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# Natural plant products - As protectant during grain storage: A review

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**Abstract**

Since 1960s, natural plant products have been utilized in controlling the insect-pests in the bulk storages. Grain protection gained economic importance from various insect-pest infestations during storage. Integrated pest management is one of the widely adopted pests control strategies that involves various contact and residual insecticides in addition to the fumigants. Today's major concerns are residue problem and health risks to the consumers that forced synthetic pyrethroids either banned or restricted use. To the most of currently available fumigants and synthetic chemicals pests have developed resistance. Such constraints paved a way to use need based plant derived products as alternatives to current chemical pesticides. The reports have shown plant-derived products to possess great insecticidal potential. Moreover, the biosafety studies of various plant based insecticides should be carried out to ascertain their toxic effects on human, animals and agricultural crops. This paper includes various aspects like storage losses by insect pests, side effects of pesticides as grain protectants, plant products as alternative to synthetic compounds, classification of plant based compounds, powder and oil formulations as grain protectants.

**Keywords:** Protectant, natural, plant products, grain, storage

## 1. Introduction

More than 20,000 species of field and storage pests have been reported to destroy about one-third of the global food production annually, valued over $100 billion among which highest losses (43 % of the potential production) happen in the developing Asian countries [1, 2]. Pingale [3]) determined about 83.0 per cent wheat grain loss during 360 days of its storage period. The quantitative and qualitative losses to the stored grains and product by insect pests range from 20 to 30 per cent in the tropical while 5-10 per cent in the temperate zone [4]. Of 250 million tonnes food grain production in India during 2010-2011, about 20-25 per cent food grains were damaged by stored grain insect pests [5].

The major pests of stored grain and pulses of the Indian subcontinent have been categorized into two groups namely, primary pests which are capable of penetrating and infesting intact kernel of grain and have immature stages develop within kernel of grain, i.e., rice weevil, *Sitophilus oryzae* (L.), lesser grain borer, *Rhyzopertha dominica* (F.), granary weevil, *Sitophilus granaries* (L.), *Khapra* beetle, *Trogoderma granarium* (Everts) and the pulse beetle *Callosobruchus chinensis* (L.), and the secondary pests which cannot initiate infestation and infest the whole grain but feed on as broken kernels, debris, high moisture weed seeds, and grain damaged by primary pests, viz., rust-red flour beetle, *Tribolium castaneum* (Herbst), rusty grain beetle, *Cryptolestes ferrugineus* (L.), sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), mites, *Liposcelis corrodens*. Generally, the immature stages of the secondary pest species are found external to the grain.

## 2. Stored grain losses by insect pests

A heavy per cent infestation of grains due to various insect pests during storage causes loss of germination capacity of seeds making them unfit for human consumption. In a survey, Rehman [6] recorded 2.5 per cent losses of total grain production in Punjab. Hafiz and Hussain [7] reported 10.8 per cent losses due to insects, rats and moulds in Pakistan. Koura and Holfany [8] reported 24.2-47.8 per cent stored grain losses in silos/bins. The weight loss in wheat during storage was evaluated due to *R. dominica* [9] and *S. garanarius* [10]. Girish *et al.* [11] reported 7.0-22.0 per cent weight loss in wheat due to various storage pests within 180 days of its storage in Uttar Pradesh (India).

Adams [12] reported up to 18.30 per cent of substantial losses in the stored grains by *S. oryzae*. Campbell and Sinha [13] reported up to 60 per cent weight loss to occur with exposure of a single wheat grain kernal to the *R. dominica*. Khan and Cheema [14] determined 2.32 per cent weight loss in stored wheat in some parts of Punjab (Pakistan). Simwat and Chahal [15] recorded an increase of 2.80 to 6.37 per cent adult population of *S. oryzae* and *Tribolium* spp. on wheat during its six months storage period. Mohammad [16] reported significantly high grain weight loss (10.0 to15.0%) due to various stored grain insect pests on wheat. Khan and Kulachi [17] registered 3.40 and 6.53 per cent wheat losses, respectively, in Count and Weigh and Thousand Grain Method. They also recorded 1.93 per cent average grain infestation due to *R. dominica* and other stored grain insect pests. Talukder *et al.* [18] estimated nearly one-third of the world's food production to be destroyed by more than 2,000 field and storage pest species. The poor status of storage has resulted up to 0.2-30.0 per cent grain losses due to various insect pests [19]. The insect-pests have been considered to cause damage to the stored grains and grain products which may range from 5.0-10.0 per cent in the temperate whereas 20.0-30.0 per cent in the tropical zones [20]. Rajashekar *et al.* [21] reported about 20-25 per cent of the total food grain production (250 mt) to be damaged by various stored grain insect pests in India. Ahmedani *et al.* [22] reported an initial infestation of grains with only 10 pairs of *Khapra* beetle larvae to cause more than 20.0 per cent weight loss in stored wheat seeds after 6 months of its natural storage.

## 3. Pesticide adverse effects as grain protectant

Synthetic insecticides and various fumigants have been extensively used since 1960s in stored grains for the control of storage pests. However, their uninterrupted and indiscriminate use has not only led to the resistance development [23] but also accumulation of toxic residues on food grains has resulted into health hazards in human. Champ [24] has reported a widespread resistance development to almost all groups of pesticides for protection of stored grains and other stored food by major insect pests. The development of pest resistance to one or more chemical insecticides was found in about 500 species of insect pests and mites [25]. Methyl bromide has been found responsible to deplete the ozone layer and therefore, its use has got banned in several developed nations, and the developing countries have also committed its restricted use by 20 per cent in 2005 and phase it out in 2015. Similarly, widespread resistance development to Malathion by several storage pests has been reported in countries such as USA, Australia and Canada [26, 27]. The insecticidal resistance is one of the emerging problems in stored grains protection. The control failures from high levels of phosphine resistance in some countries including India and Australia resulted to ban, restrict or replace several insecticides by plant based pesticides [28,29, 30]. Although the chemical insecticides are effective but their repeated use has led to several problems like residual toxicity, environmental pollution and adverse effects on food and humans besides increasing cost of their application [31,32,33,34]. Moreover, the poor storage facilities at traditional levels in the developing nations were considered unsuitable for effective conventional chemical control, as most of the storage types were open to re-infestation by insect-pests [35]. Stored grain resistance in relation to population build up of various insect-pests relied upon factors such as moisture content [36], hardness of grain [37, 38], the chemical composition of a variety and insect species. The new classes of naturally occurring insecticides that might be environmentally safe and compatible with newer pest control approaches is the focus of today's research in several laboratories around the world [39]. Worldwide reports have shown that the plant derived powder or oil mixed stored grains not only have impact on reduced oviposition rate and suppressed adult emergence of *R. dominica* and *S. oryzae* but also on reduced seed damage rates [40, 41]. Present paper involves a detailed review of several studies on use of plant products for prevention of stored grains/ food commodities from various pests.

## 4. Plant products as alternative to synthetic compounds

The development of insecticidal resistance in various insects and their residual effects are some of the serious threats. The biosphere contamination is associated with the large-scale use of broad spectrum chemicals especially the synthetic pyrethroids that has led to the necessity for the most effective and selective biodegradable chemicals. Chachoria *et al.* [42] revealed *neem* kernel powder at 1.0-2.0 per cent to be the most effective protectant against *C. chinensis* and *C. maculatus* than ethylene dibromide- carbon tetrachloride (ED-CT) in stored maize. They also reported *neem* kernel powder at 2.0 per cent as the highly effective grain protectant based on no grain damage by these insects on gram and pigeon pea. No progeny emergence of *C. maculatus* and *C. chinensis* even after 360 DAT on treated lentil seeds (*Lens culinaris*) was attributed to the oviposition inhibition [43]. Rajendaran [44] reported that *neem* seed kernel powder at 2.0 per cent when admixed to the pigeon pea and mung bean gave protection against *C. maculatus*. Schmutterer [45] reported *neem* seed kernel powder at 1.0-2.0 per cent as the best based on reduced pest infestation on cereals for considerable storage period. Mohan *et al.* [46] reported that maize treated with deoiled *neem* seed kernel powder at 0.1 per cent had no grain damage by *S. oryzae*. Singh *et al.* [47] reported *neem* seed kernel powder at 0.5 per cent to be the most effective to provide cent percent protection against *C. maculatus* in green gram. The awareness about pesticidal resistance, environmental pollution and health hazardous effects of the broad spectrum pesticides has created a worldwide human interest to develop some alternative strategies, including the discovery of newer chemical approaches [48, 49]. The new chemical approaches required some entirely different standards like their pest specificity, nonphytotoxic nature, safety to the mammals, less prone to pesticide resistance, relatively cost effective and their easy availability [50]. The re-examination of century old traditional practices was required for protecting stored products using plant materials known to resist the insect pest incidence [51, 52, 53]. Among the various indigenous plants, Indian *neem* is a well-known example and its different components viz., leaves, crushed seeds, powdered fruits, oil, and so forth have been found very effective against various stored grain insect pests [54, 55]. Jamil *et al.* [56] reported crude extract from *neem* as effective on the basis of reduced insect development, larval and adult mortality with its cuticle melanisation. Yadava and Bhatnagar [57] reported dried leaves of *neem* as effective protectant against insects when mixed with stored grains. Azadirachtin is an active principle from the *neem* plant and is an effective grain protectant to control the insect pest infestation [58]. Liu *et al.* [59] have reported various products from *Dictamnus dasycarpus* to inhibit the development of eggs and immature stages of stored grain pests inside the grain kernel. Azadirachtin is derived from the *neem* tree grown in India and Africa [60]. The research workers are also in an effort to seek more new classes of naturally available insecticides which might be compatible to the newer pest management strategies [61]. The several natural occurring plant products possess broad spectrum activity against a large number of insects including stored grain insect pests, aphids, caterpillars and mealy bugs [62]. Rajashekar *et al.* [63] reported that root powder extracts of *Decalepis hamiltonii* when admixed to the stored grains gave protection against various stored grain insect pests. Devi and Devi [64] tested insecticidal potential and antiovipositional properties of eighteen commercial botanical insecticides against *S. oryzae* and reported Azadirachtin extremely less toxic to the mammals with least toxic effect (LD50 of 13,000 mg/kg) and was an contact poison besides having some systemic activity in the plant foliage with its general safety to the beneficial insects and mites. Singh [65] tested various powder formulations of neem, castor, dharek, and oil formulations of neem, eucalyptus and castor and found neem powder and oil formulations as the most effective against *R. dominica* and *S. oryzae* on stored.

## 5. Classification of botanicals

Since 1960s, efforts have been made to sharpen the focus on the toxicant and grain protectant activity of essential oils, extracts and their constituents. Jacobson [66] observed the plant families like Annonaceae, Asteraceae, Canellaceae, Labiatae, Meliaceae and Rutaceae as most promising natural grain protectants, in general, and conventionally classified the plant derived compounds into six different groups viz., insect repellents, feeding deterrents, insect toxicants, growth inhibitors, chemosterilants, and attractants based on the physiological effects in the insects. The use of various plant parts like leaf, bark, seed powder, or oil extracts as admixture to the stored grains have resulted into in reduced rates of seed damage, reduced insect oviposition and suppression of adult emergence in various stored grain insect pests [67, 68, 69, 70, 71].

### i). Natural grain protectants

Plant derived products are used as powder formulations or liquid or oil formulations.

### a). Powder formulations

Jotwani and Sircar [72] were the first in India to test that *neem* kernel powder mixed with grains at 1.0 or 2.0 per cent protected treated wheat grains against *R. dominica* and *S. oryzae* up to 370 and 320 days, respectively. Deshpande [73] reported seed kernel powder at 2 per cent as highly effective to give protection of sorghum grains from feeding damage by *S. oryzae*. Pradhan and Jotwani [74] reported that *neem* kernel powder when admixed to the wheat gave effective protection from infestation by *R. dominica, S. oryzae* and *Khapra* beetle at 300, 270 and 360 DAT, respectively. Atwal and Sandhu [75] revealed the drupes of *M. azadirach* as very effective against *T. castaneum* when admixed to the wheat over the BHC (0.25%). Saramma and Verma [76] evaluated three plant powders viz., *dharek* kernel powder, *neem* kernel powder and costus root powder at 0.5, 1.0 and 2.0 per cent (w/w) against *T. granarium* on stored wheat and revealed *neem* kernel powder as the most effective to give promising results followed by costus root powder and *dharek* kernel powder. Jilani and Malik [77] reported *dharek* powder to be less effective against *R. dominica* as compared to the *neem* powder on wheat. Girish and Jain [78] reported *neem* seed powder at 1.0 and 2.0 per cent as most effective to reduce oviposition of adult *S. oryzae*. Subramaniam [79] reported *neem* kernel powder at 2.0 per cent as more effective against *S. oryzae* on stored hybrid sorghum. Siddig [80] in their studies on efficacy and persistence of *neem* seed powder at 1.0, 2.0 and 4.0 per cent (w/w) in stored wheat against *Trogoderma granarium* (Everts) reported it as the highly effective to reduce the wheat grain damage by *T. granarium* for a period of 7 to 16 months. Pereira and Wohlgemuth [81] reported *neem* kernel powder at 2.0 per cent (v/w) as the most effective grain protectant against *S. oryzae, T. castaneum, R. dominica* and pulse beetle, *Callosobruchus chinensis* (Linnaeus).The *neem* leaf powder at 5.0 per cent was reported to be very effective against *S. oryzae* in the stored wheat at 90 DAT [82]. Akou-Edi [83] reported *neem* kernel powder at 3.0 per cent to be effective for repellency of *S. oryzae* in stored paddy. Jilani and Haq [84] in their investigations on some indigenous plant materials as grain protectants against various stored grain insect pests, reported *neem* seed kernel powder at 0.25-1.00 per cent (w/w) as the highly effective based on reduced population of *R. dominica* on wheat during storage. Ketkar [85] in their studies on use of tree derived non-edible oils as surface protectants revealed *neem* kernel powder at 0.5 and 1.0-2.0 per cent (w/w) effective to reduce population and oviposition rate of *S. oryzae* and *R. dominica*, respectively, in stored wheat and paddy. Seck *et al.* [86] studied the protection of stored cowpeas by using powders from dry *neem* leaves and *neem* kernel against *C maculatus* and revealed powder from dry *neem* leaves effective to give better results as compared to the fresh *neem* leaves. They also reported the dipping of cowpeas in aqueous solution of dry seeds effective to reduce fecundity and oviposition of the pest. Dakshinamurthy and Goel [87] revealed *neem* leaf powder at 0.5 per cent (w/w) as most effective to prevent the grain infestation by *S. oryzae* and *R. dominica* on stored wheat for up to 360 DAT. They also reported higher seed germination (89.5-91.5%) in the treated over the untreated control (80.75%). Jacob and Sheila [88] in their laboratory evaluation of powders from *Datura alba, Calotropis procera, Chromolaena odorata* and *neem* at 2.5 and 5.0 per cent against *R. dominica* on rice grains at $28^0$C temperature found all the treatments effective with significant reduction of number of adults emerging from the grains. Patel *et al.* [89] reported *neem* kernel powder at 5.0 per cent (w/w) DAT to be the most effective to reduce grain damage (2.55, 3.15 and 7.13%) due to *R. dominica* in the stored wheat over the untreated control (6.57, 13.60 and 24.71%), respectively, at 32, 64 and 96. Fatope *et al.* [90] evaluated various plant powders at 2.5, 5.0, 10.0 and 20.0 per cent (w/w) against maize weevil on wheat grains and found these as most effective to give better protection. Sharma [91] reported *neem* kernel powder at 2 per cent (w/w) as the most effective against *S. oryzae* on maize seeds at 15 DAT. Nazli [92] reported *neem* oil at 0.025, 0.05 or 0.10 per cent mixed with 2.5 ml acetone (v/w) effective to cause hindrance effect to the development of *R. dominica* and *S. oryzae* on wheat grains. Kalasagond [93] reported *neem* kernel powder at 0.8, 1.0, 1.2 and 1.4 per cent as effective to produce higher adult mortality in *S. oryzae* (25.00, 8.33, 8.33 and 6.66%), (43.33, 26.66, 25.00 and 8.33%), (51.66, 41.66, 35.00 and 10.00%) and (61.66, 53.33, 43.33 and 26.66%), respectively, over the untreated control (0.00, 0.00, 6.66 and 5.00%) at 60, 120, 180 and 240 DAT. Rama Rao and Sarangi [94] reported *neem* kernel powder at 5.0 per cent as most effective to cause 87.70 and 82.50 per cent adult mortality in *S. oryzae*, respectively, at 30 and 90 DAT. Sharma [95] reported *neem* kernel powder at 4.0 per cent (w/w) as highly effective based on good protection of maize grains from *S. oryzae* infestation for up to

150 DAT. Yadu *et al.* [96] in their studies on evaluation of *neem* kernel powder, *neem* leaf powder, eucalyptus leaf powder, sarifa leaf powder and lantana leaf powder at 1.0 and 2.0 per cent (w/w) for recording their adverse effects on the development of *S. cereaella* in stored maize and paddy, *neem* kernel powder was found to be the most effective as it registered less grain damage and adult emergence where as lantana leaf powder was the least effective. They also observed no seed germination impaired in any of the powder treatment. Sivasrinivasu [97] reported *neem* kernel powder at 5.0 per cent as effective to register cent percent adult mortality and no grain weight loss by *S. oryzae* in stored rice, respectively, at 7 and 90 DAT. Mahanti [98] reported *neem* kernel powder at 0.2 per cent (w/w) as the highly effective to inflict cent percent mortality in *S. oryzae* on maize seed at 10 DAT. Sunilkumar [99] reported *neem* kernel powder at 1.0 per cent as the most effective to inflict low grain damage over the untreated control, respectively, at 30 and 60 DAT. Kumawat [100] recorded no adult emergence, grain damage and weight loss due to *R. dominica* in the *neem* powder treated wheat grains for up to 90-270 DAT. He also recorded no adverse effect of *neem* powder on wheat seed germination for up to 270 days. Ileke and Bulus [101] reported the powders and extracts of *neem* and black pepper (*Piper guineense*) at 5.0, 10.0 and 20.0 per cent (w/w) as the most effective to cause cent percent mortality of *R. dominica* on wheat grains during storage within 4 DAT. Kemabonta and Falodu [102] revealed no significant difference in wheat seed germination in *neem* leaf powder and *neem* oil over the untreated control at 90 DAT. Arya and Tiwari [103] revealed *neem* leaf powder, jatropha seed powder, mustard oil, cow dung powder, cow dung ash powder and cow urine at 2.0 per cent as the effective to produce highest mortality, low adult emergence, grain damage and weight loss in *S.oryzae* on stored wheat. They registered higher seed germination and vigour index in both the treatments. Kakde *et al.* [104] reported minimum adult emergence of *R. dominica* in wheat grains treated with *neem* leaf powder at 2.0 per cent (1.33 adults) followed by *dharek* leaf powder (2.33 adults). The grain damage and weight loss they reported was, respectively, as lowest in *neem* leaf powder at 2.0 per cent (1.00 and 1.33%) which was followed by *dharek* leaf powder (6.67 and 1.66%). Mishra and Pandey [105] reported *neem* leaf powder at 1.0 per cent (w/w) as the most effective against *S. oryzae* based on low grain damage (5.36, 8.43 and 16.02%) and weight loss (5.36, 7.87 and 13.13%) over the untreated control with high grain damage (9.20, 18.55 and 29.60%) and weight loss (8.72, 14.40 and 20.99%) in stored wheat, respectively, at 30, 60 and 90 DAT. They also recorded higher seed germination (87.50, 85.00 and 81.00%) in *neem* treated samples over the untreated control (92.00, 71.25 and 54.37%), respectively, at 30, 60 and 90 DAT.

**b). Oil formulations**

Pereira and Wohlgemuth [106] reported *neem* oil at 1.0 per cent (v/w) as the highly effective grain protectant against stored grain insect pests like *R.dominica*, *S. oryzae, T. castaneum* and *C. chinensis*. Verma *et al.* [107] found oils and cakes of *neem*, castor and mustard to be effective to reduce the fecundity, hatching and adult emergence in *Sitotroga cerealella* (Olivier). Their studies recorded no adverse of all the oil treatments on seed viability. Ali *et al.* (1983) [108] reported *neem* oil at 0.5 per cent on gram seed as most effective on the basis of reduced fecundity and adult emergence with 55.0 per cent adult mortality in *C. chinensis* within 3 DAT. The admixing of *neem* oil at 0.2 per cent admixed to the gram was reported to reduce adult emergence of *C. maculatus* when adults were introduced 33 DAT [109]. Pandey *et al.* [110] reported various oils viz., *neem* oil, *neem* kernel powder, *neem* cake, *neem* leaves, *neem* flowers and babul gum at 0.1, 1.0, 5.0, 1.0, 0.5 and 1.0 per cent (w/w or w/v) as effective against *C. cephalonica* in stored wheat based on reduced developmental period, survival period, fecundity and fertility of the adults in the treated over the untreated control. They also reported no seed germination to be impaired in any of the plant products. Devakumar [111] reported a *neem* oil fraction as the potent fumigant and sterilant against pulse beetle. Babu *et al.* [112] reported *neem* and karanj oils at 0.25, 0.5 and 1.0 per cent as the most effective ones to reduce the fecundity in *C. chinensis* on green gram seed during storage. Kumari *et al.* [113] reported *neem* oil at 1.0 per cent as the highly effective against *C. chinensis* based on reduced adult emergence and grain damage in pea seeds during storage for up to 90 DAT. Singh and Mall [114] found a significant reduction of adult emergence in *S. oryzae* with castor, *neem*, mustard and linseed oils at 0.1 per cent (v/w) on stored wheat. Dey and Sarup [115] reported mustard, soybean, coconut, *neem*, groundnut, sesame and castor oils as highly effective based on significant reduction in the average population of *S. oryzae* in stored maize grains. Saxena and Singh [116] found significantly reduced adult longevity of *R. dominica* on stored wheat when treated with castor cake and mustard oil. Reddy *et al.* (1999) [117] applied four different plant oils viz., *neem*, karanj, mohua and palmolein (*Elaeis guineensis*) at 0.5 and 1.0 per cent (v/w) against *C. chinensis* on green gram and found *neem* oil at 1.0 per cent as the most effective based on its reduced oviposition rate and adult emergence followed by palmolein, karanj and mohua oils. These oils were also reported to cause a significant reduction in oviposition and adult emergence. Hassan [118] in studies on the effect of three plant oils viz., sesame, sunflower and castor oils at 0.5, 1.0 and 1.5 per cent (v/w) on the oviposition, hatchability, eclosion and population of *T. granarium* and *S. granarius* on stored wheat and sorghum recorded reduced oviposition, egg hatchability and adult eclosion of *T.granarium* in all the oil concentrations with no significant effect on seed germination. Bhargava and Meena [119] tested oils of castor, mustard, groundnut, sesamum, coconut and sunflower at 1.0 per cent (v/w) against *C. chinensis* in stored cowpea and revealed castor oil at 1.0 per cent as the most effective based on reduced oviposition (26.6 eggs/female), egg viability (61.7%) and adult emergence (85.0%) followed by mustard and groundnut oils. They recorded no adverse effect of plant oils on the seed germination for up to 150 DAT. Rahman *et al.* [120] evaluated leaf powders and extracts of Nishinda (*Vitex negunda*), eucalyptus, Bankalmi (*Ipomoea* sp.), ash of *babla* wood (*Acacia arabica*), *neem* oil, sesame and safflower against *S. granarius* on stored wheat and revealed *neem* oil at 0.25-1.0 per cent as most effective on the basis of reduced insect infestation, adult emergence, grain damage, weight loss and increased inhibition rate. Yadav *et al.* [121] evaluated different plant oils viz., *neem*, castor, karanj, lemongrass and eucalyptus oils at 0.1, 0.5 and 1.0 per cent (v/w) against *S. oryzae* in stored wheat and they reported *neem*, karanj, clove and lemongrass oils at 1.0 per cent as the most effective due to reduced fecundity, adult emergence, longevity, grain damage, weight loss and prolonged developmental period. Lal and Raj [122] in their studies revealed *neem*, eucalyptus, sunflower and castor oil at 0.1 and 0.3 per cent (v/w) as safest and most effective to minimize the incidence of *C. maculatus* on pigeon pea based on its reduced fecundity, adult emergence and delayed development. However, their investigations registered no adverse effect on seed germination for up to 120 DAT. Kumawat and Naga [123] reported low adult emergence of *R. dominica* in *neem* oil (4.7, 0.0 and 0.0 adults) followed by castor oil (7.3, 6.7 and 0.0 adults) and eucalyptus oil (13.3, 9.3 and 5.0 adults), respectively, at 0.1, 0.5 and 1.0 per cent over the untreated control (34.0%), low grain damage in *neem* oil (15.7, 9.3 and 0.0%) was followed by castor oil (23.3, 20.7 and 0.0 %) and eucalyptus oil (38.3, 18.0 and 9.7%) over the untreated control (86.0%), and weight loss in *neem* oil (4.9, 7.3,0.0%) followed by castor oil (7.3, 7.3, 0.0%) and eucalyptus oil (9.5, 5.0, 2.7%), respectively over untreated control (32.0%) at 90 DAT. They also observed no adverse effect of these plant oils on the seed viability for up to 270 DAT. Singh *et al.* [124] reported *neem* oil at 0.20 per cent as highly effective based on lowest adult emergence (22.58 adults/100g grain sample), grain damage (4.79%), weight loss (2.60%) and maximum inhibition rate (88.92%) followed by eucalyptus oil (32.75 adults, 6.37 and 3.48%) and castor oil (36.50 adults, 7.53 and 4.18%) over the untreated control with highest adult emergence (146.30 adults), grain damage (28.58%) and weight loss (18.39%). Their studies also revealed neem, eucalyptus and castor to have no adverse effects on seed viability for up to 120 DAT.

**ii). Insect repellents**

These chemicals offer protection of stored grains or food commodities from infestation of insect pests with minimal environmental impact through stimulation of olfactory or other receptors. Zanno *et al.* [125] attributed insect repellent and anti-feedant actions of *neem* due to presence of triterpenoid azadirachtin and other related compounds. The *neem* oil at 0.1 per cent caused effective repellent effect against *T. confusum* on stored corn [126]. Banarjee and Nigam [127] also reported the repellent activity of *neem* leaf powder in various stored grain pests. Mohiuddin *et al.* [128] while testing twelve vegetable oils for toxic and repellent effects against *T. castaneum* reported *neem* oil at 0.25 per cent as more effective to produce the highest repellency (80.1-100 %) at 60 days after treatment. Khatre *et al.* [129] in their investigations showed that the treatments with *neem*, castor and karanj were highly effective as they registered significant repellent action on the adult fecundity of pulse beetle. The plant derived extracts, powders, and essential oils were reported as repellent against stored grain insect pests like *C. maculates* and *T. castaneum* [130, 31, 32]. Wong *et al.* [133] compared various plant products viz., citronella, garlic oil, *neem* extract, pine oil and pyrethrum for their repellent effects against stored insect pests and found all the products to give positive results. Plant derived repellents are environmentally safe, ecofriendly, effective for pest control, less pesticide residue [134]. Kheradmand *et al.* [135] reported clove as the most potent repellent against two spotted spider mite, *Tetranychus urticae* Koch followed by spearmint and cumin oils.

**iii). Insect toxicants**

Pascual-Villalobos and Robledo [136] screened out extracts from fifty various wild plant species in southeastern Spain for their insecticidal activity against *T. castaneum* and revealed four species, viz., *Anabasis hispanica, Senecio lopezii, Bellardia trixago* and *Asphodelus fistulosus* as most promising. Major essential oil constituents from garlic, *Alliumsativum*, i.e., methyl allyl disulfide and diallyl trisulfide were to be potent toxicant and fumigants against *S. zeamais* and *T. castaneum* [137]. Rahman [138] revealed nicotine (an active component of *Nicotiana tabacum*) as a strong organic poison that acts as a contact-stomach poison having insecticidal properties. This compound is, of course, very toxic to humans as well. The essential oil vapours distilled from eucalyptus, cumin, oregano and rosemary were also reported as fumigants which caused 100 per cent egg mortality of *T. confusum* and *Ephestia kuehniella* [139]. Many species of the genus *Ocimum* oils, extracts, and their bioactive compounds possess insecticidal activities against various insect species [140, 141]. Worldwide reports have shown plant derived products as toxic to storage pests [142, 143].

**iv). Chemosterilants**

Various plant parts, powders, oil, extracts when admixed to the grains reduced insect oviposition, egg hatchability, postembryonic development and progeny production [144, 145, 146]. About 43 plant species were reported as reproduction inhibitors for the control of various storage pests [147]. Various plant derived oils caused mortality of insect eggs [148]. Several ground plant parts, extracts, oils, and vapour also were reported to suppress several pests [149].

**v). Feeding deterrents**

The chemicals which inhibit feeding or disrupt insect feeding by rendering the treated materials unattractive or unpalatable are called as feeding deterrents/antifeedants [150, 151]. Ambika Devi and Mohandas [152] in their studies on assessment of relative efficacy of eleven antifeedants and deterrents against *R. dominica* and *S. cerealella* infestation in stored paddy found *neem* extract at 1.0 and 0.5 per cent, *neem* and coconut oils at 1.0 per cent as the highly effective to provide more protection against *R. dominica* for up to 180 DAT. A few natural feeding deterrents, which have been characterized, include glycosides of steroidal alkaloids, aromatic steroids, hydroxylated steroid meliantriol, triterpene hemiacetal, and others [153]. Constituents of essential oil like citronellal, thymol and α-terpineol are most effective as feeding deterrents against tobacco cutworm, *Spodoptera litura* synergism, or additive effects of combination of monoterpenoids from essential oils were reported against *S. litura* larvae [154]. The screening of several medicinal herbs has revealed root bark of *Dictamnus dasycarpus* to possess antifeeding properties against storage insects [155]. Khan and Marwat [156] tested the deterrent effects of leaf, seed and bark powder of *neem* and oleander (*Nerium oleander*)against *R. dominica* where *neem* leaves and seeds was found as best to register a highest per cent mortality in the insect.

**vi). Insect growth inhibitors (IGRs)**

The crude extract was found effective to retard the insect development and cause larvae mortality, cuticle melanisation, and high adult mortality [157]. Plant derived extracts cause deleterious effects on growth and development of insects and reduce the larval, pupal and adult weight, and have prolonged the larval and pupal periods, thereby reducing the pupal recovery and adult eclosion [158]. Rajasekaran and Kumaraswami [159] revealed plant extract coated grains as most effective for complete inhibition of development of storage insect like *S. oryzae.* Plant derivatives were also effective to inhibit the development of eggs and immature stages of insects inside grain kernels [160]. Plant derived products were also found effective to reduce the survival rates of larvae, pupae and the adult emergence [161].

## 6. A few phytochemicals with insecticidal properties

The botanical insecticides which are commercially available include azadirachtin, pyrethrin, nicotine, avermectins, spinosads, rotenone, ryania and sabadilla.

### i). Azadirachtin

Neem has contact as well as systemic activity to leaves in the plants. It has broad mode of action as feeding deterrent, repellent IGR, chemosterilant and oviposition inhibitor [162]. The compound is derived from neem tree (*Azadirachta indica*) which is grown throughout India and Africa [163]. It is effective against broad range of insects, including storage pests, sucking pests like aphids and mealybugs and the caterpillars [164]. It is one of the least toxic chemical of the commercially available botanicals based on very low mammalian toxicity (LD50 of 13,000 mg/kg) and the chemical also nontoxic to beneficial insects and mites.

### ii). Pyrethrin (I and II)

It is one of the oldest household insecticides still available and giving immediate knockdown effects on insects. It is both a contact and stomach poison. It is derived from seeds or the flowers of chrysanthemum, *Chrysanthemum cinerariaefolium* [165] and is widely cultivated in Africa, Kenya and Ecuador. It has wide range of activity against flies, fleas, beetles and spider mites [166]. It has very short residual activity-degrading rapidly under sunlight, air and moisture, so it requires frequent applications. As no waiting interval required between first application and harvest, it can be used up to crop harvesting [167]. It has a low mammalian toxicity (LD50 1200-1500 mg/kg) [168, 169, 170]. However, cats show high susceptibility to the pyrethrin poisoning. It kills insects (mode of action) is by disrupting the sodium and potassium ion-exchange process in insect nerves and interrupting the normal nerve impulse transmission.

### iii). Nicotine

It is obtained from *Nicotiana tabacum,* is one of the toxic chemical among the botanical insecticides due to high mammalian toxicity (LD50 50-60 mg/kg) [171]. Most of sucking insect pests such as leafhoppers, aphids, thrips and spider mites are highly susceptible while caterpillars are resistant to the nicotine [172]. It is a nerve as well as contact poison. It shows mode of action by its binding to receptors at the nerve synapses, resulting uncontrolled nerve firing and mimicking acetylcholine (Ach) at the nerve-muscle junctions in central nervous system [173]. Its sprays are can cause injury to certain plants like roses.

### iv). Avermectins (Macrocyclic lactones)

These compounds are derived from the actinomycete group of fungi (*Streptomyces avermitilis*) [174]. Its LD50 in rat is 10-11.3mg/kg. It is most effective against agricultural pests (LC90 of 0.02 ppm in mites) and internal parasites of domestic but least toxic to storage pests (Mrozik *et al.*, 1989) [175]. In their mode of action in insects and mites, they block the neurotransmitter GABA at the neuromuscular junction thereby stopping the feeding and oviposition immediately after exposure without causing the death up to several days [176].

### v). Spinosads (Spinosyn A + Spinosyn D)

It was originally isolated from the soil Actinomycetes, *Saccharopolyspora spinosa* [177]. It is used to control caterpillars, leaf miners and leaf feeding beetles. It has mode of action with primary target on binding sites on nicotinic ACh receptors thereby disrupting the ACh neurotransmission [178, 179].

### vi). Rotenone

It is derived from the roots of two leguminous plants, i.e., *Lonchocarpus* sp. and *Derris* sp. which were originally available in countries such as South America, Malaya and East Indies. It is both a contact and stomach poison. It has broad spectrum activity on insects like leaf feeding beetles, caterpillars, lice, mosquitoes, ticks, fleas, fire ants and spider mites [180]. It is a slower acting compound than most of the botanical insecticides and gives knockdown effect in insects in several days. However, pests stop feeding almost immediately. It shows moderate toxicity in mammals (LD50 132 mg/kg) [181] while extreme toxicity in fish [182]. But it is more toxic to mammals than carbaryl and Malathion. It shows its mode of activity by blocking respiration by electron transport.

### vii). Ryania

This compound is derived from roots and stems of *Ryania speciosa*, which is native to Trinidad [183]. It is both a contact and stomach poison and has low mammalian toxicity (LD50 750mg/kg). It is most effective against several insect pests such as aphids, lace bugs, spider mites, caterpillars, squash bug and potato beetle [184]. It shows a prolonged residual activity among various botanical insecticides. In its unique mode of action it affects muscles by binding to Ca channels in sarcoplasmic reticulum and causes Ca ions to flow into the cells with a rapid death [185].

### viii). Sabadilla

This is derived from seeds of a feathershank plant (*Schoenocaulon officinale*) which is grown in Venezuela. It is both a contact and stomach poison. It shows its activity against various insects such as leaf hoppers, thrips, caterpillars, stink and squash bugs. It has low residual activity and degrades very rapidly in sunlight and moisture. It is one of the least toxic botanical insecticides with low mammalian toxicity (LD50 5,000 mg/kg). It shows mode of action by affecting nerve cell membranes resulting loss of nerve function, paralysis followed with death [186].

## 7. Major constraints to the use of botanical insecticides

Several plant derived products, e.g., powders, oils, extracts from neem, castor, eucalyptus, etc. which are in use as grain protectants contain secondary metabolites that are effectively control various insect pests. Botanical insecticides are generally rendered ecofriendly, non-pollutant, safe to human, animals and beneficial insect pests. In general, botanical products increase income of rural farmers thereby promoting the safety, quality of food and life [187]. Although, their successful application control several destructive insect pests and diseases, and reduce erosion, desertification deforestation, but one negative effect by acting as spermaticide perhaps they reduce human population [188]. Several constraints must be overcome and doubts be clarified prior to realization about their potential. Efforts to solve several obstacles like lack of experience and appreciation in their efficacy as pest control agents, slow action and lack of rapid knockdown effect, genetic variability of plant species in varied locations, tough registration and patenting, lack of their standardization, economic uncertainties, handling difficulties, instability of active components on exposure to sunlight, competition with synthetic pesticides, not widely available, rapid degradation, unavailable data for their long-term effects on mammals for some botanicals, unestablished tolerance limits for some botanicals ; and uncertainties regarding their use can bring a major new resource benefitting the world. Scientific efforts are required to assess practical applicability of botanical pesticides.

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