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RESEARCH ARTICLE

Plant essential oils for the management of pulse beetle, *Callosobruchus chinensis* L. in stored chickpea

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Abstract

One of the primary pests of stored chickpeas causing qualitative and quantitative loss is *Callosobruchus chinensis* L., causing about 50 - 60% of seed weight loss and 45.5 - 66.3% of protein content loss. Residual hazards caused by continuous and injudicious use of synthetic chemicals can result in several health-related problems for humans and animals. In stored chickpea to protect against severe losses and human health hazards, biorational management of the pulse beetle is undertaken, focusing briefly on biology. Using plant-derived essential oils to control pulse beetle in stored chickpeas is an efficient tactic with fewer toxicity hazards for natural enemies and non-target organisms over the field. The following experiment was conducted and studied in the Department of Entomology, College of Agriculture, Odisha University of Agriculture and Technology (OUAT), Bhubaneshwar, Odisha, during 2018 - 2021. The results showed that the essential oils as grain protectants when tested on chickpea seeds, showed the superior performance of citronella and neem oil (5 mL/kg of seeds). These oils completely protected the seeds from pest infestation for up to 4 months and significantly reduced the pest build-up without affecting seed germination. Further study may contribute to Integrated pest management (IPM) practices and may also enrich the use of plant essential oils in further management of pests, excluding harmful chemical practices.

Keywords

arrange; bio-rationals; *Callosobruchus chinensis* L.; essential oils; grain protectants; indiscriminate

Introduction

In developing countries like India, pulses occupy a unique position, signifying 20% of the total area under food grain production and 7-10% of total food grain production (1, 2). The lack of proper storage facilities is a leading constraint contributing to 25 - 50% of post-harvest losses (3, 4). In the case of stored chickpeas, a major destructive pest having wide distribution around different pulse crops is Pulse beetle *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) (5, 6). It is referred to as a pest of the field to store as its severity of infestation and damage often initiates from the field, as the adult lays eggs on mature pods (7-9). It is assumed that a rapid expansion in its population, with significant economic loss within 3 - 4 months, is often observed after contaminated seeds are harvested and stored (10). Pre-reviewed information on the pest revealed that the development, growth, fecundity and ovipositional preference are

comparatively higher and more suitable in chickpeas than in other pulses (11). The grubs completely ingest the endosperm, leaving only an outer thin seed coat, making it unfit for human consumption. Both the grubs and adult stages are considered to have potential damage to the crop. The continuous and excessive misuse of synthetic pesticides has had detrimental effects on storage, leading to pesticide resistance and serious deficiencies. This misuse has also resulted in biodiversity loss and secondary pest outbreaks. Residual toxicity from these pesticides may also pose serious human health hazards (12). Consequently, biorational, non-chemical and environmentally friendly approaches have been adopted for storage insect pest management and are regarded as a significant improvement and alternative (13). Among such biorational approaches, plant oils have proven effective in adequately managing the pests. Additionally, a lesser toxicity effect is observed when used as seeds and for consumption.

Materials and Methods

Management of pulse beetle in chickpea by using essential oils

The study investigated the efficacy of plant essential oils as ovicidal and insecticidal agents against *Callosobruchus chinensis* and was carried out in the laboratory conditions of the Department of Entomology, College of Agriculture, OUAT, Bhubaneswar. The experiments were conducted in a completely randomized design (CRD) with 12 treatments comprising 11 plant essential oils, each at 5 mL/kg of seed concentration. These seeds were evaluated and treated for their ovicidal and insecticidal activity. Simultaneously, one untreated control was taken and replicated thrice. The essential oils were collected from the All India Coordinated Research Project (AICRP) on Medicinal and Aromatic Plants, OUAT and the Central Institute of Medicinal and Aromatic Plants, Lucknow. Plant-based oils like basil (*Ocimum basilicum* L.) (14), castor (*Ricinus communis* L.) (15), citronella (*Cymbopogon citratus* L.) (16), clove (*Syzygium aromaticum* (L.) (17), coconut (*Cocos nucifera* L.) (18), eucalyptus (*Eucalyptus globulus* L.) (19), karanja (*Pongamia pinnata* L.) (20), mustard (*Brassica juncea* L.) (21), neem (*Azadirachta indica* A.), sesamum (*Sesamum indicum* L.) (22) and soybean (*Glycine max*) (15) were used against the insect individually. These oils were extracted with the help of the soxhlet apparatus and were used without further dilution. Chickpea genotype JG 16 seeds were heat sterilized at 50 ^{0}C for 1 h in a YORCO® hot air oven to eliminate pre-existing pathogens. Sterilized seeds of about 100 g were kept in a 500 g sterilized glass jar. Each oil treatment was mixed thoroughly with 100 g of chickpea seeds by shaking well manually for 4-5 min to ensure that the oil was spread uniformly on all the seed surfaces and then replicated thrice. In this jar, about 5 pairs of freshly emerged adults of *C. chinensis* were released in the M:F ratio of 1:1. The Bruchids were reared on the seeds of the chickpea and the mother culture was maintained in the laboratory conditions. The control group consisted of the seeds that were not treated. The opening of these rearing jars used for the division of the pulse beetle was wrapped with muslin cloth and secured with a rubber band. To evaluate the impact of these plant-based essential oils on adult mortality rates and lifespans, pulse beetle was released on the treated chickpea seeds at 5 mL per kg of seed and was recorded at 1, 2, 3, 4 and 5 days after release. The total number of adults that emerged and the total number of eggs released by the pulse beetle following storage were recorded manually using a hand magnifier of 10x power at intervals of 30 days, i.e., at 30, 60, 90 and 120 days. The percentage of seeds germinating in each treatment was evaluated using the paper method and was recorded (23). The data were statistically assessed using factorial CRD with suitable transformations and the analysis was carried out using R software.

Results and Discussion

Efficacy of plant essential oils on the adult mortality of Callosobruchus chinensis L.

Significant variations were observed in the adult mortality percentage of test insects exposed to chickpeas treated with plant essential oils. After 24 hr of exposure to the essential oils, the highest mortality (46.67%) was obtained with neem oil at 5 mL/kg after the same concentration of citronella oil and eucalyptus oil (36.33% and 33.33% respectively). All the treatments except castor oil at 5 mL/kg were revealed to be superior to control (Table 1). After 48 hr, maximum mortality (63.67%) showed up in neem oil at 5 mL/kg, followed by the same concentration of citronella and eucalyptus oil (53.33% and 51.67%, respectively) which were at par. In contrast, the

Table 1. Efficacy of essential oils on adult mortality (%) of *C. chinensis* L

Treatments	Dosages (mL/kg of seeds)	Adult mortality (%)					
		After 24 hr	After 48 hr	After 72 hr	After 96 hr	After 120 hr	Overall mean
T_1- Citronella oil	5.0	36.33 (37.01)	53.33 (46.90)	66.67 (54.79)	80.00 (63.38)	90.00 (71.62)	65.27 (53.90)
T_2-Basil oil	5.0	26.67 (31.13)	46.67 (43.08)	63.00 (52.56)	76.33 (60.81)	90.00 (71.62)	60.53 (51.08)
T_3-Clove oil	5.0	20.00 (26.55)	36.67 (37.30)	43.33 (41.14)	63.33 (52.75)	80.00 (63.38)	48.67 (44.27)
T_4-Castor oil	5.0	0.00 (0.00)	23.33 (28.82)	42.00 (40.39)	56.00 (48.42)	66.33 (54.49)	37.53 (37.73)
T_5-Karanja oil	5.0	23.33 (28.88)	36.33 (37.01)	46.67 (43.08)	70.00 (56.82)	86.67 (68.59)	52.60 (46.47)
T_6-Mustard oil	5.0	16.00 (23.58)	33.33 (35.24)	43.33 (41.15)	56.67 (48.85)	76.67 (61.16)	45.20 (42.22)
T_7-Soybean oil	5.0	10.00 (18.43)	26.67 (31.13)	33.33 (35.24)	50.00 (44.99)	76.67 (61.16)	39.33 (38.83)
T_8-Sesamum oil	5.0	16.67 (24.14)	33.33 (35.24)	41.67 (40.24)	60.00 (50.71)	70.00 (56.82)	44.33 (41.76)
T_9-Eucalyptus oil	5.0	33.33 (35.24)	51.67 (45.97)	60.33 (50.99)	76.67 (61.16)	93.00 (74.58)	63.00 (52.56)
T_{10} - Coconut oil	5.0	13.33 (21.41)	30.00 (33.23)	40.33 (39.42)	53.33 (46.90)	70.00 (56.82)	41.47 (40.09)
T_{11} - Neem oil	5.0	46.67 (43.08)	63.67 (52.94)	76.33 (60.81)	88.33 (70.05)	100.00 (90.00)	75.00 (60.00)
Control	-	**0.00 (0.00)**	**0.00 (0.00)**	**0.00 (0.00)**	**0.00 (0.00)**	**0.00 (0.00)**	**0.00 (0.00)**
SE(m) ±	-	**0.989**	**1.413**	**1.791**	**2.233**	**2.666**	**1.824**
CD (p=0.05)	-	**2.90**	**4.14**	**5.25**	**6.55**	**7.82**	**5.35**

Figures in parentheses are angular transformed values

least mortality was seen in castor oil at 5 mL/kg (23.33%), followed by soyabean oil at 5 mL/kg (26.67%). Yet, all treatment options were found to be more effective to control. A similar trend was observed even after 72 and 96 hr of treatment, where neem oil (5 mL/kg) showed the highest level of effectiveness and afforded a cent percent mortality after 120 hr. However, from the overall mean data, the highest total mortality was seen in neem oil (75.00%), followed by citronella oil (65.27%) and eucalyptus oil (63.00%) at 5 mL/kg and the lowest in castor oil (37.53%) at 5 mL/kg (Table 1). All the essential oil treatments were found to be significantly superior to control. The superiority of neem oil and citronella oil over other plant oils tested in the study (24) causes 100% mortality of *C. chinensis.* Meanwhile, studies reported that neem oil, castor oil and *Mentha* oil had more adult mortality in the case of pulse beetle (25, 26).

Impact of plant essential oils on the oviposition of Callosobruchus chinensis L.

In the present study, the repellent action of essential oils on egg hatching and oviposition deterrent activity is assessed and estimated. The test insect's fecundity varied significantly between treatments when exposed to chickpea seeds infused with plant oils (Table 2). After 30 days of treatment, the neem oil at 5 mL/kg proved quite effective and did not allow the pulse beetle to lay eggs as against 63.00 eggs recorded in the control. Likewise, citronella oil at a concentration of 5 mL/kg could reduce the fecundity of pulse beetle to 1.67 eggs. Castor oil has been demonstrated to be the least effective, resulting in more egg laying (9.00 eggs) at the concentration of 5 mL/kg of seed. After 60 days of treatment, the lowest fecundity was observed with neem oil (1.67 at 5 mL/kg), which was at par with citronella oil (3.33) of the same concentration.

In contrast, the highest fecundity was noticed in castor oil (20.33 eggs at 5 mL/kg). Following treatments for 90 and 120 days, neem oil-treated seeds had the lowest number of eggs at 5 mL/kg (4.33 eggs and 7.67 eggs, respectively), whereas the maximum egg laying was noticed on castor oil at 5 mL/kg (33.67 and 45.00 eggs, respectively). The effect of numerous essential oils such as mustard, karanja, sunflower, oil palm, neem and coconut oils affecting the fecundity of *C. chinensis* in green gram and concluded that Karanja and neem among all the taken treatments after 60, 90 and 120 days showed relevant results (26-28). The smallest number of eggs per 50 seeds was noted, along with comparable outcomes. Subsequently, no harmful effect on the seeds was noticed in the case of germination. The application of plant essential oil did not have any such prominent impact on the germination of the chickpea seeds. It only inhibited the egg-laying activity of *C. chinensis* and was proved efficient.

Impact of plant essential oils on the adult emergence of Callosobruchus chinensis L.

After being treated for 30 days with neem and citronella oils, no adult emergence was seen in the chickpea seeds. Castor oil at 5 mL/kg was the least effective, resulting in 7.00 adult emergence. All the treatments were superior to the control, where 51.33 adults emerged (Table 3). After 60 days of

Table 2. Efficacy of essential oils on fecundity of *C. chinensis* L. on chickpea seeds

Treatments	Dosages (mL/kg of seeds)	Fecundity of *C. chinensis* (Number of eggs laid/female)				
		30 DAT	60 DAT	90 DAT	120 DAT	Overall mean
T_1- Citronella oil	5.0	1.67 (1.29)	3.33 (1.82)	5.00 (2.24)	9.33 (3.05)	3.87 (1.97)
T_2-Basil oil	5.0	2.67 (1.63)	5.33 (2.30)	11.67 (3.41)	16.00 (4.00)	8.92 (2.98)
T_3-Clove oil	5.0	3.00 (1.73)	9.67 (3.10)	14.00 (3.74)	21.33 (4.61)	12.00 (3.46)
T_4-Castor oil	5.0	9.00 (3.00)	20.33 (4.50)	33.67 (5.80)	45.00 (6.70)	27.00 (5.19)
T_5-Karanja oil	5.0	2.67 (1.63)	7.67 (2.76)	13.33 (3.65)	19.00 (4.35)	10.67 (3.26)
T_6-Mustard oil	5.0	3.33 (1.82)	12.33 (3.51)	19.00 (4.35)	28.67 (5.35)	15.83 (3.97)
T_7-Soybean oil	5.0	6.67 (2.58)	21.33 (4.61)	31.00 (5.56)	40.67 (6.37)	24.92 (4.99)
T_8-Sesamum oil	5.0	4.00 (2.00)	13.67 (3.69)	21.33 (4.61)	31.67 (5.62)	17.67 (4.20)
T_9-Eucalyptus oil	5.0	2.33 (1.52)	4.67 (2.16)	9.33 (3.05)	12.00 (3.46)	7.08 (2.66)
T_{10} - Coconut oil	5.0	6.33 (2.51)	15.00 (3.87)	27.67 (5.26)	35.33 (5.94)	21.08 (4.59)
T_{11} - Neem oil	5.0	0.00 (1.00)	1.67 (1.29)	4.33 (2.08)	7.67 (2.76)	3.42 (1.84)
Control	**-**	**63.00 (7.93)**	**87.67 (9.36)**	**112.67 (10.61)**	**127.33 (11.28)**	**97.67 (9.88)**
SE(m) ±	**-**	**0.748**	**1.051**	**1.344**	**1.591**	**1.184**
CD (p=0.05)	**-**	**2.19**	**3.08**	**3.94**	**4.67**	**3.47**

Figures in parentheses are square root transformed values DAT: Days after treatment

Table 3. Efficacy of essential oils on adult emergence of *C. chinensis* L. on chickpea seeds

Treatments	Dosages (mL/kg of seeds)	Number of adults emerged				
		30 DAT	60 DAT	90 DAT	120 DAT	Overall mean
T_1- Citronella oil	5.0	0.00 (1.00)	1.00 (1.00)	3.67 (1.91)	7.00 (2.64)	2.92 (1.70)
T_2-Basil oil	5.0	2.00 (1.41)	5.33 (2.30)	9.00 (3.00)	10.67 (3.26)	6.75 (2.59)
T_3-Clove oil	5.0	2.33 (1.52)	9.33 (3.05)	13.00 (3.60)	16.67 (4.08)	10.33(3.21)
T_4-Castor oil	5.0	7.00 (2.64)	22.67 (4.76)	29.33 (5.41)	31.33 (5.59)	22.58 (4.75)
T_5-Karanja oil	5.0	2.33 (1.52)	5.67 (2.38)	10.33 (3.21)	13.00 (3.60)	7.83 (2.79)
T_6-Mustard oil	5.0	2.67 (1.63)	11.33 (3.36)	15.00 (3.87)	18.67 (4.32)	11.92 (3.45)
T_7-Soybean oil	5.0	5.67 (2.38)	18.33 (4.28)	25.00 (5.00)	29.33 (5.41)	19.58 (4.42)
T_8-Sesamum oil	5.0	3.00 (1.73)	13.33 (3.65)	17.67 (4.20)	19.00 (4.35)	13.25 (3.64)
T_9-Eucalyptus oil	5.0	1.00 (1.00)	4.00 (2.00)	5.33 (2.30)	9.67 (3.10)	5.00 (2.23)
T_{10} - Coconut oil	5.0	4.33 (2.08)	13.33 (3.65)	18.67 (4.32)	25.00 (5.00)	15.33 (3.91)
T_{11} - Neem oil	5.0	0.00 (1.00)	1.33 (1.15)	2.67 (1.63)	6.00 (2.44)	2.50 (1.58)
Control	**-**	**51.33 (7.16)**	**72.00 (8.48)**	**91.67 (9.57)**	**106.33 (10.31)**	**80.33 (8.96)**
SE(m) ±	**-**	**0.640**	**0.931**	**1.142**	**1.299**	**1.004**
CD (p=0.05)	**-**	**1.88**	**2.73**	**3.35**	**3.81**	**2.95**

Figures in parentheses are square root transformed values DAT: Days after treatment

treatment, neem oil remained the most effective treatment, where the minimum number of adults had emerged (1.33). Maximum adults were observed with castor oil at 5 mL/ kg (22.67). After 90 days of treatment, neem oil at 5 mL/kg recorded the lowest number of adult emergence (2.67 adults), which was superior to all other essential oil treatments, while a large number of adults developed from castor oil (29.33 adults at 5 mL/kg). The same trend continued after 120 days of treatment, where neem and citronella oil were the most potent and at par. Castor oil recorded the maximum adult emergence at 5 mL/kg (31.67 adults). The overall mean data revealed that every one of the essential oil treatments was substantially better compared to an untreated control group where 80.33 adults emerged. Neem oil at 5 mL/ kg is the most effective treatment in preventing adult emergence, which recorded 2.50 adults. In contrast, 5 mL/kg castor oil was the least effective treatment, registering 22.58 adult emergence. It was also reported that neem, sesamum and soybean oil at 5 mL/kg of seed could be determined as an excellent substitute for managing *C. chinensis* L. when storing mungbean and other pulses (29-34).

Impact of plant essential oils on seed damage due to infestation of Callosobruchus chinensis L.

The data generated on the impact of essential oils on chickpea seed damage inflicted by *C. chinensis* is described in Table 4. The results indicated the best performance of neem oil over other essential oils. Neem oil and citronella oil at 5 mL/kg provided complete protection against damage for the first 30 days after treatments (DAT) and were significantly superior to other treatments. Castor oil at 5 mL/kg proved to be the least efficient, which recorded 8.62% of seed damage and soybean oil at the same concentration (6.00%). The seed damage with basil oil treatment at 5 mL/kg (2.43%) was at the same level as eucalyptus oil at 5 mL/kg (2.37%). The untreated control recorded 33.74% seed damage. The seed damage after 60 DAT was the highest with castor oil at 5 mL/ kg (14.35%), whereas it was the lowest with the neem oil at 5 mL/kg (1.00 %), which was at par with citronella oil at 5 mL/ kg (1.37%). As compared to 54.63% damage in the control group, seed damage in the remaining treatments ranged from 3.32 to 14.35%. After 90 days of treatment, maximum seed damage was noticed with soybean oil (19.62%) at 5 mL/ kg, which was at par with castor oil (21.73%) at the same concentration. The minimum seed damage was recorded with 5 mL/kg of neem oil (2.33%) followed by the same concentration of citronella oil (3.44%), matching eucalyptus oil's effectiveness at 5 mL/kg (5.76%). It was discovered that every essential oil treatment was substantially better than the control, where the damage was 71.68%. A similar trend was witnessed after 120 days of treatment. Though none of the treatments imparted complete protection against pulse beetle infestation, the essential oils effectively reduced the damage due to bruchid infestation. The highest seed damage was found with 5 mL/kg castor oil (26.52%) and soybean oil (25.75%), whereas the lowest damage was noticed with neem oil at 5mL/kg (5.79%), which was at par with citronella oil at 5 mL/kg (6.86%). Seed damage varied from 7.68 to 19.08% in the remaining treatments, compared to 88.00% in the untreated control. A significant reduction in oviposition seed infection inhibited adult emergence. It diminished the weight of chickpea seeds following the application of various essential oils including sesame, neem, karanja and castor at concentrations of 4.0 to 8.0 mL/kg (35, 36). It is also revealed that minimum infestation and seed damage by bruchid with neem oil treatment also found that citronella, eucalyptus and neem oil treatments proved to be the most effective treatment (37).

Effect of plant essential oils on weight loss due to C. chinensis L. infestation

The data on the reduction in weight of chickpea seeds caused by the infestation of *C. chinensis* is outlined in Table 5. According to the results obtained on the percent weight loss caused by the infestation of *C. chinensis* after 30 days of treatment, the seeds administered with neem oil and citronella oil at a concentration of 5 mL/kg of seeds did not show any weight loss. Throughout the remaining treatments, weight loss ranged from 1.67% to 5.78%, while the highest weight loss of 23.38% was recorded in the control. After 60 days of treatment, the minimum weight loss of 1.00% was observed in neem oil treatment at 5 mL/kg of seeds. Citronella oil applied at 5 mL/kg of seeds registered 1.37% weight loss. In the remaining treatments, the weight loss spanned from 2.15 and 11.65%. The untreated control recorded 32.44% weight loss. The lowest percent weight loss was observed with neem oil treatment at 5 mL/kg (1.32%) after 90 days of treatment. The percent weight loss of 2.48%, 3.78%, 4.75% and 5.35% was recorded with 5 mL/kg of citronella oil, eucalyptus oil, basil oil and karanja oil respectively and these were similar to one another. Castor oil (5mL/kg) achieved the highest weight loss (15.00%). Weight

Table 4. Effect of essential oils on seed damage (%) due to *C. chinensis* L. infestation

Treatments	Dosages (mL/kg of seeds)	Seed damage (%)				
		30 DAT	60 DAT	90 DAT	120 DAT	Overall mean
T_1- Citronella oil	5.0	0.00 (0.00)	1.37 (6.78)	3.44 (10.60)	6.86 (15.25)	2.91 (9.79)
T_2-Basil oil	5.0	2.43 (8.92)	3.32 (10.49)	7.29 (15.66)	10.00 (18.43)	5.76 (13.95)
T_3-Clove oil	5.0	4.38 (12.12)	6.53 (14.77)	9.00 (17.46)	11.45 (19.82)	7.84 (16.20)
T_4-Castor oil	5.0	8.62 (17.04)	14.35 (22.27)	21.73 (27.77)	26.52 (31.00)	17.81 (24.96)
T_5-Karanja oil	5.0	3.89 (11.36)	5.56 (13.71)	8.86 (17.34)	7.68 (16.08)	6.50 (14.77)
T_6-Mustard oil	5.0	4.78 (12.65)	8.35 (16.86)	10.27 (18.72)	14.64 (22.46)	9.51 (17.94)
T_7-Soybean oil	5.0	6.00 (14.18)	11.58 (19.94)	19.62 (26.30)	25.75 (30.53)	15.74 (23.33)
T_8-Sesamum oil	5.0	4.96 (12.94)	9.30 (17.76)	11.24 (19.57)	16.88 (24.27)	10.60 (19.03)
T_9-Eucalyptus oil	5.0	2.37 (8.92)	3.56 (10.95)	5.76 (13.95)	7.98 (16.44)	4.91 (12.77)
T_{10} - Coconut oil	5.0	5.22 (13.18)	10.84 (19.21)	14.85 (22.70)	19.08 (25.91)	12.50 (20.73)
T_{11} - Neem oil	5.0	0.00 (0.00)	1.00 (5.74)	2.33 (8.74)	5.79 (13.94)	2.28 (8.74)
Control	-	**33.74 (35.52)**	**54.63 (47.65)**	**71.68 (57.89)**	**88.00 (69.72)**	**61.51 (51.63)**
SE(m) ±	-	**0.543**	**0.754**	**0.939**	**1.115**	**0.837**
CD (p=0.05)	-	**1.59**	**2.21**	**2.75**	**3.27**	**2.45**

Figures in parentheses are angular transformed values DAT: Days after treatment

Table 5. Effect of essential oils on weight loss (%) due to *C. chinensis* L. infestation

Treatments	Dosages (mL/kg of seeds)	Weight loss (%)				
		30 DAT	60 DAT	90 DAT	120 DAT	Overall mean
T_1- Citronella oil	5.0	0.00 (0.00)	1.37 (6.78)	2.48 (9.09)	3.58 (10.95)	1.88 (7.93)
T_2-Basil oil	5.0	1.67 (7.47)	3.02 (9.96)	4.75 (12.65)	6.23 (14.42)	3.91' (11.36)
T_3-Clove oil	5.0	3.06 (10.14)	5.11 (13.01)	6.72 (15.01)	8.39 (16.86)	5.82 (13.95)
T_4-Castor oil	5.0	5.78 (13.95)	11.65 (20.00)	15.00 (22.77)	17.05 (24.46)	12.37 (20.61)
T_5-Karanja oil	5.0	2.48 (9.09)	4.22 (11.83)	5.35 (13.41)	6.00 (14.18)	4.51 (12.24)
T_6-Mustard oil	5.0	3.75 (11.24)	5.48 (13.59)	8.86 (13.34)	10.22 (18.60)	7.08 (15.43)
T_7-Soybean oil	5.0	5.27 (13.30)	9.07 (17.58)	13.01 (21.16)	14.92 (22.71)	10.57 (19.03)
T_8-Sesamum oil	5.0	4.28 (11.95)	6.32 (14.54)	9.19 (17.64)	11.57 (19.94)	7.84 (16.20)
T_9-Eucalyptus oil	5.0	1.40 (6.78)	2.15 (8.51)	3.78 (11.24)	4.66 (12.53)	2.99 (9.96)
T_{10} - Coconut oil	5.0	5.17 (13.18)	8.23 (16.62)	11.20 (19.57)	12.54 (20.67)	9.28 (17.76)
T_{11} - Neem oil	5.0	0.00 (0.00)	1.00 (5.74)	1.32 (6.55)	2.68 (9.44)	1.25 (6.55)
Control	-	**23.38 (28.95)**	**32.44 (34.68)**	**46.77 (43.16)**	**58.64 (50.00)**	**40.31 (39.42)**
SE(m) ±	-	**0.462**	**0.582**	**0.715**	**0.819**	**0.647**
CD (p=0.05)	-	**1.35**	**1.71**	**2.10**	**2.40**	**1.90**

Figures in parentheses are angular transformed values DAT: Days after treatment

loss in the other treatments ranged between 6.72% to 13.01%. Every oil treatment was significantly greater than the control (46.77%). Following treatment for 120 days, the percent weight loss of the chickpea seeds infested by *C. chinensis* ranged from 2.68 to 17.05%. The highest weight loss was observed with castor oil (5 mL/kg), whereas the lowest was with neem oil at the same concentration. The untreated control exhibited 58.64% weight loss in chickpea seeds (38).

Effect of plant essential oils on germination of chickpea seeds

The results obtained from the present study on the germination of chickpea seeds after 30 days of treatment highlighted that the highest percent germination was observed in citronella oil at 5 mL/kg (87.00%), which was significantly higher than in other treatments (Table 6) whereas, the lowest germination among the treatments was noticed in castor oil (78.33% at 5 mL/kg). Neem oil and eucalyptus oil also recorded a high germination rate of 86.33% and 85.00%, respectively. Each essential oil treatment was substantially higher than the untreated control, where 70.00% germination was recorded. After 60 days of storage, the highest germination was recorded in 5 mL/kg citronella oil-treated chickpea (85.33%), followed by neem oil at the same concentration (84.67%). Seeds treated with eucalyptus oil also performed well at a concentration of 5 mL/kg of seed (83.33%). After 90 days of treatment, the germination was the highest in 5 mL/kg of citronella oil treatment (80.67 %), at comparable levels with neem and eucalyptus oil.

In contrast, 5 mL/kg castor oil registered the lowest germination (71.67%) among the treatments. All the essential oil treatments were substantially greater than the untreated control, which indicated 60.67% germination. A similar trend also continued after 120 days, where the citronella oil at a concentration of 5 mL/kg resulted in a good percentage of germination (72.33%). The overall mean data revealed that the standard germination ranged from 72.00 to 81.33% among the different oil treatments. Maximum standard germination in chickpea seeds was found by treating citronella oil at 5 mL/kg. In comparison, the minimum was reported when seeds received treatment with castor oil at 5 mL/kg compared to control (62.58%). Studies reported the same as our findings that the viability of seeds administered with botanical oils was not affected, nor did it have a major impact on seed germination (39).

Conclusion

In the present situation, due to the indiscriminate and injudicious use of chemical pesticides, leaving residues may have adverse conditions on human health and the diversity of natural enemies. It may also raise serious concerns about sustainability. The efficacy of different essential oils of medicinal plants viz., citronella, basil, clove, castor, karanja, mustard, soybean, sesamum, eucalyptus, coconut and neem were tested against pulse beetle at the concentration of 5 mL/kg of seeds. Treatments with citronella and neem oil at 5 mL/kg of seeds were superior to other plant oils. These oils completely protected the seeds from pest infestation for up to

Table 6. Effect of essential oils on germination (%) of chickpea at different storage intervals

Treatments	Dosages (mL/kg of seeds)	Germination (%)				
		30 DAT	60 DAT	90 DAT	120 DAT	Overall mean
T_1- Citronella oil	5.0	87.00 (9.33)	85.33 (9.24)	80.67 (8.98)	72.33 (8.50)	81.33 (9.02)
T_2-Basil oil	5.0	83.33 (9.13)	82.00 (9.06)	77.33 (8.79)	69.00 (8.31)	77.91 (8.83)
T_3-Clove oil	5.0	82.00 (9.06)	79.67 (8.93)	75.33 (8.68)	66.67 (8.16)	75.92 (8.71)
T_4-Castor oil	5.0	78.33 (8.85)	76.00 (8.71)	71.67 (8.47)	62.00 (7.87)	72. 00 (8.49)
T_5-Karanja oil	5.0	82.67 (9.09)	81.00 (9.00)	76.67 (8.76)	68.00 (8.25)	77.09 (8.78)
T_6-Mustard oil	5.0	81.00 (9.00)	78.33 (8.85)	74.67 (8.64)	66.67 (8.17)	75.17 (8.67)
T_7-Soybean oil	5.0	79.00 (8.89)	76.67 (8.76)	72.67 (8.52)	63.33 (7.99)	72.91 (8.54)
T_8-Sesamum oil	5.0	81.00 (9.00)	78.00 (8.83)	74.67 (8.64)	65.67 (8.10)	74.84 (8.65)
T_9-Eucalyptus oil	5.0	85.00 (9.22)	83.33 (9.13)	77.67 (8.81)	70.67 (8.41)	79.17 (8.90)
T_{10} - Coconut oil	5.0	80.00 (8.94)	77.33 (8.79)	74.00 (8.60	64.67 (8.04)	74.00 (8.60)
T_{11} - Neem oil	5.0	86.33 (9.29)	84.67 (9.20)	79.00 (8.89)	71.33 (8.45)	80.33 (8.96)
Control	-	**70.00 (8.37)**	**65.33 (8.08)**	**60.67 (7.79)**	**54.33 (7.37)**	**62.58 (7.91)**
SE(m) ±	-	**2.756**	**2.687**	**2.511**	**2.303**	**2.575**
CD (p=0.05)	-	**8.08**	**7.88**	**7.36**	**6.75**	**7.55**

Figures in parentheses are square root transformed values

4 months and significantly reduced the pest build-up without affecting germination. Therefore, seed treatment with essential oils of citronella and neem can be chosen as promising alternatives against pulse beetle in storage.

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Authors' contributions

TK, PRM, SNS and SP conceptualized the work. TK, SNS, SP, SSM and CKP wrote the manuscript. TK, SNS and CKP participated in data Analysis. SNS, SP, CKP, PB, SM and KKB edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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