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Comparative bio-efficacy of botanical and chemical pesticides against leaf-eating caterpillars (*Artona chorista* Jordan) in large cardamom fields of Bhojpur

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ABSTRACT

Large cardamom (*Amomum subulatum* Roxb.) is a vital export crop in Nepal, but its yield is threatened by the leaf-eating caterpillar *Artona chorista* Jordan, causing major economic losses. Despite its impact, field-based studies on its integrated management are scarce. This study evaluated the efficacy of selected chemical and botanical pesticides against *A. chorista* using a randomized complete block design with seven treatments and three replications. The treatments included synthetic insecticides—Imidacloprid 17.8% SL, Cypermethrin 10% EC, and Emamectin benzoate 5% SG—as well as botanicals—Dadaguard Plus (Azadirachtin 2%), Neem oil, and Tobacco extract—along with a water as a control. All treatments were applied twice at 15-day intervals. Results demonstrated that Imidacloprid reduced larval counts significantly from 22.51 to 0.00 within 12 days of the second spray, while Cypermethrin and Emamectin benzoate also achieved complete larval control over the same period ($p < 0.01$). Among botanicals, Dadaguard Plus was equally effective, reducing larval numbers from 22.25 to 0.00, with Neem oil and Tobacco extract showing moderate but statistically significant reductions (final larval counts of 0.88 and 0.92, respectively; $p < 0.05$). Similarly, leaf damage was significantly minimized by Imidacloprid, Cypermethrin, and Emamectin benzoate to pooled means of 10.77%, 11.14%, and 10.49%, respectively, compared to 22.14% in the untreated control ($p < 0.01$). Dadaguard Plus also effectively reduced leaf damage (10.12%), whereas Neem oil and Tobacco extract resulted in higher damage levels (16.66% and 16.04%, respectively), though still significantly lower than the control ($p < 0.05$). These findings demonstrate that both chemical and eco-friendly botanical pesticides can effectively manage *A. chorista*, supporting sustainable pest control and reducing reliance on synthetic inputs.

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1. Introduction

Large cardamom (*Amomum subulatum* Roxb.) is a vital cash crop in Nepal, significantly contributing to the nation's economy and supporting the livelihoods of thousands of farmers (Joshi et al., 2013; Kalauni et al., 2019; Basnet et al., 2021). Thriving at altitudes of 800–2000 meters under cool, humid conditions, it is cultivated in the shade of trees like Utis and Siris, which provide a favorable microclimate and reduce pest infestations (Pun, 2019; Kattel et al., 2020). The crop prefers well-drained, acidic soils rich in organic matter, receiving 3000–3500 mm of annual rainfall and temperatures ranging from 6–30°C (Kattel et al., 2020; Rockwood et al., 2020). Introduced to Nepal in 1865 and commercially expanded since 1953, large cardamom is now grown in 54 districts, with Taplejung being the leading producer. Its aromatic dried fruits are widely used in culinary preparations, traditional medicine, and the perfume industry, containing essential oils that treat throat infections, digestive disorders, and pulmonary issues (Kaskoos et al., 2008; Joshi et al., 2013). Nepal is the global leader in producing and exporting large cardamom, with approximately 90% of its production exported to India via the Jhapa district (Kalauni and Joshi, 2019; Yadav et al., 2021). Despite its economic significance, large cardamom cultivation faces growing threats from biotic and abiotic stresses, particularly pest and disease infestations. Major pests such as the leaf caterpillar (*Artona chorista* Jordan), stem borer (*Glyphipterix* spp.), shoot fly (*Merochlorops dimorphus*), and white grub (*Holotrichia* sp.) cause substantial damage to crop (Shrestha et al., 2018; Rockwood et al., 2020). Viral diseases like Chirke and Foorkey, transmitted by aphids, further exacerbate yield losses (Vijayan et al., 2014; Manju et al., 2018). Historically, farmers have relied on synthetic chemical pesticides to manage these threats. However, excessive and indiscriminate use of these chemicals has led to severe environmental and health concerns, including soil and water contamination, harm to non-target organisms, and the development of pest resistance (Pathak, 2008; Gudade et al., 2013). These practices disrupt the ecological balance and undermine the long-term sustainability of large cardamom farming. The persistence of chemical residues in soil and water also poses risks to human health through bioaccumulation in the food chain, increasing the prevalence of chronic diseases in communities relying heavily on such practices (Belbase et al., 2018; Shrestha et al., 2018). Eco-friendly pest management solutions have gained prominence to mitigate these issues. Biopesticides such as neem-based oil, neem seed kernel extract, and tobacco extract have shown promising results in controlling major pests of large cardamom (Waghmare et al., 2007). These bio-based treatments are environmentally benign and selectively target harmful pests without adversely affecting beneficial organisms (Basnet et al., 2021; Raj et al., 2021). Additionally, low-risk chemical alternatives like Emamectin benzoate provide effective pest control while reducing environmental risks (Gacemi and Guenaoui, 2012; Kanda et al., 2019). Furthermore, innovations in microbial pesticides, such as *Bacillus thuringiensis* and entomopathogenic fungi, have demonstrated significant potential in combating pest populations while maintaining environmental safety (Gudade et al., 2013; Gautam, 2021). Integrated Pest Management (IPM) strategies, which combine biological, cultural, and mechanical control measures with judicious use of biopesticides, offer a sustainable approach to pest management (Shrestha et al., 2018; MoALD, 2021). IPM minimizes the dependency on synthetic chemicals and enhances the resilience of crops, ensuring stable productivity and profitability for farmers (Pun, 2019; Joshi et al., 2013). Adopting such practices can also foster biodiversity conservation within agroecosystems, providing long-term ecological benefits (Kalauni and Joshi, 2019; MoALD, 2021). Adopting biopesticides and IPM strategies comes with challenges, such as higher initial costs, limited farmer awareness, and inadequate access to eco-friendly products (Basnet et al., 2021; Kattel et al., 2023). Addressing these challenges requires government support through subsidies, farmer training programs, and the development of efficient distribution channels for biopesticides (Gudade et al., 2013; Khatiwada et al., 2019). Collaborative efforts involving researchers, policymakers, and farmers are essential to promote sustainable pest management practices and reduce dependency on harmful chemical pesticides (Pathak, 2008; Pun, 2019). Leveraging advancements in agricultural technology, such as remote sensing for pest monitoring and precision application of biopesticides, can further optimize pest control efforts (Shrestha et al., 2018; Raj et al., 2021).

This study aims to compare the bio-efficacy of botanical and chemical pesticides *A. chorista* Jordan against in large cardamom fields of Bhojpur, with a strong focus on their environmental impacts. The goal is to support the development of sustainable, long-term Integrated Pest Management (IPM) strategies that reduce chemical use, protect ecosystem health, and enhance the sustainability of large cardamom cultivation.

2. Materials and methods

2.1. Site selection

The research was carried out in Bhojpur district, Koshi Zone, located in the mid-hills of Eastern Nepal, within Province No. 1. The experimental site is situated at an altitude of 1733 meters above sea level, with its geographical coordinates recorded at 27°11′52″ N latitude and 87°4′18″ E longitude (Figure 1). The study area experienced diverse climatic conditions during the experimental period. The mean temperature ranged from a minimum of 12°C to a maximum of 28°C, reflecting significant daily and weekly fluctuations (Figure 2). Relative humidity was observed to vary between 65% and 95%, indicating a generally moist environment conducive to the study (Figure 3). Precipitation levels during this time ranged from 10 mm to 120 mm per week, showcasing variations in rainfall that potentially influenced the experimental outcomes (Figure 3). The experimental field had loamy soil, which was well-drained and, moderately rich in organic matter and ideal for large cardamom (*Amomum subulatum*) cultivation. A geographical view of the experimental site was prepared using GIS tools, and detailed graphical representations were created to analyze and illustrate the temperature, relative humidity, and precipitation trends, providing comprehensive insights into the environmental conditions during the study period. The variety used for the experiment was Ramsai, a widely preferred large cardamom cultivar known for its high yield and adaptability to mid-hill regions of Nepal. This variety matures within 10-12 months, producing large pods with an average 500–600 kg ha^{-1} yield under optimal conditions. Healthy and disease-free suckers in their vegetative growth stage, produced in 2080 by a farmer's group in the Bhojpur district, were used in the experiment to ensure uniformity and vigor.

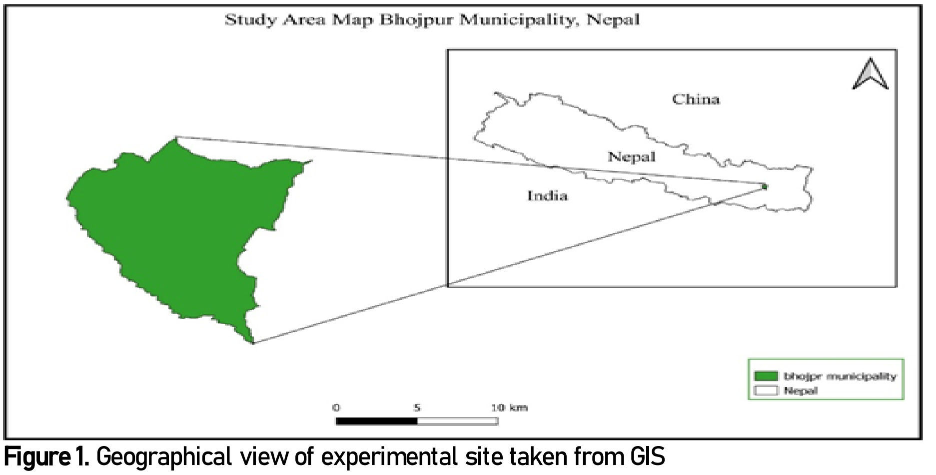

Figure 1. Geographical view of experimental site taken from GIS

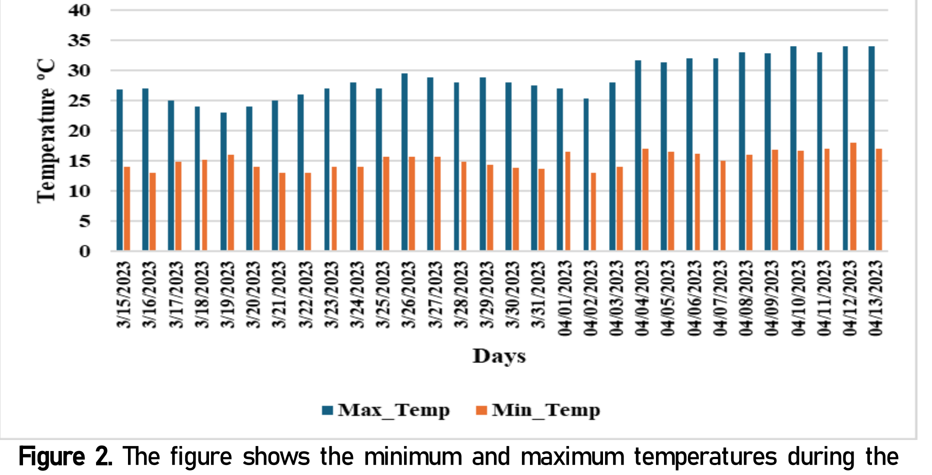

Figure 2. The figure shows the minimum and maximum temperatures during the study period

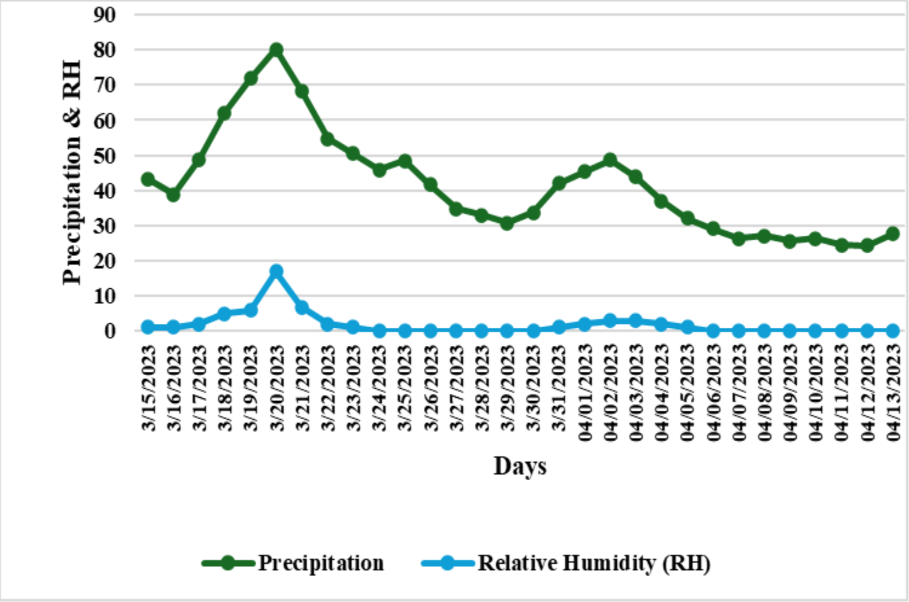

Figure 3. The figure shows relative humidity and precipitation during the study period

2.2. Experimental design

A well-structured Randomized Complete Block Design (RCBD) was employed, comprising seven treatments replicated three times, resulting in a total of 21 experimental plots. Each plot measured 4 × 3 m², contributing to a total experimental area of 336 m². The spacing between replications was maintained at 1.5 m to reduce inter-block interference, while a 1 m buffer separated individual plots within each replication. Plant-to-plant spacing was maintained at 1.2 meters and row-to-row spacing at 1.5 meters, resulting in a plant density of approximately 11100 plants per hectare or 48 plants per plot. From each plot, 10 plants were randomly selected for detailed observation and data collection. This layout ensured comprehensive coverage while minimizing edge effects and promoting unbiased evaluation.

2.3. Treatments details and its application

The experiment comprised seven treatments, including both botanical and synthetic pesticides, each with distinct chemical compositions and modes of action. T1 (Neemicide) contains neem oil, which is rich in bioactive limonoids such as azadirachtin, nimbin, and salannin compounds known to repel insects and interfere with their hormonal regulation applied at 2.5 mL L^{-1} of water as a foliar spray. T2 (Dadaguard) is formulated with Azadirachtin 2.0% w/w, extracted from neem seed kernels, functioning as an insect growth regulator and antifeedant, applied at 0.5 mL L^{-1} . T3 involves the use of tobacco leaf extract, which contains nicotine alkaloids that act as neurotoxins targeting insect central nervous systems, applied at a rate of 10 g L^{-1}. T4 (Googly) contains Cypermethrin 10% EC, a synthetic pyrethroid that disrupts sodium ion channels, leading to insect paralysis and mortality, applied at 2.0 mL L^{-1}. T5 served as the untreated control (water only). T6 (Dawn2000) consists of Imidacloprid 17.8% SL, a systemic neonicotinoid that targets nicotinic acetylcholine receptors, disrupting nerve impulses, applied at 2.0 mL L^{-1}. T7 (Ema Star) includes Emamectin benzoate 5.0% SG, a semi-synthetic avermectin derivative that activates chloride channels, causing paralysis and feeding inhibition in larvae, applied at 0.7 g L^{-1}. All treatments were applied uniformly using a high-volume knapsack sprayer to ensure even distribution of the specified concentrations. Applications were conducted at 15-day intervals, beginning at the start of the experiment, during early morning or late afternoon, to minimize volatilization and maximize efficacy. The leaf-eating caterpillar (*A. chorista*) infestation was observed on 10 randomly selected plants per treatment per replication. Data collection occurred before each spray and at 2, 5, 7, and 9 days after every pesticide application. Detailed information on all treatments is presented in Table 1.

Table 1. The treatment used in the experiment

S. N	Chemical composition	Trade name	Treatment	Dose
1.	Neem oil	Neemicide	T1	2.5 mL L^{-1}
2.	Neem seed kernel, Azadirachtin 2.0%w/w	Dadaguard	T2	0.5 mL L^{-1}
3.	Tobacco extract		T3	10.0 g L^{-1}
4.	Cypermethrin 10%EC	Googly	T4	2.0 mL L^{-1}
5.	Water control		T5	
6.	Imidacloprid 17.8% SL	Dawn2000	T6	2.0 mL L^{-1}
7.	Emamectin benzoate 5.0% SG	Ema star	T7	0.7 g L^{-1}

2.4. Cultural practices

For large cardamom (*Amomum subulatum*) cultivation, specific cultural practices and inputs were followed to ensure high yield and pest management. Fertilization was done using 10 tons per hectare of farmyard manure (FYM) in combination with 80 kg of nitrogen (N), 40 kg of phosphorus (P), and 40 kg of potassium (K) per hectare, applied annually. In the experimental field, irrigation was done using a drip irrigation system, ensuring a steady supply of water to maintain moisture levels, especially during the dry season. Weed management was conducted using manual weeding and mulching, with occasional use of herbicides when necessary to prevent competition for nutrients. Harvesting occurred after 10-12 months when the cardamom pods turned yellow or orange. Pesticide applications were carried out using a knapsack sprayer, with 3 liters of solution applied per plot. Sprays were focused on the underside of the leaves to target the *A. chorista*. The treatments were applied at 15-day intervals, starting with the first spray when caterpillar populations peaked. Regular applications are followed to control pest infestation effectively.

2.5. Data collection and observation

During the field trials, regular visual inspections were conducted on a daily basis to monitor the presence of pest damage on the cardamom plants. The primary pest observed was the leaf-eating caterpillar (*A. chorista*), which caused characteristic damage to the leaves, resulting in a papery, skeletonized appearance due to feeding on the chlorophyll on the underside of the leaves. This damage made the leaves appear transparent and darken over time, making the pest activity easier to identify. Additionally, the leaves of cardamom plants in shaded areas under Uttis trees were found to be covered with a sooty mold-like fungus. As the infestation progressed, the leaves and pseudostem started to dry out, and within a short period, the symptoms became widespread, causing significant damage across the entire field. Fallen branches from Uttis trees also contributed to plant injury during windy conditions. Data were collected from ten randomly selected leaves per plot, and parameters recorded included the percentage of infestation (PI), number of infected leaves per pseudostem, number of pests per leaf, and weather conditions. Pest damage severity was assessed using a scale from 0 (no damage) to 5 (complete consumption of leaves and part of the stem), as described in Table 2.

The percentage of infested shoots per clump was calculated using the formula as equation 1:

$$PI = \frac{\text{Total number of affected shoots or leaves per clump}}{\text{Total number of shoots or leaves per clump}} \times 100 \quad \text{(Eq. 1)}$$

This formula was adapted from Raj et al. (2021).

Table 2. Scale for visually assessing cardamom for the severity of pest damage

Damage score	Percentage damage	Description
0	0	No apparent damage
1	20	Approximately a quarter of the total leaf area is eaten
2	40	Approximately half of the total leaf area is eaten
3	60	Approximately three-quarters of the total leaf area is eaten
4	80	Most leaves eaten, few leaves intact, stem green
5	100	All leaves and part of stem eaten

2.6. Statistical analysis of data

The data gathered throughout the research period was carefully recorded in MS Excel for preliminary examination. Statistical analysis, including Analysis of Variance (ANOVA) and mean estimation, was conducted using RStudio. Duncan's Multiple Range Test (DMART) was applied at a 5% significance level to compare treatment means. The results of the analysis were presented in tables and figures, with the findings interpreted in the context of relevant literature. Additionally, various graphs were created to represent the results visually.

3. Results

3.1. Effect of pesticides on larva number of leaf-eating caterpillar (*Artona chorista*) in large cardamom

The study on the effect of pesticides against the larval population of *Artona chorista* Jordan in large cardamom (Table 3) revealed significant differences among treatments, particularly after the first and second sprays. Water control (untreated plants) had the highest larval counts across all stages, with an initial mean of 29.81 larvae (32.93) before treatment. Even after the second spray, larval numbers remained high at 8.48 (13.57) at 9 and 12 DAS, confirming the necessity of pesticide application for effective control. Among the synthetic pesticides, Imidacloprid demonstrated the most rapid and effective reduction, starting from 22.51 (28.3) before treatment to 1.62 (5.58) at 3 DAS after the first spray and reaching near elimination (0.00) by 12 DAS after the second spray, showing a highly significant effect ($p < 0.001$). Similarly, Cypermethrin was highly effective, reducing larval numbers from 28.40 (31.9) before treatment to 3.48 (8.67) at 3 DAS and achieving complete suppression (0.00) by 9 DAS after the second spray, also showing a highly significant effect ($p < 0.001$). Emamectin benzoate followed a similar trend, significantly lowering larval counts from 17.40 (24.2) before treatment to 2.11 (8.21) at 3 DAS, reaching almost total control (0.03, 0.63) by 12 DAS after the second spray (significant at $p < 0.01$). Dadaguard, a bio-pesticide, also performed well, with larval counts decreasing from 22.25 (28.0) to 0.66 (2.71) at 3 DAS and achieving complete control (0.00) after the second spray ($p < 0.01$). In contrast, botanical treatments such as Tobacco extract and Neem oil showed moderate effectiveness but were less potent than synthetic pesticides. Tobacco extract reduced larval numbers from 20.03 (26.5) to 3.48 (8.47) at 3 DAS, but larvae were still present after the second spray (0.92, 4.46 at 9 and 12 DAS).

Table 3. Larva number on the bio-efficacy of different pesticides against leaf-eating caterpillar (*Artona chorista*)

Treatments	DBS	First spray					Second spray					Overall
		3 DAS	6 DAS	9 DAS	12 DAS	Pooled	3 DAS	6 DAS	9 DAS	12 DAS	Pooled	pooled
Imidacloprid	22.51^{a}	1.62^{b}	0.33^{b}	0.22^{a}	0.07^{a}	4.95^{b}	0.00^{a}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{b}	2.47^{b}
	(28.3)	(5.58)	(2.66)	(2.17)	(0.90)	(12.8)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(9.02)
Cypermethrin	28.40^{a}	3.48^{b}	1.33^{b}	1.18^{a}	1.00^{a}	7.08^{b}	0.03^{a}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{b}	3.54^{b}
	(31.9)	(8.67)	(5.06)	(4.88)	(3.32)	(15.3)	(0.63)	(0.00)	(0.00)	(0.00)	(0.31)	(10.8)
Emamectin benzoate	17.40^{a}	2.11^{b}	2.03^{b}	2.22^{a}	0.07^{a}	4.77^{b}	0.00^{a}	0.03^{b}	0.03^{b}	0.03^{a}	0.02^{b}	2.39^{b}
	(24.2)	(8.21)	(8.06)	(8.28)	(1.27)	(12.4)	(0.00)	(0.63)	(0.63)	(0.63)	(0.63)	(8.77)
Dadaguard	22.25^{a}	0.66^{b}	0.18^{b}	0.18^{a}	0.00^{a}	4.65^{b}	0.00^{a}	0.00^{b}	0.00^{b}	0.00^{a}	0.00^{b}	2.32^{b}
	(28.0)	(2.71)	(1.42)	(1.42)	(0.00)	(12.4)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(8.76)
Tobacco extract	20.03^{a}	3.48^{b}	3.00^{b}	3.40^{a}	2.70^{a}	6.52^{b}	0.51^{a}	0.92^{b}	0.92^{b}	0.48^{a}	0.71^{b}	3.61^{b}
	(26.5)	(8.47)	(6.94)	(8.98)	(5.51)	(14.3)	(2.38)	(4.46)	(4.46)	(2.30)	(3.80)	(10.6)
Neem oil	23.00^{a}	3.33^{b}	1.74^{b}	1.62^{a}	1.74^{a}	6.28^{b}	1.14^{a}	0.88^{b}	0.88^{b}	0.22^{a}	0.78^{b}	3.53^{b}
	(28.2)	(10.2)	(7.09)	(5.99)	(6.96)	(14.3)	(5.02)	(4.20)	(4.20)	(1.56)	(4.05)	(10.6)
Water control	29.81^{a}	30.03^{a}	30.33^{a}	17.51^{a}	15.88^{a}	24.71^{a}	14.92^{a}	8.48^{a}	8.48^{a}	6.88^{a}	9.69^{a}	17.20^{a}
	(32.93)	(33.10)	(33.15)	(20.16)	(18.70)	(29.50)	(17.73)	(13.57)	(13.57)	(12.01)	(14.3)	(23.8)
Grand mean	23.34	6.38	5.56	3.76	3.06	8.42	2.37	1.47	1.47	1.08	1.60	5.01
CV (%)	17.33	4.94	5.03	10.53	14.36	19.83	20.76	16.24	16.24	20.96	17.25	26.78
SEM (±)	4.49	6.01	6.38	4.95	4.88	4.52	4.78	2.43	2.43	2.06	2.91	3.60
F value	NS	***	***	NS	NS	***	NS	*	*	NS	*	***

DAS: Day after sowing. CV: Coefficient of variation. SEM: Significant error of the mean. NS: Non significant. * Significant at 5% level of significance; ** Significant at 1% level of significance. *** Significant at 0.1% level of significant. Values with same letters in a column are not significantly different at 5% level of significance by DMRT test. Values in parentheses indicate square root transformation.

Neem oil followed a similar pattern, reducing larvae from 23.00 (28.2) to 3.33 (10.2) at 3 DAS, but larvae remained at 0.88 (4.20) at 9 and 12 DAS, indicating a weaker but still significant effect ($p < 0.05$). Overall, the results indicate that synthetic pesticides, particularly Imidacloprid, Cypermethrin, and Emamectin benzoate, provided the most effective control, significantly reducing caterpillar numbers to nearly zero after two sprays. Bio-pesticides like Dadaguard also showed promising results, while botanical extracts (Tobacco and Neem oil) provided only partial control. These findings underscore the effectiveness of chemical pesticides for integrated pest management (IPM) in large cardamom, with the potential for incorporating bio-pesticides to reduce chemical reliance. Effect of pesticides on leaf damage by leaf-eating caterpillar (*Artona chorista*) in large cardamom.

The effect of pesticides on leaf damage severity (%) caused by *A. chorista* in large cardamom (Table 3) revealed significant differences among the treatments, with synthetic pesticides showing superior efficacy compared to botanical treatments and the untreated control. The water control (untreated plants) exhibited the highest leaf damage throughout the study, starting with 17.98% (4.29) before treatment and increasing to 22.14% (4.71) at 12 DAS after the second spray, confirming that without intervention, caterpillar infestation leads to severe leaf damage. Among synthetic pesticides, Imidacloprid was highly effective in minimizing leaf damage, reducing it from 10.88% (3.37) before treatment to 10.71% (3.34) at 3 DAS, maintaining consistent control over time, and achieving a final pooled mean of 10.77% (3.35). Similarly, Cypermethrin significantly reduced leaf damage from 10.62% (3.28) before treatment to 9.76% (3.17) at 3 DAS, showing effective control and a final pooled value of 11.14% (3.36). Emamectin benzoate also provided strong protection, decreasing leaf damage from 12.35% (3.55) before treatment to 9.88% (3.20) at 3 DAS, with a final pooled mean of 10.49% (3.30), making it one of the most effective treatments. Dadaguard, a bio-pesticide, also performed well, reducing leaf damage from 11.40% (3.44) before treatment to 8.47% (2.96) at 3 DAS, and maintaining a final pooled mean of 10.12% (3.23), indicating its potential as an alternative to chemical pesticides. On the other hand, botanical treatments like Tobacco extract and Neem oil showed moderate effectiveness but were less efficient than synthetic insecticides. Tobacco extract had higher leaf damage, starting at 13.31% (3.71) before treatment, and although it showed some reduction, it still maintained relatively high values, reaching 17.63% (4.22) at 12 DAS, with a pooled mean of 16.04% (4.04). Neem oil exhibited a similar trend, with an initial damage level of 14.71% (3.90) and only slight reductions over time, recording 17.07% (4.18) at 12 DAS and a final pooled mean of 16.66% (4.13).

Table 4. Effect of pesticides on leaf damage by leaf eating caterpillar (*Artona chorista*) in large cardamom

Treatments	DBS	First spray					Second spray					Overall
		3 DAS	6 DAS	9 DAS	12 DAS	Pooled	3 DAS	6 DAS	9 DAS	12 DAS	Pooled	pooled
Imidacloprid	10.88^{a} (3.37)	10.71^{bc} (3.34)	10.27^{bc} (3.27)	10.50^{b} (3.31)	10.66^{b} (3.34)	10.53^{bc} (3.32)	10.67^{ab} (3.33)	11.17^{a} (3.41)	11.17^{ab} (3.41)	10.99^{b} (3.38)	11.00^{b} (3.39)	10.77^{b} (3.35)
Cypermethrin	10.62^{a} (3.28)	9.76^{bc} (3.17)	10.29^{bc} (3.23)	10.50^{b} (3.27)	9.56^{b} (3.14)	10.03^{bc} (3.20)	12.44^{ab} (3.54)	12.04^{a} (3.48)	12.13^{ab} (3.50)	12.36^{b} (3.53)	12.24^{ab} (3.51)	11.14^{b} (3.36)
Emamectin benzoate	12.35^{a} (3.55)	9.88^{bc} (3.20)	10.62^{bc} (3.33)	9.88^{b} (3.20)	9.85^{b} (3.20)	10.06^{bc} (3.24)	9.36^{b} (3.13)	14.11^{a} (3.72)	10.16^{b} (3.25)	10.09^{b} (3.24)	10.93^{b} (3.36)	10.49^{b} (3.30)
Dadaguard	11.40^{a} (3.44)	8.47^{c} (2.96)	8.83^{c} (2.97)	8.83^{b} (2.97)	10.21^{b} (3.25)	9.08^{c} (3.04)	9.92^{ab} (3.19)	9.78^{a} (3.16)	15.01^{ab} (3.93)	9.92^{b} (3.19)	11.16^{ab} (3.40)	10.12^{b} (3.23)
Tobacco extract	13.31^{a} (3.71)	13.95^{ab} (3.79)	14.98^{abc} (3.92)	15.15^{ab} (3.94)	15.00^{ab} (3.92)	14.77^{abc} (3.89)	16.79^{ab} (4.12)	17.41^{a} (4.20)	17.41^{ab} (4.20)	17.63^{ab} (4.22)	17.31^{ab} (4.18)	16.04^{ab} (4.04)
Neem oil	14.71^{a} (3.90)	16.03^{a} (4.06)	15.99^{ab} (4.06)	15.44^{ab} (3.98)	15.95^{ab} (4.04)	15.85^{ab} (4.04)	17.45^{ab} (4.21)	17.67^{a} (4.25)	17.67^{a} (4.25)	17.07^{ab} (4.18)	17.47^{ab} (4.23)	16.66^{ab} (4.13)
Water control	17.98^{a} (4.29)	17.82^{a} (4.26)	18.53^{a} (4.32)	18.53^{a} (4.32)	18.53^{a} (4.32)	18.36^{a} (4.30)	18.34^{a} (4.31)	18.67^{a} (4.36)	17.10^{ab} (4.18)	22.14^{a} (4.71)	19.06^{a} (4.40)	18.71^{a} (4.35)
Grand mean	13.03	12.37	12.79	12.69	12.82	12.67	13.57	14.41	14.38	14.31	14.17	13.42
CV (%)	11.26	11.46	14.32	15.38	12.55	13.09	15.49	17.33	12.28	15.38	13.83	12.99
SEM (±)	1.97	2.34	2.68	2.70	2.51	2.52	2.94	3.03	2.41	3.35	2.69	2.54
F value	NS	*	*	*	*	*	*	NS	*	*	*	*

DAS: Day after spraying. CV: Coefficient of variation. SEM: Significant error of the mean. NS: Non-significant. * Significant at 5% level of significant. Values with the same letters in a column are not significantly different at 5% level of significance by DMRT test. Values in parentheses indicate square root transformation.

These results indicate that while botanical treatments provide some level of control, they are not as effective as synthetic pesticides in significantly reducing leaf damage. Statistical analysis also confirmed that pesticide effects on leaf damage were significant at the 5% level ($p < 0.05$) in most cases, particularly after the first spray, reinforcing the importance of chemical interventions in managing caterpillar-induced damage. However, Dadaguard, a bio-pesticide, emerged as a promising alternative, showing significant efficacy in reducing leaf damage, though not as strongly as synthetic chemicals. The study's findings highlight that Imidacloprid, Cypermethrin, and Emamectin benzoate were the most effective pesticides, significantly reducing leaf damage and maintaining control after two sprays, whereas botanical treatments like Tobacco extract and Neem oil had limited but noticeable effects. This suggests that while synthetic pesticides remain the most effective option for immediate caterpillar control, bio-pesticides like Dadaguard could be integrated into an Integrated Pest Management (IPM) strategy to minimize chemical use while still effectively controlling pest-induced damage in large cardamom crops.

4. Discussion

Leaf-eating caterpillar (*Artona chorista* Jordan) is a major pest of large cardamom, causing significant economic losses due to extensive leaf damage and reduced plant vigor (Subedi et al., 2022; Kattel et al., 2023). The present study, conducted in Bhaisipankha, Bhojpur, aimed to evaluate the bio-efficacy of different botanical and chemical pesticides in managing this pest. The findings revealed that both chemical and botanical pesticides significantly reduced larval populations and minimized leaf damage, supporting previous research on insect pest management in large cardamom (Basnet et al., 2021; Raj et al., 2021). The study observed larval population and leaf damage levels at the second, fifth, and seventh days after each spray. Table 3 results indicated that Imidacloprid, Cypermethrin, and Emamectin benzoate were the most effective synthetic insecticides, significantly reducing larval numbers and leaf damage severity. Imidacloprid, a chloronicotinyl insecticide, reduced larval numbers to near-zero by 9 and 12 DAS after the second spray, aligning with Elbert et al. (1998), who found that Imidacloprid provides long-lasting protection against sucking and chewing pests (Joshi et al., 2013; Yadav et al., 2021). Cypermethrin, a pyrethroid, also demonstrated strong efficacy, significantly reducing larval populations (Elbert et al., 1998). Emamectin benzoate, another effective insecticide, minimized both larval counts and leaf damage, supporting findings by Gacemi and Guenaoui (2012), who confirmed its high efficacy against lepidopteran pests (Shrestha et al., 2018). The botanical pesticides, while slightly less effective than chemical pesticides, still demonstrated significant control over the pest population. Among botanicals, Dadaguard Plus (Neem seed kernel extract containing Azadirachtin 2.00% w/w) was the most effective, significantly lowering larval numbers and reducing leaf damage severity (Table 4), corroborating the findings of Kattel et al. (2023) and Subedi et al. (2022), who reported Dadaguard Plus as the best-performing botanical pesticide in large cardamom pest management (Bhattarai et al., 2013; Rout et al., 2003). Neem oil, though moderately effective, exhibited notable insect-repelling and antifeedant properties (Waghmare et al., 2007). Tobacco extract, which contains nicotine as a neurotoxin, showed moderate effectiveness, supporting Subedi et al. (2022), who found that tobacco extract acts as both a repellent and an antifeedant by interfering with the insect’s nervous and digestive systems (Kishore et al., 2011; Shrestha et al., 2018). The study also highlights the risk of pesticide overuse, which can lead to pest resistance, resurgence of secondary pests, and environmental hazards (Basnet et al., 2021; Raj et al., 2021). Research by Kattel et al. (2023) supports the integration of insecticide mixtures like Lambda-cyhalothrin and Chlorantraniliprole, which prevent resistance and enhance pest control (Gudade et al., 2013; Belbase et al., 2018). Given these concerns, Integrated Pest Management (IPM) approaches, which incorporate botanical pesticides and selective chemical use, are recommended for sustainable pest management (Baniya et al., 2019; Pathak, 2008). Furthermore, environmental factors such as temperature, humidity, and precipitation significantly influenced larval populations and pesticide efficacy, aligning with observations by Gudade et al. (2013), who found that climatic variations directly impact pest infestations in large cardamom fields. Notably, this study also found that pesticide applications were highly effective after the first spray, as chemical applications were not previously common in the region, leading to higher initial mortality rates in the caterpillar population. These results reinforce previous findings on the efficacy of chemical and botanical pesticides in pest control strategies across various crops, including large cardamom, cowpea, and okra (Asare-Bediako et al., 2017; Gautam, 2021).

Additionally, research by Shrestha et al. (2018) indicates that eco-friendly pest management strategies, such as botanical pesticide integration, are essential for long-term sustainability in cardamom farming (Vijayan et al., 2014; Manju et al., 2018). The study strongly supports the adoption of IPM strategies, integrating effective chemical pesticides like Imidacloprid, Cypermethrin and Emamectin benzoate, alongside botanical alternatives like Dadaguard Plus, Neem oil, and Tobacco extract, to reduce pesticide resistance and environmental impact (Kalauni et al., 2019). Given the potential risks associated with frequent pesticide use, farmers should rotate pesticide applications and integrate biological control agents to minimize adverse effects (Gudade et al., 2013; Khatiwada et al., 2019). These findings are consistent with prior studies on pest management strategies in Nepal, India, and other large cardamom-producing regions (Pun, 2019; Kattel et al., 2023), reinforcing the importance of sustainable and scientifically backed pest control approaches (Saju et al., 2013). Future research should focus on optimizing botanical pesticide formulations, improving bio-rational insecticides, and integrating natural predators, as emphasized in studies by Raj et al. (2021) and Koirala (2022). The findings from this study provide valuable insights for farmers, researchers, and policymakers, encouraging the adoption of a balanced approach combining chemical, botanical, and ecological pest control methods to ensure sustainable and profitable cardamom farming (Rockwood et al., 2020; MoALD, 2021).

5. Conclusion

Leaf-eating caterpillar (*Artona chorista* Jordan) is one of the major pests of cardamom and causes heavy economic loss. It can destroy and skeletonize the whole cardamom field in severe cases. This study demonstrates that synthetic pesticides, particularly Imidacloprid 17.8% SL (Dawn2000), Cypermethrin 10% EC (Googly), and Emamectin benzoate 5.0% SG (Ema Star), are highly effective in managing *A. chorista* in large cardamom, significantly reducing larval populations and minimizing leaf damage. Among botanical alternatives, Neem seed kernel extract with Azadirachtin 2.0% w/w (Dadaguard) emerged as the most effective bio-pesticide, offering substantial pest control and demonstrating potential as a sustainable alternative. Neem oil (Neemicide) and Tobacco extract also showed moderate efficacy. The results underscore the necessity of integrating these treatments into an Integrated Pest Management (IPM) strategy to ensure sustainable pest control, minimize chemical dependency, and delay resistance development. Future research should focus on optimizing botanical formulations, exploring eco-friendly insecticides, and incorporating natural predators to enhance pest management strategies further. Adopting such balanced approaches will support long-term productivity and environmental sustainability in large cardamom farming.

Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no conflict of interest.

Authors' contributions

Tika BAHANDARI, Daurik Lal PANDIT and **Sova YADAV**: Conceptualization, funding acquisition, investigation, Data curation, methodology. **Bijay GHIMERE** and **Sulok POKHREL**: Data curation, methodology. **Dipesh Kumar MEHATA**: Conceptualization, funding acquisition, investigation, methodology, resources, software, supervision, writing–review & editing, validation, visualization. **Saurabh TRIPATHI**: Data curation, methodology. **Savyata ACHARYA, Riya POUDEL** and **Sudikshya NEPAL**: Data curation, methodology.

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