillation	Water	Under Heat	Atmospheric	Long	None	Essential Oil (Usually Non-Polar)

Source: Zhang et al., (2018)

Terpenoids, the largest group of natural plant products, encompass essential oils, flavors, fragrances, and fat-soluble pigments. Derived from isoprene units, they are known for their anti-herbivorous and anti-pathogenic activities. Terpenes, found in various plants, can cause paralysis and death in insects, making them active ingredients in commercial pesticides (Scalerandi et al., 2018). Tannins, the most abundant secondary metabolites in plants, serve as inhibitors of enzyme activity in insect digestion (Rahayu and Mairawita, 2018). Constituting 5-10% of the dry weight of leaves, tannins protect plants from herbivorous insects through prevention and toxicity (Dehghanian et al., 2022). The insecticidal effect is attributed to the generation of high levels of reactive oxygen species, impacting insect digestion. Insects' ability to tolerate ingested tannins arises from various biochemical and physical defenses in their gut (Barbehenn and Constabel, 2011).

3.4. Botanical Insecticide Industry

The agricultural sector serves as a pivotal driver in enhancing the value of agricultural commodities, thereby exerting a profound impact on the economic growth of both regions and nations (Ma et al., 2022). A crucial prerequisite for any industry to contribute significantly to economic advancement lies in its ability to produce goods derived from superior commodities tailored to meet the demands of local consumers (Manuchehr, 2022; Huo et al., 2023; Zhonghua and Xiang, 2022). Pesticides, vital in agricultural practices, undergo classification based on the primary raw materials employed in their production (Souto et al., 2021). In Indonesia, particularly in North Sumatra, the categorization of pesticides aligns with the guidelines established by the Indonesian government under Regulation No. 7 of 1973. Industries reliant on synthetic compounds as their primary raw materials fall under the umbrella of chemical pesticide industries. Those centered around microorganisms find classification as biopesticides industries, while those predominantly utilizing plant-based ingredients are termed vegetable pesticide industries (Ministry of Agriculture, 2019). Each industry within this classification produces distinct products tailored to specific targets. Notably, the vegetable pesticide industry stands out as an environmentally sound option, causing no harm to the food chain and leaving no residual traces on applied plants (Lengai et al., 2019). Surprisingly, despite its environmental advantages, the vegetable pesticide industry is yet to find its footing in the provinces of Sumatra and Indonesia at large.

The products stemming from the vegetable pesticide industry have found widespread use among farmers in various provinces of Indonesia, notably in North Sumatra (Hendriadi et al., 2021). This industry primarily relies on ginger as a key raw material, with its target audience being the *spodeptera* pests (Liu et al., 2022). In the province of Sumatra, ginger holds a prominent position among medicinal plants, serving as a leading commodity with the highest production rates. In North Sumatra Province, ginger plays a pivotal role in international trade, with a substantial 87.10% exported to various countries for utilization as a raw material in culinary spices. Conversely, only 12.9% of ginger is allocated for domestic consumption, highlighting its significance as an export commodity (Siregar et al., 2022a). Both North Sumatra and Indonesia at large possess the potential to cultivate a plant-based pesticide industry, with ginger as a central component and the *S. frugiperda* pest as the primary target (Siregar et al., 2022b). Ginger, being a leading commodity in medicinal plants in North Sumatra, exhibits remarkable abilities to control the development of the *S. frugiperda* pest on maize plants. This efficacy is attributed to its diverse components, including essential oils, alkaloids, flavonoids, triterpenoids, tannins, and saponins. These compounds act as repellents, antifeedants, toxicants, growth retardants, chemosterilants, and attractants (Hikal et al., 2017). The strategic use of ginger as the main raw material for vegetable insecticides not only generates added value but also meets the needs of maize farmers in effectively controlling *S. frugiperda* pests. Additionally, this approach contributes to reducing the reliance on chemical pest management for *S. frugiperda*, thereby mitigating associated production costs (Mendez et al., 2011).

The potential for North Sumatra Province to spearhead the development of a plant-based pesticide industry in Indonesia is emphasized in the work of Faustin et al. (2015). This initiative gains significance as the non-vegetable pesticide industry witnessed a decline in its contribution to Indonesia's economic growth, evidenced by a drop in export values from 2008 to 2009 (Ministry of Agriculture, 2010). This decline is attributed to the growing global preference for plant-based products devoid of residual values (FAO, 2015). Furthermore, the decrease in import values can be linked to regulations set forth by Indonesia's health and agriculture ministries, promoting organic farming and providing subsidies to farmers adopting such practices (Ministry of Agriculture, 2019). To fortify the potential of North Sumatra Province in this endeavor, regulatory support is imperative. Government Regulation of the Republic of Indonesia Number 28 of 2021 underscores the vegetable pesticide insecticide industry as a crucial strategic category, directly impacting the lives of many citizens. The implementation of this regulation involves technology and capital procurement assistance (Ministry of Finance Republic of Indonesia, 2020; Economic Report on Indonesia, 2019; Puspitawati, 2021). Moreover, Indonesia positions the plant-based pesticide industry as a key pillar in achieving Indonesia Gold by 2045, as outlined by the Ministry of National Development Planning (National Development Planning Agency (BAPPENAS), 2019). Various forms of government support for the development of the plant-based pesticide industry are evident. This includes the formulation of strategies for economic structural change and industrial policies, drawing inspiration from the successful development of the plant-based insecticide industry in China (Blue Economy Development Framework for Indonesia's Economic Transformation, 2021; Roadmap of SDGs Indonesia A Highlights, 2021).

3.5. Agricultural Landscape Planning Strategies for Maize Plants

Regional arrangement and planning are strategic steps to address future challenges. In the context of arranging the region of a district/city, the steps involve the analysis of demographic potential (population/human resources) and geographical features (land, forests, mountains, agriculture, and plantations). Regional planning should be perspective, futuristic, and anticipatory. Regions can be divided into functional regions (integration of components), homogeneous regions (similarity), and administrative regions (clear geographical boundaries). Regional planning involves aspects of spatial arrangement, location of economic activities, and values in the context of community life. Regional planning can be divided into sub-fields such as social-economic planning, spatial planning, special planning, and project planning. Steps in regional planning include identifying conditions, establishing vision and mission, identifying surrounding areas, projecting relevant variables, setting targets, establishing cooperation formats, identifying constraints, selecting alternatives, determining locations and times, and formulating policies (Figure 6).

The holistic development of an area is aimed at enhancing socio-economic well-being, mitigating regional disparities, and preserving the environment. In the specific context of regional planning, particularly for maize cultivation, a series of straightforward yet impactful strategies should be implemented. Initially, the selection of maize varieties tailored to the region's climate and soil conditions constitutes the foundational step. Subsequently, the identification of zones characterized by similar soil and climate features enables the selection of maize types best suited for each specific zone. Land use planning follows, incorporating crop rotation to sustain soil fertility. Efficient irrigation planning is deemed crucial, necessitating the identification of sustainable water sources. Environmental considerations play a pivotal role, prompting the evaluation of the impact of pesticide and fertilizer use. The adoption of sustainable farming practices becomes imperative in this regard. A proactive risk management approach involves identifying potential weather or pest-related issues and devising solutions, including the implementation of agricultural insurance.

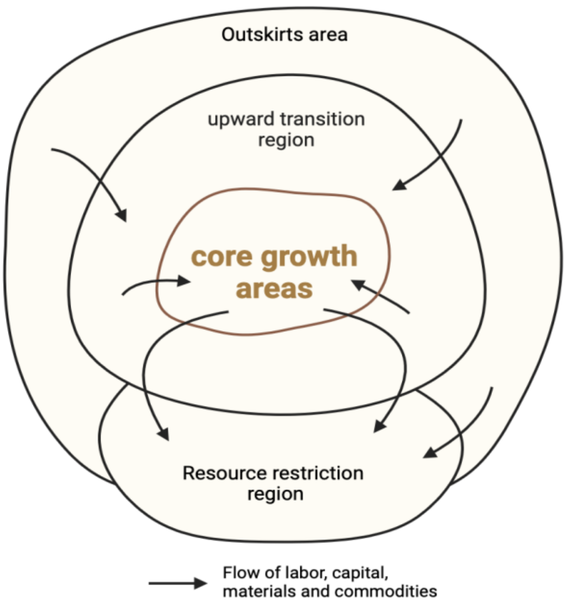

Figure 6. Model Development of the Core-Periphery Region. Source: Adapted from Friedmann & Alonso, 1964.

Strategic planning extends to the development of agricultural infrastructure, encompassing elements such as irrigation systems and storage warehouses. To enhance farmers' capabilities, training programs covering best practices and the latest agricultural technologies are implemented.

The integration of modern technology, exemplified by Geographic Information Systems (GIS) and drones, facilitates meticulous monitoring of farm activities. The comprehensive approach extends to soil and water conservation practices, including the implementation of soil cover cropping. This multifaceted strategy ensures not only the enhancement of agricultural productivity but also the cultivation of an environmentally friendly farming system. Furthermore, the application of innovative strategies, such as utilizing biopesticides derived from ginger plants, becomes instrumental in supporting the development of agricultural areas, especially for maize cultivation. Biopesticides, with their natural antimicrobial and anti-insect properties extracted from ginger, present an appealing method for pest control without leaving harmful residues on the harvest. The synergy between the development of ginger and maize crops exemplifies a holistic approach to agricultural area planning (Figure 7).

The integration of these strategies aligns with the Hexa Helix concept, involving collaboration between various stakeholders. This collaborative effort, coupled with the application of modern technologies, strategic infrastructure planning, farmer empowerment through training, and innovative pest control methods, not only addresses agricultural challenges effectively but also paves the way for the creation of environmentally sustainable and inclusive regions.

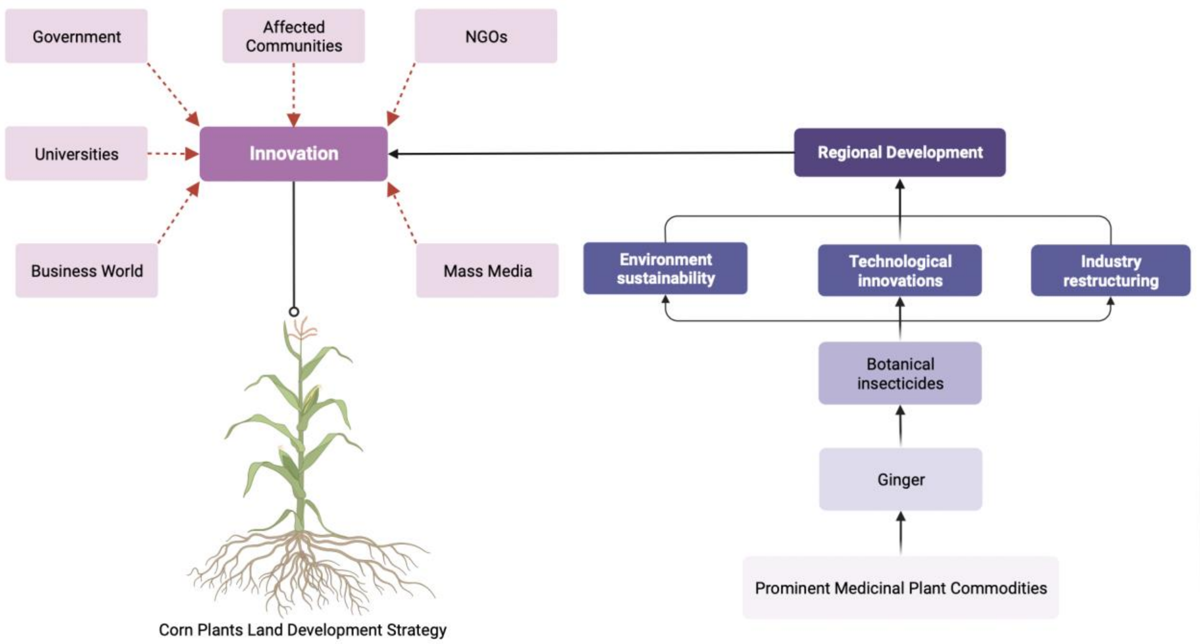

Figure 7. Regional Development Based on the Hexa Helix Concept

4. CONCLUSION

Recent research highlights the utilization of ginger as a botanical insecticide to manage Spodoptera frugiperda pests in maize crops. The focus encompasses the insecticidal properties of ginger, ecological aspects, and the development of sustainable pest management strategies. Influential articles delve into biopesticides, the antimicrobial capabilities of plants, and sustainable pest control strategies, with a keen emphasis on food safety and environmental sustainability. These findings reflect comprehensive efforts to enhance maize farming effectively and sustainably, addressing challenges such as Spodoptera frugiperda through technologies like biological control, botanical pesticides (e.g., ginger extracts), and various essential oils. The utilization of ginger-based botanical pesticides proves not only effective against pests like armyworms but also supports environmental sustainability. Beyond providing protection for biodiversity and fostering residue-free farming, the use of ginger as a natural pesticide holds positive economic potential. In the context of maize farming planning, a holistic approach involving the selection of suitable varieties, natural environmental management, and the integration of modern technology forms the foundation for productive and environmentally friendly agriculture in North Sumatra. Proper training and knowledge in pest management are crucial to maximizing economic benefits and ensuring the sustainable application of ginger-based botanical pesticides. In conclusion, the amalgamation of scientific research and ginger-based agricultural practices can serve as a model for effective, economical, and sustainable farming.

THE AUTHOR'S CONTRIBUTION

All authors contributed to the literature search and writing of this article.

ORCID

CONFLICT OF INTEREST

All authors declare that they have no conflict of interest in publishing this article.

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