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MINI-REVIEW

Phyto-derivatives: an efficient eco-friendly way to manage *Trogoderma granarium* (Everts) (Coleoptera: Dermestidae)

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Abstract

Worldwide, stored products are attacked by a large number of pests resulting in significant economic losses. Among these stored grain pests, khapra beetle, *Trogoderma granarium* (Everts) (Coleoptera: Dermestidae) is one of the top ranked pests that has ability to survive under diverse climate conditions. The management of this pest is mainly done by using synthetic chemicals which have side effects on consumers, ecosystem and non-target organisms. However, phyto-derivatives were found to be the effective environment friendly alternatives against *T. granarium*. Therefore, in this review, success of phyto-derivatives against khapra beetle from conventional means to modern research has been critically analyzed, summarized and discussed. In context, the different life stages of the insect starting from egg laying to adult development have been briefly explained. The review focuses upon recent research conducted on the evaluation of dozens of phyto-derivatives. In addition, the article has also highlighted some limitations of plant derived compounds and concludes via hoping that the future formulated pesticides will be safer, economical, least toxic to human and our planet ecosystem.

Keywords Botanicals · Phyto-chemicals · Food security · Extracts · Stored products

Introduction

Agricultural and animal stored products are attacked by more than 20,000 field insects including six hundred species of beetles, more than 70 moth species and around 355 species of mites, resulting in quantitative and qualitative losses worldwide (Nagpal and Kumar 2012; Rajendran 2005). These losses are more associated with developing countries because of poor sanitary conditions during commodity procurement, processing, non-hygienic transportation, conventional storage techniques and technically and poorly maintained storage units (Dubey et al. 2008; Hubert et al. 2004).

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Stored grain insect infestation exhibits 10–20% grain losses worldwide (Pedigo and Rice 2014; Rajendran and Sriranjini 2008). The damages in terms of quality and quantity due to stored pests infestation are very high, which not only results in human health hazards (malnutrition), but also causes millions of dollars loss to national exchequer annually (Nagpal and Kumar 2012).

The khapra beetle, *Trogoderma granarium* (Everts) (Coleoptera: Dermestidae) is a key stored product insect pest that has been categorized as an A2 quarantine organism by European and Mediterranean Plant Protection Organization (EPPO 2011). The pest is considered as one of the hundred "world's worst" invaders (Lowe et al. 2000). The khapra beetle presence is observed in stored grain commodities throughout the year worldwide, indicating that the pest have developed a survival ability in worst conditions, and have become a global threat to food security (Dwivedi and Shekhawat 2004).

Infestations are difficult to control because of the insect's ability to survive without food for long periods, its preference for dry conditions and low-moisture food, and its resistance to many insecticides (Derbalah 2012; Islam 2017a). Khapra beetle infested grains harbor the insect residues leading to severe adverse effects upon human being digestive system and reduction of the nutritional values of the grains (Arain et al. 2006).

Management of the pest is very important for quality assurance and food safety of the cereal stored grain commodities. According to quarantine laws, it is pre-requisite to ensure the pest free grains before export to other countries, which highly limit exportation of infested grains and consequently subjected to rejections of export orders. Although conventional and non-conventional chemical management of the khapra beetle minimize the pest pressure, however, it was observed that repeated use of these techniques year after year has resulted in development of resistance in the pest against the chemicals and the scenario has become challenging for entomology researchers (Ahmedani et al. 2007). Also, chemicals pose adverse effects on human health and surrounding ecosystem (Damalas and Eleftherohorinos 2011; Islam and Ahmed 2016; Islam et al. 2016a). Therefore, the importance of phyto-derivatives as an alternative to manage the khapra beetle increases ten folds more as they are environmentally safe, cheaper, locally available and pest did not acquire resistance against them as well (Islam 2017b; Islam et al. 2016b).

In this review, we highlighted the importance of phyto-derivatives by underlining the conventional approach of plant extracts and their success stories. Furthermore, we reviewed the recent research focusing on the application of phyto-extracts against *T. granarium* in 21st century. The biology of the pest was also discussed through its life stages for better understanding of the insect behavior and consequently pointed out some limitations in phyto-derivatives control strategies. The review aims to increase awareness among the readers and community, and guide stakeholders on the new means of successful eco-friendly management approaches against khapra beetle.

An overview on khapra beetle

To understand and improve the management of the pest, it is important to have knowledge about the pest identification, biology and its ecological distribution so that adequate and effective control measures could be developed and adopted against this insect pest.

Identification

Oblong to oval shaped adult beetles are about 1.6-3.0 mm in length and 0.9–1.7 mm wide. Male beetles are brown-black in color having reddish brown marks, while females exhibit lighter color in contrast. Females are larger than males. The antennae of the insect are mounted upon a small deflexed head and it bears eleven segments fitting into a groove like structure. Female could lay approximately 125 eggs during its life span. These eggs are cylindrical, round ended at one side (0.7 by 0.25 mm), and are initially milky white containing spiny projections, but later, after several hours, eggs turn into pale yellowish. At hatching point, the larvae are yellowish white and have brownish hairs ranging between 1.6 and 1.8 mm in length constituting a hairy tail. The larval color changes to reddish or golden with increasing age gradually shortening towards the tail. At maturity, they occupy 6 mm length and 1.5 mm width (Hadaway 1956). The khapra beetle's physiology and development are significantly impacted by its diet.

Biology

Although the adults bear wings, they do not use them for flying. Adults carry out mating process for reproduction and fertilized females can live up to seven days, but non-fertilized ones can survive up to a month, while males' life span is about two weeks. Five days after emergence, the reproductive mating is initiated, leading to egg laying (25 eggs on an average per female per day) at higher temperature regimes such as 40 °C, but the oviposition stops at lower temperature, i.e., 20 °C. Egg hatching occurs after approximately 10–14 days, while completion of life cycle from egg to adult can vary from 26 to 220 days depending on the temperature and diet. However, eggs hatch better under the optimum temperature of 35 °C, while lower temperatures lead the eggs to diapauses condition, where they can survive for years (Anonymous 1981) (Fig. 1).

Distribution

As many countries now rely upon quarantine measures to control entry of invasive insect pests and diseases, the distribution maps or data of particular insect globally is very

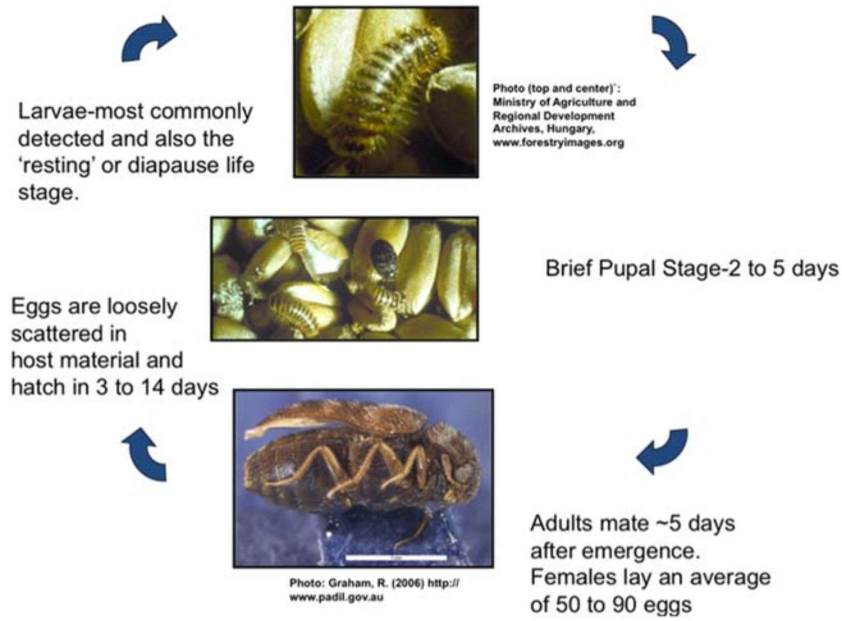

Fig. 1 Life cycle of khapra Beetle, *Trogoderma granarium* (http://khaprabeetleathreat2australia.weebly.com/life-cycle.html)

important (Banks 1977). Khapra beetle is distributed worldwide (Szito 2006) and exhibits resistance against many conventional synthetic chemicals. Mass eradication campaigns were launched in several countries such as USA in 1960s to reduce the pest infestations. However, complete eradication of the insect species was not achieved in USA because 67% of the country climate is favorable for the pest survival (French and Venette 2005).

Why phyto-derivatives?

In the 19th century, extensive use of chemicals as fumigants and insecticides was coined. These chemicals are still effective against some life stages of khapra beetle (Nayak et al. 2013; Pimentel et al. 2007). The practice of using fumigants is still favorite in developing countries (Rehman et al. 2013; Wasala et al. 2016). The continuous use of chemicals has allowed khapra beetle to acquire resistance against them (Donahaye 2000). This resistance is alarming in south Asia, USA and Australia which may lead to big disaster toward the control of the pest in future (Leelaja et al. 2007; Rajashekar et al. 2006). Chemicals are the major cause of destruction to human health and global ecosystem (Dubey et al. 2007; Islam et al. 2017b). For example, ozone depletion is caused by extensive use of methyl bromide globally, and was consequently banned from the international markets (WMO 1995). Contact insecticides have been found to have more detrimental effects upon human specifically during handling and utilization. More than 500 insect species and mites are resistant to the synthetic contact poisons such as deltamethrin, cypermathrin, chloropyrifos and malathion (Subramanyam and Hagstrum 1995). Furthermore, Champ (1985) reported that the stored grain insects including khapra beetle have developed resistance at some stage of their life against the synthetic chemicals. This resistance in the pests is leading gradually towards the emergence of immune strains (Sharma and Meshram 2006), and consequently led to the banning of a lot of chemicals.

Due to the concerns of public about the effects of chemical residues accumulation into stored food grains, efforts have been made to search for alternatives methods that are safer, cheaper and environment friendly (Isman 2006; Kéïta et al. 2000). The phyto-derivatives were therefore found very useful to tackle the issue.

Conventional success stories of phyto-derivatives led to explore the botanicals

Consumers concerns toward the critical effects of chemicals, led researchers to focus pest control strategy on newer, cheaper, nontoxic and safer insecticides (Dayan et al. 2009). The ultimate actions converged to the conventional means where plants were used as toxicants with anti-insecticidal activity and other different purposes in daily life (Talukder 2006). Plant derived products are bio degradable, least hazardous to ecosystem and mammals, and efforts to exploit plant derived compounds for their insecticidal potential become important (Dubey et al. 2008; Yao et al. 2008). Anciently, ashes approach was famous in Indian subcontinent and in Egyptian zones to manage stored commodities (Varma and Dubey 1999). Similarly, the false hellebore scientifically known as *Veratrum album* and pyrethrum were also used by Romans and Chinese as rodenticide (Ahmed and Grainge 1986). In Indian subcontinent, neem leaves were popular for management of stored grain pests (Ahmed and Koppel 1985). Clay or mud granaries are still famous in developing areas where a mixture of ash and cowpeas are added in granaries for their sterilization (Wolfson et al. 1991). Leaves of *Ocimum suave* and *Eugenia aromatica* are traditionally used for protecting granaries in Africa (Okwute 2012). For storage of beans in Rwanda, *Ocimum canum* leaves are used for their anti-toxic properties against insects (Mishra et al. 2012). Mixing the turmeric powder in wheat and rice granaries was a traditional practice for controlling stored insect pests in south Asia (Saxena et al. 1988). Many more approaches underline the use of phyto-derivatives such as *Citronella, Derris, Pyrethrum* and *Necotiana* as insecticides for centuries (Park et al. 2003; Sim et al. 2006). Plant products have been successfully exploited as insecticides, insect repellents and insect anti-feedants in the 20th century (Hedin and Hollingworth 1997; Mordue and Blackwell 1993). A large number of primary and secondary metabolites have been extracted from the tropical plants to utilize against stored product insect pests (Hiiesaar et al. 2001). Scientists in previous century exploited plant derived products and concluded that plant-derivatives are least harmful to environment because of their novel and specific mode of action Berger 1994; Klepzig and Schlyter 1999; Lindgren et al. 1996; Schmutterer 1990).

Phyto-derivatives as a shield against khapra beetle

Ancient practices have proven the success of phyto-chemicals, but these practices actually need to be carried out in different physiological ways that may clearly explore the anti-feedant, toxic, repellency, attractant and detergency or growth retarding effects (Ng 2006). However, whatever way the plant derived compounds should be used, the main purpose is always to manage the stored insects like khapra beetle (Fig. 2). Nowadays, *Rynia, Azadirachta, Nicotina, Rotenone, Sabadilla* and *Pyrethrin* are commercially available and are considered successful against the infestation of khapra beetle. Active ingredient extracted from roots and woody parts of *Ryania speciosa* has lower toxic and residual effects. There is specific botanical ingredient (ryanodine) that affects khapra beetle muscles by enhancing rapid calcium flow into cells leading to death of the beetle (Dayan et al. 2009; Dimetry 2012). *Azadirachta indica* is the most popular plant in Asia and African regions that is categorized as contact poison against khapra beetle (Isman 2006). It also bears systemic properties, deterrent potential and growth inhibitory or oval inhibition properties against khapra beetle (Isman 2006; Morgan 2009). Another popular and anciently known toxic agent is Nicotine, which is basically derived from *Nicotiana tobacum*, have direct effects on the nervous systems of khapra beetle. The poison occupies the nerve junctions leading to the insect death (Isman 2006). Root extracts derived from *Lonchocarpus* and *Derris* plant species, commercially known as Rotenone, are popular in India and China as a slow poison that neutralizes almost all the stored grain pests including khapra beetle. Rotenone shows broad spectrum action by blocking the respiratory system of khapra beetle. Derivatives from *Schoenocaulon officinale* seeds are known as stomach poison for the khapra beetle and also effectively occupies the nervous system of the insect leading to its paralysis and death (Copping and Duke 2007). Multiple seed derivatives of *Chrysanthemum cinerariaefolium* play a significant role of conventional household insecticide that shows degradable activity against the target insect and can be immediately used when the commodity is stored (Copping and Duke 2007; Isman 2006).

Researchers actively started documenting the successful effects of phyto-derivatives against khapra beetle in late 20th century, when increased doses of palm, groundnut and coconut oils were found to significantly minimize the adult emergence, as well as enhancing larval and adult mortality of khapra beetle (Odeyemi 1991). In addition, increased level of oils exhibited reduction in seed damage and weight loss in groundnut seeds. Jood et al. (1996) exploited the efficiency of citrus, garlic, podina powders and neem oil against khapra beetle larvae that infested sorghum grains for six months, and found that both neem kernel powder and neem oil highly minimized the grain damage by khapra beetle larvae. Further observations about other treatments (citrus, garlic, podina powders) revealed that after initial three months, grain damage started becoming visible and become more prominent after six months. However, the damage level was least in neem based treatments compared to citrus, garlic and podina. After the six months of storage, the color of the grains remained the same but their aroma, texture, taste and overall conditions become adverse in all the treatments. Dwivedi and Kumar (1999) investigated twelve acetone compounds and ether based plant extracts for their oviposition deterrent properties against khapra beetle and reported that leaves and seed extracts of *Cassia occidentalis* and *Withania somnifera* were effective in deterring oviposition of the pest. Reports of Sharma (1999) explained that 4% neem seed kernel powder and 5% neem leaf powder protected maize seeds for five months against *Rhyzopertha dominica* and *T. granarium* infestation.

At the beginning of 20th century, attempts of using phyto-extracts entered a desperate research phase, when several scientists evaluated a large number of plant-derivatives against khapra beetle. Some authors also evaluated *Citrus reticulate, Acacia nilotica, Lantana camara, Tegetus indica, Cassia fistula, Anethum sowa, Emblica officinalis, Ziziphus jujube* against khapra beetle and reported the success of their different parts, decoctions and derived essential oils (Dwivedi et al. 2003; Dwivedi and Shekhawat 2004; Sagheer et al. 2013). Following the importance of *A. indica* for management of various agricultural pests, many researchers also tried to explore its potential against the various growth stages of khapra beetle, and reported its inhibitory effects on the beetle (Hanif et al. 2015; Haq et al. 2014; Hasan et al. 2012; Howard et al.

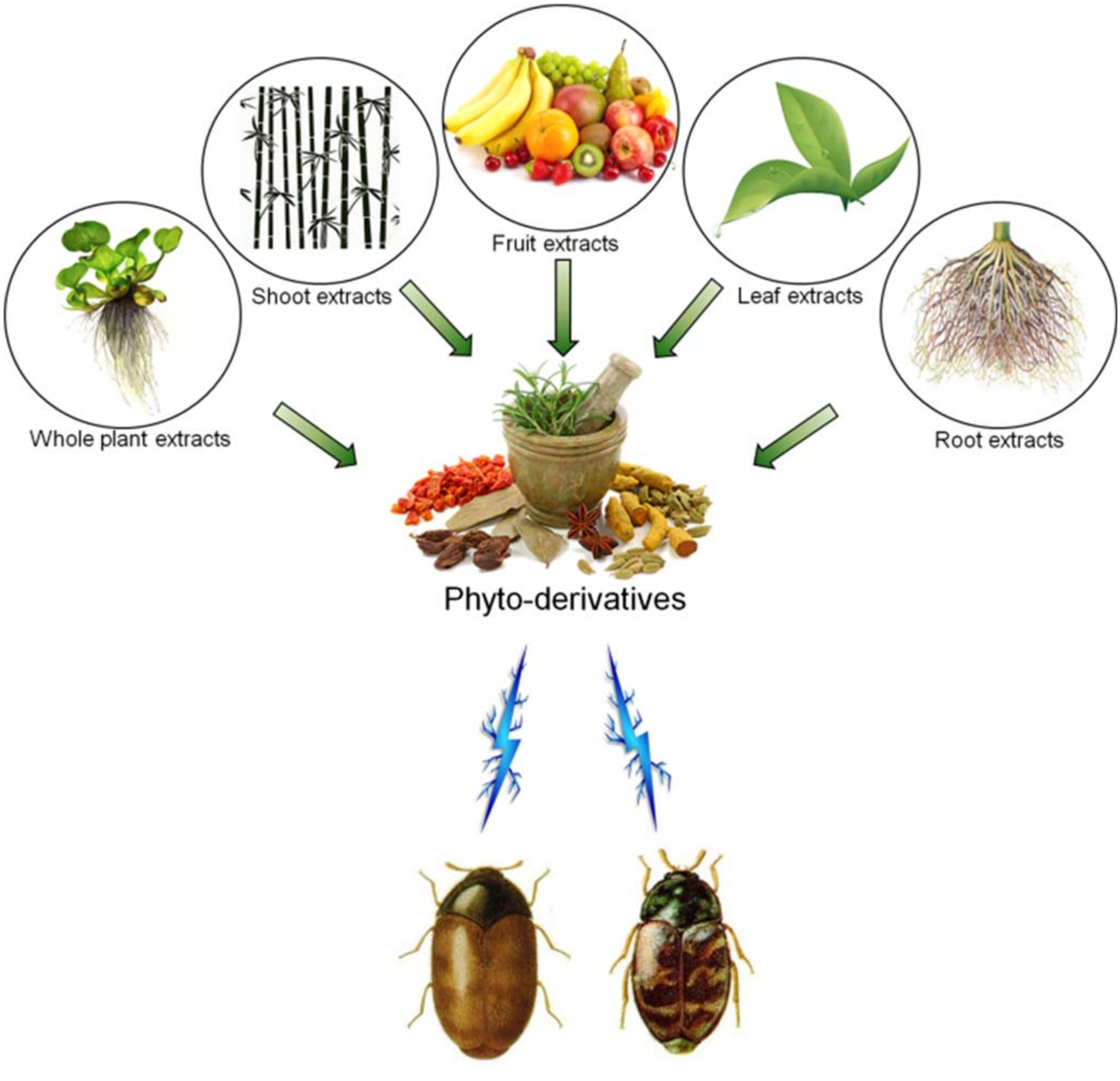

Fig. 2 Various types of phyto-dertivatives that can be used against khapra beetle

2009). Additionally, various *Datura* species were proved toxic and shown repellent effects against khapra beetle (Ali et al. 2012; Mahfuz and Khanam 2007; Omar et al. 2012; Saleem et al. 2014).

Another relevant aspect in application of phyto-products is the effective required dose against the khapra beetle. Many scientists reported that relatively higher doses of the phyto-derivatives were proved lethal against the target insect. For example, 100% larval mortality was observed at 75% concentration of citrus decoctions (Dwivedi and Bajaj 2001) (Table 1). Similarly, Al-Moajel (2004) reported that 73% concentration of *Capsicum frutescens, Lawsania inermis* and *Allium ascalonicum* resulted 62–85% mortality of khapra beetle, seven days post-application. Similarly, leaf extract of *Rhazya stricta* (Alvi et al. 2018) as well as *Myrtus communis* and *Ruta graveolens* (Othman 2018) caused higher mortality of *T. granarium* (Table 1). In addition, *Mesua ferrea* and *Raphanus sativus* caused approximately 82% mortality, however, the mortality was reduced to 62%, when application dose of dried leaf powders was reduced (Al-Moajel 2004) (Table 1).

Table 1 Recent research findings illustrating about the successful utilization of phyto-extracts for management of khapra beetle

Plant species	Types of plant extract	Successful results at Applied dose	References
Citrus reticulata	Seed extracts	100% larval mortality at 75% concentration level	(Dwivedi and Bajaj 2001)
Acacia nilotica, Lantana camara, Tegetus indica, Cassia fistula	Acetone based leaf extracts	75.21%-88.66% ovicidal activity at 80% concentration level	(Dwivedi and Bajaj 2001)
Rhazya stricta, A. indica, Helitropium bacciferumm	Aqueous, acetonic and methanolic extracts	Aqueous extracts of *R. stricta* at 1000 ppm concentration with six days exposure recorded 80% adult mortality followed by *A. indica* (73.3%) and *H. bacciferumm* (70%. Acetonic extracts of *R. stricta* at 1000 ppm concentration with six days exposure recorded 86.7% adult mortality followed by *A. indica* (80%) and *H. bacciferumm* (73.3%. Similarly, methanolic extracts of *R. stricta* at 1000 ppm concentration with six days exposure recorded 90% adult mortality followed by *A. indica* (86.7%) and *H. bacciferumm* (80%.	(El Nadi et al. 2001)
A. indica	Seed oil	100% adult mortality at 50–200 µl doze and No egg hatching at 100–200 µl doze	(Arivudainambi and Singh 2003)
Anethum sowa	Leaf extracts	Reduced insect feeding by recording 13.61% seed weight loss as compared to control (53.40%) at 8 ppm concentration.	(Dwivedi et al. 2003)
Emblica officinalis, Ziziphus jujube	Acetone based leaf extracts	100% repellency at 85% concentration level	(Dwivedi and Shekhawat 2004)
Capsicum frutescens, Lawsania inermis, Allium ascalonicum, Mesua ferrea, Raphanus sativus	Powders of different dried leaves and roots	62–85% larval mortality at 6% concentration level	(Al-Moajel 2004)
Amaranthus vitidis, Salsola baryosma	Leaf extracts	19.58% and 22.08% larval mortality at 1.5% concentration	(Hassan et al. 2005)
Annona squamosa	Hexane, methanolic and ethyl acetate extracts	Ethyl extract resulted in 55.73% antifeedent activity at 7 days old larvae followed by 53.45% by hexane and 38.65% for methanolic extract	(Rao et al. 2005)
Haloxylon recurvum	Leaf extracts	17% insect mortality at 1.5% concentration level with the exposure of 168 h.	(Hasan et al. 2006)
Acorus calamus	Rhizome extracts	Insect showed 11.10, 22.59 and 44.70% morality at exposure time of 3, 5 and 7 days, respectively, whereas 22.18, 24.44 and 27.77% mortality was observed with 30, 50 and 70 uL of oil respectively.	
Hyptis suaveolens Poit.	Methanol based seed and leaf extracts	Seed extracts provided 24.9% more mortality than leaf extracts	(Musa et al. 2009)
Schinus molle	Fruit and leaf essential oils	80.43% insecticidal activity was resulted by fruit oils followed by 74.84% activity by leaf oils.	(Abdel-Sattar et al. 2010)
Limonium echioides, Tamarix boveana, Suaeda fruticosa	Ethyl acetate and methanolic extracts	At 50 µg/ 20 mg, both extracts from L. *echioides* recorded moderate anti-feeding activity followed by *Tamarix boveana* and *Suaeda fruticosa.* Similarly, *L. echioides* extracts showed 93% and 70% larval mortality after 28 and 18 days, respectively.	(Saidana et al. 2010)
Nicotiana tabacum, Cardaria draba, Sinapis arvensis	Aqueous extracts of vegetative parts	Mean larval mortality by 6% concentration of tobacco extract was 1.54% at 96 h	(Sarmamy et al. 2011)

Table 1 (continued)

Plant species	Types of plant extract	Successful results at Applied dose	References
		exposure time while *C. draba* exhibited 1.96% and *S. arvensis* shown 1.21%.	
Datura alba	Leaf extracts	2.5% concentration exhibited 33.5% and 45% mortality after 30 and 60 days exposure periods.	(Ali et al. 2012)
D. stramonium, Solanum nigrum, Quercus infectoria, Xanthium strumarium	Ethanolic fruit extracts	100% adult mortality at 2 and 4% concentration of *D. stramonium* and *X. strumarium* fruit extracts. 100% and 97.43% larval mortality at 1% concentration and 8 days exposure time by *D. stramonium* and *S. nigrum* respectively. Similarly 91.87% and 91.45% repellent action was recorded by *D. stramonium* and *S. nigrum* respectively at 4% concentration after 24 h of treatment.	(Omar et al. 2012)
P. nigrum, N. sativa, A. indica, C. longa	Leaf extracts	Mortality rate was 14.36% and 6.78% by *A. indica* and *P. nigram* after an exposure of one month.	(Hasan et al. 2012)
Curcuma longa, Zingiber officinale, A. sativum, Ficus exasperate, Garcinia kola	Seed, bulb, rhizomes and leaf powders	Adult mortality between 80-96.2% at 49 days of exposure by *A. sativum* as compared to control (10.6%).	(Asawalam and Onu 2014)
A. indica, D. stramonium	Leaves and peel extracts	15% of *A. indica* and *D. stramonium* gave 32.10 and 27% larval mortality after 9 d.	(Haq et al. 2014)
D. stramonium, Eucalyptus camaldulensis, Moringa oleifera, Nigella sativa	Essential oils	*D. stramonium*, *E. camaldulensis*, *N. sativa* and *M. oleifera* gave 25.0, 20.2, 16.1 and 12.8% mortality after 168 h.	(Saleem et al. 2014)
A. indica, Calotropis procera, Solenostemma argel, Aristolochia bracteolate	Ethanolic extracts of leaves, shoots and seeds	*A. indica* seed extract 95% larval mortality 10% concentration 30 days. *C. procera* and *S. argel* leaf extract 37.5% and 32.5% mortality, respectively. *A. bracteolate* shoot extract 17.5% larval mortality.	(Mahmoud et al. 2015)
Syzygium aromaticum, E. camaldulensis, Elettaria cardamomum, Foeniculum vulgare, A. cepa, Carum carvi	Essential oils	Clove oil showed 60% repellency (highest) while funnel oil was categorized having least repellent effects as 20%. Furthermore clove oil gave 91.67% adult mortality at 4% after 48 h.	(Gharsan 2015)
Melia azadarach, D. stramonium, A. indica	Essential oils	*D. stramonium, A. indica* and *M. azadarach* 15% and 300 ppm phosphine 72 h exposure, gave 86.47, 83.03 and 76.24%, respectively.	(Hanif et al. 2015)
Eruca sativa, Piper nigrum, Withania somnifera	Leaf and seed extracts	8% of *P. nigrum, W. somnifera* and *E. sativa* gave 26.30, 15.39 and 10.84% larval mortality, respectively.	(Javed et al. 2016)
A. indica, D. stramonium, Eruca sativa	Seed and leaf extracts	12% concentration of *D. stramonium* gave the most mortality (39.3%) followed by *A. indica* giving 32.2% and *E. sativa* (19.9%.	(Islam et al. 2017a)
R. stricta	Seed and leaf extracts	After 120 h, the leaf extract caused 72.11% mortality, while seed extract caused 69.50% mortality	(Alvi et al. 2018)
Myrtus communis, Ruta graveolens, Rosemarinus officanalsi, Ocimum basilicum, Mentha piperita	Leaf extracts	7% and 9% concentrations of *M. communis* and the concentration 9% of *R. graveolens* caused 100% mortality of *T. granarium*.	(Othman 2018)
D. alba, Calotropis procera	Essential oils	20% concentration of *C. procera* showed a maximum mortality of 55.96% while 20% concentration of *D. alba* caused mean	(Khan et al. 2019)

Table 1 (continued)

Plant species	Types of plant extract	Successful results at Applied dose	References
		mortality of 57.44%	
Mentha piperita, Thymus vulgaris, Rosmarinus officinalis, Melissa officinalis	Leaf extracts	96 h of exposure to *R. officinalis* extracts resulted in 78.67% mean mortality	(Panezai et al. 2019)
Lantana camara, *Ruta chalepensis*, *Rhazya stricta*	aqueous, ethanolic and acetonic extracts	The ethanolic and acetonic extracts of *L. camara* was the most effective, where caused mortality rates of 73.3 and 83% at 400 ppm after 2 d, respectively, and 86.7 and 90% mortalities after 6 d, respectively	(Asiry and Zaitoun 2020)

The extraction solvents of the phyto-derived extracts also play a significant role in their activity. The popular extraction agents can be water, hexane, acetone or methanol. For example, acetonic extract of *Cassia fistula* caused 88.66% larvicidal activity on the pest (Dwivedi and Bajaj 2001). Similarly, acetonic extraction of *R. stricta, A. indica* and *Helitropium bacciferumm* caused 1.4 folds more mortality of *T. granarium* larvae than methanolic and aqueous extracts (El Nadi et al. 2001) (Table 1). Rao et al. (2005) reported significant mortality (35.68%-55.58%) of seven days old *T. granarium* larvae by hexane, acetone and methanolic based *Annona squamosa* extracts. Selection of different plant parts (leaves, roots, stem and seed) in the extraction of the valuable toxic products against khapra beetle is also related to the plant species. For instance, Musa et al. (2009) evaluated methanolic extracts of *Hyptis suaveolens* leaves and seeds against *T. granarium* in stored groundnut and observed 75–80% mortality as compared to control. Correspondingly, Javed et al. (2016) reported the toxic activity of leaves and root extracts of *Eruca sativa, Piper nigrum* and *Withania somnifera* against the target insect (Table 1).

All the efforts in the current era exhibit positive intend from the researchers to identify the safe approaches of managing khapra beetle. We have tried to summarize the recent research findings related to utilization of phyto-derivatives against khapra beetle in Table 1.

Limitations of phyto-derivatives against khapra beetle

Although the phyto-chemicals or plant-derived extracts have been proven successful as an alternative control strategy against khapra beetle, there are still some obstacles or limitations. For example, when we talk about the plant extracts, our immediate intention goes towards making traditionally the plant products which sometimes could be hazardous because of lack of extraction experience and technical knowledge. Technically safe and highly careful routes are taken in the extraction of phyto-derivatives, which should be strictly followed to meet the quality of the phyto-derived products. Similarly, the high variation in the genetics of the plants, species diversity, and their seasonal availability sometimes reduce their application anytime. Furthermore, no mechanized means of collection, storage, processing and packaging of these plant products are common or well documented, which leads to the deterioration of these products faster than other synthetic chemicals (Islam et al. 2018a, b; Rajashekar et al. 2012). Although the criteria for commercialization of plant extracts for organic agriculture farming was introduced by International Federation of Organic Agriculture Movements (IFOAM 2012) (Fig. 3) but still proper commercialization has not been done regarding phyto-derivatives. This lack of proper commercialization is an indication that we do not have any credited laboratories to test the quality, purity and efficacy of commercially available plant extracts in the market (Kühne 2008). Some ethical and religious aspects also consider the use of some plant products as harmful for human beings, since they think that residual effects of these plant extracts may act as spermicides (Obeng-Ofori 2010). In addition to the lack of technical knowledge, the assessment of the toxicity of phyto-derivatives extracts to mammalians and other non-target organisms of the food chain remained negligible and needs adequate attention. For example, rotenone derived from various plants genera such as *Derris*, *Lonchocarpus* and *Terphrosia* was found toxic to mammals, fish and human beings as their lethal dose (LD_{50}) ranged between 132 and 1500 mg.kg^{-1} (Rajashekar et al. 2012) thus making these plant genera more suspected to be one of the cause of Parkinson disease (Zehnder et al. 2007). Furthermore, the awareness and lack of knowledge on the application these phyto-derivatives represent a major factor that reduces their use against the khapra beetle.

Conclusions and future prospects

The research efforts documented in this review clearly illustrate the available possibilities in manufacturing the phyto extracts, curtailing the economic population growth of khapra beetle. The phyto-products are less hazardous to environment, human beings, easy to use, cheaper in context, biodegradable and locally available. There is therefore a strong need to conduct more research on the phyto-toxic plants against khapra beetle commercialization of these phyto-products should be focused. This would not only make them available for small scale farmers, but also at low prices so that people may

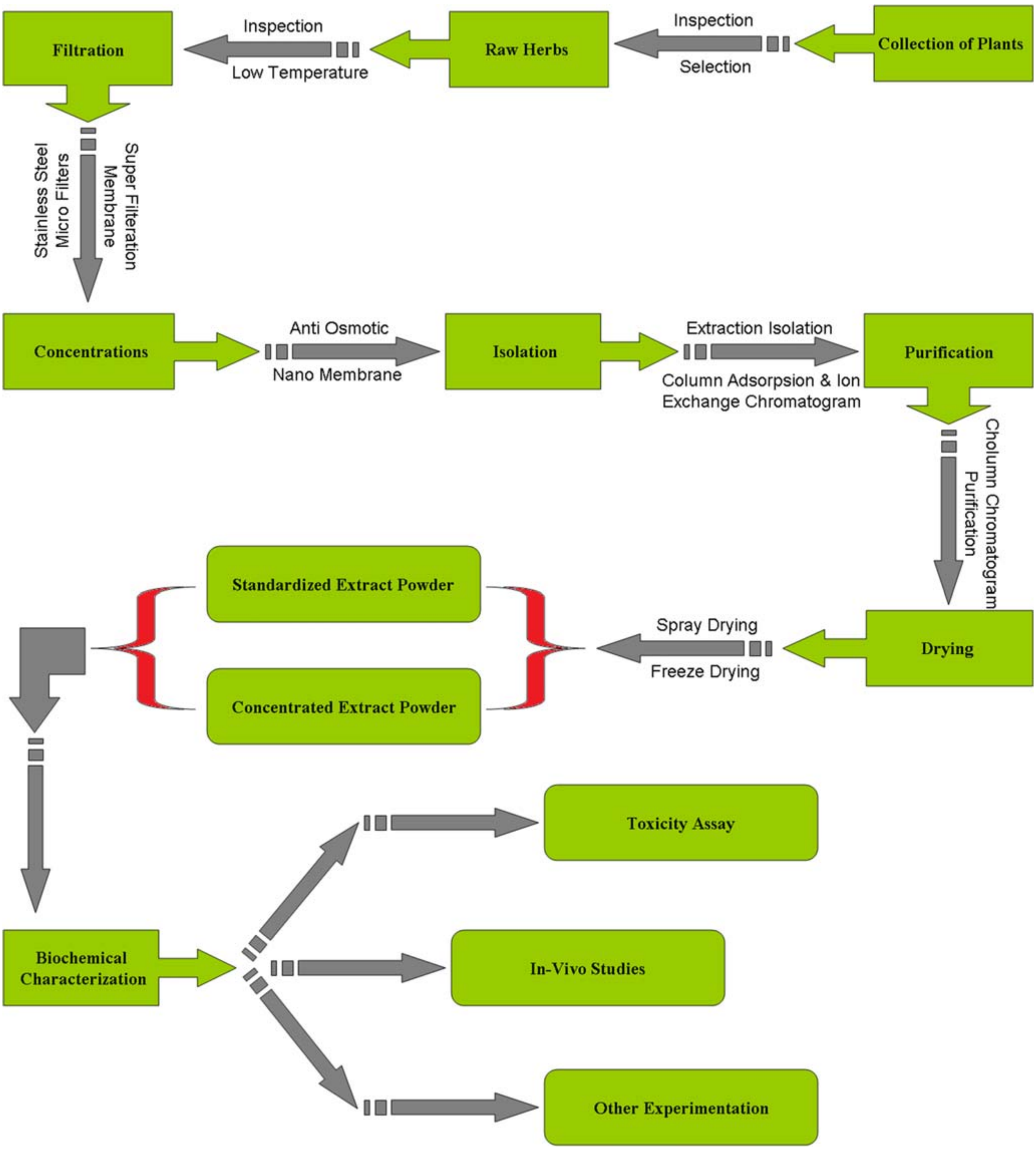

Fig. 3 Standard procedure for preparation of plant extracts

identify a clear difference between both synthetic and botanical products. Awareness campaigns about the khapra beetle damage, biology, ecology, and importance of plant extracts should also be run within farmer communities and other stake-holders so that our ecosystem may be saved from harmful chemicals application against target insects.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest.

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