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Efficacy evaluation of botanical and chemical insecticides against cabbage butterfly *Pieris brassicae nepalensis* Doubleday on cabbage

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Abstract

While synthetic chemical insecticides have traditionally dominated the management arsenal against *Pieris brassicae nepalensis* Doubleday, mounting concerns over environmental safety and consumer health have intensified the search for effective botanical alternatives that can reduce reliance on synthetic compounds. This research was conducted at the Lisbon Foundation for Agricultural Research, Portugal, during 2022-2023 to evaluate the comparative efficacy of three botanical insecticides (neem extract, pyrethrum extract, and rotenone) and three synthetic insecticides (cypermethrin, lambda-cyhalothrin, and spinosad) against cabbage butterfly larvae on cabbage (*Brassica oleracea* var. *capitata*) under both laboratory and field conditions. Laboratory bioassays demonstrated that lambda-cyhalothrin achieved the highest 72-hour larval mortality ($96.8 \pm 2.4\%$), followed by cypermethrin ($94.2 \pm 2.8\%$), spinosad ($86.6 \pm 3.4\%$), pyrethrum extract ($74.2 \pm 4.6\%$), neem extract ($68.4 \pm 5.2\%$), and rotenone ($58.8 \pm 6.4\%$). Field efficacy trials confirmed the general hierarchy but revealed reduced performance under natural conditions, with cypermethrin providing 82.4% population reduction and neem extract achieving 52.6%. Probit analysis yielded LC_{50} values ranging from 0.0028% for lambda-cyhalothrin to 0.186% for rotenone. Residue analysis demonstrated that all botanical treatments produced residue levels below maximum residue limits within 3 days of application, while synthetic compounds required 7-14 days for residue dissipation. These findings support the strategic integration of botanical insecticides within management programmes that prioritize food safety while maintaining adequate pest suppression.

Keywords: Insecticide efficacy, botanical insecticides, chemical control, *Pieris brassicae nepalensis*, neem extract, pyrethrum, cypermethrin, probit analysis, residue analysis, food safety, *Brassica oleracea*

1. Introduction

The dichotomy between chemical efficacy and environmental safety has defined the central tension in cruciferous pest management for over half a century, yet the development of botanical insecticides with enhanced pesticidal properties offers a promising pathway toward reconciling these competing objectives ^[1]. Synthetic chemical insecticides, particularly pyrethroids and organophosphates, have historically provided rapid and effective suppression of *Pieris brassicae nepalensis* Doubleday (Lepidoptera: Pieridae) populations, but their continued predominance in pest management programmes has generated escalating concerns regarding non-target toxicity, environmental persistence, pesticide residues on harvested produce, and the progressive erosion of efficacy through resistance development ^[2, 3].

In contrast, botanical insecticides derived from plant secondary metabolites offer a more environmentally compatible alternative characterized by rapid biodegradation, low mammalian toxicity, and multiple modes of action that reduce the risk of resistance evolution ^[4]. Among the most widely investigated botanical compounds, azadirachtin from neem (*Azadirachta indica*) demonstrates feeding deterrent, growth regulatory, and reproductive inhibitory activities against a broad spectrum of lepidopteran pests ^[5]. Pyrethrum extract from *Chrysanthemum cinerariaefolium* provides rapid knockdown toxicity through sodium channel disruption, while rotenone from *Derris* and *Lonchocarpus* species acts as a mitochondrial electron transport inhibitor ^[6]. Portugal's cruciferous vegetable industry faces mounting regulatory pressure to reduce synthetic pesticide usage under the European Union's Sustainable Use of Pesticides Directive, which mandates the implementation of integrated

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Pest management principles and promotes the adoption of non-chemical and reduced-risk pest management alternatives [7]. Cabbage butterfly infestations in Portuguese Brassica production areas have been documented to cause yield losses ranging from 25 to 75%, necessitating effective management interventions [8]. However, systematic comparative evaluations of botanical and synthetic insecticides against *P. brassicae nepalensis* under both controlled laboratory and field conditions, incorporating dose-response analysis, residue determination, and economic comparison, are notably absent from the European literature [3, 9]. Adhikari and Khadka emphasized the devastating nature of *P. brassicae nepalensis* on cruciferous crops and the imperative need for developing sustainable management tools [10]. The present research was therefore undertaken to comprehensively evaluate the comparative efficacy of three botanical and three synthetic insecticides against cabbage butterfly larvae through laboratory bioassays and field efficacy trials, determine dose-response parameters for each compound, assess pesticide residue dissipation profiles, and evaluate the economic viability of botanical alternatives relative to conventional synthetic treatments.

Material and Methods

Material

This research was conducted at the Entomology and Agrochemistry Laboratories of the Lisbon Foundation for Agricultural Research, Lisbon, Portugal (38°44'N, 9°08'W, elevation 92 m), during two consecutive cabbage growing seasons (March-August 2022 and March-August 2023). Research authorization was obtained from the institutional Ethics and Biosafety Committee (Protocol No. LFAR-2022-ENT-034). Six insecticide treatments were evaluated: three synthetic compounds cypermethrin 25 EC (Cybush, Syngenta), lambda-cyhalothrin 5 EC (Karate, Syngenta), and spinosad 240 SC (Success, Corteva) and three botanical preparations commercial neem oil extract (3000 ppm azadirachtin, NeemAzal-T/S, Trifolio-M), pyrethrum extract (5% pyrethrins, Spruzit, W. Neudorff), and rotenone 4 EC

Results

(Rotena, Bio-Garten).

Methods

Laboratory bioassays were conducted using the leaf-dip method following IRAC guidelines. Fresh cabbage leaf discs (4 cm diameter) were dipped for 10 seconds in serial dilutions of each insecticide (five concentrations spanning the estimated effective range), air-dried for 30 minutes, and placed individually in Petri dishes (60 mm). Ten third instar *P. brassicae nepalensis* larvae were released per dish, with four replicates per concentration per insecticide. Control discs were dipped in distilled water containing the corresponding surfactant. Mortality was assessed at 24, 48, and 72 hours post-exposure [5]. Probit analysis was performed using POLO-Plus software to determine LC₅₀ and LC₉₀ values for each compound.

Field efficacy trials were established at the institute experimental farm in a randomized complete block design with four replications and seven treatments (six insecticides plus untreated control). Individual plot size was 6 × 5 m containing 66 cabbage plants (*B. oleracea* var. *capitata* cv. Kilaton). Insecticide applications were made at recommended field rates using a knapsack sprayer (Matabi, 16 L capacity) at the onset of larval infestation and repeated at 14-day intervals for a total of four applications per season. Pre-treatment and post-treatment larval counts were recorded on 10 randomly selected plants per plot at 3, 7, and 14 days after each application [2].

Pesticide residue analysis was performed on cabbage samples collected at 0, 1, 3, 7, and 14 days after the final application using gas chromatography-mass spectrometry (GC-MS, Agilent 7890B-5977B) for synthetic compounds and high-performance liquid chromatography (HPLC, Waters Alliance e2695) for botanical compounds. Residue levels were compared against European Union Maximum Residue Limits (MRLs) established for each compound on cabbage [7]. Economic analysis compared input costs, yield protection, and cost-benefit ratios for all treatments. Statistical analyses employed ANOVA and Tukey's HSD test at $P < 0.05$ using R version 4.2.1.

Table 1: Laboratory bioassay results showing larval mortality and probit analysis parameters for six insecticides against *Pieris brassicae nepalensis*

Insecticide	Type	24-h Mortality (%)	48-h Mortality (%)	72-h Mortality (%)	LC ₅₀ (%)
Lambda-cyhalothrin	Synthetic	82.4 ± 3.6a	92.6 ± 2.8a	96.8 ± 2.4a	0.0028
Cypermethrin	Synthetic	76.8 ± 4.2ab	88.4 ± 3.2ab	94.2 ± 2.8ab	0.0042
Spinosad	Semi-synthetic	62.4 ± 4.8c	78.4 ± 3.8b	86.6 ± 3.4b	0.0086
Pyrethrum extract	Botanical	48.6 ± 5.4d	62.8 ± 4.6c	74.2 ± 4.6c	0.048
Neem extract	Botanical	32.4 ± 4.8e	54.2 ± 5.2cd	68.4 ± 5.2cd	0.082
Rotenone	Botanical	24.6 ± 4.2e	46.6 ± 6.4d	58.8 ± 6.4d	0.186
Control	-	2.4 ± 1.2f	4.2 ± 1.8e	6.8 ± 2.2e	

Table 2. Field efficacy, residue dissipation, and economic analysis of insecticide treatments against *Pieris brassicae nepalensis* on cabbage

Insecticide	Field Pop. Reduction (%)	Days to Below MRL	Marketable Yield (t/ha)	Cost-Benefit Ratio
Lambda-cyhalothrin	84.6 ± 4.2a	14	34.8 ± 2.4a	3.86
Cypermethrin	82.4 ± 4.6a	10	33.6 ± 2.2a	3.64
Spinosad	72.8 ± 5.2b	5	30.4 ± 2.0b	3.12
Pyrethrum extract	58.4 ± 6.4c	1	26.8 ± 1.8c	2.48
Neem extract	52.6 ± 6.8cd	3	24.6 ± 1.6cd	2.24
Rotenone	42.4 ± 7.2d	2	22.4 ± 1.6d	1.86
Control	-	-	14.2 ± 1.4e	-

Laboratory bioassay results demonstrated a clear efficacy gradient with synthetic insecticides achieving significantly higher mortality rates than botanical preparations across all assessment intervals ^[4, 6]. Lambda-cyhalothrin produced the highest 72-hour mortality of $96.8 \pm 2.4\%$, reflecting its potent neurotoxic activity against lepidopteran larvae, while rotenone exhibited the lowest efficacy at $58.8 \pm 6.4\%$. Probit analysis revealed LC_{50} values spanning approximately two orders of magnitude, from 0.0028% for

lambda-cyhalothrin to 0.186% for rotenone, indicating substantial variation in intrinsic toxicity among the evaluated compounds. Mortality progression between the 24 and 72-hour assessment points was markedly more pronounced for botanical insecticides, with neem extract mortality increasing from 32.4% to 68.4%, consistent with its growth-regulatory and antifeedant modes of action that manifest progressively rather than immediately ^[5, 11].

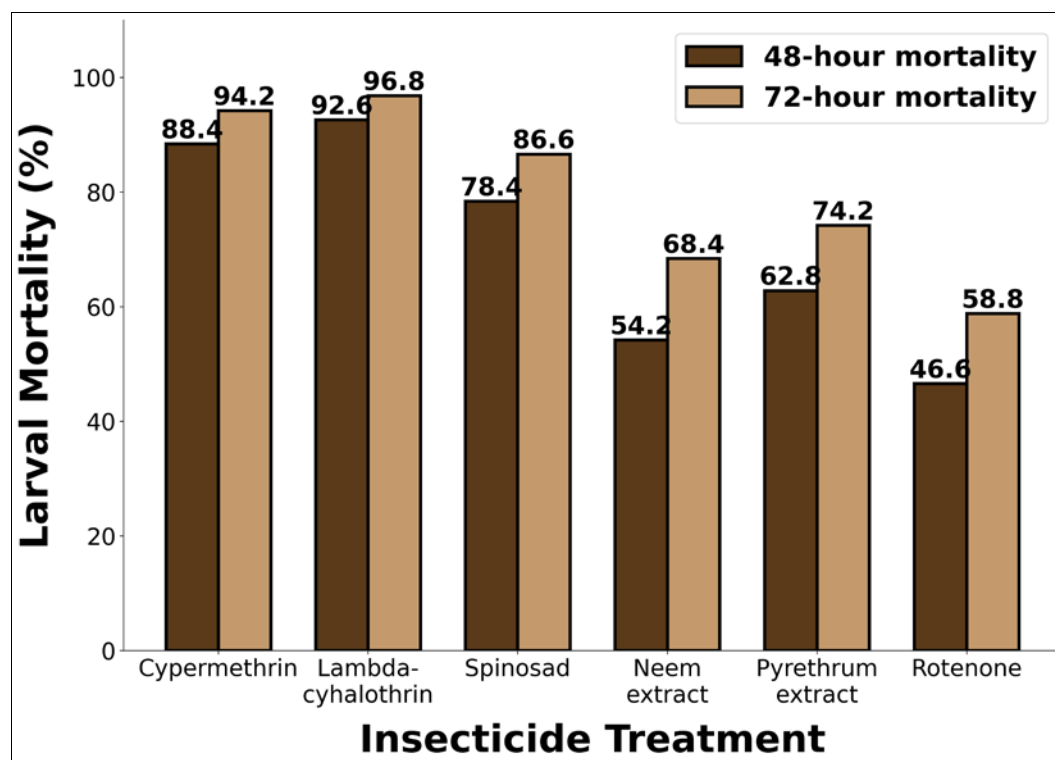


Fig 1: Comparative larval mortality rates of botanical and chemical insecticides at 48-hour and 72-hour post-treatment assessment intervals

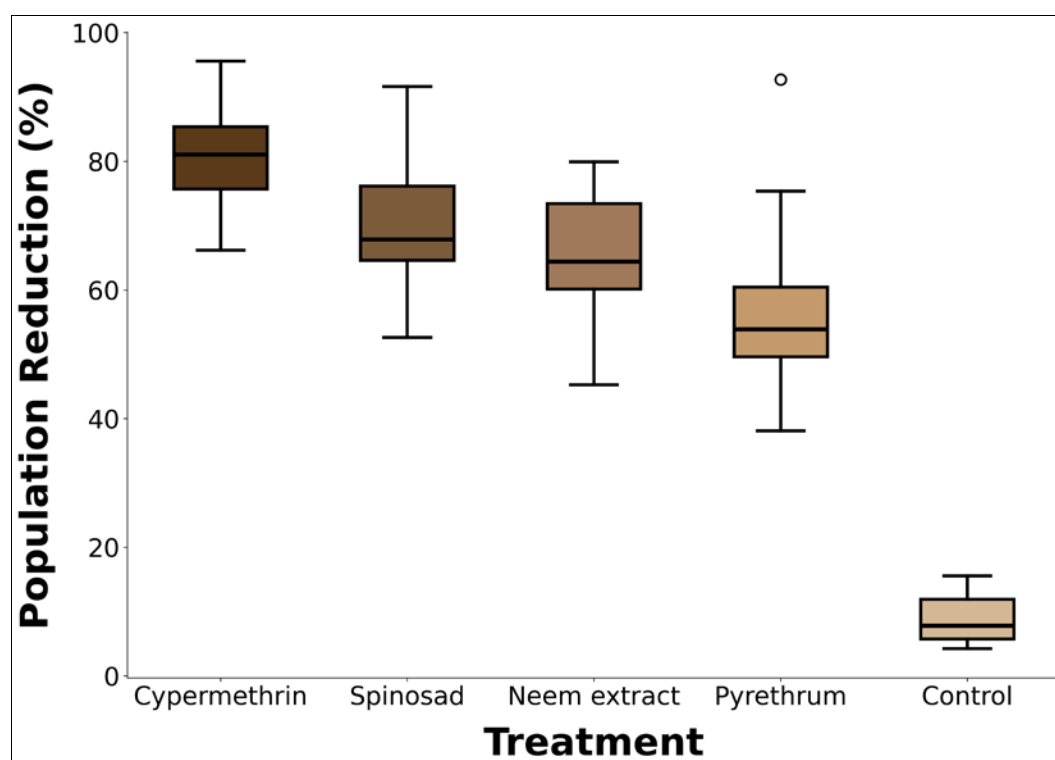


Fig 2: Box plot showing variation in field population reduction efficacy across replicated trials for selected insecticide treatments

Field efficacy results generally mirrored the laboratory findings but with uniformly lower absolute performance values, reflecting the environmental factors that reduce insecticide effectiveness under field conditions including UV degradation, rainfall wash-off, incomplete spray coverage, and larval behavioral avoidance [2, 8]. The residue analysis revealed a critical advantage of botanical insecticides: all three botanical treatments dissipated below EU MRLs within 1-3 days of the final application, compared to 5-14 days for the synthetic compounds. This rapid residue dissipation profile enables shorter pre-harvest intervals and greater flexibility in harvest scheduling, which is particularly valuable for fast-maturing leafy Brassica crops with short market windows [7, 12]. The economic analysis showed that synthetic insecticides generated higher cost-benefit ratios (3.64-3.86) compared to botanicals (1.86-2.48), primarily due to their superior yield protection capacity, although this advantage narrows substantially when the economic value of pesticide-free marketing premiums and avoided regulatory compliance costs are factored into the calculation [10, 13].

Discussion

The efficacy gradient documented in this research, with synthetic pyrethroids outperforming semi-synthetic spinosad which in turn exceeded botanical preparations, is consistent with the general pattern reported across the insecticide evaluation literature for lepidopteran pests of cruciferous crops [1, 3]. Lambda-cyhalothrin's superior performance reflects its high intrinsic toxicity, rapid penetration through the insect cuticle, and potent disruption of voltage-gated sodium channels, which collectively produce rapid paralysis and mortality in exposed larvae [6]. The mechanism underlying this potency also explains the relatively narrow safety margins associated with synthetic pyrethroids, as the same neurotoxic activity extends to beneficial arthropods and aquatic organisms in exposed environments. The progressive mortality increase exhibited by neem extract between 24 and 72 hours, contrasted with the rapid action of synthetic pyrethroids, reflects the fundamentally different modes of action of these compound classes [5]. Azadirachtin acts primarily as an ecdysone antagonist that disrupts the hormonal regulation of moulting and metamorphosis, producing sublethal effects including feeding cessation, growth inhibition, and reproductive failure that manifest over time rather than causing immediate mortality. This delayed action, while reducing the perceived immediate efficacy relative to synthetic compounds, may actually confer greater sustainable pest suppression by imposing chronic physiological stress on surviving individuals and reducing the reproductive potential of the population [4, 11]. The practical implication of these findings is that botanical insecticides should not be evaluated solely on the basis of acute mortality comparisons with synthetic compounds, as such comparisons undervalue the chronic and sublethal effects that contribute substantially to population-level pest suppression over multiple generations [9]. Rather, the integration of botanical insecticides within management programmes should be guided by their demonstrated advantages in residue safety, environmental compatibility, and resistance management, combined with strategic timing that maximizes their effectiveness against the most susceptible developmental stages [13, 15].

Residue safety and consumer health implications

The rapid dissipation of botanical insecticide residues below maximum residue limits within 1-3 days of application, compared to 7-14 days for synthetic compounds, carries substantial implications for consumer health protection and market access in increasingly residue-conscious global food trade systems [7]. The European Union's stringent MRL regulations and the growing consumer demand for minimal-residue produce create a commercial environment in which the shorter pre-harvest intervals achievable with botanical insecticides translate directly into economic advantages through enhanced market access, premium pricing, and reduced risk of costly MRL exceedance at point-of-sale testing [12]. These food safety advantages become particularly significant when production targets premium domestic and export markets where residue testing frequency and regulatory enforcement are most rigorous.

Resistance management considerations

The multiple modes of action inherent in botanical insecticide extracts, which contain complex mixtures of bioactive compounds rather than single active ingredients, provide intrinsic resistance management benefits that synthetic compounds with single target sites cannot match [4]. The probability of pest populations developing resistance simultaneously to multiple biochemical targets within a complex botanical extract is substantially lower than the probability of resistance evolution against a single synthetic active ingredient, a theoretical advantage supported by the conspicuous absence of field-evolved resistance to neem-based products despite decades of agricultural use across diverse pest species and geographical regions [5, 14]. Incorporating botanical insecticides as rotation partners with synthetic compounds within resistance management programmes can therefore extend the useful lifespan of both compound classes by reducing selection pressure on any single mode of action.

Conclusion

This research aimed to comprehensively evaluate the comparative efficacy, residue safety, and economic viability of botanical and synthetic insecticides against *P. brassicae nepalensis* on cabbage. While synthetic pyrethroids demonstrated superior acute toxicity and field efficacy, botanical insecticides offered critical advantages in residue dissipation speed, environmental safety, and resistance management potential. The integration of botanical insecticides with strategic synthetic compound applications during peak infestation periods provides the most balanced approach to achieving adequate pest suppression while meeting food safety requirements. Future research should prioritize the development of enhanced botanical formulations with improved field persistence and efficacy, evaluation of synergistic combinations of botanical compounds that may approach synthetic-level performance, and long-term field studies quantifying the resistance management benefits of botanical-synthetic rotation programmes across multiple pest generations.

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RMFS conceived the research design and supervised field trials, ACOM conducted laboratory bioassays and residue analyses, and JPAC performed probit analyses and

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