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AKADÉMIAI KIADÓ

Pulse beetle, *Callosobruchus spp.* (Coleoptera: Chrysomelidae); a major threat in legume grain storage and their management

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REVIEW ARTICLE

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ABSTRACT

Pulse beetle, *Callosobruchus spp.* are the major threat in legume grain (pulse) storage. They are very prolific and rapid in breeding and increasing their population within short period of time. Its infestation starts either in the field on the maturing pod and is carried to the stores with the harvested crops or it originates in the storage itself. If appropriate management is not adopted, then it can damage 100% of stored pulses within few months of storage. On an average they cause 5–10% pulse crop losses in the temperate and 20–30% in the tropical countries during storage. Here this article is intended to discuss their distribution, host plants, life cycle, damage symptoms, ecology, economic impact and their management by recent and effective techniques.

KEYWORDS

Callosobruchus spp., cold plasma, essential oil, identification, legume grain

Throughout the world, pulse crops (grain legumes) are the second most important crops after cereals. Globally, 840 million people are under as well as malnourished due to inadequate intake of proteins, vitamins and minerals in their diets. Pulses are excellent sources of proteins (20–40%), carbohydrates (50–60%) and are fairly good sources of vitamins and minerals

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(Bhalla et al., 2008). They are cultivated in rainfed agriculture mainly in the semi-arid tropical and subtropical countries commonly either as a sole crop or intercropped with other crops. One of the major constraints in production of pulses is the insect pests which inflict severe losses both in the field and storage. In India, over 200 species of insects have been recorded infesting various pulses (CABI, 2007). Unfortunately, in storage, pulses suffer enormous losses due to pulse beetle attack, which infestation starts either in the field on the maturing pod and is carried to the stores with the harvested crops or it originates in the storage itself (Nahdy et al., 1999; Kedia et al., 2013). Most common pulse beetle species infesting pulses are *Callosobruchus chinensis* Linn and *Callosobruchus maculatus* Fab (Eker et al., 2018) although there are almost 20 different species of *Callosobruchus* genus present in the world (Tuda et al., 2005). These pulse beetles have the ability to damage 100% of stored pulses within few months of storage (Pruthi and Singh, 1950; Gbaye et al., 2011). On an average they cause 5–10% pulse crop losses in the temperate and 20–30% in the tropical countries during storage (Lal and Verma, 2007; Kiradoo and Srivastava, 2010). Many literatures are available regarding their importance and management in laboratories (Kedia et al., 2015; Negahban et al., 2006; Kiran et al., 2017; Babarinde et al., 2017; Jayaram et al., 2022) but little is available regarding their overview as well as recent techniques for their management in storage. For this, this article is intended to discuss various aspects of their distribution, host plants, life cycle, damage symptoms, ecology, economic impact and their management.

DISTRIBUTION

C. chinensis is originated from Asia whereas *C. maculatus* is originated from Africa but currently both are present in throughout the World but mostly prevalent in the tropical and sub-tropical countries (Tuda et al., 2005; Beck and Blumer, 2014).

IDENTIFICATION

Total body length of *C. maculatus* is 4–6 mm and oval in shape, dorsum with mixed white, yellow or orange brown and brown pubescence, dense on pronotum and elytra. Large brown patches present at the apex of elytra. Pygidium present. Their eggs are small (0.6 mm) and white in colour. The larvae are cream-coloured small maggots and rarely seen on pulse crop as they feed within the seed. Pupa is also white in color. In both species, antennae have nine segmented flagellomeres. The male and female of *C. maculatus* (normal or flightless morph) can be differentiated by the plate's colour at the abdomen's end. In case of female, the plate is large and black colour on the sides with a white longitudinal line, but in the male, plate is small as well as lack in such white strip (Beck and Blumer, 2014). Antennae of female and male *C. maculatus* are serrate in shape (Hu et al., 2009). Caswell (1960) reported the presence of two forms of *C. maculatus* in environment i.e., active or flight form and inactive or normal or flightless form. Both forms are differing with both external and internal characters. In case of external feature, besides well-defined black areas in elytra in both forms, active form has thick golden and white pubescence in other areas of elytra whereas, in the normal form the pubescence is much reduced making the elytral pattern less definite. Similarly, in the active form the pygidium also covered with dense pale golden pubescence. Whereas, adult *C. chinensis* are brownish in colour, small, 2.4–3.2 mm in total length, generally square in shape, pygidium covered with white or silver setae and hind femora have a pair of parallel ridges on the ventral edge, each with an apical spine. The male and female of *C. chinensis* can be distinguished by their antennae. In case of male, antennae pectinate, curved towards each other and apical segment is elongate and oblong in shape. Pectination becomes prominent from the 4th segment onwards. Whereas in the female, antennae serrate, straight and apical segment is round or ovate in shape. Serration becomes prominent from the 5th segment onwards (Shiau et al., 1994).

HOST PLANTS

The cowpea weevil, *C. maculatus* is a major pest of economically important leguminous grains, such as cowpeas; *Vigna unguiculata* L., lentils; *Lens culinaris* Medik., green gram; *Vigna radiata* L., black gram; *Vigna mungo* L., red gram; *Cajanus cajan* (L.) Millsp. and other pulse grains in tropical and subtropical countries (Tuda et al., 2005). *C. chinensis* also known as adzuki bean weevil is a major pest of chickpeas; *Cicer arietinum* L., lentils, green gram, red gram, broad beans, soybean; *Glycine max* Mer., adzuki bean; *Vigna angularis* (Willd) ohwi & H. Ohashi, common bean; *Phaseolus vulgaris* L., cowpeas and other pulses in various tropical and subtropical regions (Modgil and Mehta, 1996; Kedia et al., 2013).

LIFE CYCLE

Due to their (both *C. chinensis* and *C. maculatus*) very similar lifestyle and habitat, their identities are often mistaken for each other (Kyogoku and Nishida, 2013). In normal form, females of both the species lay about 60–104 eggs on the seeds surface in stored pulses (Caswell, 1960; Sharma et al., 2007). The incubation period is 4–6 days on different pulses whereas larval developmental varies from 12 to 20 days. Pupal period is almost 7–10 days. Adult longevity varies from 7 to 20 days on different pulse seeds. The average duration of life cycle varied significantly range from 30 to 50 days on different pulses (Sharma et al., 2007; Hosamani et al., 2018; Omar and Mahmoud, 2020). These species complete 7–8 generations in a year (Sharma et al., 2007; Jaiswal et al., 2018). The emerging larvae immediately enter the pods to feed; several larvae may occur within the same seed. The threshold temperature for development of *C. chinensis* is 7 °C and it takes 562 degree-days for completion of a generation (Omar and Mahmoud, 2020). Adult beetles do not feed on stored product, and are very short-lived, usually not more than 12 days under optimum conditions (Sharma et al., 2007). The adults become sexually mature after 24–48 h of emergence (Beck and Blumer, 2014). But, the active or flight form of *C. maculatus* has a longer pre-adult stage as well as almost double duration life cycle than has the normal form. It was observed that on dissection, female abdominal cavity was filled with reproductive organs in the flightless form, the ovary developed completely and each ovariole contained fully developed eggs. On the contrary, the abdominal cavity of the flight form was mainly filled with fat body. The ovary did not develop, and contained only a small number of undeveloped eggs (Caswell, 1960; Utida, 1981). In optimum condition, females lay many eggs (*C. chinensis* >100), although oviposition may be reduced in the presence of previously infested seeds (Jaiswal et al., 2018). It was observed that the optimum temperature range for oviposition is high in *C. maculatus*, about 30–35 °C and low in *C. chinensis*, about 25–30 °C (Kim and Choi, 1987; Lale and Vidal, 2003; Omar and Mahmoud, 2020). As the eggs are laid, they are firmly glued to the surface of the host seed, smooth-seeded varieties being more suitable for oviposition than rough-seeded varieties (Lema, 1994). The eggs are domed structures with oval, flat bases. When newly laid they are small, translucent grey and inconspicuous. After hatching, the larva bites through the base of the egg, through the testa of the seed and into the cotyledons. The developing larva feeds entirely within a single seed, excavating a chamber as it grows. Larvae have four larval instars before enter into pupation stage. The optimum development conditions for *C. maculatus* and *C. chinensis* is around 32 °C and 90% RH (Omar and Mahmoud, 2020).

DAMAGE SYMPTOMS

In the early stages of attack the only symptoms are the presence of eggs cemented to the surface of the pulses. As development occurs entirely within the seed, the immature stages are not normally visible. At this time, seeds may be almost completely hollowed out by their feeding (Neog, 2012). Then, adults emerge through windows in the grain, leaving round holes that are the main evidence of damage (Fig. 1) (Messina and Jones, 2009).

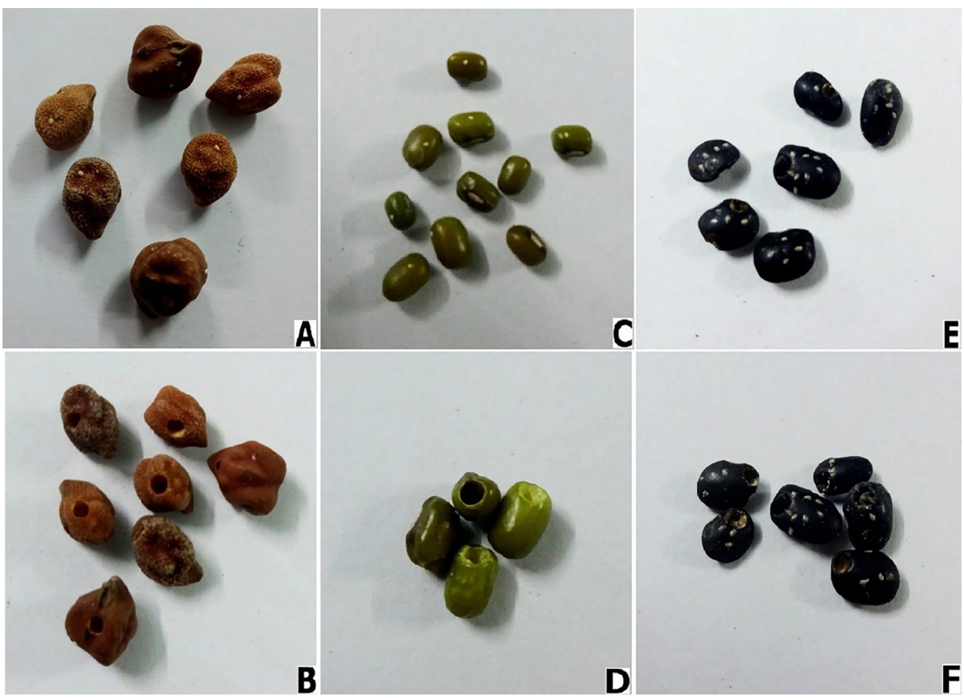

Fig. 1. A & B; *Callosobruchus chinensis* eggs and damage symptoms on chickpea C& D; *C. maculatus* eggs and damage symptoms on mungbean E & F; *C. chinensis* eggs and damage symptoms on horse gram

ECOLOGY

Both *C. chinensis* and *C. maculatus* are tropical species and their breeding stops at temperatures below 20 °C. For this, they are not visible in winter months but after 3–4 months when temperature increases their population reach at a highest level within a short period of time (Beck and Blumer, 2014). Another factor for their higher population (survival rate usually ≥90%) is due to the absence of potential predators and parasitoids in storage or if present it is difficult for them to penetrate stored pulses (Islam, 1994). Lale and Vidal (2003) evaluated four temperatures (25, 30, 35 and 40 °C) and three humid levels (30, 60 and 90% RH) for their effect on oviposition and development of *C. maculatus* on bambara groundnut, *Vigna subterranean* where temperature had significant influence on oviposition than humidity. Egg-laying and progeny development was optimal at 35 °C. Female of *C. chinensis* generally lays single egg per seed but even laid maximum number of 9 eggs per seed in horse gram, *Macrotyloma unifloram*. The number of eggs deposited by a female is varies with different pulses as well as different varieties and mainly depends on the chemical composition, seed coat hardness or thickness and texture of the seeds (Kosini et al., 2018; Eker et al., 2018). It is observed that chickpea cultivars with hairy and highly rough seed coat and dark-brown color or black were less preferred by the pulse beetle than the smooth, plumpy and light color seeds (Eker et al., 2018). Likewise, varieties with high protein content and presence of linoleic acid were less preferred by the pulse beetle (Athie-pacheco et al., 1994; Eker et al., 2018). As mentioned before, they show polyphenism characters i.e., production of more than one adult morphs in their life cycle in response to changes in ecological condition (Messina, 1990). So, two different adult morphs evolved at different times; a flightless or inactive or normal form and a flight or active form (Caswell, 1960; Utida, 1981; Nahdy et al., 1999; Zannou et al., 2003). The adults of flight morph which are less sexually active mainly evolved for adaptation to field infestation during the rainy season (high humidity and low temperature condition) and lay eggs on the maturing pods (Huignard et al., 1985). Then, when the infested seeds are harvested and stored, adults of the flightless morph emerge which are more sexually active and multiply rapidly in seeds (Monge and Huignard, 1991).

ECONOMIC IMPACT

They cause enormous losses of pulse crops in terms of both quantity and quality of the seed in storage. It is estimated that economic losses attributed by this insect in stored grain pulses to be around 73% in Kenya, 13% in Mediterranean region whereas 35% and 7–13% in Central and South America respectively (Nahdy, 1994; Weigand and Tahhan, 1990; Hu et al., 2009). Although post-harvest damage in storage, caused by the pulse beetle is varies from crop to crop as well as type of species infestation. For example, *C. maculatus* causes up to 90% yield loss in black gram, 10–78% in pigeon pea, 41% in faba bean and 4–90% in cowpea (Amusa et al., 2013; Mishra et al., 2017; Kesho, 2019). Whereas, *C. chinensis* causes 55–60% weight loss and 46–66% protein loss of stored adzuki beans (Gujar and Yadav, 1978). In mung bean, both *C. maculatus* and *C. chinensis* cause 7–73% losses in yield (Mishra et al., 2017). It was also observed that within six months, it infested 100% of the pulses and the weight loss causes almost 49% under laboratory conditions (Singh, 1985; Islam and Kabir, 1995). Infested pulse seeds become light weight and unsuitable for human consumption and loss their germinating viability

(Elhag, 2000). Heavy infestation can cause to moldiness and reduce their commercial value (Kiradoo and Srivastava, 2010). So, crop losses due to this pest not only cause direct damage by infestations, but also create conditions that bring secondary infestation by rot organisms mainly fungi and subsequent mycotoxin contamination (Kedia et al., 2013; Rees, 2004). Bamaiyi et al. (2006) evaluated nutritional content of ten cowpea varieties infested with *C. maculatus* after 1–3 months of infestation and reported an increase in total protein and crude fibre, while a decrease in ash, fat and total carbohydrates of the pulses. The carbohydrate and dietary fibre content of chickpea, green gram and pigeon pea was evaluated by Modgil and Mehta (2006) at 10, 20, 30, 40, 50 and 60% levels of infestation by the pest. With increase in level of infestation, energy, starch, total sugars and non-reducing sugars decreased, whereas significant increase in the reducing sugars, crude fiber, natural detergent fiber, acid detergent fiber, hemicellulose, cellulose and lignin.

MANAGEMENT OF PULSE BEETLE

Resistant varieties

Cultivation of resistant varieties is helpful in minimizing the infestation of these beetles in legume crops. This resistance comes through variation in pod wall, grain covering texture and protein content and chemical composition in seeds. It was observed that cowpea variety (TVu, 2027) showed high resistance against *C. maculatus* because that contents high concentration of trypsin inhibitor (Ileke et al., 2013). Beside this, that also contents amino acids having sulphur which acts as an antibiotic to developing larvae (Ileke et al., 2013). So those characters affect their survival rate and prolonged their development.

Intercropping practices

Intercropping maize or pearl millet with cowpeas, and not harvesting crops late significantly reduced pulse beetle infestation in cowpea (Olubayo and Port, 1997; Kabeh and Lale, 2008). Intercropping may create difficulty to locate its host plant due to the presence of many confusing chemical stimuli as well as physical barriers to movement (Seni, 2022).

Sanitation

Good store hygiene is helpful in limiting the infestation by these insects. The removal of infested residues from last season's harvest is necessary to prevent early infestation.

Physicals mean like temperature and moisture changes

Raising the store pulses temperature to 60–65 °C for a few minutes or reduce to below 12 °C can effectively manage the pulse beetle in storage (Sahadia and Aziz, 2011; Upadhyay and Ahmad, 2011). Reduce the moisture content to below 9% can adversely affect the biology of the stored pulses insects (Upadhyay and Ahmad, 2011). Sharon et al. (2015) reported that black gram can safely be stored with 11–12% moisture content up to 25 weeks at 20 °C temperature without losing its germination capacity. Solar heating of pulse crops can also manage pulse beetles in mung bean, cowpea and other legume seeds (Murdock and Shade, 1991; Moumouni et al., 2014). The seeds temperature can be raised to 52–65 °C by keeping them in black polythene sheet under the sun. This method helps by damaging egg viability and death of the developing stages of *Callosobruchus* effectively without affecting seed germination (Ajayi et al., 2021).

Changes gaseous condition

Creating an atmosphere with low oxygen or increasing carbon dioxide can become detrimental to pulse beetle by killing adults and developing stages of pests although most affected stages are egg and early developing stages (Kalpna et al., 2022; Navarro, 2012). Even 18% carbon dioxide concentration was helpful in their mortality (Wong-Corral et al., 2013). Similarly, a combination of low pressure and high temperature can also effective in killing the eggs, larvae of pulse beetle in cowpea (Mbata et al., 2005).

Use of inert materials and radiation

Inert dusting like sand and soil components (Golob and Wibley, 1980), diatomaceous earth (Subramanyam and Hagstrum, 1995), silica aerogel (Quarles, 1992), non-silica dusts (Fam et al., 1974; Golob and Wibley, 1980), wood ash (Wolfson et al., 1991) paddy husk ash (Ashamoet al., 2021) and particle films (Arthur and Puterka, 2002) or subjection to ionizing radiation like β- and γ-radiations can manage pulse beetle in legume grains. Insects covered with these dusts show substantial dehydration and die due to desiccation. Among those two radiations, β-radiation is comparatively safe and easier to handle because it can be turned on and off according to owner wish, while an isotope-based γ-radiation radiates continuously and is detrimental for human health (Fields and Muir, 1996). Microwave radiations may also help in reducing pulse beetle infestation in store pulses as with the help of this strategy, sawtoothed grain beetle *Oryzaephilus surinamensis* was successfully managed in wheat (Ghasemzadeh et al., 2011). Exposure to high ozone concentration like 500–1,500 ppm also kills different life stages of pulse beetle (Pandiselvam et al., 2019).

Molecular approach

Development of transgenic pulse beetle-resistant crops by introduction of gene encoding lectins (sugar-binding proteins), commonly found in the resistant legume grains (Chrispeels and Raikhel, 1991; Peumans and Van Damme, 1995; Omitogun et al., 1999; Mishra et al., 2017) also be helpful. The transgenesis of the α-amylase inhibitor (α *AI-1*) gene, obtained from the common bean (*P. vulgaris*), was successfully introduced during the development of pulse beetle resistant transgenic in the adzuki bean (*V. angularis*; Ishimoto et al., 1996), pea (*P. sativum*; Shade et al., 1994), chickpea (*C. arietinum*; Sarmah et al., 2004) and mung bean (*V. radiata*; Sonia et al., 2007). Likewise, cowpea varieties with trypsin inhibitors showed resistant against *C. maculates* (Shade et al., 1996). The primary mode of action of trypsin inhibitor is to inhibit essential digestive proteases resulting in abnormal development and death of larva due to deficiency of essential amino acids.

Decreasing population by bio-agents

Releasing bio agents in store house is also helpful but this technique is not explored so much due to storage condition. Gupta et al. (1997) observed the parasitic wasps, *Dinarmus acutus* and

Dinarmus basalis as potential parasitoids of *C. maculatus*, with parasitism ranging from 13 to 29%. Islam (1994) found that the parasitoid *D. basalis* deposited eggs on 2nd, 3rd and 4th instar larvae, pre pupae and pupae but most preferred was the 4th instars larvae. So, they have the potential to suppress the pulse beetle but more investigation is necessary regarding this.

Chemical treatment

Chemical insecticides like spinosad 45 SC @ 4.4 mg or emamectin benzoate 5 SG @ 40 mg or deltamethrin 2.8 EC @ 0.04 mL per kg pulse seed are effective against the beetles (Sanon et al., 2010; Mishra et al., 2018).

Use of botanicals

Although chemical insecticides are effective for the management of the pulse beetles but their continuous uses may cause environmental pollution, resistance development and residual toxicity. So, the use of chemicals in pulses is discouraged and use of botanicals is encouraged. For this, the use of plant-derived oils likes vegetative and essential oils are gaining momentum in present days for pulse beetle management in legume seeds as a biological alternative to synthetic insecticides. But their main drawback is availability of raw material, low production of bioactive compounds, geographical differences in active compounds, volatilization and instability. But the recent advances made in science such as biotechnology, molecular biology and nanotechnology could successfully solve the existing problems in the use of plant products and may increase their potency as well. Various plant essential oils which showed promising results against pulse beetle management in legume grains are given in Table 1. Regarding the use of vegetative oils as seed protectant, Bhargava and Meena (2002) tested six vegetable oils viz., mustard (*Brassica juncea*), castor (*Ricinus communis*), groundnut (*Arachis hypogaea*), coconut (*Cocos nucifera*), sesamum (*Sesamum indicum*) and sunflower (*Helianthus annus*) against *C. chinensis* in cowpea and observed that castor oil @ 10 mL kg^{-1} seed was best treatment in inhibiting the oviposition as well as in adult emergence in next generation followed by mustard and groundnut oil respectively. They did not notice any adverse effect of tested oils on the germination viability of cowpea seed up to 150 days after treatments. Similarly, Raghvani and Kapadia (2003) reported the effectiveness of neem and cocounut oils @ 10 mL kg^{-1} as seed protectants of red gram against *C. maculatus* for six months. Likewise, Meghwal et al. (2007) tested the efficacy of four vegetable oils viz., neem, castor, mustard and groundnut @ 4, 8 and 12 mL kg^{-1} moth bean as seed protectant against *C. chinensis* and found that all the oils were effective for adult mortality and within various doses of neem oil best treatment dose was @ 12 mL kg^{-1} grains. In our study also we observed that neem, mustard, coconut and castor oil @ 10 mL kg^{-1} grains were effective up to seven months against *C. chinensis* in horse gram without affecting the germination viability of the seeds whereas within that duration, 100% infestation was observed in untreated legume grains. So, vegetative oils are also effective in managing the pulse beetle in pulses and are economically cheaper than essential oils although more investigation are necessary for their use in bulk storage condition.

Use of cold plasma technique

Cold plasma method is the new technique which has a lot of potential to be an effective tool for store grain pest management by creating oxidative stress in insects. It works by generating energetic electrons that collide with gas molecules and causes dissociation, excitation, and

Table 1. Promising botanicals for the pulse beetle management

Plant name	Major constituents	Bioactivity	Results	References
Lantana camara L.	α-Humulene and cis-caryophyllene	Repellent action	100% repellency was observed at 0.4 μL cm^{-2} concentration.	Zandi-Sohani et al. (2012)
Mentha spicata L.	Carvone and DL limonene	Antifeedant, oviposition deterrent, Fumigate toxicity, larvicidal, Ovicidal and Pupaecidal activity	LC_{50} value of essential oil was 0.003 μL mL^{-1} air after 24 h exposure.	Kedia et al. (2014)
Cymbopogon schoenanthus L. Spreng.	Piperitone, 2-carene, elemol	Fumigant Repellent and ovicidal activity	Exposure to essential oil at 6.7 μL L^{-1} of air gave 90% mortality of adults after 24 h of treatment	Ketoh et al. (2005)
Atalantia monophylla L.	Eugenol, sabinene, 1,2-dimethoxy-4-(2-methoxyethenyl) benzene, β-asarone, and methyl eugenol	Fumigant toxicity, Repellent and ovicidal activity	Essential oil @ 160 μL L^{-1} produced >70% mortality after 24 h exposure period.	Nattudurai et al. (2017)
Acorus calamus L.	β-Asarone	Repellent activity, fumigant toxicity	Fumigant toxicity at a dose of 0.1 μL mL^{-1} and caused 100% mortality.	Shukla et al. (2016)
Boswellia carterii Roxb.	α-Thujene α-pinene, and α-phellandrene	Fumigant toxicity	100% mortality at 0.10 μL mL^{-1} of essential oil.	Kiran et al. (2017)
Cuminum cyminum L.	Cymene, γ-terpinene, cuminaldehyde, and (-)-β-pinene	Fumigant toxicity, repellent activity	100% mortality was found at 10 μL L^{-1} air concentration of essential oil.	Kedia et al. (2015)
Artemisia scoparia Waldst. and Kit.	β-Pinene, capillin, limonene, and myrcene	Fumigant toxicity, repellent activity	100% mortality was found after 24 h exposed to 37 μL L^{-1} air concentration of essential oil.	Negahban et al. (2006)
Ocimum gratissimum L.	Methyl eugenol and β-(Z)-ocimene	Fumigant toxicity, repellent activity	100% mortality was reported after 24 h treatment by 1 mL L^{-1} air concentration of essential oil.	Ogendo et al. (2008)
Cinnamomum glaucescens Hand.- Mazz.	1,8-Cineole	Fumigant toxicity, oviposition deterrence	99% oviposition deterrence was observed at 0.15 μL mL^{-1} air concentration of essential oil	Prakash et al. (2013)

(continued)

Table 1. Continued

Plant name	Major constituents	Bioactivity	Results	References
Vanillosmopsis arborea Baker	α-Bisabolol	Fumigant toxicity	LC_{95} of essential oil was 12.97 µL L^{-1} of air	Moura et al. (2019)
Eucalyptus citriodora Hook	Citronellal; citronellyl acetate; 1,8-cineole	Fumigant and repellent action	Fumigant toxicityat a dose of 6.81 µL L^{-1} of air and caused 90% mortality.	Gusmao et al. (2013)
Cymbopogon winterianus Jowitt	Geranial; citronellal 10.94%	Fumigant and repellent action	Fumigant toxicity at a dose of 21.82 µL L^{-1} of air and caused 90% mortality.	Gusmao et al. (2013)
Cinnamomum aromaticum (Nees)	Cis-cinnamaldehyde, eugenol	Fumigant and Repellent activity	Essential oil at 62.85 µL cm^{-2} caused 94.44% of insect mortality after 24 h of treatment	Islam et al. (2009)
Xylopia parviflora (A. Rich.) Benth	β-Himachalene β-Elemene, alpha-parasinsen	Repellent activity	Application of EO at the rates of 0.66–1.32 µL cm^{-2} caused higher percentage repellence (46.93–61.20%) against adult insect	Babarinde et al. (2017)
Mentha piperita L.	Neo-isomenthol and menthone	Fumigant Repellent and ovicidal activity	LC50 of essential oil was 2.06 µL mL^{-1} of air at 48 h after treatment	Jayaram et al. (2022)
Tagetes minuta L.	β-Ocimene, dihydrotagetone	Fumigant Repellent and ovicidal activity	Essential oil @ 10 µL mL^{-1} showed 100% oviposition inhibition after 24 h	Jayaram et al. (2022)

ionization of gas molecule (Calvo et al., 2016; Ziuzina et al., 2021). Pathan et al. (2021) reported that cold plasma treatment was effective for the protection of chickpea from the infestation of *C. chinensis* for four years.

FUTURE PROSPECTS

Pulse beetles are important stored legume grain insect pests distributed throughout the world but most serious in tropical to subtropical region. Initially their attack started in the field and rapidly increases their population in storage. They can infest 100% of the pulses within few months of storage (Gbaye et al., 2011). For this, proper management techniques should be adopted to save the legume seeds from this notorious pest. Although various techniques like store in sealed containers, ash, intercropping, right time harvesting, sun drying are used by farming communities (Kalpna et al., 2022) but they are not appeared so effective for long term storage. Although vegetable and essential oils showed some promising results but studies are necessary to know their effects on the odor, flavor as well as on nutrition value of the treated pulses which will be used for human consumption. Cold plasma therapy also another alternative for chemical treatment for pulse beetle management but more investigation is necessary about their effect on germination viability and nutrition quality of the storage pulses.

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