Science Letters ISSN 2345-5463 – An International Triannually Journal

Review Article
August 2017 | Volume 5 | Issue 2 | Pages 105-114

ARTICLE INFO

Received
April 07, 2017
Accepted
June 25, 2017
Published
August 15, 2017

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Keywords
Stored products
Insect
Pest
Insecticides
Resistance

How to Cite
Islam W. Eco-friendly approaches for the management of red flour beetle: *Tribolium castaneum* (Herbst). Sci Lett 2017; 5(2):105-114.

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Eco-Friendly Approaches for the Management of Red Flour Beetle: *Tribolium castaneum* (Herbst)

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Abstract

Food security is primarily dependent on proper storage and protection of stored grain commodities all over the world. The stored grain commodities face the constant attack of pests. Among those, red flour beetle, *Tribolium castaneum* (Herbst), is one of the leading causes regarding damage to commodities as the pest can survive in diverse climates globally. Preferable management of the particular pest in most of the countries is done via utilization of synthetic chemicals, but keeping in mind the devastating negative effects of these chemicals on human health and surrounding ecosystem, the need of time is to find eco-friendly approaches for this purpose. In this regard, phyto-extracts offer a safe and environment-friendly alternative. This review focuses on the success stories of botanical use against red flour beetle by summarizing the aspects from conventional to modern approaches. In context to it, different life stages of insect starting from egg laying to adult development have also been mentioned. The review focuses on the recent research conducted for the evaluation of phyto-derivatives against red flour beetle in the 21st century. The review sums up by including some limitations of usage of phyto-extracts and sheds lights by hoping that the future pesticides will be safer, economical and least toxic to human beings and the planet's ecosystem.

Introduction

Agricultural stored products are attacked by more than 20000 field insects, including 600 species of beetles, 70 species of moths and about 355 species of mites causing quantitative and qualitative losses [1, 2]. The losses are more prominent in developing countries because of bad sanitary conditions during procurement, transportation and storage; leaky and poorly maintained godowns [3, 4]. Worldwide, 10-20% of the stored cereal grains are estimated to be lost through insect infestation [5-8]. The amount of damage in quality and quantity and health hazards due to insect infestation when converted into monetary concerns may run into millions of rupees to Indian national exchequer [2]. Among the insect species causing infestations and serious damage to stored commodities, *T. castaneum* (Herbst), is one of the major pests [9]. According to the estimation of Phillips and Throne [10], the particular pest causes 9% losses to stored grains in developed countries, while more than 20% losses are recorded in developing countries worldwide. Previously, it was thought that neither larvae nor adults could generally damage sound grains and they don't feed on grains which had already been damaged by other pests [11]. But, later, Boyer et al. [12] described that almost all developmental stages of insect cause losses to stored commodities by some aspects and quickly are able to adapt the stored grain environment because of having high fecundity rates and relative longevity. Furthermore, tropical conditions highly favor the growth and development of this particular insect [13]. Sallam [14] has categorized the insect as the most common secondary pests of all stored agriculture commodities in granaries and stores worldwide.

The management of stored grain insects is dependent upon synthetic insecticides particularly developing countries which are still testing various insecticides against the stored grain pests [15]. But regular utilization of insecticides has resulted in resistance among the insects against phosphine and other insecticides at different development stages [16, 17]. Furthermore, increasing the cost of insecticides, hazardous handling, residual effects and detrimental effects on human beings and environmental are also worth notable [18-20]. The insect has become famous as it has well-documented reputation regarding its developed resistance to all the synthetic chemicals and fumigants, which are used for its management [21]. According to Whalon et al. [22], *T. castaneum* has been ranked 19th among the top 20 most insecticide resistant arthropods by recording 132 insecticide resistance reported cases. All this clearly illustrates that alternatives having the potential to replace the highly toxic chemicals must be found. In this case, the trend is towards the use of botanical extracts having insecticidal properties and they are relatively cheaper than the synthetic insecticides [19-23]. A number of plants have been reported having bioactive metabolites showing repellent and toxic properties on a wide range of insect pests [24-26]. For this purpose, many plant products have been evaluated against different stored grain pests [27]. The use of botanical extracts as insecticides is very auspicious due to their diverse advantages like highly effective, convenient, inexpensive, and safe for human beings and the environment [28]. Many of the plants have been reported recently which showed insecticidal potential against the red flour beetle [29-34]. Keeping the view of the potential of medicinal plants, the review formulates the use of eco-friendly and relatively cheaper ways that can be used to manage the red flour beetle.

Morphology and biology of red flour beetle

T. castaneum, commonly known as the red flour beetle is a major stored grain pest and found in granaries of wheat, cereals, beans, pasta, crackers, mixed cake, dried flowers and pet food, seeds, chocolate, meal, spices, nuts and even in museum dried artistic specimens [35]. The insect is 3.5 mm long reddish brown beetle. The beetle can survive up to three years of age as an adult and is regarded as a sedentary insect. The insect has the ability to disperse via flight up to considerable long distances [36]. The particular beetle has a close resemblance to confused flour beetle except it has three defining clubs at the end of each antenna. Its antennae are club type with the inclusion of three segments. The beetle has a curvy thorax. Females show polyandrous mating behavior and researchers explain that polyandry helps in conserving the fertility, thus assuring greater numbers in progeny [37, 38]. Adult females have greater survivability and can live up to three years while they have laying capacity to lay 400-500 sticky, clear white eggs. These eggs can hatch within 1-2 weeks. Its larvae are smaller in size (4-5 mm long), cylindrical, with brownish white color leading up to 5-12 installs. The particular larvae can be distinguished from other species as they have two pointed ends bossy segmented. The beetle can produce 4-5 generations in a year under favorable conditions (Fig. 1).

Fig. 1 Life cycle of red flour beetle.

Increasing insecticide resistance in red flour beetle

Global management of all the insect pests is now under constant stress as the evolution in insects has demonstrated the insecticide resistance [22, 39]. Talking about the red flour beetle, it is particularly important that the pest has acquired resistance to almost all the various categories of insecticides and fumigants worldwide (Fig. 2) [21]. The pest has been graded at number 19 among the top 20 resistant insects [22]. Including red flour beetle, more than one hundred and twenty pests were reported to be resistant against malathian [40]. Malathion resistance has been reported all over the worlds and in developing zones; the resistance had been increased 56 folds till 20th century [41, 42]. Field studies have exhibited that T. *castaneum* strain QTC279 of red flour beetle acquires immunity against deltamethrin which is actually attained via six up regulatory P450 inhibitors [43]. To clarify the picture, further studies exploited that among all these inhibitors, T. *castaneum* gene CYP6BQ9 was involved in playing a major role in acquiring resistance against deltamethrin while other three inhibitors CYP6BQ11, CYP6BQ8 and CYP6BQ 10 were showing a little involvement in this process [44]. Similar studies were carried out to find the inhibitors in Georgia-1 strain involved in acquiring resistance to deltamathrin by using expressional profiling mechanism [45].

Another most used mechanism in coping the red flour beetle used worldwide involves using the phosphine gas as it is relatively cheap and easy to use [46-48]. But again the persistent problem is that the pest has gained resistance to it and the method is no more effective [9, 48-53]. Almost all the commercial storage granaries receive fumigation twice or thrice a year due to which two strains that are particularly resistant against phosphine have been recognized which carry two new gene loci, i.e., tc_rph1 and tc_rph2 [48, 52]. Further studies revealed that dehydrogenase and dihydrolipoamide enzymes play a great role in phosphine resistance in red flour beetle [54]. The involvement of enzymes in resistance mechanism against phosphine was monitored via molecular diagnostic tools [55].

Eco-friendly approaches to manage red flour beetle

Regular utilization of insecticides has resulted in resistance among the insects against phosphine and other insecticides at different development stages [16, 17]. Furthermore, increased costs of insecticides, hazardous handling, residual effects and detrimental effects on human beings and the environment are also worth notable [18-20]. So keeping in mind the insecticide resistance in the red flour beetle and harmful chemical aspects, eco-friendly approaches must be followed to manage the target pest. These approaches may involve biological, physical and ecological approaches [56]. Furthermore, the evolving trends of using botanical derivatives can be included as a most precious, cheaper and eco-friendly method to manage the red flour beetle.

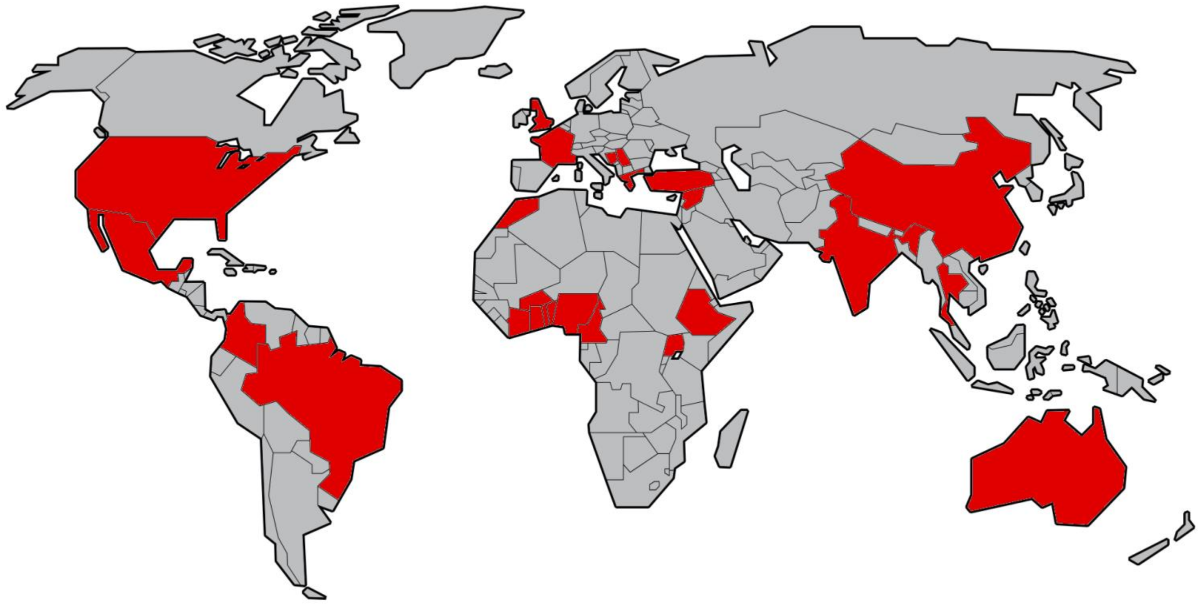

Fig. 2 Worldwide insecticide resistance in red flour beetle. Red color depicts the countries/areas where red flour beetle is considered to be resistant to insecticides and fumigants.

Biological approaches

Viable organisms regarding biological management methods include bacteria, mycoflora, viral strains, predators and parasitoids which are considered natural and eco-friendly and they already exist in our ecosystem. But so far the successful organisms only include bacteria naming *Bacillus thuringiensis* Berliner against the red flour beetle [57]. Moreover, *Trichogramma* species were evaluated in the early 21st century in Australia [58]. As the stored commodities need acute management and other biological agents may also have some negative impacts upon stored commodities so biological management of red flour beetle remained suppressed.

Physical and ecological management

It involves the usage of particle films having kaolinite dust against red flour beetle [59]. Activated silica carrying inert dust was traditionally used in developing countries for the management of red flour beetle in storage granaries [60]. Similarly, aero gels of silica and diatomaceous earth have inhibitory effects on cuticle lipids of the beetle [61]. Another conventional and rational approach that is common at household level involves the solar heating of stored commodities in tropical, arid and semi-arid areas in South East Asia, which disinfects the grains as well as kills the red flour beetle eggs and larvae [62].

Botanical insecticides

From the start of the 21st century, researchers are looking towards plants to find safer, cheaper and locally available botanical derivatives for the management of red flour beetle. Recently, scientists reported the potential of a large number of botanically derived materials against red flour beetle [29-34]. The use of plant materials as traditional protectants of stored products is an old practice used all over the world [63]. The protection of stored products generally involves mixing grains with plant based protectants [64]. The plants studied during the last 20 years have inferred that neem *(Azadirachta indica)* extracts and its compounds have proved best for the control of insect pests and pathogens as well [65]. Neem provides better control of the larvae at their different developmental stages, particularly soon after emergence from eggs, while the mid stage instars and late instars are not affected much [66]. Neem has no adverse effect on the predators, including lady beetles, lacewings, spiders and predatory bugs [67]. The insecticidal activities of neem against different insect pests have also been

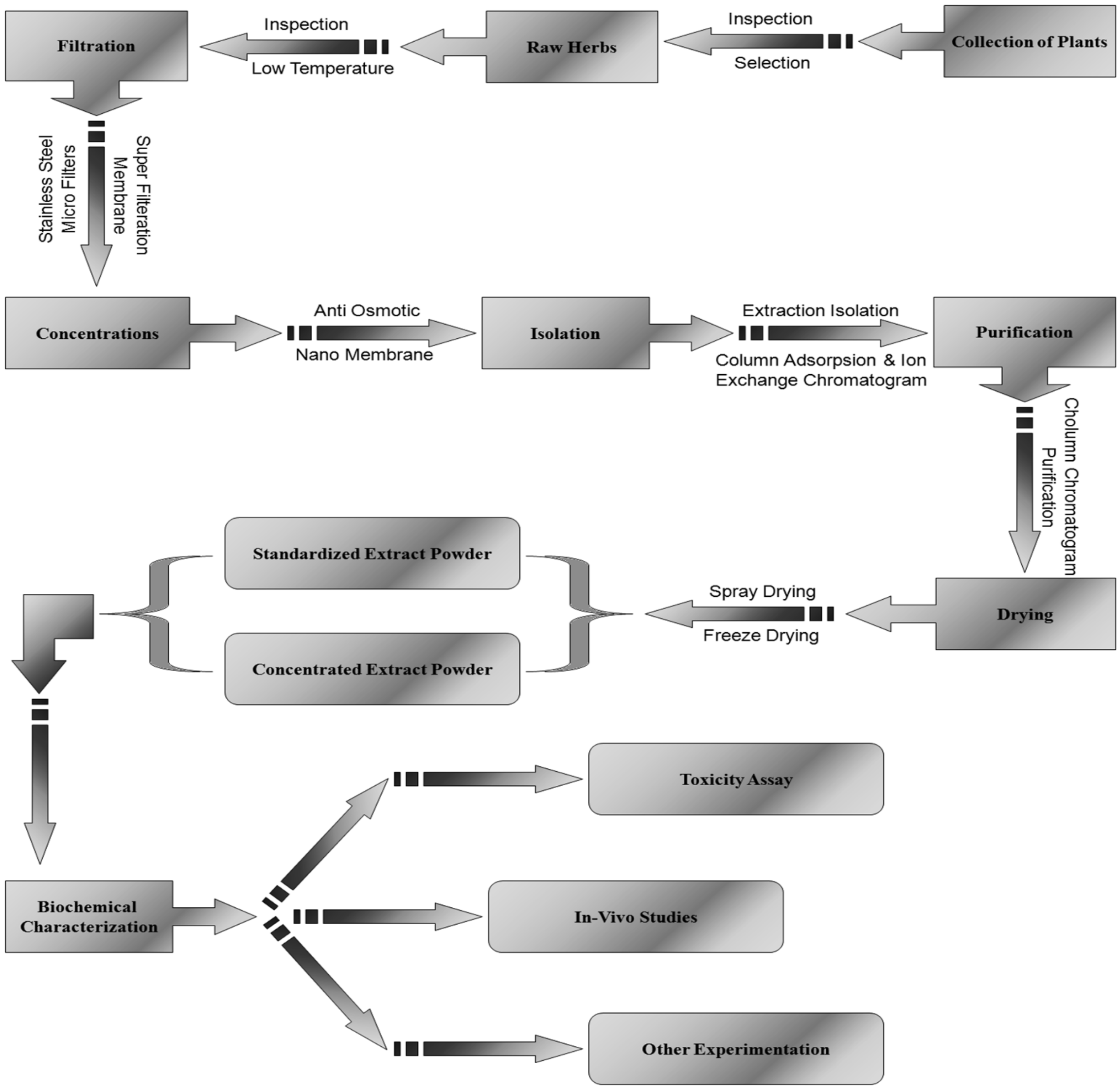

Fig. 3 Schematic diagram for prescribed method to prepare plant extracts by the International Federation of Organic Agriculture Movements (2005).

evaluated by Sharma [68] and Khattak et al. [69]. Sahayaraj and Paulraj [70] found the leaf extract of neem as the most effective repellent, against *T. castaneum* on groundnut seeds. Boeke et al. [71] made safety assessments for various neem derived preparations and compared the outcomes with the ingestion of residues on the food, treated with neem preparations. The neem crisma got stronger and stronger as researchers from different parts of the world tested the various aspects and parts of the plant against red flour beetle and recorded the success of neem against the red flour beetle without having any adverse effects on its surroundings [32, 34,71-82].

Different plant parts of *A. indica* that may include seeds, leaves, decoctions, extracts stem parts proven successful in inhibiting various growth stages of the red flour beetle. The inhibitory effects may include repellency, inhibiting fecundity, reduction in oviposition, reduced fertility and fertilization. Similarly, the other important aspect that draws the attention of the researchers was the locally available medicinal herbs which were already being used for curing some human and animal infections. *Polygonum hydropiper, Vitex negundo, Aphanamixis polystachya*, *Tagetes erecta* and *Cynodon dactylon* are locally famous herbs in Bangladesh so they were

Table 1 An updated list of the phyto derivatives evaluated time to time and declared successful to manage red flour beetle**.**

Year	Protectant plants against red flour beetle	References
2000	*Polygonum hydropiper, Vitex negundo, Aphanamixis polystachya*	[83]
2001	*Chenopodium ambrosioides*	[64]
2003	*Azadirachta indica*	[72]
2003	*Azadirachta indica*	[73]
2004	*Azadirachta indica*	[71]
2004	*Azadirachta indica*	[74]
2005	*Azadirachta indica, Tagetes erecta, Cynodon dactylon*	[75]
2005	*Eucalyptus, Ricinus communis, Azadirachta indica, Saraca indica, Bougainvillea glabra*	[76]
2006	*Azadirachta indica*	[77]
2006	*Azadirachta indica*	[78]
2007	*Trachyspermum ammi (Umbelliferae), Anethum graveolens (Umbelliferae), Nigella sativa (Ranunculaceae)*	[95]
2007	*Artemisia argyi, Dictamnus dasycarpus, Evodia rutaecarpa, Litsea cubeba, Narcissus tazetta var. chinensis, Polygonum aviculare, Rhododendron molle, Sophora flavescens, Stemona sessilifolia, Tripterygium wilfordii, Torreya grandis*	[96]
2007	*Hyptis spicigera L. (Lamiaceae), Annona senegalensis Pers. (Annonaceae) Lippia rugosa L. (Verbenaceae)*	[97]
2007	*Bishkatali plant*	[98]
2007	*Piper nigrum L.*	[27]
2008	*Chrysanthemum coronarium, C. macrotum, C. myconis, C. fuscatum, C. paludosum, C. trifurcatum, C. grandiflorum*	[99]
2009	*Zanthoxylum rhetsa, Melia sempervirens, Barringtonia acutangula, Pongamia pinnata, Swietenia mahagoni, Azadirachta indica*	[79]
2009	*Syzygium aromaticum , Eucalyptus camaldulensis, Cinnamomum verum, Elettaria cardamomum*	[94]
2009	*Prosopis juliflora, Argemone mexicana, Thomasia purpurea*	[100]
2010	*Citrus reticulate*	[86]
2010	*Punica granatum, Murraya koenigii*	[101]
2010	*Murraya exotica*	[88]
2012	*Anethum graveolens*	[102]
2012	*Azadirachta indica , Nerium oleander*	[80]
2012	*Eucalyptus globules, Ocimum basilicum*	[84]
2012	*Azadirachta indica A. Juss, Citrullus colocynthis*	[81]
2013	*Citrus reticulate, Psidium guajava*	[87]
2013	*Murraya exotica, Murraya koenigii, Nicotina tobaccum*	[89]
2013	*Azadirachta indica*	[82]
2014	*Eucalyptus camaldulensis, E. viminalis, E. microtheca, E. grandis, E. sargentii*	[85]
2014	*Allium sativum*	[103]
2014	*Nerium oleander L, Damas Conocarpus*	[104]
2014	*Nigella sativa, Syzygium aromaticum, Trachyspermum ammi*	[30]
2015	*Citrus jambhiri, C. reticulate, C. reticulate, C. sinensis)*	[31]
2015	*Azadirachta indica, Lawsonia inermis, Annona senegalensis, Hyptis suaveolens*	[32]
2015	*Toddalia asiatica (L.)*	[33]
2016	*Piper nigrum L., Ricinus communis L., Eucalyptus camaldulensis, Cymbopogon citratus Staph. Azadirachta indica Azadirachta Juss, Mentha piperita L., Capsicum annuum L.*	[34]
2017	*Fumeria indica,Viola odorata and Linium ustatisum*	[105]

tested against the red flour beetle for their inhibitory effects and documented successful [75, 83]. In the context of the local and widely available plant in south East Asia is eucalyptus whose large number of species are collaborating with the medicinal uses. The particular plant has shown repellent and inhibitory effects against red flour beetle [34, 76, 84, 85]. Citrus peel, seeds, seed extracts and decoctions include some acidic properties that repel the adult red flour beetle when used at higher concentration levels [31, 86, 87]. In China, the medicinal qualities of *Muraya* species are not under the pillow and the plant is famous in use of recovery of various mammalian diseases. The target plant also exhibited the toxic effects against the red flour beetle [88, 89]. With the increasing awareness about the health hazards of chemicals [90-93], the interest of researchers to evaluate botanicals against red flour beetle got a huge boost up. Therefore, the list of botanicals goes on and on as a large number of botanical derivatives have shown their positive results against the red flour beetle growth. An updated list of the botanicals that have been regarded as successful against the target pest is presented in Table 1.

Although the phytochemicals or plant derived materials have been proven a great success against the red flour beetle, but still there are some obstacles that are needed to be removed for a better future. For example, when we talk about the plant materials, firstly our intention goes towards making the plant products at home, which sometimes proves hazardous because of lack of experience and lack of technical knowledge [106]. A technical and highly careful route is taken for the extraction of phyto derivatives, which should be followed strictly for making the quality phyto derived products (Fig. 3). Similarly, the high variability in the genetics of plants and seasonal availability of these plants sometimes reduces their application round the clock. Furthermore, no mechanized means of collection, storage, processing and packaging of these plant products are common, which leads to the deterioration of these products faster than the others [106]. Although, the criteria for commercialization of botanical extracts for organic agriculture, farming was introduced by the International Federation of Organic Agriculture Movements [107], but still proper commercialization has not been done regarding botanical derivatives that mean we don't have proper laboratories to test the available commercial plant extracts in the market for their purity and efficacy [108]. Some ethical and religious aspects consider the use of some botanicals harmful for human beings as they think residual effects of some plant extracts may act as spermicide [109]. Due to the lack of technical knowledge, another aspect that remains suppressed is the toxicity of phyto extracts to the mammalians, and the other food chain consumed by human beings. For example, rotenone derived from various plants of genus *Derris*, *Lonchocarpus* and *Terphrosia* is most toxic to mammals, fish and human beings as its lethal dose 50 ranges between 132-1500 mg/kg. Due to this, it is a suspected cause of Parkinson disease [110]. Lastly and mainly, the awareness and lack of knowledge are the major factors that reduce their usage against the red flour beetle.

Conclusions and future prospects

Dependency on the chemical management of red flour beetle is resulting in enormous problems that include residual toxicity, human health hazards and acute resistance in the pest. So the eco-friendly means are required to be insured for the management of the pest and neutralizing all the other factors. All other methods other than the chemical usage have their equal importance such as physically exposing the grains to the sun heat traditionally acquires an importance while the botanical derivatives that may involve the derived essential oils, decoctions, powders or different plant parts are the recent trends in the management of red flour beetle. These plant derived materials have been evaluated by dozens of times recently by the researchers against different life stages of the target insect. Among these, the neem plant that is a traditional medicinal plant proven as the most successful as different plant parts have been evaluated again and again recently. But sometimes, the environmental stresses may not allow the single method to be the most reliable against the red flour beetle so, by and large, using all possible means involving different available eco-friendly tactics can help in efficient management of the pest.

Conflicts of Interests

The author has no conflicts of interest.

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