Development of an IFOAM-compliant Prototype for Organic Chili Pepper Production: Innovations in Sustainable Cultivation and Pest Management

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The International Federation of Organic Agriculture Movement (IFOAM) indicates that the detrimental impact of pesticide residues in chilli pepper production for consumption prompted the creation of a prototype approach for cultivating organic chilli peppers to safeguard safety and human health. Researchers conducted an inquiry on a chilli pepper crop in Lampang province and examined the simulation of organic chilli growing in an IFOAM-certified region at the Biological Control Technology Learning Centre, Maejo University, Chiang Mai, Thailand. The analysis effectively optimised organic chilli pepper output to comply with regulations by meticulous selection of planting materials, fertilisers, and pest management techniques. The research was carried out in Lampang province and at the IFOAM-certified site at Maejo University, Chiang Mai, Thailand. The inquiry effectively adhered to organic standards through the selection of planting materials, fertilisers, and pest management techniques. The prototype technique involved utilising certified seeds, organic fertilisers, Trichoderma sp. for pest management, and natural predators such as stink bugs. The objective was to attain a plant density of 5,000-6,000 plants per rai. Researchers controlled insect pests by employing stink bugs to manage chilli pepper cutworms 7-14 days post-transplantation, thereafter applying Beauveria bassiana and neem extract solution at 21 and 28 days after transplantation, respectively. The prototype yielded chilly paper at 1,680 ± 4.27 kg/rai, comparable to the regular manufacturing schedule. The study found a favourable correlation between pest control approach and pest epidemic number (R^2 = 0.86) as well as plant disease (R^2 = 0.53). Simultaneously, the quantity of insect epidemics and plant diseases had a positive link with crop yield, with R^2 values of 0.65 and 0.67, respectively. The research established a prototype that presents a sustainable, pesticide-free production technique for chilli peppers, promoting the green economy and furnishing a practical guidance for farmers to implement organic methods.

1. Introduction

The chilli pepper (Capsicum spp., Solanaceae) is an internationally important vegetable and condiment, valued for its economic impact and culinary adaptability. Conventional chile production significantly depends on chemical inputs, especially pesticides, which present considerable dangers to human health, biodiversity, and environmental sustainability owing to pesticide residue exposure. These challenges have prompted increased emphasis on sustainability in agricultural techniques, including organic agriculture. Toepfer et al. (2020) characterise organic farming, as defined by the International Federation of Organic Agriculture Movements (IFOAM), as an integrative production system focused on enhancing soil health, reducing chemical reliance, and attaining ecological equilibrium through natural processes. Another factor driving interest in organic chilli cultivation is the rising global demand for pesticide-free and environmentally sustainable food. Nevertheless, the distribution of efficient methodologies and technological innovations remains insufficient for expansion (Bouri, Arslan, & Şahin, 2023).

To surmount these challenges, it is imperative to implement sustainable agricultural methods, utilise organic fertilisers, and employ biological pest management (Nchu, 2024). Organic amendments employed in organic chilli systems comprise compost and biofertilizers, which augment nutrient availability, organic matter, and soil pH to improve sustainability and productivity. Biological controls, including predators, parasitoids, and entomopathogens, are extensively employed to mitigate pest populations for effective biological control in sustainable agriculture. Research demonstrates the efficacy of Beauveria bassiana and neem extract in combating aphids, whiteflies, and soil-borne diseases, consistent with the tenets of Integrated Pest Management (IPM) (Patil & Tayde, 2022). Integrated Pest Management (IPM) employs cultural, mechanical, and biological strategies to reduce chemical application while ensuring crop hygiene and yield (Kumar et al., 2022).

Improvements in organic methods such as cover cropping, decreased tillage, and organic mulches have facilitated the suppression of vegetation, water retention, and enhancement of soil fertility in chilli production systems (Kumar et al., 2022; Liu et al., 2020). Field studies in Southeast Asia (Damavandian, 2007) have demonstrated the advantages of incorporating biofertilisers and biological pest management in organic chilli systems to mitigate pest pressures and secure elevated yields. To promote sustainable practices, it is essential to develop prototypes for organic chilli farming that adhere to IFOAM criteria. These approaches mitigate environmental impacts, promote sustainable livelihoods, and improve the competitiveness of organic chilli growing in eco-aware markets (Bažok, 2022).

In Thailand, chilli pepper is regarded as a significant spice crop. The cultivation of chillis significantly depends on chemicals, especially for pest control. The implementation of organic cultivation in chilli pepper agriculture addresses chemical toxicity to humans, environmental concerns, and agricultural residues, offering sustainable answers to these issues. Organic agriculture is a farming strategy that maintains soil fertility, ecosystems, and human health, utilising ecological processes, biodiversity, and cycles tailored to local conditions. Deguine et al. (2021) The consumption of organic produce in Thailand demonstrated a rising demand, signifying substantial expansion in the organic sector. (Fernando, Hale, & Shrestha, 2024). The current ratio of organic chilli pepper cultivation area to organic yield is not significantly evident in the agricultural market due to the limited availability of information regarding technology or production methods for organic chilli peppers. Researchers identified a study examining production aspects, particularly the application of organic fertilisers to enhance soil quality prior to planting in an organic chilli pepper cultivation method. The results indicated an increase in pH, organic matter, accessible phosphorus, exchangeable potassium, calcium, and magnesium content of the soil. The PGPRI microbial compost and accelerator compost (PD.1) treatment exhibited the maximum output of chillies. The investigation into the optimal utilisation of bio-fermented solutions for organic chilli cultivation revealed that the use of fermented fish and fruit solution every seven days yielded no significant difference compared to other treatments, yet resulted in the highest net profit. Various methods can be employed in conjunction for pest control. Research was conducted on disease- and insect-resistant varieties, specifically assessing the resistance of chilli to yellow leaf curl disease, evaluating tomato varieties resistant to yellow leaf curl virus, and examining large-fruited fresh tomato cultivars for resistance to Fusarium wilt (Fusarium oxysporum f.sp. lycopersici race 2). The biology of pest control involves employing living creatures, including parasites, parasitoids, predators, and diseases, to regulate pest populations and mitigate their potential harm (Franco et al., 2004).

This study aimed to gather comprehensive knowledge to establish an organic chilli production method, resulting in the advancement of chilli production technology within organic farming. The benefit of new knowledge can be leveraged for the advancement of sustainable commercial development associated with the green economy concept. This fosters sustainable and stable livelihoods for individuals while enhancing the competitive capacity of the ecologically sustainable agriculture sector, grounded in science and technology (Gelaye & Negash, 2023). This project aims to integrate knowledge of organic crop production and pest management to develop expertise and prototype methods for organic chilli production in accordance with IFOAM standards (George, Rao, & Rahangadale, 2019).

2. Materials and Methods

2.1. The Type of Insect Pest and its Population Dynamic Study On Chili Pepper to Assess the Epidemic Dispersal

A survey of plant diseases, pest insects, and their natural antagonists was performed in the chilli pepper fields across five locations: Pan City, Chae Hom, Ngao, Wang Nua, and Mae Phrik in Lampang province (figure 1). The survey area comprised six plots per province, each with a sampling size of 1,600 square meters. The population of chilli pepper bug pests and their natural predators was gathered as follows: The plant was taped to collect insect pest samples that landed on a plastic plate measuring 20 × 30 cm. The insect pests and their natural predators were identified and preserved in a plastic tube containing 70% ethyl alcohol. The survey area's details, including location, host plants, pictures, and geographic coordinates, were documented using GPS (Garmin-Oregon-450). Morphology was examined in the laboratory using stereo and compound microscopes at the Biological Control Technology Learning Centre, Maejo University (MJU-BCTLC). They were preserved as voucher specimens made from wet specimens using an alcohol-glycerin-acetic acid solution (AGA) and 60% ethanol, as well as permanent slides in Canada balsam and Hoyer's solution. All components of the plant exhibited a 50% infestation level, collected in quantities of 5-10 pieces/parts and preserved in a plastic tube containing a 70% alcohol solution, totalling 10 ml. The answer was linked to the separation of insect pests and plants. Samples were gathered using an aspirator with a cylinder extractor for laboratory identification, and the modified insect pest and natural enemies were mapped using the Google Earth software. All data were approximated for population dynamics (Figure 1).

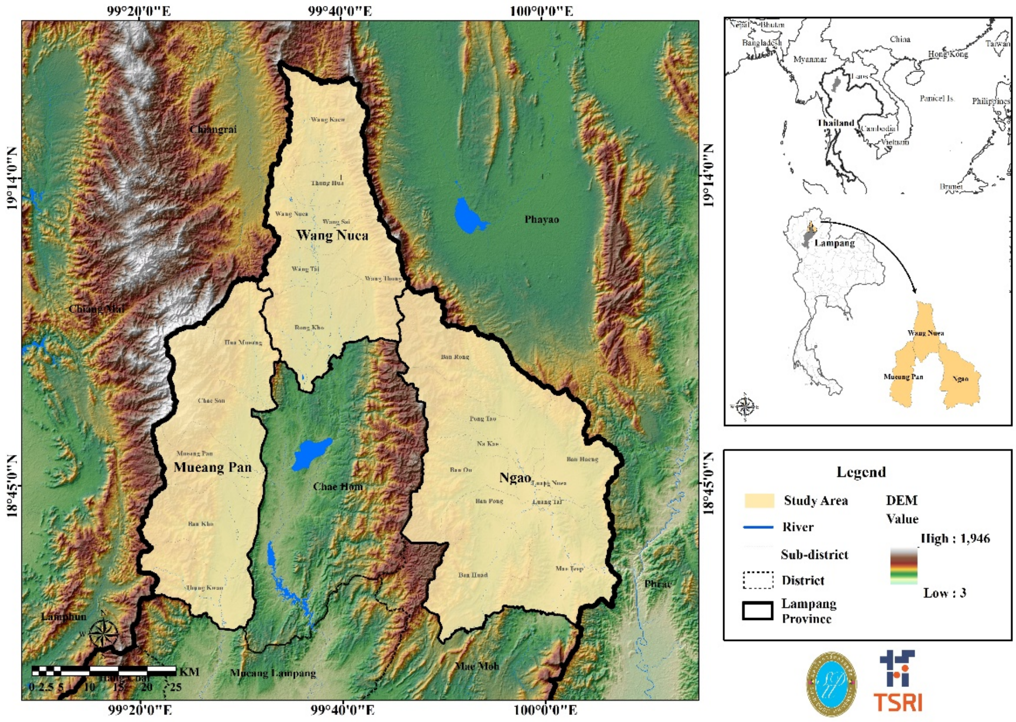

Figure 1: Field Survey of Chili Pepper Crop in Pan City, Chae Hom, Ngao, Wang Nua and Mae Phrik of Lampang Province.

2.2. Crop Production Study and Pest Control by Bio-production Factor Testing Under IFOAM Standard Guidance

The data collection process for the chilli pepper crop involved the following parameters: pepper variety, plant density, fertiliser management, irrigation, and insect control. The data was integrated with contemporary fundamental chilli pepper crop production and IFOAM standard recommendations for crop production standards. Pest management was executed in accordance with the treatment protocols for the organic net house and field experiment. The sun-hot type underwent seven treatments as detailed below: 1) Unutilised pest

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control product (control treatment), 2) Kaolin clay for plants administered biweekly, 3) Sulphur for plants administered biweekly, 4) Neem extract, 5) Beauveria bassiana strain BCTLC026 at 150 g/120 L (fresh culture on sterilised cooked rice grain with a 14-day lifespan), 6) Trichoderma harzianum strain BCTLC001 at 150 g/120 L (fresh culture on sterilised cooked rice grain with a 14-day lifespan), and 7) A combination of microorganisms, extract solutions, and predatory insects tailored to epidemic dispersal conditions. Both conditions were executed utilising the optimal methodology for pest control collection (Figure 2).

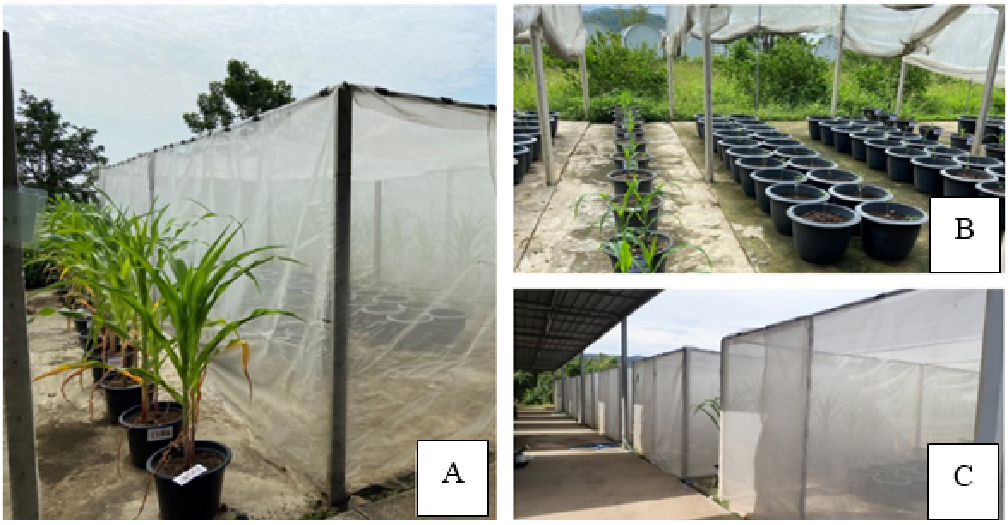

Figure 2: Crop Experiment in Net House Condition at Biological Control Technology Learning Center Maejo University (MJU-BCTLC); Net House and Guard Row (A), Crop Experiment in Net House Condition (B) and All of Net House Experiment (C).

2.3. Technological Development in Pest Management According to IFOAM Standard Guidance

The experimental outcome was evaluated utilising the regression equation and integrated pest management techniques for chilli in organic farming systems in accordance with IFOAM international standards. The data was synthesised for organic chilli pepper crop production and handbook organisation.

2.4. Data Analysis

The experiment employed a completely randomised design (CRD), utilising Duncan's Multiple Range Test (DMRT) for comparative analysis of means and variances at 95% and 99% confidence levels. The population dynamics of insect pests and their natural predators were analysed via the regression equation. Let x represent the logarithm of the populations of insect pests and natural enemies, and let y denote the growth stage of chilli pepper. The data was converted to log(n)+1 to normalise the distribution, facilitating the analysis of the population dynamics of insect pests of chilli pepper and their natural predators throughout the year, in accordance with the Dent and Walton methodology.

3. Results and Discussion

3.1. Species of Plant Pest and its Population Dynamic on Chili Pepper Crop

The assessment of the insect pest pandemic identified cutworm, aphid, tobacco whitefly, thrips, and wide mite (Figure 3). Identified plant diseases include fusarium wilt, anthracnose (Colletotrichum gloesporioides), and pepper mild mottle virus (Figure 4). Population dynamics fluctuated during several stages of plant growth, demonstrating a positive association among insect pests, their natural predators, and the stages of plant development. The correlation indicated that the seedling stage was associated with wilt disease, damping off, cutworm, and aphid infestations. The vegetative stage was associated with leaf spot, anthracnose, pepper mild mottle virus, cutworm, and tobacco whitefly. The flowering phase was associated with anthracnose, pepper mild mottle virus, tobacco whitefly, aphids, and thrips. The fruit-setting phase was associated with anthracnose, thrips, and the Solanum fruit fly. The harvesting phase was associated with fruit flies, aphids, and thrips (Figure 5).

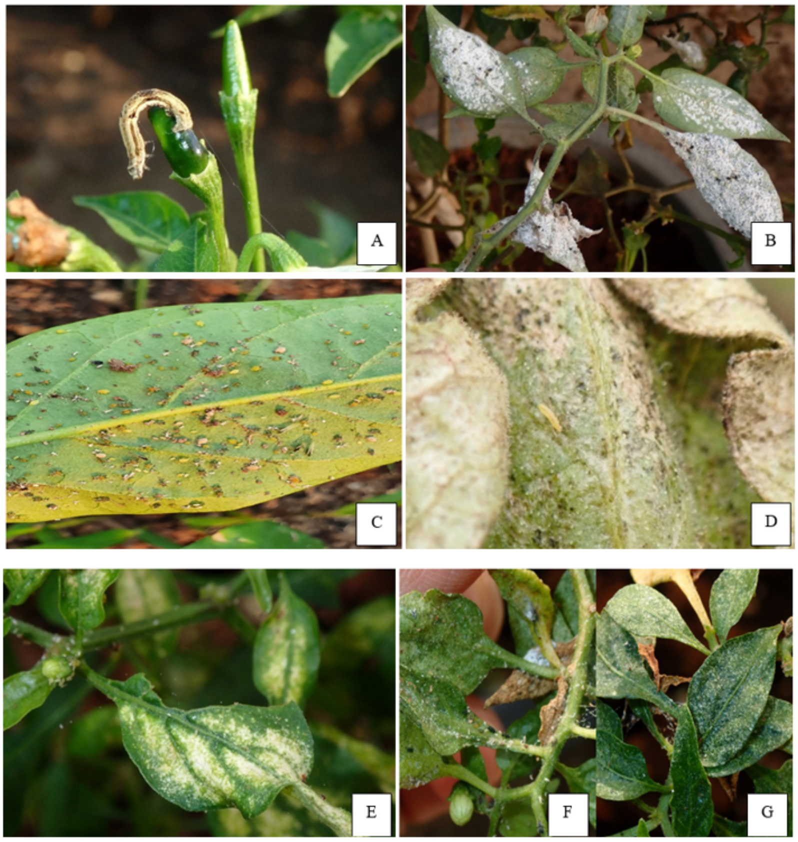

Figure 3: Survey of Insect Pest in Chili Pepper Crop at Lampang Province; Cutworm (A), Tobacco Whitefly (B), Aphid (C), Thrips (D), Broad Mite (E) and Kanzawa Spider Mite (F, G).

Figure 4: Survey of Plant Disease in Chili Pepper Crop at Lampang Province; Fusarium wilt (*Fusarium oxysporum* var. vasinfectum) (A), Pepper Mild Mottle Virus (B) and Anthracnose (*Collectotrichum gloespoloides*) (C).

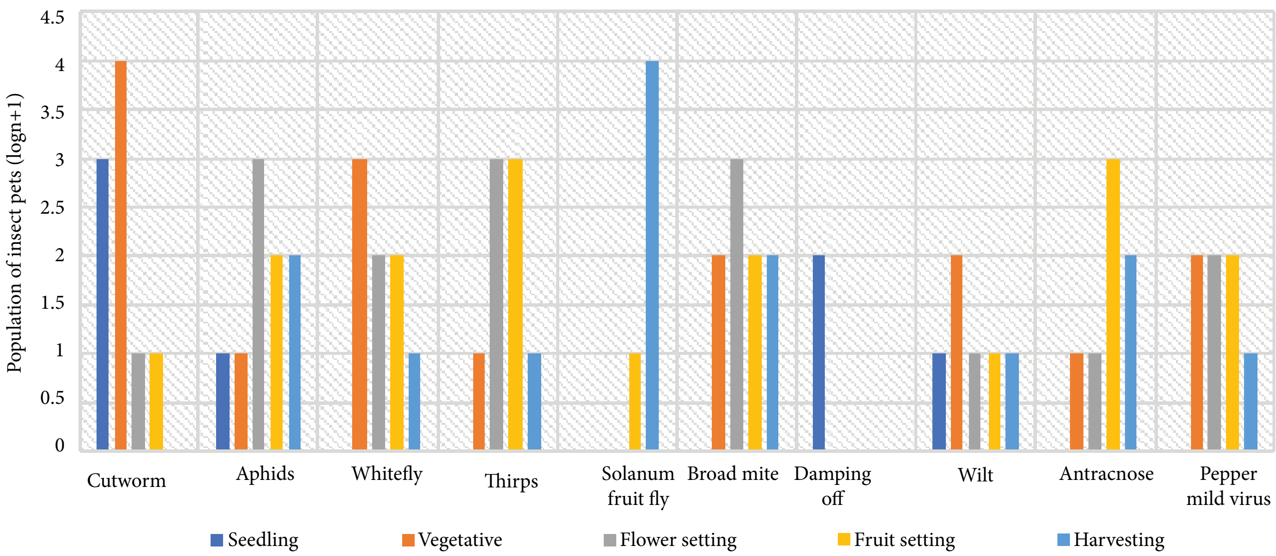

Figure 5: The Population Dynamic of Insect Pests, Natural Enemies and Plant Growth Stage in Chili Pepper Crop at Lampang Province.

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3.2. Chili Pepper Crop Production According to IFOAM Standard Guidance

Comprehensive trends in pest epidemics and input variables in field crops were evaluated to develop methods for organic chilli pepper production, encompassing planting material, seedling cultivation, nutrition management, and pest control in accordance with IFOAM standard guidelines. Chilli crops necessitate loose, loamy soil. pH range of 6.0 to 6.5. Organic fertiliser was used to enhance soil fertility at a rate of 800-1,000 kg per rai. Compost and manure enhance soil structure and microbial activity. Seeds sown in the field require ample sunlight during the day and should be placed away from low-lying areas. The plot was elevated to 1 metre, and soil quality was enhanced through the use of compost, manure or rice husk at a rate of 2 kg per square metre. The seedling density was 2-3 × 10 cm, with a depth of 0.5-1.0 cm, and was subsequently coated with a single layer of a compost and rice husk mixture following sowing. The seedling was sheltered beneath a nylon mesh structure for shade purposes. Utilising trays for seed sowing necessitates certified planting materials for organic farming systems, like peat moss, compost, manure, and loose soil surrounding tree trunks or bamboo clusters where leaves have fallen and decomposed effectively. A blend of loose soil and compost/manure was utilised in a 1:1 ratio. Seeds were soaked in warm water at 50 °C for 30 minutes. Dry seeds were treated with the antagonistic fungus Trichoderma harzianum to mitigate root or foliar infections. Following planting, T. harzianum was administered at around 100 cc per 20 litres for a duration of 7 days, and the seedling trays were enclosed with plastic coverings to maintain a consistent moisture level for 3 to 5 days. Upon germination of the seeds, remove the covering and consistently apply treated organic liquid fertilisers at a dosage of 100 g per 20 L every 15 to 20 days for approximately 30 days. The seedling was acclimatised to full sunshine and reduced watering for one week prior to transplantation. The field was cultivated through ploughing and subsequently left fallow for 7 to 14 days. Soil quality was enhanced by three months of applying fermented compost or manure at a rate of 800-1,000 kg per rai. Dolomite is utilised to elevate the pH level of acidic soils at a rate of 100-200 kg per rai. The plot dimensions were increased to a height of 25-30 cm and a width of 100-120 cm. The plant density was 40 cm for 2-3 plantings per plot, with a spacing of 50-80 cm between plots. The plant density was 5,000-6,000 plants per rai. Weed management, soil temperature, and moisture were regulated by mulching techniques, utilising materials such as rice straw, corn cobs, cogongrass leaves, or plastic. The plant should remove the minor branches beneath the initial pair of major branches to enhance canopy transparency, mitigate disease transmission, augment the contact area during the application of biological insecticides, and simplify harvesting. Nutrition management employed as foundational manure and compost application at 800-1,000 kg per rai, utilised by spreaders or positioned at the foot of the planting hole at 30 kilogramme per rai. Certified organic fertiliser was applied at a rate of 20 kg/rai 15 days post-transplantation, followed by applications of 30 kg/rai at 25, 40, and 55 days post-transplantation, respectively.

The outcome of pest control, assessed through bio-production factor testing in accordance with IFOAM standards, revealed that outbreaks varied at different phases of plant growth.

Cutworms and mealybugs (adult females, representing the early outbreak stage) were detected 7-14 days post-transplantation. Aphid exhibited a significant epidemic prevalence under both Trichoderma and control treatment settings, with outbreak rates of 76.55 ± 2.42% and 75.65 ± 2.00%, respectively. Beauveria exhibited a lower epidermic percentage of 10.12 ± 0.64%. The cutworm exhibited a significant epidemic prevalence of 10.12 ± 3.62% during pest outbreak treatment with plant protection inputs, while the neem extract treatment resulted in a decreased incidence of 3.25 ± 2.32%. Whitefly exhibited a significant epidemic under Trichoderma, with plant protection measures predicated on pest outbreak management at 5.11 ± 1.3% and 5.20 ± 3.62%, respectively. The Beauveria treatment demonstrated a reduced epidermic level of 1.22 ± 0.28%. The incidence of trips was significantly elevated at 5.57% ± 2.68% with plant protection interventions targeting insect outbreaks, compared to lower rates of 5.00 ± 2.35% to 5.22 ± 2.36% under control, neem extract, trichoderma, and beauveria treatment settings. The incidence of Other was significantly elevated under sulphur treatment for plants and Trichoderma application, recorded at 4.14 ± 3.25% and 4.14 ± 2.54%, respectively, demonstrating a reduced rate under control conditions. Plant protection measures, influenced by insect outbreaks and kaolin clay application, yielded rates ranging from 3.00 ± 2.11% to 3.32 ± 41.00%. Leaf spot exhibited a significant epidemic prevalence under Beauveria and Trichoderma conditions at 5.44 ± 1.08% and 5.35 ± 2.22%, while other treatment conditions had a lower incidence ranging from 5.00 ± 2.05% to 5.26 ±

2.55%. Viral infections exhibited reduced epidemic rates with kaolin clay treatment at 5.06 ± 3.51%, but other treatments recorded higher rates ranging from 5.12 ± 3.55% to 5.32 ± 2.33%. The integrated therapy involving microorganisms, extract solutions, and predatory insects, tailored to epidemic dispersal conditions, utilised stink bugs for cutworm management 7 to 14 days post-transplantation. Beauveria was applied 21 days post-transplant, and neem extract was utilised 28 days post-transplant, exhibiting no differential epidemic incidence compared to the sulphur treatment condition (Table 1 and Figure 6). The yield harvesting results indicated a significant weight for the Beauveria treatment at 54.90 ± 3.63 kg/rai, achieving a quality rating of 90%. The minimum levels of plant protection inputs, determined by insect outbreaks, Trichoderma, and control treatment, were 30.5 ± 5.64, 32.3 ± 5.96, and 32.4 ± 7.00 kg/rai, respectively, accompanied with diminished fruiting and 50% coverage of black fungi on the fruit, leading to fruit drop. Table 2 and Figure 7.

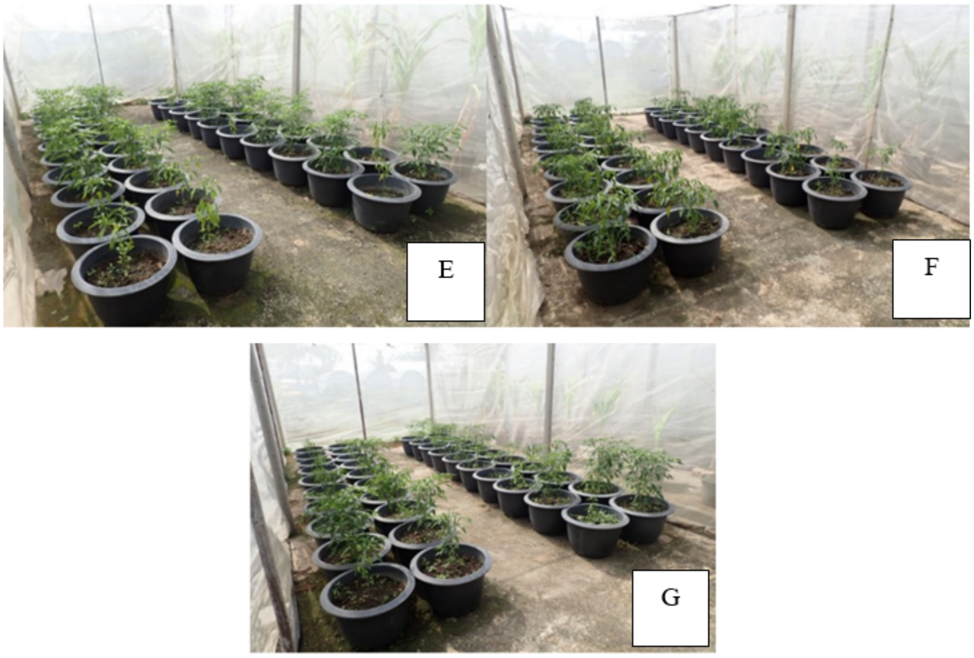

Figure 6: Chili Pepper Growth on Various Treatment As Control (A), Kaolin Spraying (B), Sulfur Spraying (C), Neem Extract (D), Beauveria (E), Trichoderma (F) and Combination Treatment (G).

Table 1: The Epidermic (outbreak rate) of Important Pests in the Greenhouse of Organic Chili Pest Control Factors at each Growth Stage at Biological Control Technology Learning Center Maejo University (MJU-BCTLC), Chiang Mai, During April to July 2022.

Treatment	Insect Pest Outbreak (average ± SD percentage)						
	Cutworm	Aphid	Whitefly	Thirps	Other	Leaf spot	Viral Diseases
Control	5.00 ± 2.35c	75.65 ± 2.00e	3.00 ± 1.11c	5.00 ± 2.35a	3.00 ± 2.11a	5.00 ± 2.05a	5.12 ± 3.55b
Kaolin clay sprayed	5.35 ± 2.5c	62.35 ± 2.42c	4.35 ± 2.26d	5.37 ± 2.22b	3.32 ± 41.00a	5.15 ± 2.12a	5.06 ± 3.51a
Sulfur for plant sprayed	5.44 ± 3.55c	30.65 ± 1.25b	2.56 ± 0.26b	5.40 ± 3.01b	4.14 ± 3.25d	5.26 ± 2.55a	5.22 ± 2.98b
Neem extract	3.25 ± 2.32a	30.45 ± 2.11b	2.11 ± 0.08b	5.12 ± 2.22a	3.65 ± 2.55b	5.22 ± 2.10a	5.24 ± 3.01b
Beauveria	4.32 ± 1.36b	10.12 ± 0.64a	1.22 ± 0.28a	5.22 ± 2.36a	3.42 ± 1.36b	5.44 ± 1.08b	5.32 ± 2.33b
Trichoderma	5.14 ± 2.75c	76.55 ± 2.42e	5.11 ± 1.3e	5.18 ± 2.44a	4.14 ± 2.54d	5.35 ± 2.22b	5.23 ± 2.88b
Plant protection inputs based on pest outbreaks	10.12 ± 3.62d	70.22 ± 3.55d	5.20 ± 3.62e	5.57 ± 2.68c	3.15 ± 3.00a	5.22 ± 3.03a	5.24 ± 3.08b

Table 2: Yield quality of pest control on organic chili pepper production at Biological Control Technology Learning Center Maejo University (MJU-BCTLC).

Treatment	Yield Weigh (kg/rai)	Yield Quality
Control	32.4 ± 7.00d	Low fruiting and 50 % of curling fruit
Kaolin clay sprayed	36.5 ± 4.65cd	Low fruiting, 50 % of curling and black fungi covers fruit
Sulfur for plant sprayed	43.2 ± 10.17bc	Low fruiting and 50 % of black fungi cover fruit
Neem extract	47.5 ± 10.17ab	50 % of black fungi covers fruit
Beauveria	54.90 ± 3.63a	90% of perfect fruit
Trichoderma	32.30 ± 5.96d	Low fruiting and 50 % of black fungi cover fruit
Plant protection inputs based on pest outbreaks	30.5 ± 5.64d	Low fruiting, 50 % of black fungi covers fruit and falling

Figure 7: Chili Pepper Yield of Organic Crop Production at Biological Control Technology Learning Center Maejo University (MJU-BCTLC).

3.3. Pest Control Development According to IFOAM Standard Guidance

The regression equation indicated a positive link between pet management and pest epidemic quantity ($R^2 = 0.86$) as well as plant disease ($R^2 = 0.53$). The incidence of insect outbreaks ($R^2 = 0.65$) and plant diseases ($R^2 = 0.67$) exhibited a favourable connection with crop yield. The analysis of agricultural production parameters was conducted in accordance with IFOAM standards, with organic seed sourced by Maejo University, the inaugural provider of organic seed. The cultivation occurred in an agriculturally certified organic farming site, the Biological Control Technology Learning Centre at Maejo University (MJU-BCTLC). The sowing of seeds necessitates approved plant material for organic farming systems to comply with organic agricultural regulations. The seed was immersed in warm water and planted in a medium treated with the Trichoderma harzianum strain BCTLC001 at a ratio of 2:1, utilising a seedling tray with 104 compartments. They increased the moisture using a concentrated fish marinade at 10% and irrigated after sowing the seeds, maintaining dark circumstances for 7 days. Organic fertiliser (10% concentration) applied to seedlings 14 days post-germination, with neem extract sprayed every 7 days. Seedling transferred to the fields 30 days post-germination. The soil mixture for planting consisted of black soil, raw rice husks, cow manure, and Trichoderma fungi in a ratio of 2:1:1:1, confined within a plant container and treated with a 10% concentrated fish marinade. The seedling was transferred to the field 14 days post-treatment with a spacing of 50 cm between plants. Organic fertiliser is utilised to enhance soil quality, applied at a ratio of 10% during the seedling stage and 7-14 days post-transplantation. The fertiliser content was increased to 20% between 15 and 28 days post-transplant during the vegetative development phase. Weed control and treatment commenced with soil preparation through ploughing, followed by plot flooding and a drying period of 14 days. Weeds were eradicated by manual removal every seven days following the transition to vegetative growth and the initiation of inflorescence development. Subsequently, weed management was conducted biweekly until the completion of harvesting. Trichoderma fungi were employed during soil preparation to mitigate plant diseases, specifically root rot induced by Fusarium oxysporum and Sclerotium rolfsii. Sticky traps were employed to deter insect pests and assess their populations.

This study's findings underscore the potential benefits of implementing IFOAM-compliant techniques in organic chilli pepper cultivation to enhance pest management, nutrient application, and sustainable yield improvement. This survey indicated the prevalence of primary pests and diseases, including aphids, cutworms, whiteflies, anthracnose, and Fusarium wilt, consistent with prior research highlighting the challenges posed by these pests in organic farming systems (Mansour et al., 2018; Nadeem et al., 2022). B. bassiana and neem extract were effectively combined as biological controls to mitigate insect infestations. The incidence of aphid outbreaks was markedly reduced (10.12 ± 0.64%) in plants treated with Beauveria compared to those subjected to kaolin clay and sulphur sprays. Owili et al. (2024) demonstrated that nutrient management strategies contributed to plant health and fertilisation yield. According to Riddick (2022), the utilisation of compost and manure at 800–1,000 kg/rai enhanced soil fertility and microbiological activity. The incorporation of dolomite into the soil substantially optimised the pH for chilli cultivation. Nonetheless, these modifications resulted in a much superior production relative to Beauveria treatments, which produced 54.90 ± 3.63 kg/rai, or 90% optimal fruit quality, underscoring the agronomic advantages of combining biological pest control with organic nutrient management (Salem, Hamzah, & El-Taweelah, 2015).

The study emphasised the significance of mulching with materials like rice straw and maize cobs in mitigating weed pressure and maintaining soil moisture. This aligns with Kumar et al. (2022), who discovered that mulching enhances water retention and diminishes weed competition in chilli systems. Pruning lower branches further diminished the dissemination of viral and fungal infections and enhanced pesticide application to decrease disease prevalence. Regression study indicated a robust link among insect management, plant health, and yield. A positive association was observed between yield parameters ($R^2 = 0.65$ and $R^2 = 0.67$, respectively) and pest population dynamics as well as disease severity, underscoring the necessity for prompt and focused pest management interventions (Scrinis & Lyons, 2007; Shaw, Nagy, & Fountain, 2021). The integration of biological control, organic amendments, and strategic cultural practices enhanced productivity and mitigated environmental effect, thereby promoting a sustainable paradigm for chilli production. Nonetheless, these achievements have not surmounted economic obstacles, such as the expense of organic inputs, which impede widespread use. Singerman & Rogers (2020) contend that financial incentives and training programs are essential to facilitate the shift to organic systems. Subsequent study should concentrate on minimising input expenses and optimising region-specific methodologies to improve the scalability of organic chilli cultivation.

Contemporary agriculture approaches prioritise sustainable pest management as essential due to the escalating issues of insect resistance and environmental sustainability. Toepfer et al. (2020) assert that agricultural extension programs require enhancement to provide farmers with improved pest management approaches that foster sustainability. This strategy enhances crop health by diminishing the need of chemical pesticides, therefore concurrently promoting biodiversity (Santos et al., 2022). Bouri et al. (2023) analyse climate-smart pest management by examining its dual advantages and challenges encountered during its implementation in contemporary agricultural systems. Integrated pest management plans must encompass both environmental considerations and socioeconomic factors. The scientific community is currently conducting experiments into various eco-friendly insect control methods. Nchu's (2024) study assesses biological control measures, which he deems a promising approach for the future, as natural predators exhibit significant potential to reduce pest populations without chemical treatments. Fernando et al. (2024) examined indigenous and non-native cover crop species to assess their efficacy in weed suppression, highlighting the potential of integrated systems for enhancing pest management. Deguine et al. (2021) assert that the practical use of integrated pest management (IPM) encounters numerous hurdles, notwithstanding the positive intentions in existing methods. The prevailing academic agreement indicates that sustainable pest management technologies must adjust to environmental changes while meeting farmer needs and promoting ecological sustainability (Zhang & Georgescu, 2022).

The scientific community is currently investigating alternative pest control alternatives to conventional chemical pesticides, emphasising sustainable farming practices (Toffolatti et al., 2023). Salem et al. (2015) investigated the efficacy of aluminium and zinc oxide nanoparticles as regulators of the red flour beetle, Tribolium castaneum. These nanoparticles demonstrate potential as a substitute for conventional insecticides, underscoring the capabilities of nanotechnology in pest management. This strategy enables businesses to mitigate environmental hazards while sustaining agricultural productivity. Emerging concepts in nanotechnology are intricately associated with the advancement of pest management strategies and influence food system operations. Scrinis & Lyons (2007) delineate the 'nano-corporate paradigm,' which exemplifies the dual impact of nanotechnology on agrifood systems and natural ecosystems. The authors examine the impact of technology on society regarding sustainability and public perception of these developments (Ziaee & Babamir-Satehi, 2020). The application of biopesticides in pest management tactics significantly enhances the overall ecological equilibrium in the ecosystem. Ullah et al. (2018) investigated the pest control efficacy of the beneficial fungus Beauveria bassiana and Isaria fumosorosea for the sustainable management of Diaphorina citri. Advancements in agriculture require the prompt adoption of sustainable, eco-friendly pest management techniques to maintain relevance. Vermelho et al. (2024) emphasise the significance of microorganisms in biopesticide development according to their research findings, whilst Góngora & Silva (2024) advocate for the integration of several management strategies to sustainably address diseases and pests. The current study illustrated resource conservation and underscored the necessity for ecological well-being, resulting in holistic and sustainable development. Sustainable growth in agricultural systems will effectively tackle the intricate issues and challenges posed by pests and climate change.

The research developed a prototype system for organic chilli pepper cultivation that complies with IFOAM standards, marking a substantial advancement in sustainable agriculture in light of growing pesticide concerns and their related health hazards. Employing Trichoderma sp. for biological pest control and natural predation techniques enables farmers to proficiently tackle plant health issues and pest management requirements. The study indicates that organic pest management strategies offer results similar to conventional farming, with distinct quality and quantity differences between the two ways. The study presents excellent methods for sustainable chilli cultivation, emphasising the potential for advancing organic farming practices throughout the agricultural sector. The research influences the entire chilli pepper industry, extending beyond merely the producing sector. Numerous studies have effectively shown that organic fertilisation techniques and the application of biological pest treatments, in conjunction with compost, have markedly diminished chemical usage, thus fostering sustainable agriculture. The research substantiates the necessity for investment in knowledge-sharing initiatives and technology support systems for organic agriculture in undeveloped sustainable farming regions. IFOAM standards are essential to this research by ensuring product authenticity and organic standards while advancing sustainable ecological practices in soils. This prototype provides farmers with pragmatic information and promotes the shift of agricultural systems towards sustainability in response to the increasing global demand for pesticide-free produce.

IFOAM-compliant organic chilli pepper cultivation has exhibited remarkable outcomes in promoting sustainability in agriculture to tackle significant environmental and health issues. Research indicates that organic approaches are beneficial and provide numerous benefits when farmers use holistic agricultural methods. This research primarily focusses on biological pest management through the utilisation of natural antagonists for the regulation of pest populations (Smaili, Boutaleb-Joutei, & Blenzar, 2020). Farmer productivity remains consistent when they employ Trichoderma sp. alongside stink bugs as natural biocontrol agents, thereby eschewing conventional pesticides for the sake of environmental sustainability. Given consumers' heightened concern for food safety and health awareness following COVID, these findings are highly significant. Research indicates that enhancing agricultural productivity is a function that contributes to soil health preservation. Organic fertilisers incorporating compost enhance soil by supplying vital nutrients, improving structure, and fostering microbiological activity, so augmenting the resilience of chilli pepper crops against failure. Numerous studies reveal that healthy soils absorb greater quantities of water, exhibit reduced erosion rates, and demonstrate enhanced resilience to environmental uncertainties, all of which are critical factors in the context of contemporary climate change. Organic farming practices can alleviate weather uncertainties in Thailand by establishing a crucial defensive mechanism for farmers to sustain their economic stability amid climate fluctuations. The research findings indicated that the prototype generated yields comparable to the standard method, suggesting that organic farming can be equally productive as conventional farming. This study will enhance the motivation for farmers to adopt organic farming, particularly in resource-deficient places, as every kilogramme harvested is crucial.

Research indicates that farmers necessitate adequate education and capacity development programs. Successful organic farming relies on the procurement of superior materials and the implementation of educational activities pertaining to sustainable farming methods. The implementation of this prototype relies on training programs that instruct on organic farming and pest control techniques, since they will facilitate the dissemination of these technologies. Agricultural extension services, in collaboration with universities and local cooperatives, should synergise to disseminate information and resources, empowering farmers to devise and tailor organic farming techniques for their specific agricultural regions. The study results indicated a sustainable agriculture that will address both food security and health protection.

The manufacturing of IFOAM-compliant organic chilli peppers, via prototype development, has made significant strides towards creating a sustainable agricultural future. Contemporary methodologies and ecological research demonstrate that organic agriculture yields results that are at least comparable to traditional agricultural systems and, at times, exceed them. This holistic agricultural method benefits the environment, enhances farmers' livelihoods, and increases sales of organic produce. This study offers critical insights for pandemic recovery and climate change challenges, as sustainable agriculture practices enhance agricultural resilience and planetary health. The advocacy for organic farming as a viable advantageous alternative will motivate farmers, consumers, and government authorities to cultivate sustainable food production practices for future generations.

4. Conclusion

The species of pest bug and its fluctuating trends on the chilli pepper crop in Lampang province exhibited variability across different planting regions, as did the population dynamics. The crop method and environment are identical. They are reliable and applicable in the actual agricultural zones. Selection of pest management agents, including Beauveria, Metarhizium, Trichoderma, neem extract, wood smoke juice, tobacco fermentation, and insect predators, based on the characteristics and type of insect pest outbreak. The study's findings, excluding climate, region, and nutrient management conditions, demonstrate the impact on chilli pepper yield in both control and crop protection factor treatments. The investigation resulted in the selection of organic agricultural production parameters in accordance with IFOAM standards. Expertise in net house and field experiments is accessible for field preparation, seedling transplantation, crop management, and the creation of pest control technologies, alongside the requisition of organic area and chilli production certification in accordance with established criteria. An uncomplicated organic crop production method is developed through the academic services of the Biological Pest Control Technology Learning Centre. The prototype approach benefits farmers interested in cultivating organic chilli for market purposes. This consequently broadens the pool of expertise and opportunities in production, enhancing the possibility for rivalry with chemical applications. The green economy exhibits significant efficiency growth.

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