Research Article

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Controlled delivery of essential oils for the management of rhinoceros beetle (*Oryctes rhinoceros* L.) in coconut

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Abstract

Rhinoceros beetle, *Oryctes rhinoceros* L. (Coleoptera: Scarabaeidae), causes damage to coconut palms by feeding on the unopened fronds affecting photosynthesis. Management measures adopted include use of chemical insecticides and bioagents. Though chemical insecticides are effective, the undesirable effect on human and non-target organisms have led to dependence on botanochemicals for pest management. Essential oils derived from plant parts have the ability to cause desired control on insect pest. The limitation for use at field level is attributed to quick decline in its efficacy due to evaporation and photo degradation. Hence, this study aims to develop a polymer based delivery matrix for the release of essential oils more effectively. Essential oils (citriodora, basil and ajowan) and major constituent thymol, caused growth regulating effect in *O. rhinoceros* at 0.1 per cent. Among the essential oils screened, matrix loaded with basil and citriodora oils were superior with only 18 and 22 per cent incidence of spindle damage, respectively. Pest infestation in the control plots were over 74 per cent. The physical properties of the polymer matrix and dissipation pattern of actives loaded into the sheet were determined. This offers a potential to be incorporated as a component in IPM measures of rhinoceros beetle.

Keywords: Botanochemicals, coconut, controlled delivery matrix, essential oil, pest control, rhinoceros beetle

Introduction

Oryctes rhinoceros L. (Scarabaeidae: Dynastinae) beetle occurs in coconut growing tracts of India (Singh and Rethinam, 2005). The overall incidence of rhinoceros beetle attack in palms in Kasaragod district was assessed to be 8.5 per cent. (Chandran *et al*., 2017). The feeding damage caused by rhinoceros beetle leads to secondary infestation by red palm weevil (*Rhynchophorus ferrugineus*) and bud rot disease caused by *Phytophthora palmivora* (Catley, 1969). Integrated management of rhinoceros beetle involves cultural, mechanical, chemical and biological methods (Sivapragasam and Tey, 1995). Among the integrated pest management (IPM) components, adoption of mechanical methods is labour intensive and time consuming (Nair *et al*., 1997). Increased dependence on chemical leads to buildup of pesticide residue in crop matrix coupled with adverse effect on environment and end users (Abhilash and Singh, 2009). Bio-agents are effective but their timely availability for management is a difficulty in its use. To keep up with the eco-friendly approach, plant derived metabolites like essential oils are an alternative option as they possess broad spectrum activities against pest insects *viz*., cidal, antifeedant, repellent, oviposition deterrent and growth regulatory (Isman, 2006). Active ingredients of botanochemicals interfere with the octopaminergic nervous system in insects (Enan, 2001; Kostyukovsky *et al*., 2002; Price and Berry, 2006). The qualities of botanochemicals mentioned above make them suitable as components in IPM (Enan, 2001). Though botanochemicals are being used in the field, (Isman, 2006), quick

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photodegradation, evaporation and run off from surface (Koul *et al.*, 2008) are big constraints in their use. Hence, developing a matrix for controlled delivery of essential oils would be effective for its use at field level. Plasticizers and stabilizers from polymer matrices have been used for developing controlled release pesticide formulations (Shailaja and Yasin 1995; Dubey *et al.,* 2011). Hence, an attempt was made to develop a suitable polymer based matrix for the delivery of essential oil for management of coconut rhinoceros beetles.

Materials and methods

Insect culture

Adult rhinoceros beetles were collected from ICAR-CPCRI experimental farm and neighbouring field at Kasaragod (Longitude12^{0} 31' 40.06'', Latitude 74^{0} 58' 06.99''), Kerala. The beetles were reared on coconut petioles of West Coast Tall cultivar (20 cm length and 3 to 4 cm width) placed in a poly propylene plastic jars (1000 mL). Ten pairs of adult males and females were kept in these jars and maintained at 27 ^{0}± 0.5 ^{0}C. The fresh petioles were replaced as feed once in 4 days.

Growth regulatory effect of essential oil on adult beetles

Essential oils (ajowan oil, basil oil, citriodora oil and thymol) were procured from Southern Spice Industries, Madurai. The oils were diluted in dichloromethane to obtain various concentrations. Neem oil, procured from local market in Kasaragod, was used for comparison. Coconut petioles (WCT) (size 20×2.5 cm) were smeared with varying concentration of essential oils and placed in 1000 mL Tarsons® polypropylene container. Ten beetles (female) of 10 days old were weighed individually and introduced into separate containers having treated petioles. The treated petioles were replaced daily. The beetles were weighed ten days after starting the experiment. Each treatment was replicated four times.

Preparation of polymer delivery matrix for controlled delivery of essential oil

To prepare the polymer matrix sheets, 20 mL of distilled water was heated in a 100 mL beaker at 135 ^{0}C in Tarson's Spinot digital magnetic stirrer with hot plate. Four gram of polyvinyl alcohol (PVA) (Sigma-Aldrich®) was added into this. The content was mixed using a magnetic stirrer maintained at 780 rpm. Five gram polyvinyl pyrrolidone (PVP) (Sigma-Aldrich®) was added gently to this mixture. This mixture was heated till a clear solution was obtained without clumps. In one case, activated charcoal (1 mg) was added to the mixture to check if it improved the binding capacity of the chemical insecticides. This mixture was brought to bearable warmth prior to addition of essential oil, neem oil/chlorpyriphos along with 1 mL of Triton-X. After thorough mixing, 5 mL polymer matrix with active ingredients were transferred to a clean disposable Petri-dish and kept at room temperature 27 ± 0.5 ^{0}C for cooling. Upon cooling the oil/chlorpyriphos entrapped sheets were stored in airtight containers till use.

Mechanical and physical characterization of controlled delivery polymer matrix

The polymer sheets were subjected to tensile test, thermogravimetric analysis (TGA) and hydrophilicity test for determining the mechanical strength and physical characteristics. In addition to this, Fourier Transform Infrared Spectroscopy (FTIR) was also done to analyse chemical properties of the polymer film.

Tensile test

Tensile test was conducted using ASTM D-638 Computerized Universal Testing Machine (UTM) at a loading rate of 500 mm min^{-1}. The dimension of the tested specimen strip was 100 mm x 10 mm x 1 mm. The tensile strength of composite samples of three replications were made.

Hydrophilicity test

The hydrophilicity tests were done for the following: polymer sheet, polymer sheet + charcoal, citriodora oil and chlorpyriphos. Dry weight of these polymer sheets was measured prior to dipping the sheet into deionized water (10 mL). The sheets were placed in water for pre-determined time. Following this, the wet weight of each sheet were recorded at different time intervals (12 h, 24 h and 48 h). All the treatments were triplicated.

Thermo gravimetric analysis

Thermo gravimetric analysis was carried out to study the thermal stability of polymer matrices using a Toledo 850TGA. Measurements were conducted in the temperature ranging from 30 to 800 ^{0}C under oxygen atmosphere. The temperature ramp used was 10 ^{0}C min^{-1}.

ATR Fourier Transform Infrared (FT-IR) spectroscopy of polymer matrix

Attenuated total reflection Fourier-transform infrared spectroscopy (ATR-FT-IR) was used for the identification of functional groups present in polymer matrices. A Perkin Elmer Premium HATR instrument with germanium (Ge) crystal was used to acquire the FT-IR spectra. All the samples were dried properly before subjected to the measurements.

Fumigant toxicity of phytoncides on adult rhinoceros beetle

Twenty µL of varied doses of essential oil applied on Whatmann filter paper (3 cm dia) were placed in the lid of glass bottle (100 mL) with piece of adhesive tape. The glass bottles were maintained in air tight condition. This setup was assembled prior to start of the experiment. Newly emerged adult rhinoceros beetle of three day old (both sexes) were starved for 24 hours and placed individually in glass bottles (100 mL) containing the essential oils loaded in filter paper. Per cent mortality of the beetles were recorded after 24 hours of starting the test.

In another experiment, the essential oils, loaded into the polymer sheets (method described below), were placed in the container and the mortality of beetles exposed to vapors of essential oil was observed after 24 hours starting the test.

Dissipation pattern of essential oils loaded in controlled delivery matrix

The dissipation of the essential oils loaded in polymer matrix was estimated by gravimetric method. Essential oil loaded polymer matrix sheets were placed in oven at 50 °C. The airflow of the oven was maintained at 0.5 lit min^{-1} to avoid saturation of the chamber with volatiles. The sheets were weighed in precision balance (Precisa®-Swiss made) at 30 minutes intervals up to 270 minutes and percentage reduction in weight was calculated. This was compared with dissipation of essential oils that were placed on glass cavities (without any dispensers). One mL of the essential oil was placed in clean glass plate and placed in the oven with air flow with the same parameters mentioned above and the weight loss was determined at 30 min interval for 270 minutes by gravimetric method.

Field evaluation to assess efficacy of essential oil loaded in polymer matrix

Effect of essential oils and neem oil loaded in polymer matrix, in warding off leaf damage caused by rhinoceros beetle on coconut palms, was assessed. Eight year old Chowghat Orange Dwarf palms, raised on littoral sandy soils in Beach Block of ICAR-CPCRI, Kasaragod were used for the study during 2014-2015. Pre-treatment observations on the number of leaves and spindle damaged were made in December 2014. The polymer matrix loaded with essential oil (0.5%)/chlorpyriphos (0.05%) were placed in leaf axil of the palms and were replaced at 30 days interval. Neem oil treated palms were used as positive check. The per cent leaf and spindle damage was observed after six months. The experiment was laid out in completely randomized design (CRD) with three replications of seven palms each. Control palms did not receive any treatment.

Results and discussion

Growth regulatory effect of essential oil on adult beetles

Observations on weight loss of adult beetles fed on fresh coconut petioles smeared with essential oils and neem oil were made after 10 days of continuous exposure to treated food. Among the oils, citriodora, ajowan oil and thymol caused weight loss in rhinoceros beetles ranging from 11.75 to 14.26 per cent and were at par. Basil oil was on par with neem oil in causing weight loss. Essential oils have variety of volatile compounds with diverse bio-action on insects (Maciel *et al.,* 2010). They possess diverse bio-action on insects (repellents, growth regulator and cidal). The compounds in essential oil are perceived by olfactory and gustatory receptors. Food substrates treated with essential oil deter the insect which lead to growth regulating effect. Citridora and ajowan oil, with thymol as its major constituent, caused reduction in weight in beetles when exposed to coconut petioles treated with these oils. Several reports highlighted the impact of terpenoids on insects includes impaired maturation growth inhibition, appetite suppression, poor reproductive capacity, (Elmhalli *et al.,* 2009) and death of predator insects by starvation or direct toxicity (D'Incao *et al.,* 2013).

Table 1. Effect of essential oils on growth of *O. rhinoceros*

Essential oils	Weight loss in beetle (%)
Citriodora oil	14.26[a]
Thymol	11.75[a]
Ajowan oil	13.57[a]
Basil oil	5.10[b]
Neem oil	3.07[b]

According to DMRT, means with same alphabet do not differ significantly by p=0.05

Mechanical and physical characterization of polymer matrix

Tensile test

The tensile test was done to determine the mechanical strength of the polymer film loaded with citriodora oil (citriodora was selected as a representative sample for essential oils) and chlorpyriphos (chlorpyriphos was selected as chlordust was recommended @ 5 g palm^{-1} for rhinoceros beetle management). Ultimate modulus indicates the stiffness of the matrix resistance to tearing. Pure PVA and PVP sheet has a Young's modulus ranging from 30 to 40 MPa. All the doses of citriodora oil (0.25, 0.5 and 1.0) had ultimate modulus ranging from 23.53 to 35.85. This clearly shows low modulus values are resistant to tearing. In case of chemical insecticide chlorpyriphos, the modulus values were between 25 and 38. At higher concentrations of 3 mL sheet^{-1}, the values were above 50 per cent. It shows that the controlled delivery polymer matrix is strong enough (Table 2) (load cell used:50 KN; loading rate:500 mm min^{-1}).

An ultimate modulus of 25 to 45 (MPa) is ideal for a good quality polymer material. Hence, the tested material is suitable as a delivery matrix.

Hydrophilicity test

The water uptake test was conducted to study the swelling effects on the stability of the composite films. All of the composite films showed significant water uptake with an increase in the weight within 24 hour. No further swelling (or water uptake) was observed up to 48 hours. Water uptake and subsequent swelling did not cause any structural damage in composite films. This confirms that the film loaded with pesticides or botanochemicals is a suitable candidate for field applications even under rain conditions.

Thermo-gravimetric analysis

Thermo-gravimetric analysis (TGA) is a method in which the mass of a sample is measured over time as a function of temperature. This is done to assess the capacity of the polymer to hold essential oil and insecticide.

The synthesized polymer (PVA) films undergo two step degradation processes. At 100 ^{0}C, minimum 3.6 per cent and maximum 4.7 per cent weight loss was logged for PVA-citriodora and PVA-charcoal-chlorpyriphos, respectively (Fig. 1). This can be attributed to elimination of moisture present in the films. It is clear that the synthesized polymer films were stable and did not show any significant weight loss till 200 °C. However, the weight loss began above 200 °C; maximum 39 per cent and minimum 18.81 per cent weight loss was recorded at 250 ^{0} C for

Table 2. Mechanical strength of polymer matrix loaded with essential oil and insecticide

Polymer matrix type with active ingredients	Tensile strength at peak load (Nmm^{-2})	Per cent elongation at break	Ultimate modulus (Mpa)
Polymer film with citriodora oil 0.25%	27.74	1463.1	35.85
Polymer film with citriodora oil 0.5%	15.24	1188.8	23.53
Polymer film with citriodora oil 1.0%	11.90	1184.5	32.35
Polymer film with chloropyriphos 1 mL	18.56	1048.6	25.66
Polymer film with chloropyriphos 2 mL	24.08	985.4	38.54
Polymer film with chloropyriphos 3 mL	24.28	985.1	54.22

All the test parameters are average of three replications polymer-charcoal-chlorpyriphos and polymer-citriodora respectively, indicating the loss of organic molecules of insecticide and essential oil from the corresponding films. It was noticed that from 250 ^{0}C to 450 ^{0}C, there was an instantaneous weight loss of around 40-72 per cent, beyond which it was gradual. This reveals that the thermal breakdown of the main chains of both amorphous and crystalline regions of polymer films occurs in this range of temperature. Maximum wt. loss > 85 per cent was recorded at T_{max}. However, pure oils and chlorpyriphos degraded quickly within 200 ^{0}C.

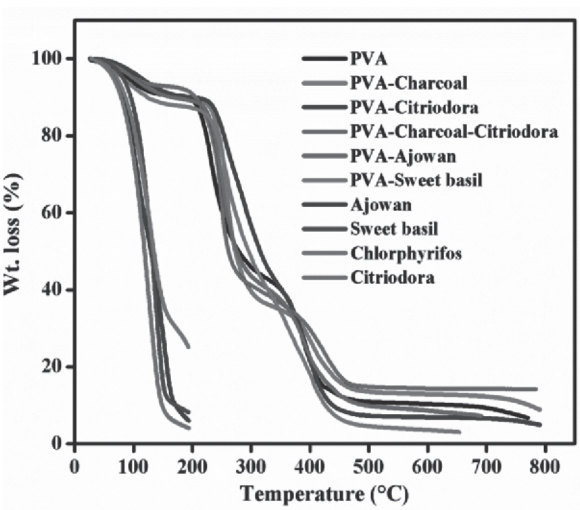

Fig. 1. TGA of polymer matrix for delivery of essential oils and insecticide

ATR Fourier Transform Infrared (FT-IR) Spectroscopy of polymer matrix:

Samples of polymer matrices loaded with essential oils *viz.,* citriodora oil, was tested using Fourier-transform infrared spectroscopy for identification of the functional groups present in the polymer matrix (Fig. 2). The additional peaks present in essential oil loaded polymer PVA films compared to blank polymer PVA shows the successful loading of essential oil to the polymer matrix (Table 1). Similarly, the PVA-charcoal loaded with chlorphyriphos also showed additional peaks compared to blank PVA-charcoal films indicating the successful loading of chlorphyriphos (Fig. 3).

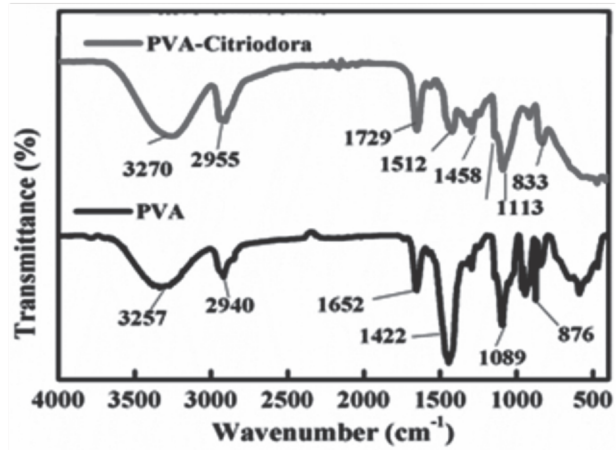

Fig. 2. FTIR spectra of PVA based essential oil delivery films

Table 3. List of peaks present in the FT-IR spectrum of respective polymer matrix and corresponding functional groups

Polymer matrix with PVA alone

3257/3264 cm^{-1}: OH stretching (hydroxyl group)

2940 cm^{-1}: C-H asymmetric stretching

1652/1653 cm^{-1}: C=O Carbonyl stretch

1420/1422cm^{-1}: C-H bending of CH_2

1376/1377 cm^{-1}: C-H deformation vibration

1088/1087 cm^{-1}: C-O Stretching of acetyl groups

844/834 cm^{-1}: C=C stretching vibration

Polymer matrix with PVA – Charcoal

3257/3264 cm^{-1}: OH stretching (hydroxyl group)

2940 cm^{-1}: C-H asymmetric stretching

1652/1653 cm^{-1}: C=O Carbonyl stretch

1420/1422 cm^{-1}:C-H bending of CH_2

1376/1377 cm^{-1}: C-H deformation vibration

1088/1087 cm^{-1}: C-O Stretching of acetyl groups

844/834 cm^{-1}: C=C stretching vibration

PVA+ citriodora

3270 cm^{-1}: OH stretch

2955 cm^{-1}: C-H stretch alkane

1729 cm^{-1}: C=O stretch

1512 cm^{-1}: C=C bending

1458 cm^{-1}: C-C stretching of aromatic rings

1113 cm^{-1}: C-N stretching (aliphatic amine)

833 cm^{-1}: C-H bending

PVA+ charcoal + chlorpyriphos

3461 cm^{-1}: OH stretching (hydroxyl group)

2934 cm^{-1}: C-H asymmetric stretching

1549 cm^{-1}: P = S

1411 cm^{-1}: C = C Stretching

1336 cm^{-1}: C-H deformation vibration

1025 cm^{-1}: C-O stretching

967 cm^{-1}: = C-H bend (alkene group)

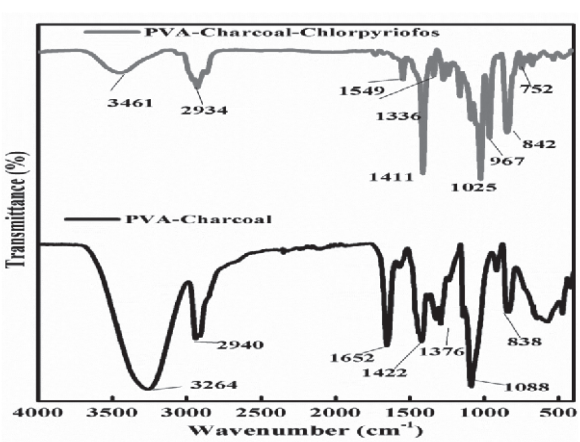

Fig. 3. FT-IR spectra of PVA-charcoal and PVA-charcoal-chlorphyriphos

Dissipation of essential oil from controlled delivery matrix

Dissipation pattern shows that essential oils, when used as such without loading into a dispenser, dissipate quickly as compared to it being loaded in a dispenser. Essential oil trapped in polymer delivery matrix is released in a controlled manner. In the case of basil oil, when the sheets were subjected to temperature at 100 °C, the dissipation was less than 8.2 per cent for the first 30 minutes and 13.6 per cent in 270 minutes. Whereas, more than 75 per cent was lost in the first 30 minutes and over 97 per cent was lost in 270 minutes when basil oil was exposed as such. In case of the citriodora oil, the dissipation was higher as compared to basil oil. The dissipation from citriodora dispenser ranged from 6.9 per cent at 30 minutes and 9.05 per cent at 270 minutes and when citriodora oil was exposed as such, 81 per cent was lost in first 30 min and over 95.5 per cent was lost in 270 minutes. In all the essential oils tested, the dissipation rate was much low, when compared to oils exposed as such. The dissipation studies indicate that essential oil entrapped polymer matrix offers an appropriate dispensing mechanism for controlled delivery (Fig. 4 a-d). Compounds present in essential oils are of low molecular weight and have high vapour pressure. This is a major reason for their quick dissipation when applied in field condition. Polymers loaded with essential oils have ability to hold the volatile compounds and release them slowly when exposed to open conditions. The polymer matrix developed by us is a membrane-moderated monolithic system in which the botanochemicals or pesticides are dispersed or dissolved. Membrane moderated monolithic system do not have the zero-order release kinetics. The actives are first released from the surface layers of a monolithic device followed by those which are embedded deep and the time required for them to diffuse to reach the surface increases with time (Lewis and Cowsar, 1977).

Fumigant toxicity of essential oils to adult rhinoceros beetle

The toxicity of essential oils to adult rhinoceros beetle was done in two methods *viz*., essential oil loaded in (a) filter paper and (b) loaded in polymer matrix. In both the methods, the mean per cent mortality recorded for citrodora, basil and ajowan oil at 6 per cent caused mortality of over 96 per cent and was at par. At these levels of dose, toxicity caused by both the methods was above 97 per cent. This clearly brings out the information that there is no difference in the quantum of chemicals released from both matrices at a given point of time in causing mortality to the beetles. Similar trends were observed in the lower doses loaded in two

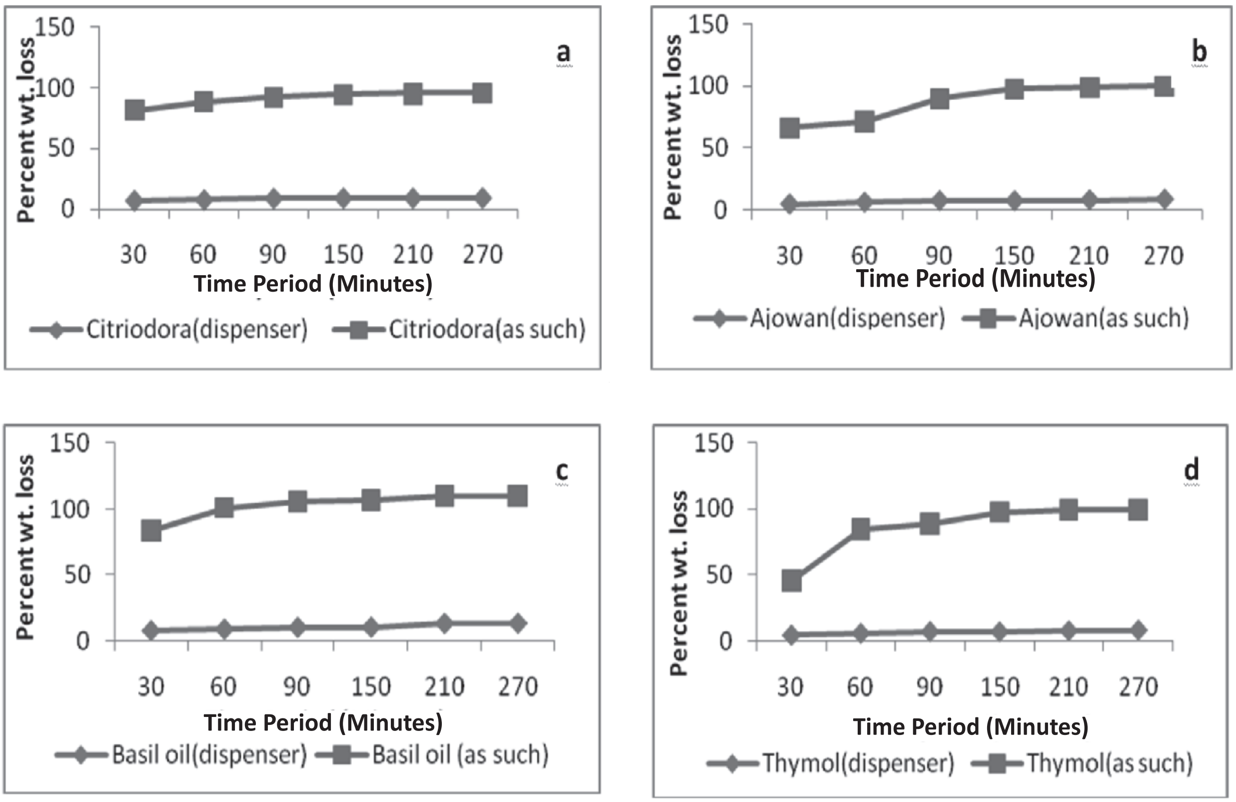

Fig. 4. Dissipation pattern of essential oil entrapped matrix against oil as such a. citriodora oil, b. ajowan oil, c. basil oil and d. thymol

Table 4. Fumigant toxicity of essential oils to adult *O. rhinoceros* beetles

Essential oil	Per cent mortality					
	Oils loaded in filter paper			Oils loaded in polymer matrix		
	2%	4%	6%	2%	4%	6%
Citriodora	72.5 (58.44)^{de}	72.5 (58.44)^{de}	100 (85.93)^{a}	70 (57.09)^{de}	90 (71.56)^{bc}	97.5 (82.34)^{a}
Basil	72.5 (58.44)^{de}	90 (71.56)^{bc}	100 (85.93)^{a}	67.5 (55.28)^{def}	87.5 (69.52)^{c}	97.5 (82.34)^{a}
Ajowan	67.5 (55.43)^{e}	92.5 (75.15)^{b}	100 (85.93)^{a}	72.5 (58.44)^{de}	87.5 (71.09)^{bc}	100 (85.93)^{a}
Thymol	52.5 (46.44)^{f}	82.5 (65.46)^{cd}	92.5 (75.15)^{b}	55 (47.88)^{fg}	80 (63.80)^{cd}	95 (78.74)^{ab}
Neem	35 (35.78)^{g}	45 (42.11)^{fg}	70 (57.09)^{e}	32.5 (33.96)^{h}	47.5 (43.55)^{g}	65 (53.77)^{ef}
Control		0 (4.05)^{h}			0 (4.05)^{I}	
CV(%)		8.56			10.18	
SE(d)		3.70			4.31	
LSD at 5%		7.44			8.67	

According to DMRT, means with same alphabet does not differ significantly by p=0.05

different matrices. Neem oil at 6 per cent caused a mortality of 65-70 per cent (Table 4). This indicates that the release of essential oils loaded in polymer matrix was sufficient to cause fumigant toxicity to beetles (Table 4).

On fumigant toxicity, basil oil, containing linalool and methyl chavicol, is highly toxic and is on par with citriodora oil. Though basil oil is effective, the limitations of using it in field is due to higher content of methyl chaviocol (estragole) that has undesirable effect on human health. Fractionating the estragole from basil oil would make it fit to be used in pest management. The effect of fumigant toxicity of essential oils has been described earlier. The monoterpene limonene demonstrated insecticidal activity by penetrating the cuticle of the insect (contact effect), by respiration (fumigant effect) and through the digestive system (ingestion effect) (Pratesa *et al.,* 1998). *Ocimum suave* was reported to have strong inhibiting effect on coleopterans, *Sitophilus granaries* and *Prostephanus truncates* (Obeng-Ofori and Reichmuth, 1997). As fumigants, essential oils of anise *(Pimpinella ansium)*, cumin *(Cuminum cyminum)*, eucalyptus *(Eucalyptus camaldulensis)* and oregano *(Origanum syriacum* var. bevanii) were effective against *Aphis gossypii* and the carmine spider mite *(Tetranychus cinnabarinus)*, two greenhouse pests (Tuni and Sahinkaya, 1998).

Field evaluation on efficacy of essential oil and insecticide entrapped matrix

Essential oil trapped in polymer sheets, when placed in leaf axil of the palms, were effective in warding off the beetles from feeding on the unopened spindle leaf. Among the oils, basil oil caused lowest level of damage (18.9%) followed by citriodora, thymol, and ajowan oils that were at par ranging from 22 to 23 per cent. The differences in the damaged leaves in control palms (74.29%) as compared to treated palms are significant. Analysis of variance shows that, there is significant difference in spindle damage in the palms treated with essential oil dispenser and control. Further, multiple comparisons were carried out and the results presented in Table 5 below reveals that basil oil and citriodora oil resulted in 18.3 per cent and 22.3 per cent spindle damage only whereas in control treatment 74.3 per cent.

Table 5. Per cent incidence of spindle damage

Essential oil	Spindle leaf damage (%)
Basil oil	18.09[a]
Citriodora	22.33[b]
Ajowan	23.81[b]
Thymol	23.81[b]
Neem oil	32.79[c]
Control	74.29[d]

Secondary metabolites derived from Lamiaceae possess insecticidal property against storage, domestic and field crop pests. *Ocimum gratissimum* L. oil and its constituents have repellent and fumigant action against many storage pests (Kim *et al.*, 2003; Ogendo *et al.*, 2008)

Chlorpyriphos is a recommended insecticide for management of rhinoceros beetle. A comparison was made to assess applying chlorpyriphos as spray and placing the polymer matrix sheet loaded with chlorpyriphos during June 2013. Placing the controlled delivery polymer matrix loaded with chlorpyiphos was effective and superior to direct spray of insecticide during monsoon period. The mean percentage spindle damage on palms given direct spray of insecticide near spindle leaf region on recommended dose was 52.4 per cent where as that of insecticide applied through placing polymer matrix near spindle leaf was 28.5 per cent only during monsoon season (Fig. 5).

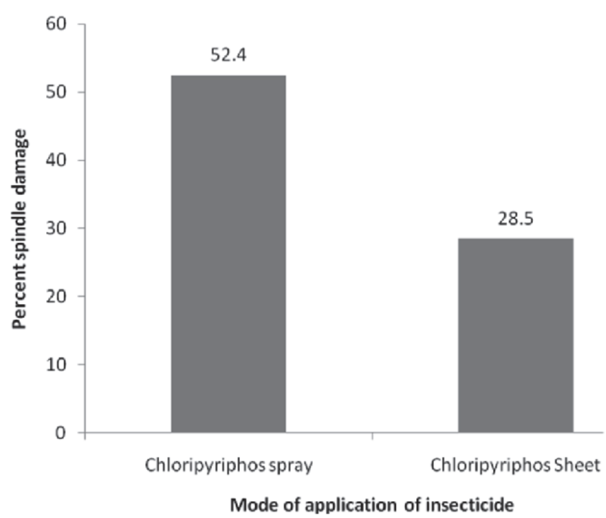

Fig. 5. Comparative efficacy of chlorpyriphos spray and entrapped matrix

The statistical analysis of data using t test shows a ‘t’ value of 2.22 (significantly different at 5 % level of significance). Proportion of infested palms for direct spray is 0.524 and control delivery polymer matrix is 0.285.

Polymers extruded to films and nets are used for controlling the release of pesticides. Polymer latex particles are also used as carriers of pesticides to control the rate of release. Use of polymer matrix to load the essential oils and insecticide and then placed in coconut leaf axils gave extended protection as compared to applying oils or insecticides in leaf axils that was washed away by rains during monsoon as there is around 2000 mm that is received during a span of 3-4 months. The tensile strength of the polymer sheets makes it ideal to load the bio-actives to be used in coconut ecosystem. The advantage of controlled-release matrix is that they allow lower level of pesticide to be used for the same period of activity. Application of pesticides by conventional methods, leads to leaching, evaporation and degradation, which results in reduction of actives in target area. However, the biopolymers are highly prone to enzymatic chain breakdown by microorganisms. In such a scenario natural polymers (agar, starches, alginates, pectins and cellulose derivatives), in combination with synthetic biodegradable polymers like polycaprolactone, polylactide and polyvinyl alchol are the ideal alternative (Briassoulis, 2004).

The dissipation pattern of actives loaded in polymer matrix is much slower when it is exposed without a dispenser suggest that polymer sheets are a good matrix for loading bioactive compounds for pest management. This offers a potential to be incorporated as a component in IPM measures of rhinoceros beetle.

Polymers are being widely used in agricultural applications like controlled release of pesticides and other active ingredients minimizing environmental hazards to a great extent. Microcapsules with chlorpyriphos cores and polyurea walls having advantage of long term thermal stability (Roy *et al.*, 2014). The advantage of controlled-release matrix is that they permit less pesticide to be used for the same period of activity. This is also beneficial at a time when the normal half-life of a potent pesticide is short. When botanochemicals or pesticides are applied by conventional methods like spraying, botanochemicals or pesticides are subject to leaching, evaporation, and degradation by photolytic, hydrolytic and microbial. This is a cause for removal of active materials from point of application before they can perform their function.

Conclusion

Essential oil *viz.*, citriodora, basil, ajowan and its constituent have growth regulating and cidal effect on *O. rhinoceros*. Polymer matrix developed is a good platform to load the essential oils and insecticide for controlled release. It has good tensile strength and hydrophilicity and this is essential for maintaining the integrity of the matrix that is loaded with essential oil or pesticide. This facilitates the use of essential oil in polymer matrix during monsoon period also for management of *O. rhinoceros* a period when the incidence of the beetle is high. Using of polymer matrix for delivery of essential oil and pesticide in leaf axils of coconut palms will be a complementing method with IPM measures for management of rhinoceros beetle.

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