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ASSESSMENT OF ANTIXENOSIS PROPERTIES AND TOXICITY OF SELECTED INDIGENOUS PLANT EXTRACTS AGAINST LASIODERMA SERRICORNE (FAB.)'

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Abstract
Lasioderma serricorne (F) is a perilous pest of stored goods. The utilization of botanical extracts is considered the most secure and eco-friendly approach for managing this insect/pest. This research investigated the impact of seven different plant species on *L. serricorne*, focused on factors such as fecundity, developmental time from egg to adult, growth index, incubation period, adult emergence, weight loss, repellency, as well as contact and fumigant toxicity. The *L. serricorne* showed significantly lowest fecundity (0.673±0.106), lowest growth index (-0.846±0.431), longest incubation duration (mean 1.785±0.004) on *Parthenium hysterophorus*, whereas *L. serricorne* had the highest fecundity (2.371±0.002), highest growth index (1.376±0.052), and shortest incubation duration (1.500±0.012) on *Nigella sativa*. At adult stage, essential oils (EOs) of some plants exhibited higher repellant effect on cigarette beetle after 48 hours for example, *P. hysterophorus* (RD_{50} = 2.406%), *D. vescosa* (RD_{50} = 1.649%), and *V. jatmansi* (RD_{50} = 1.137%). The maximum contact toxicity at the adult stage of beetle was observed on *P. hysterophorus* after 24h exposure (LD_{50} = 3.762 µl/ml insect), followed by *D. vescosa* and *V. jatamansi* (LD_{50} = 3.551 and 2.678, respectively). *P. hysterophorus* provided the highest fumigant toxicity to beetle after 24h exposure (LC_{50} = 4.262 µl/ml air), followed by *D. vescosa* and *V. jatamansi* (LC_{50} = 3.669; 3.274, respectively). The cigarette beetle was least hazardous to *N. sativa*, with just 1.295 mortality noted at 50% of the utilized concentration (LC_{50}). The *P. hysterophorus* essential oil exhibits the best repellency contact and fumigation toxicity against *L. serricorne* adults, supporting the potential for commercial use of plant essential oils, as environmentally friendly insect control agents.

Keywords: Stored grain pest, botanicals insecticides, cigarette beetle, toxicology

Introduction

Stored product insect pests pose a serious threat to the quality and quantity of stored products (Tadesse, 2020) (Phoonan *et al.,* 2014). Of the 1,000 described species of Anobiids, the *Lasioderma serricorne* is alone responsible for causing significant economic damage to stored commodities, including seeds, tobacco, food products, plant, and animal-sourced products (Ravi Kumar *et al.*, 2017) . Non-food commodities infested by *L. serricorne* include dried plants, herbarium specimens, dried flowers, drugs and pills, medicinal herbs, pinned insects, wooden furniture stuffing, flax, museums, and books (Ebadollahi *et al.*, 2010a). The larval stage of *L. serricorne* is particularly gregarious, thus causing the highest damage to stored products. Mature larvae and adults can easily chew through packaging materials to infest stored products in warehouses (Wang *et al.,* 2015). Control of *L. serricorne* populations primarily relies on the use of synthetic pesticides (Mojtaba Ghane Jahromi, 2011). The continued application of phosphine is used to control this pest (Wu *et al.,* 2017). Although it is effective but its continuous and repeated use has disrupted the balance especially biological control, development of resistance to insecticides, effects on non-target organisms, environmental and human health worries apart from direct toxicity to users (Lü and Ma, 2015). The increasing concern about the detrimental effects has illuminated the necessity for the creation of more precise insect-control alternatives (Kim *et al.,* 2003). Plant materials may offer viable alternative to the insect-control agents currently in use, as they are a rich source of bioactive chemical. Consequently, much effort has been devoted to plant-derived materials for potentially useful products as commercial insect control agents (Rajendran and Sriranjini, 2008).

Plant essential oils have been extensively studied for their larvicidal, repellent, toxic, ovicidal, anti-feedant, growth inhibiting and anti-oviposition effects (Bosly, 2013). Despite the fact botanical as insecticides occupies around 1% of the global pesticide market (Rozman *et al.,* 2007). Several Chinese and Pakistani plants have been proven to be potential sources of biopesticides and have exhibited toxic bioactivity against stored grain insects (You *et al.,* 2014)*;* (Saleem *et al.,* 2014). However, there are some plants such as *Thuja orientalis* L., *Nicotiana rustica* L., *Valeriana jatamansi* J., *Cannabis sativa* L., *Dodonaea viscosa* L., and *Parthenium hysterophorus* L., which have greater economic importance. Studies have shown that *Thuja orientalis* oils possess fumigant toxicity against many pests (Abbasipour *et al.,* 2011). *Nigella sativa* or black cumin is highly valued for its insect repellent qualities and its many health benefits (Khan, 2014). *Valeriana jatamansi*, is widely used due to its larvicidal and repellent properties against various insect and pest species. Studies have shown it to be effective against *Aphis craccivora* (Tewary *et al.,* 2005) and several mosquito species (Dua *et al.,* 2008). Research has revealed that the dry parts of *Cannabis sativa* L., are particularly effective against stored grain insects (Hamilton *et al.,* 2021). *Dodonaea viscosa*, commonly known as the Broadleaf Hopbush, has been explored for its insecticidal properties to control stored grain bruchid, *C. maculatus* (Gangotia and Saddam, 2017). *Parthenium hysterophorus* can be used as pest control agent due to presence of alkaloids, terpenoids and other components in it (Rajapakse and Ratnasekera, 2010) . Researchers are focusing on the establishment and development of plant-based pesticides from *Parthenium hysterophorus* (Siddiqui *et al.,* 2009; Tariq *et al.,* 2010). It possesses a wide range of insecticidal properties, making it an ideal candidate for use in pest control program (Kumar *et al.,* 2011).

Considering the growing economic importance of the above-mentioned plants, these are not studied against *L. serricorne*. The aim was to determine the efficacy of different extracts/essential oil of these plant as feeding deterrent, repellent, fumigant or contact toxin and establish a potential of these plants as a biopesticide. This study will reduce the health risks associated with synthetic chemicals, mitigating resistance issues, and helping the tobacco and stored products industry develop an efficient Integrated Pest Management (IPM) model.

Materials and methods

Lasioderma serricorne Culture

In Swabi, Khyber Pakhtunkhwa, tobacco factories and warehouses, cigarette beetles were captured,

raised, and cultured across several generations in the Entomological Laboratory of the Department of Agriculture at the University of Swabi. The culture was maintained at 28±2 °C temperature 65%±5% relative humidity.

Plants and Samples Preparation

Seven different medicinal and aromatic plants i-e. *Thuja orientalis*, *Dodonaea vescosae*, *Nigella sativa*, *Parthenium hysterophorus*, *Nicotiana rustica*, *Valeriana jatamansi*, and *Cannabis sativa* were chosen, and they were all sourced from different areas of Khyber Pakhtunkhwa, Pakistan. On these plants, *Lasioderma serricorne*, biology, repellency, contact and fumigant toxicity were carefully observed and investigated. The plant leafs specified in were dried for a week in the shade, out of the heat and sunlight. For use in subsequent extraction procedures, the dried leafs of the chosen plants were crushed into a powder using a blender (Wu *et al.*, 2015). One thousand grams of powder extracted from each plant were subjected to hydro distillation with (1:2) in (Soxtec System Model: H-2 1045 Extraction Unit, Hoganas, Sweden, according to method described in AACC, 2000) for ten hours and extracted with organic solvent. An anhydrous sodium sulphate was used to remove the excess water from the sample after it had taken in the form of an oil-water combination (Wu *et al.*, 2015). The collected oil samples were put into glass flasks, filled nearly to the top, and placed in a 4°C refrigerator. Then prepared the four concentrations of 2, 4, 6 and 8 µl by mixing n-hexane as solvent. These concentrations were used for experiments as given under different chapters.

Varietal preference and antixenosis

Ovipositional response

Ten newly emerging adults were placed in separate glass vials (15x5cm) on (FCV) tobacco treated with each plant EOs for oviposition response research. After fifteen days of release, the female's entire egg production was counted.

Adult emergence

Each test tube had a 20-gram sample (tobacco) treated of each selected plant and contained twenty newly emerging larvae. Muslin cloths were used to cover the specimen tubes. The dates and numbers of adults that appeared were recorded beginning on the day that fresh emergence began. The formula used to compute adult emergence was as follows:

$$\%Adult\ emerged = \frac{Adult\ emerged}{total\ number\ of\ larvae\ formed} \times 100\ (Rolania\ and\ Bhargawa, 2015)$$

Developmental period (eggs to adults)

Each test tube weighed ten grams of processed tobacco treated with selected plant materials, and it was covered with muslin and secured with rubber bands. The test tube was entirely wrapped in a black cloth to create darkness. Each test tube included a pair of adults along with a food supply and was kept at room temperature. The test tubes were observed daily, and the days required for egg, larvae, pupae and adult development were recorded. The total developmental period was calculated as the sum of the egg, larval, pupal and adult stages (Kathirvel *et al.*, 2019).

Incubation period

A random sample of 20 recently deposited eggs was collected for the incubation period and placed in tiny specimen tubes. To determine the "IP" for each variety, the dates from egg laying to the first day of adult emergence were recorded (Jehajo, 2020).

Weight loss

Following the release of the eggs for 60 days, the weight decrease was noted. The sample with treated selected plants was laid out on a white sheet for this purpose, and the damaged pieces were weighed. The percentages of sample treated with selected plants that were damaged were computed. Following

the removal of all insect stages and frass, the weight loss was measured. This was computed as a percentage by deducting the final weight from the starting weight. The formula shown below was employed:

$$Weight\ loss = \frac{(Intial\ weight - final\ weight)}{intial\ weight} X\ 100\ (Rolania\ and\ Bhargawa, 2015)$$

Growth index

By dividing the percentage of adult emergence by the overall developing time in days, growth index was calculated. The growth index was calculated using a formula:

$GI = \frac{N}{AV}$ (Howe, 1971)

Where, N = percentage of adult emergence and AV = average total developmental period (days).

Repellency Bioassay

Plant essential oils (PEOs) repellent assays were distributed in accordance with the (Lü and Ma, 2015) technique. Two sections of Whatman filter sheets with an 8cm diameter were separated. 2, 4, 6, and 8 microliters of PEOs were dissolved in 1 millilitres of n-hexane to create four check solutions. Converted the doses into correspondingly 0.2, 0.4, 0.6, and 0.8 equivalent concentrations. Use a micropipette to evenly distribute each solution over half of a filter-paper disc. As a control, only the other half of the filter paper received the n-hexane treatment. To completely evaporate the solvent, the treated and control half discs were air dried in the shade using a fan. Using adhesive tape, the treated and untreated sliced up was linked to the opposite and put in the petri dishes (Du *et al.*, 2014) . Twenty adult beetles (1:1) that were 7 days old and of mixed sexes were released individually into the petri dishes centre. After the beetles had fled, the dishes were sealed with parafilm and covered. For each concentration, there were four repetitions. After 12, 24, 48, and 72 hours, data were recorded (Mojtaba Ghane Jahromi, 2011). RD_{50} median repellent dose was calculated by using probit analysis ("Probit Analysis," 1971). Percentage Repellence (PR) were calculated according to the method of Nerio et al. 2009.

$$PR = (Nc - Nt \div Nc + Nt) \times 100$$

Where Nc is the "number of insects on the untreated area after the exposure interval and Nt is the "number of insects on the treated area after the exposure interval".

Contact Toxicity

According to (Liu and Ho, 1999), contact toxicity tests of PEOs against *L. serricorne* adults were conducted. We made aliquots of (PEOs) 2, 4, 6, and 8 µl in 1 ml n-hexane. The dorsal thorax of adult insects and larvae were topically treated with 0.5 ml of a subsequent dilution. N-hexane was used to identify the controls. For each concentration, including the control, three repeats were used (Ebadollahi *et al.*, 2010b). Each concentration was applied to twenty *L. serricorne* adults (with a maximum age of 7 days). The insects were then transferred to the petri dishes and covered after treatment. According to (Yang *et al.*, 2014b), mortality of the insects was detected after 24 hours for seven days in a row (Liu and Ho, 1999). Probit analysis was used to determine the LD_{50} values (Sakuma, 1998). Corrected mortality was calculated using Abbott's formula.

Fumigant Toxicity

According to (Liu and Ho, 1999) research, the fumigation activity of PEOs against *L. serricorne* adults was examined. By dissolving 2, 4, 6, and 8µl of the plant essential oils in 1 ml of n-hexane, a dilution of the oils was created. The screw top of the glass jars (D 2.5 inches, H 6 inches, V 455 milliliter) was placed on a Whatman filter paper (3 inches in diameter) that had been diluted by 10 microliters. Twenty mature *L. serricorne* adults (with a maximum age of 7 days) were inserted in each sealed compartment after the solvent had been allowed to vaporize for 20 seconds. According to research by (Yang *et al.*, 2014a), the solvent can evaporate in just 20 seconds. We utilized n-hexane as a control.

Three repeats were employed for each concentration (Ebadollahi *et al.*, 2010c). The insect was moved to the clean jars after 24 hours and left there for a further seven days. Insect deaths were recorded, and data was analysed using Probit analysis to establish LC_{50} standards (Sakuma, 1998) for seven days straight following each 24-hour period (Liu and Ho, 1999). Corrected mortality was calculated using Abbott's formula:

$$Mortility\ rate\ (\%) = \frac{Number\ of\ dead\ insects}{Number\ of\ total\ insects}\ x\ 100\ (Ren\ et\ al., 2022)$$

$$CMR\ \% = \frac{Mortility\ rate\ of\ treatment\ group - \ Mortility\ rate\ of\ control\ group}{1 - Mortility\ rate\ of\ control\ group}\ x\ 100$$

Statistical Analysis

The experiments were carried out using a randomized complete block design, where the treatments consisted of different treated food sources. Each treatment was replicated three times. Prior to analyzing the data, various measurements such as the number of eggs, egg development time, larval development time, pupal development period, adult developmental time, total developmental time, incubation period, and weight loss were converted to a log10 (X+1) scale. This transformation was done to ensure that the data met the assumptions of normality and homogeneity of variances (Zar, 1984). Following this, the percentage values were compared across different food sources. The RD_{50}, LD_{50} and LC_{50} values were calculated using probit analysis. Chi-square (χ^2) test were applied to test the homogeneity ratio (1:1) in order to assess the repellent, contact and fumigant activity of essential oils (Sokal and Rohlf, 1981). To determine significant differences between treatments, all the data were subjected to analysis of variance (ANOVA) using SPSS Version 16.0 software. The actual means and standard errors (SEs) can be found in the text, table, and figures.

RESULTS

Preference and antixenosis

Ovipositional response

Cigarette beetle female adults' laid eggs on seven different treated plants. Deposited Eggs were translucent, and oblong. The number of eggs laid on *Nigella sativa* treated were greater than that of all other plants as shown in Figure 1. The average number of laid eggs on *N. sativa* found highest significantly (average mean 2.371±0.002) among all others. For *Tuja orientalis*, the number of laid eggs found significantly higher (2.243±0.004) with other plants. However, lowest significantly different (0.673±0.106) number of eggs laid on *P. hysterophorous*.

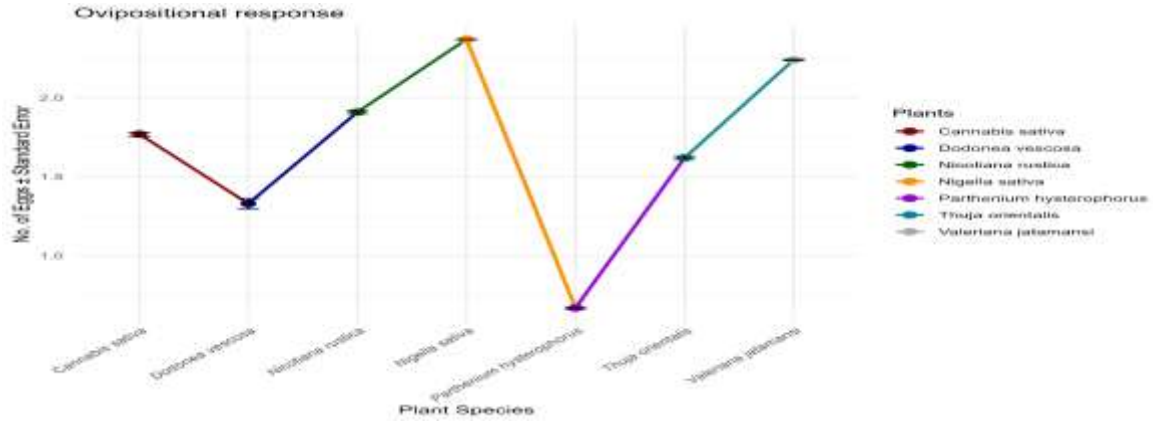

Figure 1. Effect of seven different plants on the ovipositional response of *Lasioderma serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test $P \leq 0.05$) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Total developmental period

The total developmental period of cigarette beetle while exposure to different plants varied. *P. hysterophorus* showed significantly (mean 2.116±0.003) longer developmental period from egg to adult stage among all others plant as shown on Figure 2. Similarly, total developmental periods on two other plants *Dodonea vescosa*, and *Valeriana jatamansi* insects found to be higher than other. However, *Nigella sativa* exposure showed lowest total developmental periods of cigarette beetle (Figure 2).

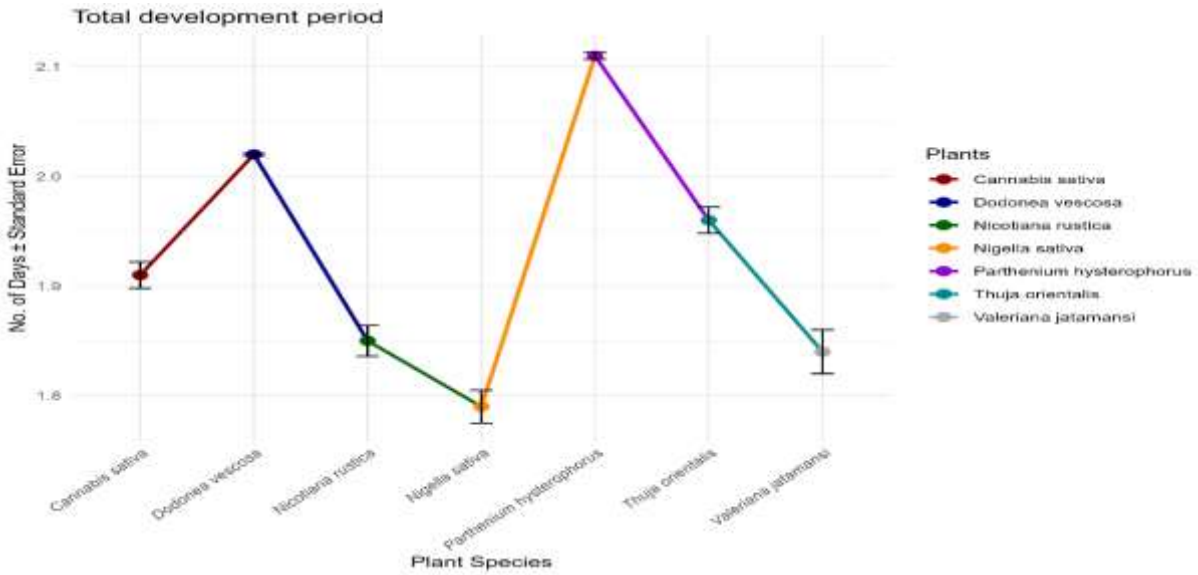

Figure 2. Effect of seven different plants on the total developmental period of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Developmental period for egg

There were not significantly different in the mean egg's developmental periods among seven plants inside the test tube with food supply of processed plants. *P. hysterophorous* found to be lengthy eggs development time (1.436±0.013) than all other plants. Whereas eggs developmental period of cigarette beetle found lowest on *N. sativa* (Figure 3).

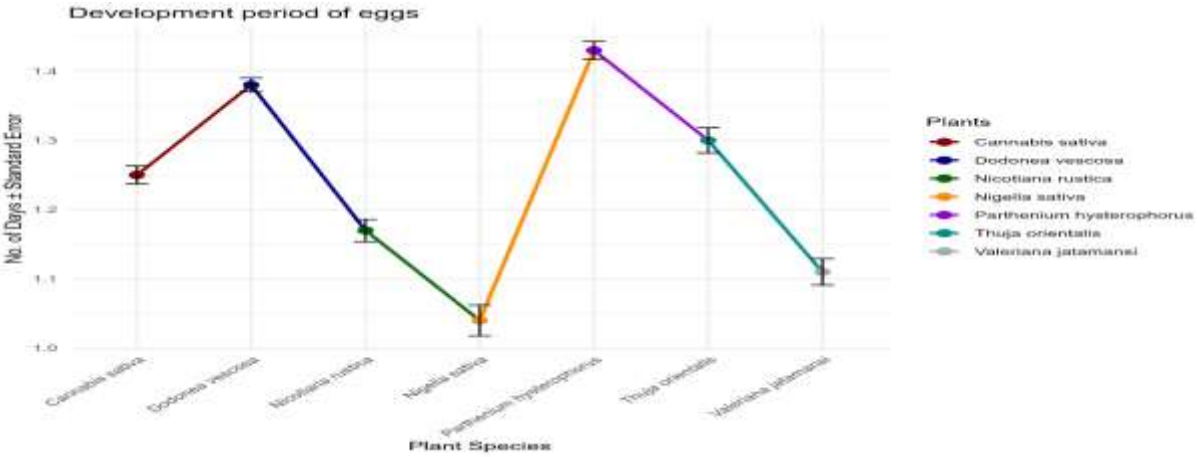

Figure 3. Effect of seven different plants on the developmental period for eggs of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Developmental period for larvae

Larval developmental periods of cigarette beetles observed among seven plants as shown in Figure 4. However, mean significant difference observed in larval developmental time among *P. hysterophorous* and *N. sativa* (1.726±0.007; 1.348±0.017 respectively).

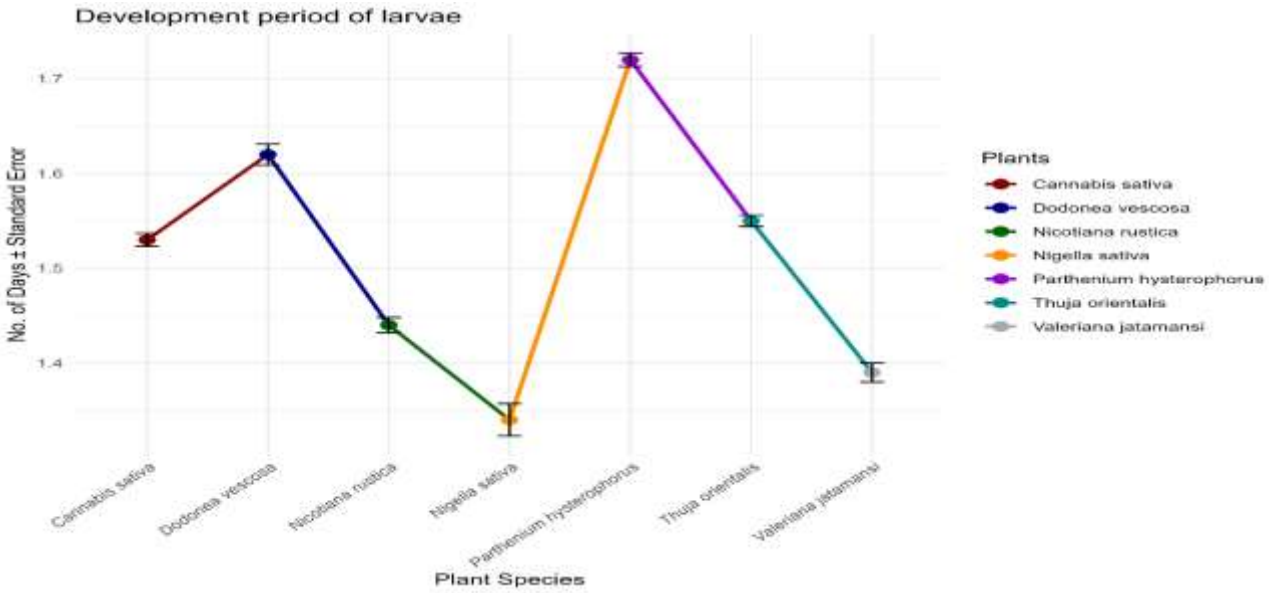

Figure 4. Effect of seven different plants on the developmental period for larvae of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Developmental period for pupae

The pupal development periods ranged from mean log converted 0.900 days to 1.254 days on seven different plants. The shortest development periods (0.900 ±0.031) in pupae of cigarette beetle occurred on *N. sativa* (Figure 5).

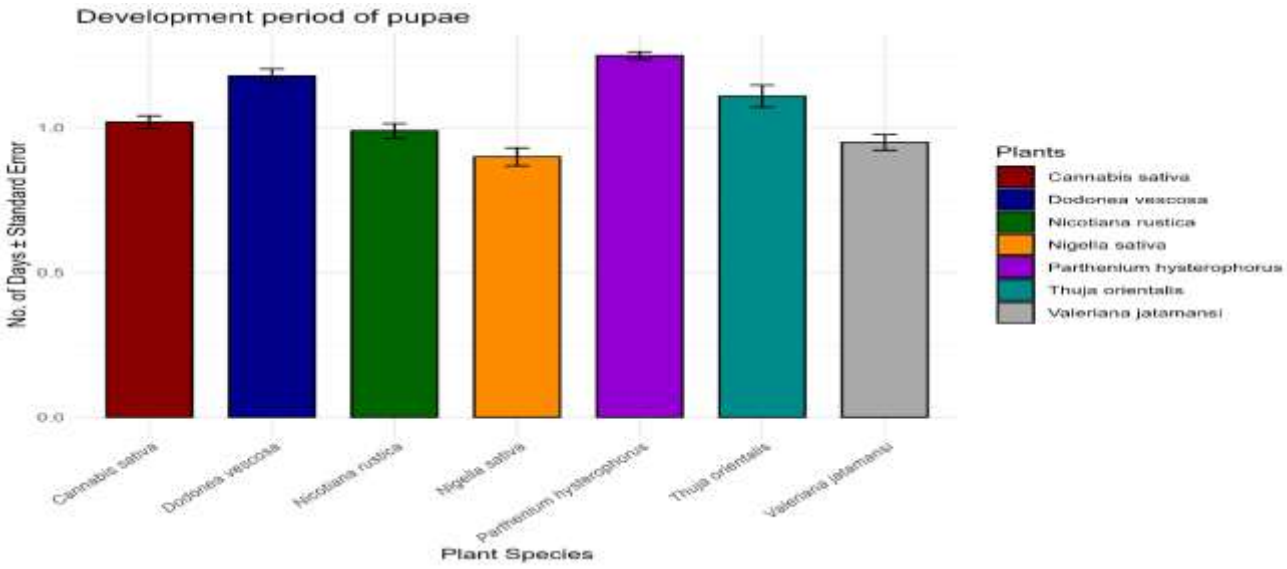

Figure 5. Effect of seven different plantson the developmental period for pupae of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Developmental period for adult

The developmental period for adult while exposure to different plants varied among the test insect. *P. hysterophorous* showed significantly (1.505±0.007) longer developmental period for adult stage among all others plant as shown on Figure 6. Similarly, adult developmental periods on two other plants *Dodonea vescosa*, and *Valeriana jatamansi* insects found to be higher than other. However, *Nigella sativa* exposure showed lowest adult developmental periods of cigarette beetle.

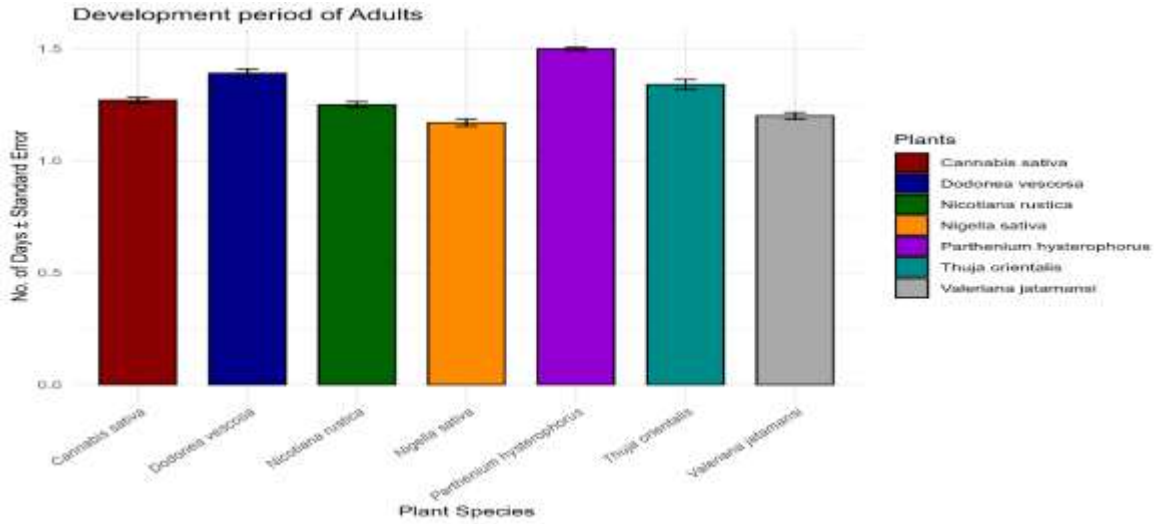

Figure 6. Effect of seven different plants on the developmental period for adult of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Growth Index

The growth index of cigarette beetle was observed with varying rate in all seven treatments of plants. The maximum growth index was found in *N. sativa* (1.376±0.052) whereas, least growth index was noted in *P. hysterophorous* (-0.846±0.431). There were significantly different in the mean growth index in above mentioned plants as shown in (Figure 7).

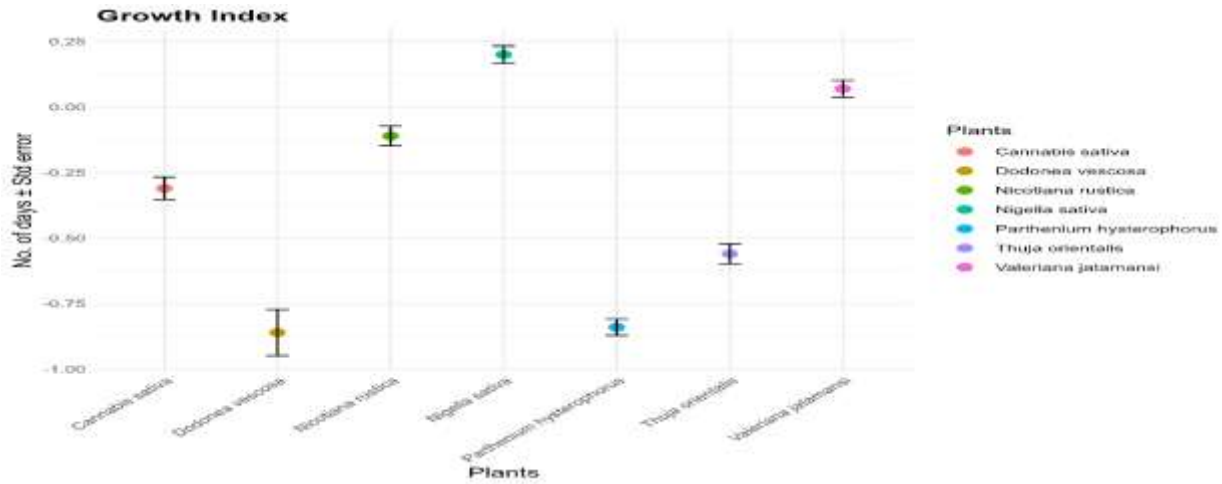

Figure 7. Effect of seven different plants on growth index of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Weight loss

Results shows that weight loss significantly varied (0.365±0.20 to 1.376±0.05) among cigarette beetle individuals reared on seven different plant treated food as shown in (Figure 8). Beetles have lost more weight of plant during feeding on *N. sativa* (1.376±0.05). Similar weight loss observed in beetles which fed on *T. orientalis* (1.360±0.06). However, less weight loss observed in *P. hysterophorous* (0.365±0.20). It seems that *P. hysterophorous* was not his favorite food besides all other plants.

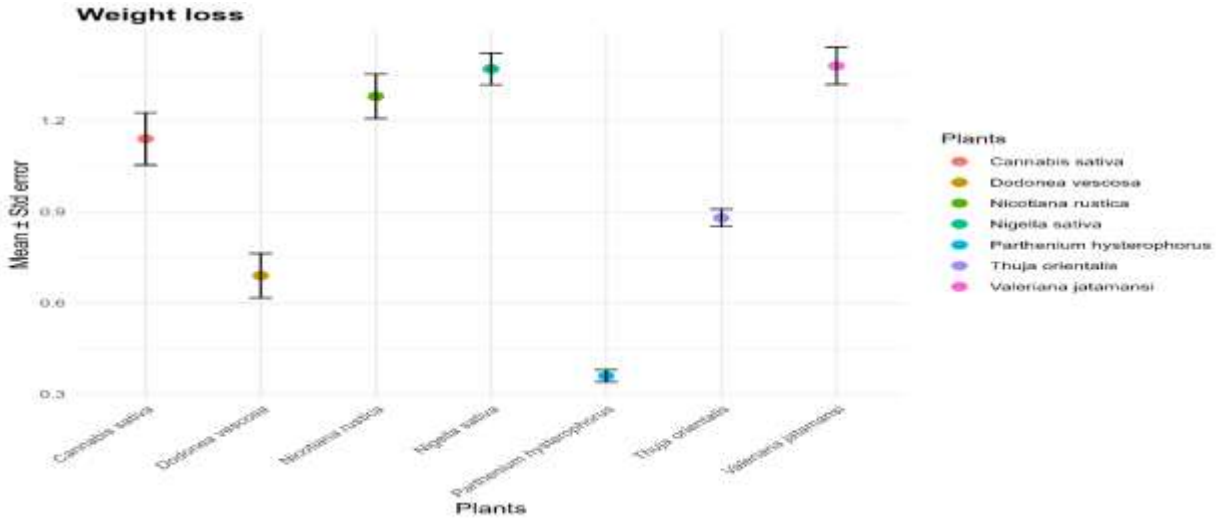

Figure 8. Effect of seven different plants on weight loss by *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Incubation period

The incubation period of cigarette beetles was found significantly varied among selected plant as shown in (Figure 9). The maximum incubation period was observed in *P. hysterophorous* (1.785±0.00) and minimum found in *N. sativa* (1.500±0.01), and statistically significant. Cigarette beetles also showed longer incubation period on *Dodonea vescosa*.

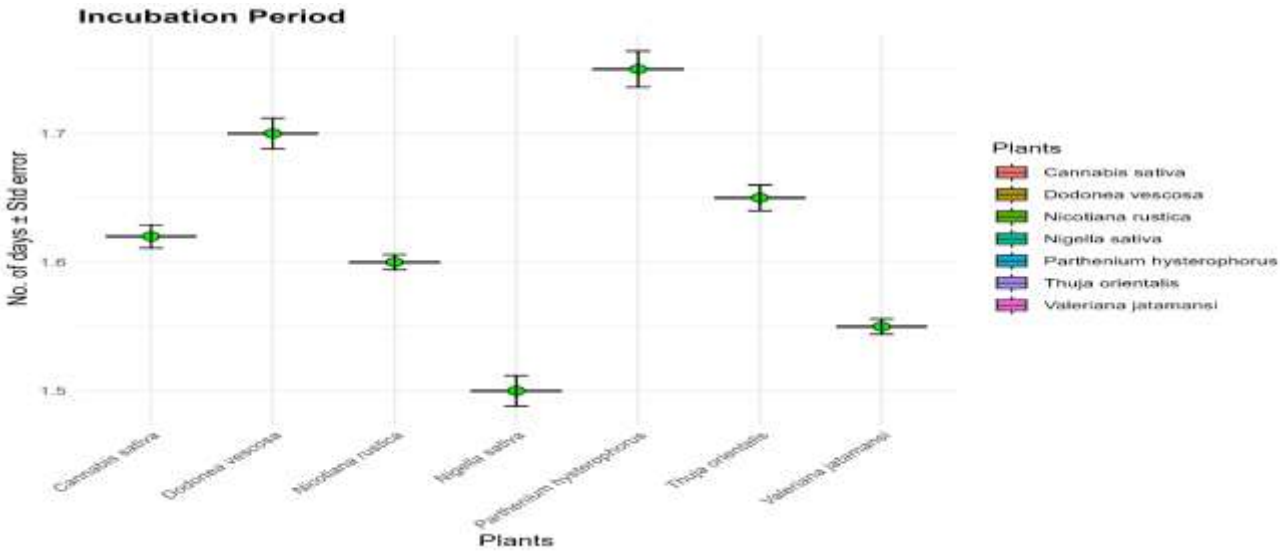

Figure 9. Effect of seven different plants on incubation period of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test P ≤ 0.05) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Adult emergence

The adult emergence of cigarette beetle while exposure to different plants varied among tested insect. *P. hysterophorous* showed significantly (0.566±0.296) longer adult emergence from larvae to adult stage among all others plant as shown on (Figure 10). Similarly, adult emergence time on two plants *Dodonea vescosa*, and *Valeriana jatamansi* insects found to be higher than other. However, *Nigella sativa* exposure showed lowest adult emergence periods of cigarette beetle.

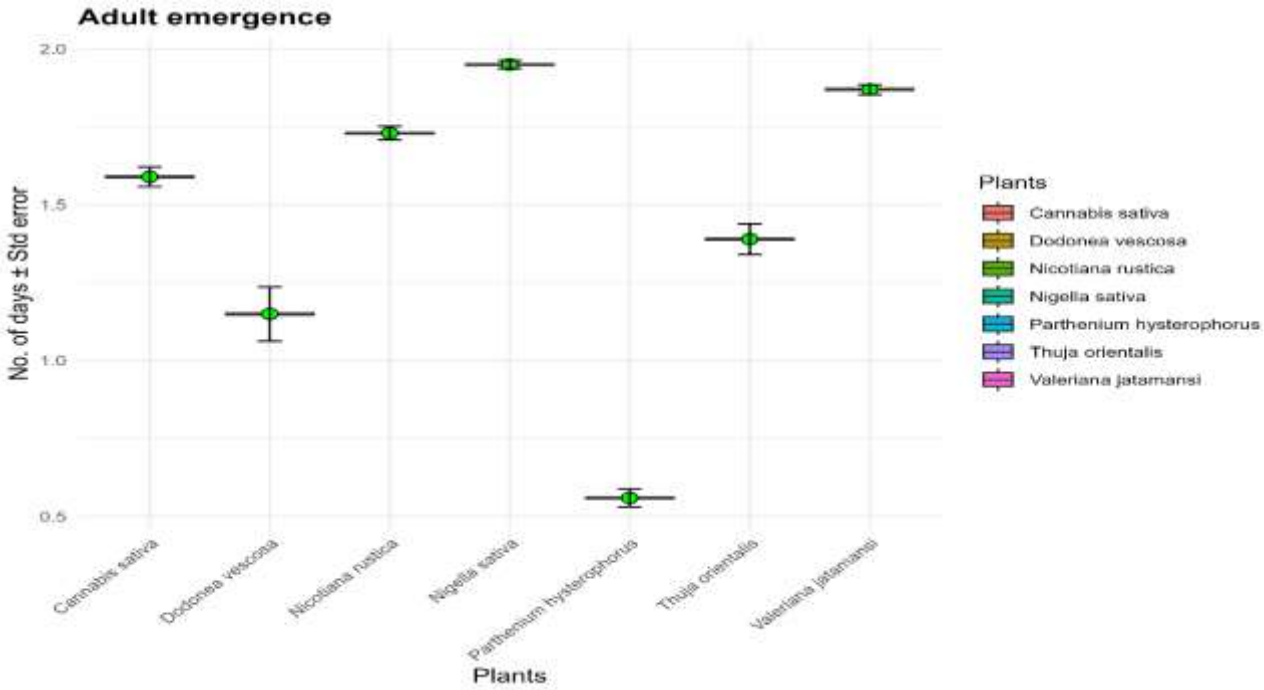

Figure 10. Effect of seven different plants on adult emergence of *L. serricorne*. Different lower-case letters indicate significant difference (One-Way ANOVA, Means are compared using of LSD test $P \leq 0.05$) values are days of means. Error bars shown in the figure represent (±SE) of replications.

Repellent effect of plant essential oils

At adult stage, *P. hysterophorus* were showed stronger repellent effect (RD_{50} = 2.642 %) against cigarette beetle than that of the other six EOs after 12h of exposure as shown in Table 1. But this time *N. sativa* was proven weakest repellent (RD_{50} = 0.388 %) against cigarette beetle among all other essential oils. However, after 24h of EOs exposure to tested beetles, *V. jatamansi* repellent effect (RD_{50} = 3.543 %) was observed inferior among all and seems to be higher repellency. Regarding the *P. hysterophorus*, the repellent effect was comparable to that of the others at 24h post-exposure. Similar repellency trends were observed after 48h of EOs exposure but *P. hysterophorus* (RD_{50} = 2.287 %) found inferior to others. In fact, the repellency effect was found similar in adult and larval stage after 72h of EOs exposure (Table 1).

Table: 1. Behavioral preference test of different plants essential oil against adult of *Lasioderma serricorne* after 12 to 72h exposure

Plants	12h					24h					48h					72h				
	RD 50 (95 %	Slope	Y-interc	DF	Chi-sq	RD 50 (95 %	Slope	Y-interc	DF	Chi-sq	RD 50 (95 %	Slope	Y-interc	DF	Chi-sq	RD50 (95 % CF)	Slope	Y-interc	DF	Chi-sq

	CF)		**ept**		**uare (x^2)**	**CF)**		**ept**		**uare (x^2)**	**CF)**		**ept**		**uare (x^2)**			**ept**		**uare (x^2)**
Nigella sativa	0.388(0.248-0.474)	2.215	0.912	2	2.415	0.356(0.243-0.432)	2.706	1.212	2	0.774	0.340(0.229-0.413)	2.839	1.331	2	3.740	0.433	3.311	1.202	2	10.2811
Tuja Orientalis	0.539(0.308-0.655)	2.427	0.652	2	0.077	0.530(0.530-0.622)	3.354	0.924	2	2.871	0.643	3.934	0.754	2	6.212	0.548(0.412-0.632)	3.619	0.945	2	0.854
Nicotiana rustica	0.881(0.780-0.952)	4.858	0.266	2	1.474	0.712(0.509-0.821)	0.855	0.079	2	0.978	0.749 (0.595 - 0.839)	0.877	0.079	2	0.424	0.714(0.431-0.844)	0.824	0.077	2	0.074
Cannabis sativa	0.987(0.874-1.060)	6.631	0.038	2	2.448	1.069(0.976-1.335)	6.518	-.190	2	1.342	0.987(0.874-1.060)	6.038	0.303	2	2.438	0.946(0.794-1.036)	1.061	0.125	2	0.360
Valeriana jatamansi	1.240(1.048-1.351)	5.647	-0.528	2	0.433	3.543	-1.044	0.574	2	2.574	1.347(1.200-1.441)	1.063	0.227	2	0.563	1.204(0.904-1.349)	4.266	-0.344	2	0.865
Dodonea vescosa	1.728	10.433	-2.478	2	5.742	1.792(1.670-1.879)	11.044	-2.799	2	2.908	1.832(0.367-2.016)	1.815	0.562	2	4.523	1.411(0.385-1.685)	4.213	-0.629	2	0.905
Partheinum hysterophorous	2.642	6.864	-2.896	2	3.963	2.504(2.047-2.733)	5.828	-2.323	2	0.639	2.287	4.375	-1.572	2	5.811	2.638	5.400	-2.275	2	4.236

Application for 12, 24, 48 and 72h, Concentration (µl/adult), number of adults/insects 20.
$^{RD}_{50,}$ 95% Confidence Interval, Chi-sqaure test, and PR (%).
PROBIT model: = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm)

Contact toxicity of plant essential oils

The contact toxicity of seven essential oils on adult of cigarette beetle with different exposure were presented in Table 2. At adult stage, the essential oils (EOs) of seven plant species found unique levels of contact toxicity against cigarette beetle. *P. hysterophorus* found to be higher toxic (LD_{50} =4.856) against beetle after 24h of its exposure but surprisingly, two EOs namely *C. sativa*, and *V. jatamansi* showed zero contact toxicity. However, *N. sativa* least toxic (LD_{50} = 1.829) among EOs. After 48h, 72h, and 96h of EOs exposure, the efficacy was found somewhat similar adult stage. *D. vescosa* provided the highest contact toxicity after 120h exposure (LD_{50} = 6.382), while *P. hysterophorus* caused no mortality as shown in Table 2. *N. sativa* was the least toxic to the cigarette beetle, as only LD_{50} = 1.16 mortality were observed at 50% of concentration used. Among seven EOs, three of them (*V. jatamansi, N. rustica,* and *P. hysterophorus*) found to be zero toxic against cigarette beetle after 144h of exposure to test insect. However, *D. vescosa* caused highest toxicity (LD_{50} = 4.612) as shown in table 3. After 168h of EOs exposure to adult cigarette beetle, all plants showed zero toxicity against adult beetle as in Table 2.

Table: 2. Contact toxicity of different plants essential oil against adult of *Lasioderma sericorne* after 24 to 144h exposure

Plants	**24h**					**48h**					**72h**				
	LD_{50} (95% CF)	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**	**LD_{50} (95% CF)**	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**	**LD_{50} (95% CF)**	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**
Nigella sativa	1.829 (1.285-37.067)	4.700	-1.232	2	3.103	1.295 (0.964-2.904)	2.974	-0.333	2	0.934	1.550 (0.977-7.038)	1.590	-0.303	2	0.081
Tuja Orientalis	1.906	2.482	-0.695	2	4.784	1.522 (1.120-4.085)	2.390	-0.436	2	0.003	1.146 (0.944-1.788)	2.798	-0.165	2	0.684
Nicotiana rustica	2.021	5.840	-1.785	2	6.420	1.972 (1.682-3.278)	4.601	-1.357	2	0.039	1.826 (1.566-3.227)	3.702	-0.968	2	0.001
Cannabis sativa	_	_	_	_	_	2.295 (2.102-2.872)	9.933	-3.584	2	1.986	2.341 (2.074-3.447)	6.039	-2.231	2	0.066

Valeriana jatamansi	_	_	_	_	_	2.684 (2.499-3.221)	12.199	-5.231	2	2.071	2.724 (2.479-3.725)	7.466	-3.249	2	0.086
Dodonea vescosa	3.747 (3.290-8.019)	10.480	-6.012	2	3.043	3.568 (3.033-15.372)	6.193	-3.421	2	0.414	3.416 (2.942-15.384)	5.527	-2.948	2	0.687
Parthenium hysterophorous	4.856	-6.542	4.490	2	4.793	3.669 (3.494-4.156)	17.837	-10.070	2	2.185	.702(3.464 - 4.576)	11.020	-6.264	2	0.117
	96h					**120h**					**144h**				
Nigella sativa	1.024 (0.779-1.879)	2.060	-0.022	2	0.622	1.162 (1.016-1.526)	5.015	-0.327	2	1.691	1.491 (1.181-2.928)	4.206	-0.729	2	3.266
Tuja Orientalis	1.032	2.756	-0.038	2	3.801	1.877 (1.442-29.339)	6.665	-1.822	2	1.408	1.731 (1.389-138.766)	8.509	-2.028	2	0.270
Nicotiana rustica	2.384 (1.775-57.935)	2.810	-1.060	2	0.813	2.253 (1.848-9.488)	8.277	-2.920	2	3.509	_	_	_	_	_
Cannabis sativa	2.207 (1.962-3.400)	4.872	-1.675	2	0.002	2.368	17.209	-6.444	2	4.427	3.249	9.697	-4.963	2	3.103
Valeriana jatamansi	2.596 (2.362-3.679)	6.034	-2.500	2	0.005	2.955 (2.665-4.457)	6.993	-3.290	2	2.484	_	_	_	_	_
Dodonea vescosa	2.988 (2.767-3.898)	7.497	-3.564	2	0.121	6.382	3.762	-3.028	2	12.195	4.612	8.938	-5.934	2	2.833
Parthenium hystero	3.494 (3.314-	9.664	-5.241	2	1.382	1.162 (1.016-	5.015	-0.327	2	1.691	_	_	_	_	_

phorous	4.108)	1.526)	

Application for 24, 48, 72, 96, 120 and 144h, Concentration (µl/adult), number of adults/insects 20. LD50, 95% Confidence Interval, Chi-sqaure test and Abbot formula used
PROBIT model: = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm)

Fumigant toxicity of plant essential oils

The fumigant toxicity of seven EOs against adult *L. Serricorne* with different exposure are presented in Table 3. *P. hysterophorus* based EOs was found to be higher toxic (LC_{50} = 1.45) against beetle after 24h of exposure but surprisingly, *V. jatamansi* showed zero fumigant toxicity. On the other side, *N. sativa* was found to be the least toxic (LC_{50} = 6.20) among EOs. After 72 and 96h of EOs exposure, *D. vescosa* was found to be more toxic than *P. hysterophorus* and other plants at adult stage. Out of selected plant EOs, *P. hysterophorus, D. vescosa, T. orientalis* and *C. sativa* showed zero fumigant toxicity against *L. Serricorne* after 144h of exposure. In contrast to this, *N. rustica* exhibited the highest toxicity (LC_{50} = 3.47) against adult beetle as shown in Table 3. However, all selected plant EOs showed zero fumigant toxicity against adult *L. Serricorne* after 168h of exposure.

Table: 3. Fumigant toxicity of different plants essential oil against adult of *Lasioderma serricorne* after 24 to 168h exposure

Plants	**24h**					**48h**					**72h**				
	LC_{50} (95% CF)	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**	**LC_{50} (95% CF)**	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**	**LC_{50} (95% CF)**	**Slope**	**Y-intercept**	**DF**	**Chi-square (x^2)**
Nigella sativa	1.455 (1.285-1.974)	7.004	-1.140	2	1.392	1.339 (1.112-2.337)	2.751	-0.349	2	1.080	1.865	2.318	-0.627	2	6.312
Tuja Orientalis	1.580 (1.439-1.923)	7.863	-1.561	2	1.271	1.516 (1.356-1.928)	5.023	-0.908	2	0.375	1.355 (1.249-1.558)	5.582	-0.736	2	0.833
Nicotiana rustica	2.292 (2.119-3.018)	15.173	-5.464	2	1.574	2.196 (2.054-2.532)	11.389	-3.891	2	2.106	2.098 (1.957-2.427)	8.144	-2.621	2	0.940
Cannabis sativa	5.447	5.655	-4.163	2	2.950	3.654 (3.061-27.299)	5.963	-3.356	2	0.700	2.989 (2.761-4.005)	7.192	-3.420	2	0.009

Valeriana jatamansi	6.575	5.417	-4.431	2	3.427	3.472 (3.313-4.072)	25.239	-13.643	2	1.700	3.313 (3.178-3.617)	14.487	-7.536	2	0.378
Dodonea vescosa	-	-	-	-	-	4.016 (3.777-5.277)	22.734	-13.726	2	2.614	4.089 (3.777-5.504)	12.280	-7.511	2	0.162
Parthenium hysterophorous	6.207	12.270	-9.729	2	2.728	5.155	4.825	-10.559	2	7.207	4.385 (4.225-4.792)	18.482	-11.865	2	2.265
	96h					**120h**					**144h**				
Nigella sativa	1.868 (1.443-4.790)	4.205	-1.141	2	3.220	1.374 (1.259-1.746)	10.889	-1.501	2	0.631	_	_	_	_	_
Tuja Orientalis	1.716 (1.526-2.643)	10.172	-2.386	2	1.434	2.356	6.790	-2.527	2	2.272	_	_	_	_	_
Nicotiana rustica	2.205 (1.980-3.079)	5.494	-1.886	2	1.564	2.292 (2.119-3.018)	15.173	-5.464	2	1.574	_	_	_	_	_
Cannabis sativa	2.890 (2.752-3.209)	11.510	-5.304	2	0.496	3.112 (2.867-4.049)	8.890	-4.384	2	0.101	_	_	_	_	_
Valeriana jatamansi	3.380 (3.176-4.95)	9.461	-5.004	2	1.455	3.471 (3.295-3.965)	16.710	-9.032	2	2.168	3.472 (3.313-4.072)	25.239	-13.643	2	1.700
Dodonea vescosa	3.562 (3.432-3.877)	11.605	-6.403	2	0.841	3.989	5.313	-3.187	2	0.383	4.016 (3.777-5.277)	22.734	-13.726	2	2.614

Parthenium hysterophorous	4.376 (4.160-5.278)	11.237	-7.202	2	0.018	4.376 (4.160-5.278)	11.233	-7.202	2	0.018	5.155	4.825	-10.559	2	7.207

Application for 24, 48, 72, 96, 120 and 144h, Concentration (µl/adult), number of adults/insects 20. $^{LC}_{50,}$ 95% Confidence Interval, Chi-sqaure test and Abbot formula used
PROBIT model: = Intercept + BX (Covariates X are transformed using the base 10.000 logarithm)

Discussion

In the current study, the experiment is performed to test the efficacy of seven different plant EOs to find out the preference and antixenosis parameters against *L. serricorne*. The number of eggs laid by each individual female of *L. serricorne* was counted during oviposition. *L. serricorne* showed minimum number of eggs on *P. hysterophorus*. *P. hysterophorus* has antifeeding or mortality properties, making females reluctant to lay eggs and not choosing this plant as a food source for the next generation. Female *L. serricorne* in a confined environment may prevent individuals from realizing their full oviposition potential because of this (Mahroof and Phillips, 2008). This compound is used by females to mark ovipositional sites so that conspecific females can identify and avoid those locations. The availability of food for the freshly hatched larvae is also ensured by this natural adaptation (Howlader and Ambadkar, 1995). Our findings indicated that a single female's average egg production changed depending on the type of plant material used as the oviposition medium, suggesting that *L. serricorne* females may be able to distinguish between various plant parts. It appears that this plant can be employed as a host for feeding and oviposition site for the cigarette beetle after the maximum fecundity of *L. serricorne* on *N. sativa* was observed in our study. These findings imply that variations in chemical composition of plant, both quantitatively and qualitatively, may have a direct impact on *L. serricorne* oviposition behaviour. We believed that the plant such as *P. hysterophorus*, *T. orientalis*, and *D. vescosa* can be use as oviposition deterrents to the control of cigarette beetle.

Egg hatching times were consistent across all plants, indicating that the type of host material used to lay the eggs had no bearing on when the eggs would hatch. However, *L. serricorne* showed more eggs development time to *P. hysterophorus* and that were continue in the larval, pupal, and overall developing times across the examined plants demonstrate that the kind of plant material has an impact on larval development, which may have an impact on pupal development. On *N. sativa*, *L. serricorne* reached the adult stage more quickly than on the other plants, and this quicker development may be due to the balanced and essential nutrients present in *N. sativa*, or it may be because it produces fewer compounds that are protective of cigarette beetles. Developmental times observed in other may be nutritionally poor and chemically defended foods such *V. jatamansi*, and *C. sativa* were moderate. Development time and growth of Cigarette beetle on *P. hysterophorus* explored the ability of *L. serricorne* to utilize toxin-rich hosts as food may be correlated to the ecological tendency of this species to breed in food sources containing defensive substances, and relate to the association of *L. serricorne* with a yeast-like symbiont, *Symbiotaphrina kochii* (Shen and Dowd, 1991). According to (Dowd and Shen, 1990) and (Shen and Dowd, 1991), the symbionts of *L. serricorne* may assist the insect in utilizing host materials that are rich in plant allelochemicals and converting them into nutrients and carbon sources. However, a related study that was conducted on another plant revealed that cigar tobacco had a delayed *L. serricorne* development period.

There was more weight loss caused by *L. serricorne* while feeding on *N. sativa*, which show growth at larval stage it consumes more weights (Lefkovitch and Currie, 1967). However, on the other hand, lost less weight on *P. hysterophorus* during feeding, it seems due to less nutrient and toxic substance urges larvae to reserve the body nutrients and that why it has more development time (Lefkovitch and Currie, 1967); (Shinoda and Fujisaki, 2001). Seven EOs' contact toxicity to *L. serricorne* at adult stages showed varying degrees of toxicity. The least hazardous of the seven plant EOs tested was *N.*

sativa. However, *P. hysterophorus* was the one that was the most harmful to cigarette beetles. These findings account for the extended beetle development time during feeding on *P. hysterophorus*. The cigarette beetle exhibits such a sensitivity variance to the seven different EOs, as demonstrated in other EOs by (Feng *et al.,* 2019). This study also showed that the effectiveness of contact exposure to larvae and adults decreased with time after EO exposure, maybe disappearing altogether after 7 days, as indicated in the Tables 3 and 4. Plant extracts appear to have a short shelf life, according to (Lengai *et al.,* 2020) research. The weakest and strongest toxicity may be caused by insecticidal components of plant extracts, according to a comparison of the contact toxicity of all plant extracts against *L. serricorne*. To evaluate the insecticidal elements against the cigarette beetle, additional study is needed.

All seven plant EOs showed the potential to resist the cigarette beetle. Even after post-exposure, the repellent effects of *P. hysterophorus, T. orientalis,* and *D. vescosa* worked better in terms of capacity and endurance. Additionally, it demonstrated *P. hysterophorus* extraordinary ability to reject *L. serricorne*. Such phenomena previously noticed in other insects by *T. castaneum* (Seifelnasr *et al.,* 1982), *Sitophilus zeamais* (Ukeh *et al.,* 2010), *Callosobruchus maculatus* (Ndomo *et al.,* 2015), *Stegobium paniceum* (Cao *et al.,* 2018), and had been recently described in *L. serricorne* (Cao *et al.,* 2019). According to Cao's most recent research, the cigarette beetle was strongly attracted to four Chinese medicinal plants: *Euphorbia kansui* T.N. Liou ex T.P. Wang, *Aconitum carmichaelii* Debeaux, *Eucommia ulmoides* Oliver, and *Pinellia ternate* Breitenbach. The results of the current study's repellent experiments showed that attractancy was more likely to happen at low concentrations. We began to speculate as to what exactly drove the repelency towards the attractancy. Additional research must be conducted to learn that.

Many plant extracts and essential oils exhibit fumigant properties because of their high volatility (Coats *et al.,* 1991); (Kim *et al.,* 2003). This investigation verified that *P. hysterophorus, T. orientalis,* and *D. vescosa* were exhibited effective fumigant activity against *L. serricorne*. In contrast to other fumigants, *P. hysterophorus* is more effective with prolonged exposures. According to our findings, the essential oil of *P. hysterophorus* functions as a fumigant and is extremely poisonous to adult *L. serricorne* (Ahn *et al.,* 1998). These results imply that the insecticidal mode of action of these chemicals may be significantly influenced by fumigant action. Because of their fumigant action, some plant extracts and essential oils may be useful for managing coleopterons insects, such as *L. serricorne*, for a prolonged period in enclosed spaces like storage bins, glasshouses, or buildings. However, this is only true if a carrier that provides a slow release of the active ingredient can be chosen or created. However, there are issues with *P. hysterophorus*' use in terms of health and safety.

Conclusion

In the current study we found that *N. sativa, N. rustica, V. jatamansi* and *C. sativa* were suitable food sources for the ovipositional preference, survival, and development of *L. serricorne* under laboratory conditions. Whereas, *P. hysterophorus, T. orientalis* and *D. vescosa* act as deterrent against cigarette beetle and may help in the development of pest management tools for this serious insect pest. The purpose of this study is to investigate the behavioral reaction, fumigant activity, and contact activity of seven different types of plant essential oils against *L. serricorne* adults. According to our findings, four plant essential oils can draw *L. serricorne* adults whereas only three plant essential oils can repel them. The best contact and fumigation activity against *L. serricorne* adults was demonstrated by *P. hysterophorus* essential oil, supporting the potential for commercial use of plant essential oils, as environmentally friendly insect control agents. Moreover, this work provided some information on compositional formulation for ecofriendly and sustainable insecticides. The essential oil of *P. hysterophorous, D. vescosa* and *T. orientalis* can be incorporated into grain storage practices for safer and better management of *L. serricorne*.

Conflict of Interest

The authors declare no conflicts of interest.

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