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Bioactivities of bay leaf (*Syzygium polyanthum*) fumigant tablets againts *Araecerus fasciculatus* (De Geer) (Coleoptera: Anthribidae)

Bioaktivitas fumigan tablet daun salam (*Syzygium polyanthum*) terhadap *Araecerus fasciculatus* (De Geer) (Coleoptera: Anthribidae)

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ABSTRACT

The use of bay leaves (*Syzygium polyanthum*) as an alternative fumigant has the potential to control *Araecerus fasciculatus* (De Geer) (Coleoptera: Antribidae). The objective of this study was to evaluate the bioactivities of bay leaf fumigant tablet (BLFT) with exposure times (24, 48, and 72 h) on adult mortality, oviposition deterrence, inhibition of F1 progeny, and feeding activity of the internal feeder pest, *A. fasciculatus*. This study was used seven concentration levels of BLFT (i.e., 0, 1.25, 2.5, 3.75, 5, 6.25, and 7.5 ml/l air) replicated four times and arranged in a completely randomized design. The observed variables were adult male and female mortality, number of eggs, F1 progeny, and inhibition of feeding activity. The results showed that bay leaf tablets have very significant potential as a fumigant against *A. fasciculatus*. Bay leaf tablets fumigant at a concentration of 3.75 ml/l air within 24 hours of application were able 100% inhibit feeding activity, oviposition, F1 progeny, prevent perforation, and weight loss of Katana 1 peanut seeds, and mortality of male and female *A. fasciculatus*

Key words: feeding deterrence index, F1 progeny inhibition rate, oviposition deterrence, seed perforation, seed weight loss

ABSTRAK

Penggunaan daun salam (*Syzygium polyanthum*) sebagai alternatif fumigan berpotensi untuk mengendalikan hama *Araecerus fasciculatus* (De Geer) (Coleoptera: Anthribidae) karena memiliki beberapa kandungan senyawa volatil. Penelitian ini bertujuan mengevaluasi bioaktivitas fumigan tablet daun salam dengan waktu paparan yang berbeda (24, 48, dan 72 jam) terhadap mortalitas imago, penghambatan oviposisi, terbentuknya imago F1, dan aktivitas makan hama *internal feeder*, *A. fasciculatus*. Penelitian ini terdiri atas tujuh taraf konsentrasi fumigan tablet daun salam (0; 1,25; 2,5; 3,75; 5; 6,25; dan 7,5 ml/l udara) dan diulang empat kali yang disusun dalam rancangan acak lengkap. Variabel yang diamati meliputi mortalitas imago jantan dan betina, jumlah telur, imago F1, dan penghambatan aktivitas makan. Hasil penelitian menunjukkan bahwa tablet daun salam berpotensi sangat signifikan sebagai fumigan terhadap hama *A. fasciculatus.* Tablet daun salam dengan konsentrasi 3,75 ml/l udara dalam 24 jam setelah aplikasi mampu 100% menghambat aktivitias makan, oviposisi, pembentukan imago F1, mencegah kerusakan dan kehilangan berat biji kacang tanah Katana 1 serta mortalitas hama *A. fasciculatus* jantan dan betina.

Kata kunci: indeks penghambatan makan, penghambatan terbentuknya imago F1, penghambatan oviposisi, persentase kerusakan biji, penurunan berat biji

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INTRODUCTION

Araecerus fasciculatus (De Geer) (Coleoptera: Anthribidae) is a polyphagous pest that can attack high-value stored products in tropical and subtropical regions (Hill 2003; Yue-kai et al. 2011). *A. fasciculatus* has been reported to attack various stored products, including nuts (peanut, Brazil nut, shea nut, Bambara peanut, mung bean, and soybean), seeds (maize, cocoa, coffee, nutmeg, and sorghum), tubers (cassava, sweet potato, taro, and potato), spices, medicinal materials, and dried fruits (Hagstrum & Subramanyam 2009; Hagstrum et al. 2013; Koval et al. 2019; A. Kumar & Ray 2022). *A. fasciculatus* as an internal feeder can cause losses of stored products by larval and adult stages (Alba-Alejandre et al. 2018). The larvae enter the commodities and remain until they become adults, causing damage in the form of holes in the seeds, producing frass, and emergence holes of the adults (Soeprapto 1992; Agona et al. 1999; A. Kumar & Ray 2022). In addition, damage caused by *A. fasciculatus* has been reported to cause losses of 15–39% in coffee, 26% in cocoa, and 14–91.51% in tubers (Danjuma 2002; Chijindu & Boateng 2008; Danjuma et al. 2008; Dharmaputra et al. 2018; Wahyuni et al. 2022).

Pest control in the form of disinfection of stored products generally involves synthetic chemical fumigation (Daglish et al. 2017). The use of synthetic chemical fumigants is effective in controlling each stage of insect development, but some insects are more tolerant to fumigants; therefore, it is necessary to strategize their concentrations (Bell 2006). In addition, synthetic chemical fumigant tablets are more widely used because they are more effective, convenient to use, and have minimal residue (Phillips et al. 2012). Furthermore, stored product insect pest control with botanical fumigants has been widely developed as an alternative fumigant to overcome the limitations of synthetic fumigants and is more environmentally friendly (Shivkumara et al. 2019). Several studies have shown that the use of botanical fumigants can cause oviposition deterrence (Kim et al. 2012), antifeedants (Ikawati et al. 2020), and mortality (Wagan et al. 2022). Consistent with this, Shafaie et al. (2019) reported that Arizona cypress (*Cupressus arizonica* (Greene) (Cupressaceae)) extract resulted in feeding inhibition (13.66%) and decrease in F1 progeny (49.74%) of *Callosobruchus maculatus* (Fabricius) (Coleoptera: Chrysomelidae). In addition, Sartika et al. (2022) reported that the use of bay leaf fumigant tablets can inhibit the population growth and feeding activity of *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrychidae). Based on these reports, the use of botanical fumigants is a potential alternative for pest control in stored products.

There are some characteristics of plants that have the potential as botanical fumigants, namely, they are annual plants; they have a wide distribution area and abundant presence, they are easy to harvest and cheap, and they have effective active ingredients at low levels (Shivkumara et al. 2019). One plant with ideal characteristics to be developed as a botanical fumigant is the bay leaf (*Syzygium polyanthum* (Wight) Walp. (Myrtaceae)). This is supported by the analysis of bay leaf extract content. Abd Rahim et al. (2017) reported that bay leaves contain nerolidol, α-pinene, linalool, hentriacontane, and tocopherol compounds. The main volatile compounds in bay leaves belong to the terpenoid group (monoterpenoids, diterpenoids, and sesquiterpenoids). In addition, Ribeiro et al. (2015) reported that terpenoid compounds have high volatility and may be neurotoxic to insects.

Based on the potential use of botanical fumigants in the control of pests in stored products, this study developed botanical fumigant tablets that are easier to prepare and apply. Regarding the unavailability of information on the use of bay leaf fumigant tablets (BLFT) to control *A. fasciculatus* pests with shorter exposure times, it is relevant to conduct this study. Therefore, this study aimed to evaluate the bioactivity of BLFT with shorter exposure times (24, 48, and 72 hours) on adult mortality, oviposition deterrence, inhibition of F1 progeny, and the feeding activity of *A. fasciculatus*, an internal feeder pest.

MATERIAL AND METHOD

Insect culture

The *A. fasciculatus* used in this study was obtained from cultures maintained at the Plant Pest Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas

Brawijaya. *A. fasciculatus* insects were reared using 250 g of dried cassava in a rearing box (d = 9 cm, h = 26 cm) set at 27.15 ± 1.12 °C, 42.45 ± 5.36 % RH, and 12:12 (L:D). Then, 200 adults of *A. fasciculatus* were placed in the rearing box for 7 days without distinguishing between males and females. After 7 days, the adults were removed and allowed to produce F1 progeny. Adults aged 7–14 d were used in the experiment.

Bay leaves used in the study

Bay leaf was collected from farmers in the Turen Subdistrict of Malang Regency in September 2023. A total of 2 kg of bay leaves was washed using flowing water and shade-dried under laboratory conditions at 23–27 °C and 60 ± 5% RH (Loni & Panahi 2015) for 5 days until the leaves were dry, resulting in 750 g of dried bay leaves. The dried bay leaves were pulverized using a grinder, and sieved through a 20-mesh sieve to obtain a uniform size (Mario et al. 2023).

Preparation of fumigant tablets

Bay leaf was extracted according to the method described by Sartika et al. (2022). Bay leaf powder was placed in an Erlenmeyer flask and 98% ethanol solvent was added at a ratio of 1:10 (w/v). The mixture of bay leaf fine powder and solvent was then homogenized using an orbital shaker at 100 rpm for 72 h. The mixture was filtered through Whatman filter paper no. 1. The bay leaf extract was then concentrated by removing the solvent using a rotary vacuum evaporator at a temperature at 60 °C and 100 rpm for 4 h.

Bay leaf fumigant tablets were prepared by measuring the extracted bay leaves according to the treatment. This study consisted of seven concentrations rate, namely 0, 1.25, 2.5, 3.75, 5, 6.25, and 7.5 ml/l air. Each concentration of the bay leaf extracts were mixed with 4 g of talc and homogenized using a mortar and pestle. Fumigant tablets were molded using a manual tablet press, and BLFT were placed in a spunbond bag (l = 7 cm, w = 5 cm).

GC-MS analysis

The volatile compound content of BLTF were analyzed at the Customs and Excise Laboratory Center (BLBC) Class II Surabaya. The chemical compound contents in the bay leaves were analyzed using gas chromatography-mass spectrometry (GC-MS). Analyses were conducted to identify the type and value of the volatile compounds in the bay leaf extract.

Toxicity bioassay

The toxicity bioassay of BLFT against mortality of adult *A. fasciculatus* consisted of seven concentration levels, repeated four times, arranged in a completely randomized design (CRD). The experiment was conducted with 7–14 days old adults of *A. fasciculatus*. Each treatment jar (d = 5 cm, h = 9.5 cm, v = 195 ml), containing 30 g of Katana 1 peanut and BLFT according to the treatment was infested with 25 pairs of *A. fasciculatus* adults. The difference between male and female dimorphisms of adult *A. fasciculatus* lies in the pygidium. Male *A. fasciculatus* adults have a vertical pygidium, while female adults have a tapered pygidium that is clearly visible from the dorsal side (Kumar & Ray 2022). The treatment jars were then sealed with a cover and were wrapped with plastic wrap to prevent air exchange within the treatment jar. The exposure of *A. fasciculatus* adults to BLFT was conducted at three duration times, namely 24, 48, and 72 hours. Mortality of male and female adults was recorded at the end of the exposure period. The mortality (%M) of *A. fasciculatus* adults was calculated using the equation of Mosip et al. (2018).

$$\text{M (\%)} = \frac{\text{Number of dead } \textit{A. fasciculatus}}{\text{Total } \textit{A. fasciculatus}} \times 100\%$$

Oviposition and F1 progeny inhibition test

The experiment of oviposition and F1 progeny inhibition of BLFT against *A. fasciculatus* consisted of seven concentration levels, repeated four times, arranged in CRD. The experiment used 25 pairs of *A. fasciculatus* adults (7–14 days old) infested in jars containing the BLFT according to the treatment and 30 g of Katana 1 peanut. Infestation was performed according to the exposure period (24, 48, and 72 h) to allow the *A. fasciculatus* females to mate and lay eggs. At the end of the exposure period, the infested *A. fasciculatus* adults were removed from each treatment jar and the egg-infested Katana 1 peanut was returned to the treatment jars. Eggs successfully laid by *A. fasciculatus* females during the exposure

period were counted using a stereomicroscope and hand counter. The number of *A. fasciculatus* eggs laid was used to determine the percentage of oviposition deterrence. The oviposition deterrence (%OD) was calculated using the method of Kedia et al. (2015).

$$OD\ (\%) = \frac{(Ts - Cs)}{Cs} \times 100\%, \text{ where}$$

Ts: the number of eggs laid in the treatment; Cs: the number of eggs laid in the control.

In addition, Katana 1 peanuts, which had been infested with *A. fasciculatus* eggs, were kept to remain until the F1 progeny appeared. The number of F1 progeny was recorded on the 50th day after the number of eggs had been counted (Salbiah et al. 2022). Calculations were also done for egg laying inhibition, the number of F1 progeny and inhibition of F1 progeny formation ware also calculated. The F1 progeny inhibition rate (%FPI) was calculated as described by Ekoja et al. (2021).

$$FPI\ (\%) = \frac{(Cn - Tn)}{Cn} \times 100\%, \text{ where}$$

Cn: the number of F1 progeny appearing in the control; Tn: the number of F1 progeny appearing in the treatment.

Feeding inhibition test

The experiment on the bioactivity of BLFT on the feeding activity of *A. fasciculatus* consisted of seven concentration levels, repeated four times, and arranged in a CRD. The experiment was conducted by infesting 25 pairs of *A. fasciculatus* adults (7–14 days old) in treatment jars containing BLFT according to the treatment and 30 g of Katana 1 peanut. Infestation was carried out according to the exposure period (24, 48, and 72 h). At the end of the exposure period, the infested *A. fasciculatus* was removed and Katana 1 peanut was returned to the treatment jar. Peanuts infested with *A. fasciculatus* eggs were cultured until the F1 progeny appeared. The emerging *A. fasciculatus* F1 progeny were removed and left to remain until no more *A. fasciculatus* adults appeared. Damage seeds were counted at the end of the observation period. The percentage of seed perforation was determined by observing the surface of the seeds with damage in the form of exit holes of *A. fasciculatus* adults and/or holes due to larval excavation. Seeds with one or more holes were considered damaged seeds. The percentage reduction in seed perforation (%SP) was calculated using the equation of Kedia et al. (2015).

$$SP\ (\%) = \frac{(Tb - Nud)}{Tb} \times 100\%, \text{ where}$$

Tb: the number of seeds (damaged and undamaged; Nud: the number of undamaged seeds.

Seed weight loss was calculated at the end of the experiment. The percentage of seed weight loss (%SWL) was calculated using the equation of Kiran & Prakash (2015).

$$SWL\ (\%) = \frac{(Wi - Wf)}{Wi} \times 100\%, \text{ where}$$

Wf: the seed weight after insect damage; Wi: the initial weight before damage.

The weight loss due to feeding activity of *A. fasciculatus* was used to calculate the inhibition of feeding activity of *A. fasciculatus* in Katana 1 peanuts. The feeding deterrence index (%FDI) was calculated using the equation of (Kiran & Prakash 2015).

$$FDI\ (\%) = \frac{(C - T)}{C} \times 100\%, \text{ where}$$

C: the weight of feed loss in the control; T: the weight of feed loss in the treatment.

Statistical analysis

The data normality test was based on the Shapiro-Wilk test, and data that were not normally distributed were transformed. Data on mortality, number of eggs, F1 progeny, OD, FPI, SP, SWL, and FDI of *A. fasciculatus* were analyzed using an arcsine transformation. The data were analyzed using analysis of variance at 5% level of error, followed by the Duncan's multiple range test (DMRT) test at 5% error level for further analyses. Data analysis was performed using R statistical software version 4.2.1 (R Core Team, 2022).

RESULTS

Volatile compound content of bay leaf fumigant tablet

GC-MS analysis showed that BLFT contained major volatile compounds (≥9%) with retention

times of 4.625, 14.845, 21.050, and 35. 087 minutes for α-pinene ($C_{10}H_{16}$), [1,6,10-dodecatrien-3-ol,3,7,11-trimethyl] ($C_{15}H_{26}O$), [2,6,10-trimethyl-14-ethylene-14-pentadecene] ($C_{20}H_{38}$), and geranylgeraniol ($C_{20}H_{34}O$), respectively. Meanwhile, minor volatile compounds (1.5%) contained in BLFT with retention times of 5.532 and 24.640 minutes were beta-myrcene ($C_{10}H_{16}$) and [9-octadecenoic acid (Z)-, methyl ester] ($C_{19}H_{36}O$). The major volatile compounds contained in BLTF belong to the terpenoid compound group (monoterpenoids, diterpenoids, and sesquiterpenoids), whereas the minor volatile compounds belong to the monoterpenoid and ester compound groups.

Bioactivity of bay leaf fumigant tablet on the mortality of *Araecerus fasciculatus* adults

There were significant effects of different concentrations rates of BLFT on the mortality of *A. fasciculatus* adult males and females (Table 1). The experiment showed a consistency results. The concentration rate of 3.75 ml/l air was the most efficient because it effectively killed 100% of both adult males and females of *A. fasciculatus* during exposure time of 24 h, moreover during 48, and 72 h (Table 1).

Bioactivity of bay leaf fumigant tablet on oviposition and F1 progeny inhibition of *Araecerus fasciculatus*

The BLFT was significantly affected on the number of eggs laid by *A. fasciculatus* and oviposition deterrence on seeds of Katana 1 peanut (Table 2). Normal number of eggs laid was observed on control, namely 28.25 eggs/female, then being reduced or oviposition deterrence of 31.52 and 51.01% at concentration rates of 1.25 and 2.5 ml/l air, respectively. There was no egg laid at all on a concentration rate of 3.75 to 7.50 ml/l air. Hence, the concentration rate of 3.75 ml/l air was the effective and most efficient to prevent totally or 100% *A. fasciculatus* to lay eggs.The concentration rates significantly and strongly positively correlated with and affected oviposition deterrence. The simple linear regression and correlation values between concentration rates and oviposition deterrence for 24, 48, 72 h exposure time were P values <0.01, <0.01, <0.01; r = 0.90, 0.90, 0.85 and R^2= 0.81, 0.81, 0.73, respectively.

The F1 progeny is of course determined by the egg production. Effect of the concentration rates was similar to egg production and oviposition deterrence. There were significant effects of different concentrations of BLFT on the number

Table 1. The mean mortality of adult male and female *Araecerus fasciculatus* at various concentrations rates and exposure durations times of of bay leaf fumigant tablet

Exposure time (hours)	Concentrations rates (ml/l air)	Male (%) ($\bar{x}$ ± SD)	Female (%) ($\bar{x}$ ± SD)
24	0	0.00 ± 0.00 d	0.00 ± 0.00 d
	1.25	3.00 ± 3.83 c	7.00 ± 2.00 c
	2.5	8.00 ± 0.00 b	22.00 ± 5.16 b
	3.75	100.00 ± 0.00 a	100.00 ± 0.00 a
	5	100.00 ± 0.00 a	100.00 ± 0.00 a
	6.25	100.00 ± 0.00 a	100.00 ± 0.00 a
	7.5	100.00 ± 0.00 a	100.00 ± 0.00 a
48	0	0.00 ± 0.00 d	0.00 ± 0.00 d
	1.25	7.00 ± 3.83 c	21.00 ± 8.87 c
	2.5	11.00 ± 3.83 b	37.00 ± 7.57 b
	3.75	100.00 ± 0.00 a	100.00 ± 0.00 a
	5	100.00 ± 0.00 a	100.00 ± 0.00 a
	6.25	100.00 ± 0.00 a	100.00 ± 0.00 a
	7.5	100.00 ± 0.00 a	100.00 ± 0.00 a
72	0	0.00 ± 0.00 d	0.00 ± 0.00 d
	1.25	31.00 ± 8.87 c	53.00 ± 15.45 c
	2.5	41.00 ± 14.38 b	90.00 ± 10.07 b
	3.75	100.00 ± 0.00 a	100.00 ± 0.00 a
	5	100.00 ± 0.00 a	100.00 ± 0.00 a
	6.25	100.00 ± 0.00 a	100.00 ± 0.00 a
	7.5	100.00 ± 0.00 a	100.00 ± 0.00 a

The mean at the same column followed by the same letters is not significantly different based on the DMRT test (P < 0.05). Data was transformed into arcsine form for analysis purposes. SD is the standard deviation.

Table 2. The mean number of eggs and oviposition deterrence (OD) of *Araecerus fasciculatus* at various concentrations rates and exposure duration times of bay leaf fumigant tablet

Exposure time (hours)	Concentrations rates (ml/l air)	Number of eggs ($\bar{x}$ ± SD)	OD (%) ($\bar{x}$ ± SD)
24	0	28.25 ± 2.06 a	-
	1.25	19.25 ± 0.96 b	31.52 ± 7.05 c
	2.5	13.75 ± 0.96 c	51.05 ± 5.80 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a
48	0	36.50 ± 6.35 a	-
	1.25	26.25 ± 8.26 b	29.35 ± 10.13 c
	2.5	18.50 ± 5.20 c	50.00 ± 5.79 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a
72	0	77.50 ± 2.08 a	-
	1.25	42.25 ± 3.78 b	45.53 ± 3.87 c
	2.5	17.75 ± 7.68 c	77.22 ± 9.29 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a

The mean at the same column followed by the same letters is not significantly different based on the DMRT test ($P < 0.05$). Data was transformed into arcsine form for analysis purposes. SD is the standard deviation.

and inhibition rate of *A. fasciculatus* F1 progeny within exposure times duration of 24, 48, and 72 hours (Table 3). The highest mean number of F1 progeny of *A. fasciculatus* was at control (13.75 individuals) then reduced significantly approximately 22.59, 45.41, and 100% at concentration of 1.25, 2.50, 3.75 to 7.5 ml/l air for 24 h exposure. The longer the duration of exposure time the smaller F1 progeny and the higher inhibition of F1 progeny. Regression analysis showed a positive relationship between BLFT concentration rates and inhibition of *A. fasciculatus* F1 progeny at exposure times of 24 hours ($R^2 = 0.691$; $P < 0.01$), 48 hours ($R^2 = 0.677$; $P < 0.01$), and 72 hours ($R^2 = 0.645$; $P < 0.01$). In addition, regression analysis showed a positive relationship between the length of exposure time and inhibition of *A. fasciculatus* F1 progeny ($R^2 = 0.847$; $P < 0.01$).

Bioactivity of bay leaf fumigant tablet on feeding activity of *Araecerus fasciculatus*

Feeding activity rate is indicated by seed perforation (SP), seed weight loss (SWL), and feeding deterrence index (FDI). The concentrations rates of BLFT significantly reduced the feeding activity of the weevil on seed of Katana 1 peanut, either on SP, SWL, or FDI within exposure times of 24, 48, and 72 h (Table 4).

The mean percentage of SP and SWL in Katana 1 peanut due to *A. fasciculatus* infestation was the highest at the BLFT concentration rate of 0 ml/l air and both significantly decreased with increasing concentration rates within exposure-time duration of 24, 48, and 72 h until 0% at concentration rate of 3.75 ml/l air. The higher the concentration rates the smaller SP and SWL within all exposure-time durations. In accordance with the correlation analysis, which showed a strong negative relationship between the concentration of BLFT and the percentage of SP and SWL of Katana 1 peanut seeds due to *A. fasciculatus* infestation. Correlations (r) for percentage of SP within exposure time of 24, 48, and 72 h were r = -0.90, r = -0.90 and r = -0.64 with $P < 0.01$). Correlations (r) for percentage of SWL within exposure time of 24, 48, 72 h were r = -0.89, r = -0.82, and r = -0.75 with $P < 0.01$).

Table 3. The mean number of F1 progeny *Araecerus fasciculatus* and inhibition of F1 progeny (FPI) at various concentrations rates and exposure duration times of bay leaf fumigant tablet

Exposure time (hours)	Concentrations rates (ml/l air)	Number F1 progeny ($\bar{x}$ ± SD)	FPI (%) ($\bar{x}$ ± SD)
24	0	13.75 ± 2.87 a	-
	1.25	10.50 ± 1.29 b	22.59 ± 8.33 c
	2.5	7.25 ± 0.96 c	45.41 ± 14.25 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a
48	0	17.25 ± 2.22 a	-
	1.25	10.00 ± 0.82 b	41.59 ± 5.69 c
	2.5	5.00 ± 0.82 c	70.35 ± 7.57 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a
72	0	21.75 ± 0.96 a	-
	1.25	8.25 ± 1.71 b	62.08 ± 7.86 c
	2.5	3.75 ± 0.96 c	82.67 ± 4.84 b
	3.75	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	100.00 ± 0.00 a

The mean at the same column followed by the same letters is not significantly different based on the DMRT test ($P < 0.05$). Data was transformed into arcsine form for analysis purposes. SD is the standard deviation.

The feeding deterrence index of *A. fasciculatus* was 100% at the BLFT concentrations of 3.75; 5; 6.25; and 7.5 ml/l air and significantly higher as compared to 0, 1.25, and 2.5 ml/l air at exposure times of 24, 48, and 72 hours (Table 4). Correlation analysis showed a positive relationship between the concentration of the BLFT and the FDI of *A. fasciculatus*. With exposure time of 24, 48, 72 h were $r = 0.83$, $r = 0.82$,, and $r = 0.82$ with $P < 0.01$). Furthermore, the correlation analysis showed a positive relationship between the exposure time and FDI of *A. fasciculatus* ($r = 0.92$; $P < 0.01$).

DISCUSSION

This study demonstrated that the use of BLFT could cause mortality, inhibit population growth, and reduce the feeding activity of *A. fasciculatus*. Similar results have been reported in previous studies showing that the use of botanical fumigant bay laurel (*Laurus nobilis* (L.) (Lauraceae)) can inhibit oviposition, anti-feeding, and population growth rates (Paparella et al. 2022) and cause mortality at any stage of insect development (Chintalchere et al. 2020; Omar et al. 2023). The bioactivity of BLFT against *A. fasciculatus* is due to the presence of major and minor volatile compounds in the form of terpenoids and esters. It has been widely reported that terpenoid compounds can affect insect enzymes, thus affecting the physiology of insects and causing mortality. Furthermore, Ribeiro et al. (2015) reported that terpenoid compounds are highly volatile compounds that enter the air, are neurotoxic to insects, and inhibit enzyme activity.

The results showed that the concentration of BLFT and duration of exposure were directly proportional to the mortality of *A. fasciculatus* adults. Consistent with previous studies, the increase in insect mortality due to exposure to essential oil fumigants were influenced by an increase in concentration and exposure time (Mishra et al. 2016; Awada et al. 2023). The mortality of *A. fasciculatus* adults may occur because of activity of volatile compounds contained in bay leaves. Plant volatiles in the form of geranylgeranyl (Kumar et al. 2023),

Table 4. The mean seed perforation (SP), seed weight loss (SWL), and feeding deterrence index (FDI) of *Araecerus fasciculatus* at various concentrations rates and exposure duration times of bay leaf fumigant tablet

Exposure time (hours)	Concentrations rates (ml/l air)	SP (%) ($\bar{x}$ ± SD)	SWL (%) ($\bar{x}$ ± SD)	FDI (%) ($\bar{x}$ ± SD)
24	0	57.54 ± 3.93 a	6.68 ± 0.48 a	-
	1.25	49.37 ± 1.62 b	4.21 ± 0.24 b	36.73 ± 06.51 c
	2.5	37.03 ± 4.37 c	2.42 ± 0.56 c	63.34 ± 10.95 b
	3.75	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 00.00 a
	5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 00.00 a
	6.25	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 00.00 a
	7.5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 00.00 a
48	0	68.31 ± 3.51 a	9.61 ± 0.52 a	-
	1.25	44.69 ± 0.72 b	3.84 ± 0.24 b	59.90 ± 3.87 c
	2.5	35.52 ± 1.20 c	1.83 ± 0.13 c	80.90 ± 2.05 b
	3.75	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
72	0	77.89 ± 4.58 a	12.56 ± 2.42 a	-
	1.25	39.76 ± 0.50 b	3.00 ± 0.04 b	75.32 ± 5.39 c
	2.5	30.13 ± 0.48 c	1.72 ± 0.04 c	85.69 ± 3.26 b
	3.75	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	6.25	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a
	7.5	0.00 ± 0.00 d	0.00 ± 0.00 d	100.00 ± 0.00 a

The mean at the same column followed by the same letters is not significantly different based on the DMRT test ($P < 0.05$). Data was transformed into arcsine form for analysis purposes. SD is the standard deviation.

α-pinene (Atay et al. 2023), 1,6,10-dodecatrien-3-ol, 3,7,11-trimethyl, and beta-myrcene (Soliman 2007) have been reported to cause mortality in insects. In addition, this study found that the mortality of *A. fasciculatus* adult females was more sensitive to exposure to BLFT than that of adult males. This was evidenced by the mortality of *A. fasciculatus* adult females being higher than that of adult males at various exposure times to BLFT, namely, 24, 48, and 72 h (Table 1). The higher mortality of *A. fasciculatus* adult females is due to the larger body size, which allows the volatile compounds of the BLFT to enter them more effectively. Kumar & Ray (2022) reported that adult males of *A. fasciculatus* are smaller than adult females. Furthermore, Wagner et al. (2022) reported that a larger body size of the insect (Scarabaeidae) resulted in an increase in the size of the spiracles, thus increasing the oxygen diffusion capacity. Consequently, higher mortality in adult females may reduce mating activity and population growth of *A. fasciculatus*.

The inhibitory activity of the BLFT was evidenced by a decrease in the number of eggs laid by the female, oviposition deterrence, number of F1 progeny, and inhibition of F1 progeny (Table 2). The oviposition deterrence of female *A. fasciculatus* was influenced by the concentration and exposure time of the BLFT. The results showed that the higher the concentration of the BLFT, the higher the oviposition deterrence of *A. fasciculatus* females. Essential oils containing complex compounds, such as of terpenoids (geraniol, pinene, limonene), ketones (menthone), aromatic phenols (thymol, eugenol), acids, and esters can inhibit insect oviposition (Kumar et al. 2022). This is in line with Mishra et al. (2016) who reported that the use of clove (*S. aromaticum* (L.) (Myrtaceae)) essential oil fumigant at a concentration of 18.465 µl/l air was able to inhibit oviposition of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) female by 45.83–69.18% during 24 hours of exposure. In addition, a longer exposure time to BLFT (72 hours) decreased the number of eggs

laid by *A. fasciculatus* females and increased the percentage of oviposition deterrence of *A. fasciculatus* females. This is in agreement with Kiran & Prakash (2015), who reported that fumigation with eastern teaberry (*Gaultheria procumbens* (L.) (Ericaceae)) essential oil for 24 h resulted in decreased fecundity in *R. dominica* and *S. oryzae* adult females. The inhibition of egg laying by *A. fasciculatus* females can also inhibit the emergence of *A. fasciculatus* F1 progeny. The inhibition of the population growth rate of *A. fasciculatus* was influenced by adult mortality, the decrease in the number of eggs successfully laid by females, and the disruption of each developmental stage due to the compound content in the BLFT. This was evidenced by the decrease in the number of F1 progeny and inhibition of the F1 progeny of *A. fasciculatus* (Table 3). Increasing the concentration and exposure time of BLFT resulted in higher inhibition of F1 progeny of *A. fasciculatus.* Ebadollahi & Sendi (2015) reported that α-pinene compounds can inhibit the development at the larval stage, causing a decrease in the emergence of F1 *T. castaneum*. In addition, Salunke et al. (2005) reported that increasing the exposure time of rooster tree (*Calotropis procera* (Ait.) R. Br. (Asclepiadaceae)) fumigant increased the inhibition of F1 progeny of *C. chinensis* by up to 100%.

Inhibition of *A. fasciculatus* feeding activity can affect the percentage of seed perforation and weight loss of Katana 1 peanut seeds owing to the content of volatile compounds from the BLFT. The content of certain plant volatile compounds can act as feeding deterrents for insects (Haider et al. 2015). Application of BLFT can reduce the percentage of perforations in Katana 1 peanut seeds caused by *A. fasciculatus* infestation. The higher the concentration of the BLFT, the lower the percentage of perforation of peanut seeds. Kiran & Prakash (2015) reported that *G. procumbens* fumigant concentrations of 5–150 µl/l could reduce the feeding activity of *R. dominica* and showed protection its seeds. Damage to seeds due to oviposition and the feeding activity of *A. fasciculatus* larvae and adults can cause seed weight loss. The higher the concentration of the BLTF, the lower was the seed weight loss. Kedia et al. (2015) reported that application of cumin (*Cuminum cyminum* (L.) (Apiaceae)) essential oil fumigant at concentrations of 12.5 µl/l air (4%), 25 µl/l air (1%), and 50 and 100 µl/l air (0%) reduced seed weight loss. The lower seed weight loss indicated the inhibition of feeding activity of *A. fasciculatus* by the application of the BLFT. The higher the concentration of the BLFT, the higher was the feeding deterrence index of *A. fasciculatus.* Kiran & Prakash (2015) reported that *G. procumbens* essential oil fumigant resulted in 100% feeding deterrence index for *S. oryzae* and *R. dominica*. In addition to the concentration level, different exposure times to the BLFT also affected the feeding activity of *A. fasciculatus*. The longer the exposure time to the BLFT, the lower the percentage of seed perforation and seed weight loss, and the higher the feeding deterrence index. Awada et al. (2023) reported that the feeding activity of *T. castaneum* decreases with increasing exposure time to *L. nobilis* botanical insecticides. Furthermore, Pandey et al. (2014) reported that the presence of terpenoid compounds inhibits reproduction in Bruchidae by affecting feeding activity, developmental stages, oviposition, and emergence of F1 progeny.

These results highlight the significant potential of botanical fumigants, particularly BLFT, as sustainable and effective alternatives to synthetic chemical fumigants. This study suggests that botanical fumigants could play a key role in integrated pest management by demonstrating high levels of insect mortality, oviposition deterrence, and feeding inhibition in *A. fasciculatus.* Their use not only reduces dependence on harmful synthetic chemicals but also supports environmentally friendly agricultural practices. Further development and application of these botanical fumigants could contribute to more sustainable and safer pest management in the future.

CONCLUSION

The study shows that bay leaf fumigant tablet is an effective botanical insecticide against *A. fasciculatus* and promising to be developed into commercial use. The efficient concentration rate is 3.75 ml/l air. At this concentration rate, within 24 h exposure time the bay leaf fumigant tablet

caused 100% mortality of adult males and females, oviposition deterrence, inhibition of F1 progeny emergence, feeding activity, perforation and weight loss of peanut seed, and feeding deterrence index of the weevil.

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