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REVIEW PAPER

Role of neem in the management of storage and crop pests : A review

D. N. KAMBREKAR[1], C. P. MALLAPUR[2], D. SAGAR[3] AND S. SINGH[4]

[1,2]University of Agricultural Sciences, Dharwad - 580 005, Karnataka, India
[3,4]Indian Agricultural Research Institute, New Delhi -110 012, India
E-mail: kambrekardn@gmail.com

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Abstract: With the continued robust growth of the global bio-pesticide market, Azadirachtin is uniquely positioned to become a key insecticide. The broad-spectrum activities of Azadirachtin at low use rates coupled with the insect growth regulator activity and unique mode of action (ecdysone disruptor) make it an ideal product with the additional advantage of prevention of insecticide resistance development in case of pests. Therefore, it could become an integral component of integrated pest management and organic pest management programmes. Azadirachtin has been exempted from residue tolerance requirements by the US Environmental Protection Agency for food crop applications. It has been found to exhibit good efficacy against key pests such as white flies, leaf miners, gnats, thrips, aphids and many leaf-eating caterpillars, fungi, bacteria, and viruses. Azadirachtin has minimal impact on non-target organisms, and is compatible with other bio-control agents. The world's largest azadirachtin extraction facility has been commissioned in India to process over 1000 tonnes of neem seeds per annum. This will ensure adequate availability of technical grade azadirachtin material in the future. At present, it can be justifiably asserted that the full potential of neem has still not been exploited.

Key words: Antifeedant properties, *Azadirachta indica*, Integrated pest management, Storage, Toxic effect

Introduction

Neem (*Azadirachta indica* A. Juss) is an attractive evergreen tree which is native to the Indian sub-continent but cultivated throughout Pakistan, Sri Lanka, South East Asia, Africa (Somalia, Nigeria, Mauritania, Togo, *etc*.), East and Sub Sahelion Africa, Fiji, Mauritius, many countries in Central and South America, the Caribbean, Puerto Rico, the Virgin Islands, and Australia. There are hosts of products obtained from every part of the neem tree, many of which have potential use in pest management programmes. Therefore, the tree has gained worldwide attention and recognition. The neem tree is indispensable to the Indian Sub-continent having cultural, medicinal, and pesticidal values.

Historically, commercial uses of the neem tree are shrouded in mystique and lore of the Vedic period of India, which began about 4000 B.C. In Ayurved, a system of medicine, neem bark, and leaves are being used for dermal problems, flowers as tonic and stomachic, and fruits as purgative and emollient.

Although the neem tree has been used for centuries by Indian farmers to control crop pests, both in the field and in storage, its chemical properties have been patented in India very recently on a limited scale. Considering the socio-economic importance of neem and its use in the integrated pest management system, it is imperative that effective formulations of neem are developed for controlling insect, disease, and nematode pests of various crops. Jahagirdar *et al.* (2003) also reported application of neem based products in traditional methods of plant disease management.

The biological effects of neem extracts were determined over the last two decades and attracted the attention of many chemists and biologists all over the world. These extracts possess antifeedant, insecticidal, nematicidal, fungicidal, and repellent qualities. More than 100 triterpenoid compounds have been isolated and identified. The development of neem research in India was initiated by Pradhan *et al.* (1962) when they demonstrated that water suspensions of neem powder against locusts have good antifeedant activity. About nine compounds possess insect growth regulatory activities which include azadirachtin, meliantriol and salannin. Govinderchari *et al.* (1996) isolated and quantified the azadirachtin and other major triterpenoids in the seed of *A. indica* and major azadirachtin A, B, D, and H have been isolated, identified, and estimated. Akila and Kumar (1996) observed that azadirachtin, salannin, meliantriol, nimbin and nimbinin are the best-known limonoids.

Xiaodong and Shanhuan (1996) reported the toxic effects and mode of action of azadirachtin. The azadirachtin has stomach and contact poison properties of many insects. The azadirachtin attracts neurosecretory cells and *Corpus cardiacum*, prothoracic glands, and thus metamorphosis of insects is disturbed.

Tonthu Bthimthong and Tasakorn (1997) reported that azadirachtin is a natural insecticide, non-toxic to mammals. They extracted the azadirachtin from defatted ground neem seed kernel using methanol. Johnson and Morgan (1998) investigated selective extraction of nimbin, solannin, and azadirachtin from neem seeds using supercritical carbon dioxide and methanol.

Akila and Rani (1999) published a review on the chemistry of neem tree in which they discussed 17 major groups of limonoids present in neem with their molecular formula, molecular weight, mode of action and mass spectroscopy, derivatives and their spectra, biological activity, and synthesis. Neem seed products have the Azadirachtal group, Meliacarpin group, Amoorastatin group,Vipinin group, Vilasinin group, Nimbin group, Salannin group, *etc.* (Fig. 1 & Fig. 2).

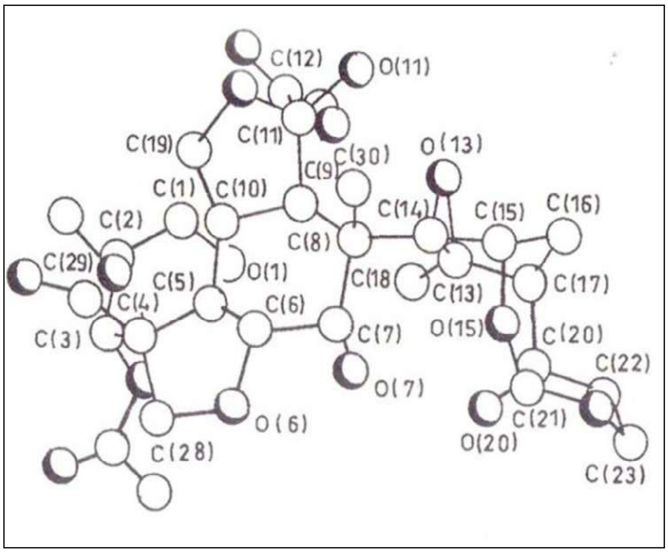

Fig. 1. Molecular Structure of Azadirachtin (Broughton *et al.,* 1986)

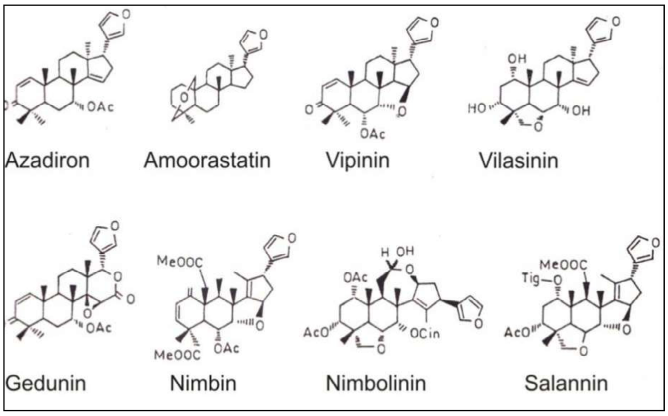

Fig. 2. Limonoids

All parts of this plant particularly leaf, bark and root extracts have the biopesticidal activities. Azadirachtin, a biopesticide obtained from neem extract, can be used for controlling various insect pests in agriculture. It acts on insects by repelling them, by inhibiting feeding, and by disrupting their growth and reproduction. Neem-based formulations do not usually kill insects directly, but they can alter their behaviour insignificant ways to reduce pest damage to crops and reduce their reproductive potential. The neem is considered as an easily accessible, eco-friendly, biodegradable, cheap, and non-toxic biopesticide which control the target pests (Adhikari *et al*., 2020).

Neem in the management of stored grain pests

Global losses due to insect and non-insect pests such as birds, rodents, *etc*. are estimated to be about 10 per cent or more. Out of this about 5 per cent is attributed to insect pests in stored grains. The use of neem dates back to the pre-historic period and its use is mentioned in the Sanskrit language. Keeping neem leaves between folds of cloth and mixing them with stored grain destined for storage. A survey conducted in eight Indian and two Pakistan places showed that farmers used 'handfuls' to 5-10 kg of air-dried neem leaves per 100 kg of grain (Paddy, Rice, Wheat, Corn, and Sorghum) (Ahmed and Grainage, 1986; Ahmed *et al*., 1988; Hedge *et al*., 1988) users found it effective in preventing the entry of beetle and weevils if neem leaves are mixed with freshly harvested grains immediately on storage. Singh and Srivastava (2015) documented an overview of neem in the management of insect pests of stored grains. A few pests of storage are described below which were controlled by neem products.

Red flour beetle *Tribolium castaneum* (Herbst) and flour beetle (*Tribolium confusum* Jacquelin du Val)

Little work has been done on the evaluation of neem products against red flour beetle. However, Qadri (1973) reported neem seed extract as a repellent to *T. castaneum.* Red corn treated with neem oil had a repellent effect on *T. confusum*. The treated corn (1 ml/kg) recorded 7.75 per cent insects as against 17.5 per cent in control (Akou-Edi, 1983). Azadirachtin incorporated at 1 ppm and above doses inhibited growth and reduced survival of *T. castaneum* (Ramachandran *et al*., 1988). Application of azadirachtin to less than 6-hour old pupae reduced the emergence of adults (Muherjee and Ramachandran, 1989). Margosan-O extract @ 800 ug/cm^2 applied to filter paper in a choice-chamber test produced 67 per cent repellency against *T. castaneum* four weeks after treatment; repellency had declined to 53 per cent eight weeks after treatment (Jilani *et al*., 1988). Treatments of jute sacs with neem oil prevented penetration of *Tribolium* spp. (Saxena *et al*., 1989). When deoiled neem kernel powder was admixed with wheat flour at the rate of 2 parts per 100 parts of the flour it completely inhibited the development of the larvae. Even at 0.125 parts per 100 parts of the flour, only 17 adults emerged as against 72 in the control (Singh *et al*., 1993).

Both petroleum ether and chloroform extract of *A. indica* showed maximum antifeedant activity against *T. castaneum* (Kumar and Gupta, 2013). The effect of neem seed extract at tested concentrations against *T. castaneum* was dose dependent; as the 64.44, 55.92, 47.77 and 35.93 per cent mortality was recorded at 10, 7.5, 5 and 2.5% concentrations, respectively (Nadeem *et al*., 2012). *Tribolium castaneum* showed 88.31, 95.08 and 97.81 per cent repellent activity at 1, 2 and 3% concentration of neem oil, respectively (Joshi *et al*., 2019).

The Nimbecidine EC @ 3.0% oil killed 25.6 per cent of larval stages within 6 days on contact bioassay. Efficacy of Nimbecidine EC, varied according to the beetle's developmental stage. Early instar larvae were more susceptible compared with and adults at 6 days post-treatment. Nimbecidine EC caused about 63 per cent reduction in total fecundity of the female adults (Younus and Mohammed, 2020).

Management of rust red flour beetle, *T. castaneum* on stored wheat revealed that neem leaf powder @ 1.5 g/100 g grains was the most effective treatment, observed the mean adult mortality of 67.22 per cent and also recorded the minimum weight loss after 60 days of storage (Sekar *et al.*, 2021). Faheem *et al.* (2019) reported that *A. indica* plant powder increased the adult mortality of *T. castaneum* in wheat grains. Mariadoss and Umamaheswari (2022) reported that Neem at 3 g and 5 g/100 g rice grains elicited more than 50 per cent adult mortality of red flour beetle, *T. castaneum* even after 60 days after treatment.

Lesser grain borer, *Rhyzopertha dominica* Fab.

Neem seed kernel powder, neem oil, and seed kernel extract have exhibited high activity against the borer. Jotwani and Sircar (1965) 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* up to 370 days. Neem seed kernel powder mixed at the rate of 1-2 parts/100 parts of the wheat offered very satisfactory protection against the pest for 321 days (Jotwani and Sircar, 1965).

Devi and Mohandas (1982) screened 11 antifeedants against the pest and reported that neem seed extract at 0.5 per cent was the best. Neem leaf extract had a repellent effect on the borer in the stored paddy (Jaipal *et al*., 1984; Malik and Naqvi, 1984).

Qadri (1977) studied the insecticidal action of custard apple (*Annona squamosa*) in combination with neem (*A. indica*) against *Callosobruchus chinensis* Linn., *R. dominica,* and *Musca domestica nebulo* F. in the laboratory. The insects of each species were exposed for 24 hrs to extracts of the seeds of neem and custard apple and to DDT as a standard of comparison, in the form of dry deposits on the glass. Statistical analysis of the results showed that neem extract alone was less toxic than either custard-apple extract or DDT, but that it had a synergistic action when combined with custard-apple extract; the combined seed extract, containing 4-5 parts of neem to 1 part of custard apple, was as toxic as DDT to *C.chinensis* and about one-fifth as toxic as DDT to *R. dominica.*

Filter paper strips treated with 200-400 ug oil/cm^2 repelled *R. dominica* for two weeks. Further, neem oil @ 800 ug/cm^2 when applied to filter paper in choice-chamber, the repellency tests produced 64 per cent repellency against *R. dominica* eight weeks after treatment, compared with 77 per cent, one week after treatment (Jilani and Saxena, 1990).

Jilani and Haq (1984) 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 highly effective based on the reduced population of *R. dominica* on wheat during storage. Lal *et al.* (2017) did experiments with plant products against lesser grain borer *R. dominica*. The wheat grains treated with neem seed kernel powder at 1 per cent concentration was found superior with no grain damage.

Kudachi and Balikai (2009) revealed that *Acorus calamus* (Linn.) rhizomes @ 1% was found to be significantly superior in protecting sorghum grains from *R. dominica* up to 180 days after treatment, followed by *A. squamosa* seed powder @ 5 %, malathion 5 % D and *A. indica* seed powder @ 5 % with minimum seed damage, higher germination percentage, minimum weight loss, and maximum adult mortality.

Meena *et al.* (2017) tested the effectiveness of botanical grain protectants *viz*., red chilli fruit power, black peppers seed powder, neem leaf powder, turmeric rhizome powder, and tulsi leaf powder in the management of *R. dominica*, a serious insect pest of sorghum under storage. The best treatment was black seed pepper powder followed by neem seed kernel powder (5 %). The germination of sorghum seed was over 80 per cent.

On overall basis, neem oil at 0.20 per cent had minimum adult emergence (22.58 adults/100 g grain sample), grain damage (4.79 %), weight loss (2.60 %) and maximum inhibition rate (88.92 %) in case of lesser grain borer, *R. dominica* when wheat grains were stored for 120 days after treatment Singh *et al*., 2016). *Rhyzopertha dominica* showed 80.49, 85.10 and 87.51 per cent repellent activity at 1, 2 and 3 % concentrations of neem oil, respectively (Joshi *et al*., 2019). Tiwari and Yadav (2022) reported that in case of *R. dominica*, maximum mortality (91.90 %) and 0 % grain damage was observed after six months in stored maize in neem oil @ 15 ml/kg seed. Neem oil @ 15 ml/kg seed showed maximum (80 %) repellency against *R. dominica*.

Deshwal *et al*. (2018) reported that at six months of storage Deltamethrin (2.5 WP) @ 40 mg/kg seed with 1.33 per cent grain damage followed by Neem oil @ 10 ml/kg seed with 2 % grain damage, Mentha leaf powder @ 10 g/kg seed with 2.33 %, Neem cake @ 15 g/kg seed and Neem dry leaf powder @ 15 g/kg seed with 2.66 % grain damage were effective in managing lesser grain borer (*R. dominica*) under *in vitro* condition in stored wheat.

Kakde *et al*. (2014) reported that the minimum adults of *R. dominica* emerged in wheat grains treated with neem @ 2 % (1.33) with minimum grain damage and weight loss (1.00 and 1.33 %, respectively). Further, the gunny bags impregnated with neem oil @ 10 % provided complete protection over the adult emergence, grain damage and weight loss by *R. dominica*.

Pulse beetles, *Callosobruchus chinensis* Linnaeus, *C. maculatus* (Fab.)

Balikai and Augustine (2018) reported that pulses are the second most important group of crops worldwide after cereals. More than 200 insects pests have been recorded infesting pulses in India and causing a considerable loss in quality and quantity. The important species reported from India are *Callosobruchus maculatus* (F.), *C. chinensis* (L.), *C. analis* (F.), *C. phaseoli* (G.) and *C. theobromae* (L.). To control these many neem products are being suggested as the use of botanicals.

Neem oil of 0.1-0.5% has given excellent control of the two beetles in green gram and cowpea (Sangappa, 1977; Yadav, 1985; Zeherer, 1984). However, neem leaf powder and deoiled kernel powder have not shown promise against *C. maculatus* (Singh, 1984). Dev Kumar (1988) reported neem oil fraction as a potent fumigant and sterilant against pulse beetle. Babu *et al.* (1989) screened the effect of pre-storage treatment of *Vigna radiata* (L.) R. Wilczek) with neem, karanja, mustard, groundnut and castor oil at 2.25, 5.0 and 10.0 ml/kg seed on infestation by *C. chinensis*. Treatment with other oils effectively reduced oviposition.

Mansour *et al.* (1997) evaluated neem-Azal against infestation of *C. chinensis* on mungbean and observed that 0.5 % concentration was effective. Compared with non-edible oils *viz*.,karanja (*Pongamia glabra* (L.) Pierre), undi

(*Calophyllum inophyllum* L.) and kusum (*Schleichera trijuga* Willd.), neem oil offered the best protection for green gram against *C. chinensis* and *C. maculatus* (Ketkar, 1987). Neem seed kernel powder (1-2 %) has consistently given well to excellent results against *C. maculatus* in cowpea, mung bean, pea, and gram (Yadav, 1973). Murugan *et al.* (1998) studied the effect of neem products against *C. maculatus* on cowpea. The neem products *i.e.,* neem extract, oil, and powder were found effective.

Neem seed extracts and the pure compound present therein have been evaluated for various biological effects on insects and other pests. There is, however, perhaps no report on the evaluation of isolated neem seed volatiles against insect pests. Neem seed volatiles were isolated from neem seed oil and evaluated for their bioactivity against eggs, 2 and 15 day-old grubs and adults of pulse beetle, *C. maculatus.* All stages were found susceptible to different doses of volatiles. At 200-50 µl it caused 100-81.6 per cent and 100-25.4 per cent mortality of adults and grubs respectively. Eggs when exposed to 100-200 µl dose for 3 days failed to hatch. At a 50 µl dose with a 5-day exposure period the eggs that hatched failed to reach the adult stage and terminated as grubs. The adults were found most susceptible followed by grubs and eggs (Reddy and Singh, 1998).

Tripathy and Sahoo (2000) studied the efficacy of some neem formulations and neem seed kernel extract (NSKE) against *C. chinensis* infesting black gram. Four commercial neem formulations *viz*., Forture Aza, Nivar, Neemgold, and Econeem, each at 0.25 and 0.5 per cent concentrations were mixed with black gram seeds. After 24 hours of treatment, adults were released but the percentage of mortality after 72 h was high and it was not possible to get any adults from the treatment although very low oviposition was recorded. Neem gold recorded lower oviposition than other treatments whereas Forture Aza recorded the highest number of eggs. The crude neem seed kernel extract was found to be equally effective in protecting the pulse seeds against bruchids attack without deteriorating the germinability of seeds.

Verma and Anandhi (2010) evaluated seven plant materials including dried leaf powder of neem, and neem seed kernel at 4.00 and 8.0 per cent w/w/100 gram of mung bean for their effects against pulse beetle, maximum adult mortality (38.33%) was recorded in the treatment of neem leaf powder. Jadav *et al.* (2015) reported that dried leaf powder of neem was much more effective in reducing the weight loss caused by pulse beetle (*C. chinensis*).

Kaur (2017) reported that neem leaf powder and Melia leaf powder at 6 % concentration caused weight loss in *C. chinensis*. Parmar *et al.* (2018) evaluated botanicals as grain protectants against pulse beetle *C. chinensis*. The grain treated with neem leaf powder @ 2 % (w/w) reported higher adult mortality. Sharma *et al.* (2016) reported that neem oil @ 10 ml/kg completely inhibited oviposition, adult emergence, and seed damage by *C. chinensis.* Brhane *et al.* (2020) studied the management of *C. maculatus* in stored cowpea by plant extract from Eritrea (South Africa). They reported that 5 % neem plant extract was found to be effective against this pest.

Laboratory studies carried out by Augustine and Balikai (2019) on the evaluation of eco-friendly grain protectants against *C. chinensis* on cowpea including plant powders, oils and inert dust revealed that the sweet flag (*A. calamus*) rhizome powder @ 5 g/kg seeds, cow dung ash @ 200 g/kg and neem oil @ 10 ml/kg seeds exhibited remarkable protectant ability. The cent per cent adult mortality observed in these as against zero mortality in the control at four days after treatment indicated their greater efficacy.

Laboratory studies revealed that neem leaf powder (6 %) followed by Melia (6 %) and datura leaf powder (8 %), recording 31.86, 40.17 and 46.06 per cent mean seed damage and 6.27, 8.61, and 10.84 per cent mean weight loss, respectively and proved the best in protecting chickpea from pulse beetle under storage. Neem leaf powder also registered the highest Cost-Benefit Ratio (1:2.09) followed by Melia leaf powder (1:1.97). Although the synthetic insecticide showed the highest C:B ratio (1:6.17), the botanicals being cheap, locally available, biodegradable, non-hazardous to human as well as animal life and the environment could be considered as seed protectants against storage pests (Mounika *et al.,* 2022).

The potential neem formulation like Nimbecidine @ 2.5 ml/ 100 g in the storage of pulses and can be used as an alternative to conventional insecticides like deltamethrin for long-term safe storage of pulses. These neem products are safe, cheap, residue-free and eco-friendly materials that can fit into the IPM package of stored grain pests of pulses (Chakraborty *et al*., 2014).

Ekoja *et al*. (2022) showed that fixed vegetable oil of neem @ 5.0 ml/kg seed could be valuable in managing *C. maculatus* attacks on stored cowpea when used over a short period (≤ 90 days). But beyond this time, the same concentration of the plant oils may not provide adequate protection for cowpea against the bruchids.

Khapra Beetle (*Trogoderma granarium* Everts)

Khapra beetle is perhaps the most sensitive insect pest of stored grain to neem product. Neem seed kernel powder mixed with wheat at the rate of 2 parts/100 parts of wheat suffered only 7.0 % damage as against 65.4 % in the control after 379 days of storage (Jotwani and Sircar, 1965). The germination test with the treated seed showed no adverse effect. Neem seed powder mixed with wheat at 0.1, 1.0 or 2.0 % protected wheat against larvae of the beetle (Saramma and Verma, 1971). Wheat treated with 2 % kernel powder had only 16 % damage by the beetle as against 46 % in control (Girish and Jain, 1974). Schmutterer (1981) reported that seed kernel powder at 1-2 % reduced the infestation of cereals for a considerable period. Wheat treated with 1, 2, or 4 % seed powder had substantially less *T. granarium* damage for 7 to 16 months than in the untreated control.

Mostafa (1991) tested the efficacy of neem flower and fruit powder against *T. granarium* and observed that the rice treated with the powdered flower of 1 and 2 per cent gave 61 to 66 per cent mortality.

Singh *et al.* (1999) tested neem dust formulation against *T. granarium*. Results revealed that neem dust has no effect on the hatching of eggs of *T. granarium* and caused 20-100 per cent mortality of 1st instar hatched larvae as against 100 per cent survival in the control by 7th day. By 14th day, all the larvae died in all the concentrations. The dust also caused high activity against the 3rd instar larvae. It was also observed that at higher concentration (0.25%) the larval mortality, pupal mortality, and percent deformed adult was 80.0, 66.26, and 88.88 per cent, respectively.

Jakhar and Jat (2010) reported that the neem oil was the most effective treatment in reducing the fecundity (24.44 eggs/ female), adult emergence (23.77 %), grain damage (9.36 %) and weight loss (3 %) in stored wheat due to khapra beetle, *T. granarium*. Further, all the above parameters gradually decreased with the increase in dose of neem oil (0.1, 0.5 and 1.5 ml/100 g seed). Kumar and Gupta (2013) reported that both petroleum ether and chloroform extract of *A. indica* showed maximum antifeedant activity against *T. granarium*.

Neem seed water and hexane extracts combined at equal percentages (1:1 ratio) were evaluated against *T. granarium* (3rd instar larvae), three doses (2.5, 1.25 and 0.625 %) were compared with individual extracts. At 14 days after post treatments, the highest dose of neem water-oil mixture (2.5 %) gained significantly comparable effect with 5 % oil and better effect than 2.5 % oil, coupled with superior saving (94.5 %) of sorghum seeds from damage. This indicated that neem oil halved mixed with neem seed water extract can save 50 % of neem oil needed to exert a similar effect when used alone (Mahmoud *et al.*, 2014).

Considering the parameters like oviposition, adult emergence, seed damage, seed weight loss and per cent seed germination and ICBR, neem oil @ 10 ml/kg was found effective treatment up to 120 days against dermestid, *T. granarium* infesting wheat in storage (Masolkar *et al.*, 2018). Tiwari and Yadav (2022) reported that the neem oil @ 15 ml/kg seed was found effective against *T. granarium* with 92.83 % mortality and 0 % grain damage after 6 months in stored maize. Neem oil @ 15 ml/kg seed showed maximum (86.67 %) repellency against *T. granarium*.

Rice weevil (*Sitophilus oryzae* Linn.) and Maize weevil (*Sitophilus zeamais* Mots.)

Jotwani and Sircar (1965) 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 *S. oryzae* up to 320 days. The average percentage of damage in the treatment was found only 0.64 % as against 7.58 in the control. Kernel powder (1-2 %) gave better protection to maize than ethylene dibromide-carbon tetrachloride (ED-CT) (Chachoria *et al.*, 1971). Maize treated with kernel powder at the rate of 2.5, 5.0, and 12.5 g/100 g of seed completely stopped post-embryonic development of the weevil and no insect could survive after five days. The powder reduced adult oviposition at lower doses and prevented it completely at higher doses. Progeny emergence was delayed for six months and very few adults emerged at the dose of 5 g/100 g (Ivbijaro, 1983). Satpathy (1997) compared the efficacy of kernel powder with phoxim and malathion and reported that kernel at 2% was more effective than malathion (8 ppm) after three months. Powdered kernel admixed with wheat reduced infestation for six months (Mishra *et al.*, 1992). Neem seed powder effectively protected stored maize against *S. zeamais* but not against *S. oryzae* (Pereira and Wohlgemuth, 1982). Kossov (1989) evaluated different products of neem against *S. zeamais*. The ethanolic extracts showed higher toxicity. Kudachi and Balikai (2010) revealed that, *A. calamus* rhizome @ 1 % was found to be significantly superior in protecting sorghum grains from *S. oryzae* up to six months after treatment, followed by *A. squamosa* seed powder @ 5 %, malathion 5 % D and *A. indica* seed powder @ 5 % with minimum seed damage, higher germination percentage, minimum weight loss and higher adult mortality. Bhubaneswari *et al.* (2014) recorded that *A. indica* powder caused 70.74 % adult mortality of rice weevil, *S. oryzae* at 30 days after treatment in rice grains. Tiwari and Yadav (2022) revealed that neem oil @ 15 ml/kg seed was the most eco-friendly treatment against *S. oryzae* with 94.76 % adult mortality, 12.54 population growth and 0 % grain damage after 6 months in stored maize. Neem oil @ 15 ml/kg seed showed maximum repellency (80 %) against *S. oryzae*.

Deepthi and Manjunatha (2016) reported that neem leaf powder (5 %) recorded rice weevil (*S. oryzae*) adult mortality of 31.10, 74.87, 76.80 and 75.87 % in the split seeds of sorghum greengram, Bengalgram and field bean, respectively at 60 days after treatment and mortality decreased as the storage period increased up to 108 days.

Yadav and Tiwari (2017) revealed that after 180 days of treatments, the less number of adults weevils of *S. oryzae* (10.33) were emerged in wheat grains treated with neem leaf powder @ 2 g/100 g of wheat grains.

The nano emulsion formulation comprising of polysorbate surfactant with 2.0 ml/kg azadirachtin was developed and tested against adult *S. oryzae* caused a 100 per cent mortality of *S. oryzae* adults after only 24 h of exposure, with the food impregnation method (Choupanian and Dzolkhifli, 2018).

Neem in vegetables, fruit and flower crops

In trials conducted in Togo, weekly high volume spray applications of 4 % methanolic neem kernel extract (NKE) (Adhikary 1985) or even 2.25 to 5% aqueous NKE (Dreyer and Hellpap 1991) almost completely protected the cabbage crop against the diamond back moth, *Plutella xylostella* L. Sombatsiri *et al.* (1987) tested the efficacy of aqueous NSKE and improved extracts against *S. litura* and *P. xylostella*. The improved extracts of 33.3 per cent was the best. Shalini *et al.* (2019) reported that neem *A. indica* was significantly more effective against the population of cabbage aphid, *Brevicoryne brassicae* (Linn.).

Okra pests, such as the leaf-cutting caterpillar, *Sylepta derogata* Fabricius, were quite susceptible to spray applications even at 0.25 % aqueous neem kernel extract (Dreyer, 1987). Fresh NSKE (5 %), fresh Garlic chilli kerosene (GCK) (0.5 %) and 1-day old GCK (0.5 %) extracts were the most effective treatments causing 90 per cent mortality of both aphids and leaf hoppers on okra at 7 days after treatment (Dhanalakashmi *et al*., 2011). Moorthy and Kumar (2012) evaluated neem products against insects of okra. It is observed that neem cake and 4 % neem seed powder extract against fruit borer and hoppers are efficacious. Ahmed *et al.* (2021) observed that three sprays at 10 days interval during the cropping period with treatments of dimethoate and neem cake extract were found to be effective on the mortality of the nymphal stage of aphids on okra and on par with respect to fruit yield.

Prasad *et al.* (2017a) revealed that out of nine neem-based treatments, neem seed kernel extract (NSKE) 5 % applied as six rounds of foliar sprays proved to be the most effective in reducing the population of two-spotted spider mite (*Tetranychus urticae* Koch) resulting in 88.80 per cent mite pest reduction. All other neem-based formulated products almost remained at par in this regard, causing mite pest reduction ranging from 81.00 to 83.60 per cent (Neem Baan and Rakshak Gold). The highest fruit yield (172.80 q/ha) of okra was obtained also in the case of NSKE @ 5 % and other neem-based formulations of pesticides *viz*., Nembecidine, Achook, Neemark, Neemguard, Rakshak Gold, and Uttam Neem remained statistically at par in this regard.

Neem seed kernel extract 5 % was effective against white fly, Jassid and Fruit borer in Okra and Red pumpkin beetle in pumpkin (Ketkar, 2000). Gujar and Mehrotra (1988) tested the biological activity of neem against *Aulacophora foveicollis* (Lucas) a major pest of cucurbits. It was observed that with 1 % methanolic neem seed kernel extracts, 50 per cent antifeedant activity was noticed. Naik *et al.* (2018) evaluated IPM modules against whiteflies *Bemisia tabaci* (Gennadius) in bitter gourd. They used insecticides, biopesticides and 1 % neem oil in the module. It was observed that application of *Metarhizium anisoplae* (2x10^8/g), *Beauveria bassiana* (2 X10^8/g) Neem oil 1 % and Pongamia oil 1 % gave the highest yield. Azam (1991) determined the toxicity of neem oil (0.5, 0.75, 1.0, 1.25 and 1.5 %) against larvae of leaf miner *Liriomyza trifolii* Burgess on cucumber. It was found that 1.0-1.25 per cent cause more than 80 per cent of mortality.

Manjunatha and Puttaswamy (1995) observed that 5 % NSKE gave better control of *Tetranychus neocaledonicus* (Andre) on French bean and produced the highest pod yield of 80-70 q/ha which remained at par with Rakshak Gold, Nimbecidine, Neemazol, and Neemguard. Prasad *et al.* (2017b) tested neem-based biopesticide for the management of red spider mite (*Tetranychus ludeni* Zacher) infesting French beans. Among the Neem-based pesticides, NSKE 5 % caused a maximum reduction to the tune of 80-70 per cent in the mite population. Nimbecidine (Aza 0.03%) @ 3.0 l/ha, Rakshak Gold (Aza 1.0%) @ 1.0 1/ha, Neemazol (Aza 0.03%) @ 1.0 l/ha Neemguard (Aza 0.03%) @ 3.0 l/ha were at par.

Neelam *et al.* (2013) studied the bioefficacy of the botanical extract against cutworm *Agrotis segetis* (Fab.) in potato. It was found that all the extracts were effective in reducing the population of cutworms. It was observed that 10 % *A. indica* and *Melia azedarach* L. were the most effective. Kumar *et al.* (2018) conducted field trials to evaluate the efficacy of azadirachtin and insecticides to control the whitefly *B. tabaci* on potato. The data revealed that neonicotinoids alone and in combination with azadirachtin showed higher efficacy against whitefly.

Natikar and Balikai (2019) undertook a field experiment to find out the effective botanical and bio-pesticide for managing insect pests of potato and recorded the highest per cent protection over control against major insect pests of potato with chlorpyriphos 20 EC @ 2.50 ml/l across two *kharif* seasons. This was followed by NSKE @ 5 % (42.36 and 66.19 %), azadirachtin 3000 ppm @ 3.00 ml/1 (42.43 and 62.16 %) and neem oil @ 2 % (35.52 and 48.39 %) with respect to shoot borer and aphids. However, in case of leafhopper, neem oil @ 2 % proved to be the next best treatment (62.92%). The treatment, azadirachtin 3000 ppm @ 3.00 ml/1 recorded the highest per cent protection over control in the case of mites (44.49%) and defoliator, *S. litura* 52.04%).

Katare *et al*. (2022) opined that neem oil @ 2 ml/l was effective against whitefly (*B. tabaci*) and thrips (*Thrips palmi* Karny) on potato with moderate reduction of 42.25 and 61.66 %, respectively with BC ratio of 1:1.84 which was on par with rest of the treatments in the trial.

Ahmad *et al*. (2018) did an experiment to test the efficacy of management modules against *Leucinodes orbonalis* Guenee, the shoot and fruit borer of brinjal. The treatment with neem insecticides was the least effective. Phukan *et al*. (2016) observed that pheromone traps in integration with neem pesticides were found effective in controlling the brinjal shoot and fruit borer, *L. orbonalis.*

Hanif *et al*. (2021) revealed that spinosad and 10 % *A. indica* aqueous extract exhibited maximum mean cumulative mortality of Hadda beetle (*Epilachna vigintioctopunctata* Fab.) grubs (*i.e*. 84.1 and 73.4 %, respectively) and adults (*i.e*. 67.4 and 58.8 %, respectively) recorded at 5th day of exposure. The combined application of both these effective treatments enhanced their toxicity to *E. vigintioctopunctata* and caused 88.9 and 77.6 % cumulative mortality of grubs and adults, respectively. Based on overall study results, the combined application of spinosad and *A. indica* extract is recommended to local vegetable growers for effective integrated management of *E. vigintioctopunctata* and other foliage-feeding beetles.

Premlata *et al*. (2017) evaluated essential plant oils against two-spotted spider mites *Tetranychus urticae* Koch on tomato and found that 3 % neem oil recorded a mean percent reduction of eggs (68.80 %) and mites (74.4 %). Nitin *et al.* (2018) tested the efficacy of insecticides and neem product azadirachtin (1 % EC) @ 2 ml/1 against tomato moth, *Tuta absoluta* (Meyrick) and observed that azadirachtin 0.1 % was effective in reducing the insect's population.

Prasad *et al*. (2017) conducted field experiments for two consecutive years and found that need-based foliar spray with neem oil proved to be the most effective in the management of mite (*Polyphagotarsonemus latus* Banks) causing up to 71.50 per cent mortality of the pest, which in turn resulted in the highest yield of green chilli (96.80 q/ha). However, all the neem-based pesticides *viz*., Multineem, Nembecidine, Neemazal and Neemguard were found significantly effective against the pest causing 67.90 to 69.80 per cent mortality of the pest resulting in an appreciably higher yield of green fruits of chilli ranging from 90.60 to 93.60 q/ha.

Patel *et al.* (2015) revealed that in the organic treatment, neem cake @ 4 q/ha was applied, and spraying of azadirachtin 1500 ppm @ 6 ml/l at 20 days intervals starting from 20 days after transplanting up to harvesting of the crop was taken up to manage different insect pests of chilli. The net return was ₹ 2.97 lakh/ha with BC ratio of 4.7 and ₹ 2.46 lakh/ha with BC ratio of 3.48 in organic and conventional practice, respectively.

Zehra *et al.* (2022) compared the efficacy of many botanicals and insecticides to control whitefly and leaf minor. Azadirachtin 0.03 % EC @ 5 ml/l was found effective in Gerbera.

Solanki *et al.* (2022) evaluated different biopesticides and botanicals against sapota moth, *Nephopteryx eugraphella* (Ragonot). Among all azadirachtin 10000 ppm @ 2 ml/l and Bt @ 2 g/l showed lower bud and flower damage up to 7.40 and 8.32 per cent with reduction up to 54.65 and 49.41 per cent over control. The highest fruit yield of 16.87 t/ha was obtained due to the application of profenophos 40 %. + cypermethrin 4 % followed by azadiractin (2 ml/l) and Bt (2 g/l).

Kernel (5 %), neem cake (5 %), neem oil (3 %) and neem leaf extract (5 %) were effective against Coriander aphid (*Hyadaphis coriandari* Das) (Kumari and Yadav, 2002).

Neem in rice crop

Raguraman and Rajasekaran (1996) tested the effectiveness of neem products against insect pests of rice *viz*., *Nilaparvatha lugens* (Stal) and *Cnaphlocrosis medinalis* (Guenee). It was observed that NSKE (5 %) with high volume applications was superior to monocrotophos (0.04 %).

Ho and Kibuka (1983) carried out tests on rice crop with neem cake and urea neem cake against the main pests *Maliarpha separatella* Rag., *Sesamia calamistis* Hmps., *Diopsis macrophthalma* Dalman and *D. apicalis* Dalman. It was found that plots treated with urea neem cake had more dead hearts than those treated with neem cake.

When azadirachtin 3000 ppm @ 3 ml/l sprayed at 85 days after transplanting against rice ear head bug, *Leptocorisa acuta* (Thunberg), suppressed the pest and produced grain yield on par with the chemical treatments *viz*., dimethoate 30 EC @ 1.75 ml/l, thiamethoxam 25 WG @ 0.3 g/l and malathion 5 D @ 20 kg/ha (Girish and Balikai, 2015).

Japur *et al*. (2012) reported that Sapindus + Neem oil mixture (1:1) @ 5 % recorded 60 % reduction in blue beetle (*Leptispa pygmaea* Baly) damage and NSKE @ 5 % recorded 56 % reduction in leaf damage. While Spinosad 45 SC @ 0.2 ml/l, *Metarhizium anisopliae* @ 2 g/ l, Emamectin benzoate 5 SG @ 0.25 g/l, Flubendiamide 39.35 SC @ 0.2 ml/l, Indoxacarb 14.5 SL @ 0.5 ml/l, Lambda cyhalothrin 5 EC @ 2 ml/l suppressed the blue beetle damage by 46.0, 42.0, 40.8, 40.0, 38.0 and 28.0 %, respectively.

Singh *et al.* (2018) reported that cow urine mixed with neem leaves @ 10 per cent (2-3 sprays) before flowering and at every 15 days intervals to control insects pests in both *kharif* and *rabi* seasons on Basmati rice in organic mode.

Prasad *et al*. (2018) reported that based on the overall results of the two years of experimentation revealed that neem cake @ 2.5 t/ha proved to be the most effective in minimizing the incidence of gall midge (*Orseolia oryzae* Wood-Mason) incidence.

Prasad *et al*. (2018a) revealed that neem cake @ 2.5 t/ha proved to be the most effective in minimizing the incidence of rice leaf folders (*C. medinalis*).

Prasad (2020) concluded that neem / karanj cake applied @ 2.5 t/ha was effective in reducing the incidence of major insect pests to its lowest and subsequently resulted in a substantial yield enhancement in the organic mode of rice production.

The alternate spray of fipronil 5SC @ 1200 ml/ha and botanical insecticide neem oil (2.5 l/ha) recorded an appreciable reduction in gundhi bug (*Leptocorisa acuta* Thunberg) population (4.21) and 23.5 per cent increase in aromatic rice grain yield over the control (Jha and Prasad, 2022).

Kumari and Prasad (2020) revealed that two sprays at 20 days interval with botanical insecticidal treatments in rice were significantly superior over control in reducing silver shoot (SS) infestation by gall midge and efficacy was maximum in Neem Baan (Aza 1.0% EC) @ 1000 ml/ha (4.71% SS) with highest grains yield (34.03q/ha), maximum net profit of ₹ 21325/ha and BC ratio of 8.5:1.

Yadav *et al.* (2022) studied the effect of botanical insecticides on the incidence of gall midge was tested with neem baan, Nemazol, Nimbecidine, Multineem, Neemoil, Achook, Pongamia oil, and Rynaxypyr. The result indicates that the minimum damage in terms of silver shoots (1.76 %) was found in Achook (Aza 0.03 %) showing superiority over all other treatments.

Highest B:C ratio of 2.99 was obtained in emamectin benzoate 5 SG @ 0.25 ml/l followed by spinosad 45 SC @ 0.2 ml/l (2.85) and profenophos 50 EC @ 2 ml/l (2.69) and that of least in azadirachtin 3000 ppm @ 3 ml/l (2.00) in a leaf folder management trial (Girish *et al*., 2015). The NSKE 5 %, neem seed kernel extract and neem oil applications proved least effective in reducing the percentage of damaged leaves due to the leaf folder (Roshan Lal, 2001). Similarly, NSKE @ 5 % and nimbecidine @ 3 ml/l were not much effective against the rice leaf folder (Rajendraprasad *et al*., 2011). Rath (2001) also quoted limited efficacy of azadirachtin formulation to leaf folder.

Azadirachtin 3000 ppm @ 3 ml/l was the next best treatment after insecticides like buprofezin 25 SC @1 ml/l, acephate 75 SP @1 g/l, thiamethoxam 25 WG @ 0.3 g/l, acetamiprid 20 SP @ 0.2 g/l, imidacloprid 17.8 SL @1 ml/l and monocrotophos 36 SL

@ 1.75 ml/l in the order of efficacy against paddy brown plant hopper, *N. lugens* (Girish *et al*., 2016).

These variations in the effectiveness of the different chemicals across the geographical areas might be due to the variations in the pest density and predatory spider pressure and also the time of transplanting and may also be due to rainy days coinciding with the time of insecticide application.

Neem in wheat and sorghum crops

Katare *et al.* (2018) tested the efficacy of 5 % neem seed extracts (NSE) and azadirachtin 1500 ppm (3.0 ml/1) to control the aphids *Rhopalosiphum maidis* (Fitch) in wheat crop and observed to be the most effective in reducing aphid population.

Rao and Srivastava (1984) evaluated neem formulations against sorghum ear head worm, *Heliothis armigera* (Hub.). It was found that pure kernel suspension was more effective than the other formulations.

Balikai and Lingappa (2005 & 2012) opined that *A. indica* kernels @ 5 % possessed as much insecticidal value as endosulfan 35 EC @ 0.07 % against aphid, *Melanaphis sacchari* (Zehntner) in *rabi* sorghum as reflected in higher grain and fodder yields comparable to endosulfan.

Mudigoudra *et al*. (2009) concluded that plant products like NSKE @ 5 % in combination with panchagavya @ 3 % or cow urine @ 5 % were as effective as that of chemical insecticides in reducing shoot fly infestation in *kharif* sorghum.

Neem in other crops

Aqueous Neem extract @ 300 l/ha was effective against corn ear worm (*Heliothis armigera* (Hub.)) (Udo and Ibanga, 2019). Klocke and Kubo (1982) observed that limonoid from Neem fruit was a potent toxicant at 10 ppm against *Spodoptera frugiperda* (J.E. Smith) and *Heliothis zea* (Boddie) on the gram. Chaudhari *et al.* (2018) tested the efficacy of six insecticides and azadirachtin 300 to control *H. armigera*. The treatments were found quite effective in controlling the insects of chickpea.

Srivastava *et al.* (1984) evaluated the effectiveness of 5-8 % neem kernel extract (NKE) for the control of *Melanagromyza obtusa* (Malloch) and *H. armigera* on red gram (*Cajanus cajan* (L.) Millsp). The results showed that treatment with 8 % NKE significantly reduced the damage. Randhawa *et al.* (2018) tested the relative efficacy of insecticides and biopesticides against the major insect pests of green gram. Neem oil 2 % and NSKE 5 % were tested against aphids, jassids and whitefly, and pod borer. The performance of neem oil was superior. However, NSKE 5 % was the least effective.

Balikai *et al*. (1997) reported that lower pod damage (39.8 %) and higher seed yield (10.2 q/ha) were recorded in the treatment that received three rounds of sequential spray of HaNPV @ 250 LE/ha - cypermethrin @ 0.01 % - neem seed kernel extract @ 5 % given at 15 days interval starting from 50 % flowering in red gram.

Sharadha *et al.* (2020) reported that soybean rust is caused by *Phakopsoro poohyrhizi* is the potential disease, causing severe losses in yield and quality of soybean. The result of the research experiment revealed that two sprays of hexaconazole 0.1 % + KNO_2 2 % recorded minimum disease severity followed by hexaconazole 0.1% + neem oil 1 % further two sprays of these treatments recorded maximum seed yield number of pods and 100 seed weight over unsprayed control. Mandawi *et al.* (2019) did a field experiment to evaluate botanical insecticides against pod borer on cowpea. Chlorpyriphos 20EC @ 300 g a.i./ha was the best treatment followed by Neem oil @ 2 % and NSKE @ 5 %.

Yelshetty and Balikai (1998) reported that neem oil @ 5% was effective in managing safflower aphid (*Uroleucon compositae* Theobald) population followed by dimethoate 30 EC @ 0.05 %.

Balikai (2016) opined that two sprays of Aza Max 1.2% @ 475 ml/acre or Aza Max 0.6% @ 700 ml/acre could be used for the effective management of white flies in Bt cotton. Shalini *et al.* (2011) reported that among the botanicals, neem oil @ 5 ml/l recorded higher mortality (70.00%) of cotton mirid bug, *Creontiades biseratense* (Distant), followed by garlic chilli kerosene extract @ 0.5 % (60.0%) and cottonseed oil @ 5 ml/l (43.33%).

Chenchaiah (2020) reported IPM module of *Spodoptera litura* consisting of sorghum barrier crop, NSKS @ 0.5 % spary, *Spodoptera* NPV 250 LE spray, Proclaim @ 5 g/10 litre water spray, Confidor @ 3 ml/10 litre water spray based on ETL was found to be effective and recommended for pest control in Flue-Cured Virginia tobacco grown areas under southern light soil domain of Andhra Pradesh.

As neem is a botanical insecticide, the quantity of insecticide required to bring the mortality is high, so, the azadirachtin 1500 ppm recorded higher LC_{50} values ranging from 399.09 to 563.45 ppm as compared to the range of 4.57 to 24.36 ppm in case of cotton leafhopper, *Amrasca biguttula biguttula* (Ishida) (Sagar and Balikai, 2014). This is the reason in many researchers' findings, neem products are not superior to insecticides. However, they are superior among the various plant products tested.

Antifungal activity of Neem

Bohra *et al*. (2018) studied the eco-friendly management of root rot of Guar with local isolates of the fungal pathogen, bacterial biocontrol agents and five neem-based formulations. They concluded that neem seed kernel extract and oil-based neem formulations (0.2 %) caused maximum growth inhibition of both *Fusarium solani* and *Rhyzoctonia solani.*

Bohra *et al.* (2018a) reported integrated management of root-rot of guar with neem oil-based neem formulation (0.2 %) and (0.1 %). They also used carbendazim 0.1 % + oil-based neem formulation (0.02 %) for better efficacy. These treatments developed around 20 % root rot up to 70 days.

Akhtar *et al*. (2022) undertook studies to assess the anti-fungal efficacy of some essential oil including neem oil against *Tilletia barclayana* (Bref.) Sacc. & P. Syd., causing kernel smut in rice and revealed that among all treatments, palmarosa oil was superior followed by cider wood oil and neem oil.

Safety of neem-based insecticides to natural enemies

Neem is one of the promising botanical insecticides used in pest management, which is safer for predatory insects and parasitoids. Preetha *et al.* (2018) tested the neem oil-based nano and macro emulsions and Rabin and Aniruddha (2018) tested NSKE (5 %) on egg parasitoid, *Trichogramma chilonis* Ishii and the results revealed that these neem products did not affect the parasitization and adult emergence of *T. chilonis* and found harmless. Based on the laboratory study conducted to check the parasitization potential of *T. chionis* on the host eggs contaminated with azadirachtin (1500 ppm), it is found that azadirachtin is slightly harmful to the egg parasitoid (Mahankuda and Sawai, 2020). The NSKE (5 %) and neem gold 0.03 EC were reported as harmless insecticides based on the contact toxicity study conducted against second instar grubs of *Chrysoperla zastrowi sillemi* (Esben-Petersen) (Poornima and Kambrekar, 2016). Commercial neem formulations *viz.,* Econeem and Neem Azal were found safer for all preimaginal stages of egg parasitoid, *Trichogramma japonicum* Ashmead compared to insecticides (Srinivasan *et al.,* 2001). A persistent toxicity study of neem oil (1500 ppm) against adults of *T. chilonis* reported that neem oil is short-lived and harmless to adult parasitoids (Sattar *et al.,* 2011). According to El-Wakeil *et al.* (2006) there were no serious side effects of Neem Azal on the parasitism and emergence of *Trichogramma pretiosum* Riley and *Trichogramma minutum* Riley and predation efficiency of *Chrysoperla carnea* (Stephens).

Bajya and Ranjith (2018) reported that NSKE-based azadirachtin 0.15 EC treated plots were safer to natural enemies, as evident from their increasing population *viz*., spiders and coccinellids in the rice ecosystem. According to Seni (2019), all the botanicals *viz*., Camphor oil, Cedarwood oil, Eucalyptus oil and Lemon grass oil @ 1000 ml/ha, Neem Azal 1 EC @ 1000 ml/ha were safe to natural enemies of insect pests of rice. Balikai and Lingappa (2004) documented that *A. indica* kernels @ 5 % when used for aphid management in *rabi* sorghum was found safe to its natural enemies.

Neem coated urea

Bijay Singh (2019) reported that the Government of India directed that all fertilizer urea manufacturers in the country or imported will have to be coated with neem oil @ 0.5 kg per tonne. The neem oil possesses nitrification inhibition properties and thus increases yield of crops. Based on published research, the mean increase in the grain yield of rice and wheat by applying neem coated urea/neem oil coated urea is around 5 to 6 per cent over the yields obtained by urea at the same N level; in about 30 per cent comparisons, no increase was observed. The same applies to other crops such as sugarcane and cotton where also respectively, 8.7 and 4.3 per cent increases in yields have been recorded in the researcher's plots.

Future thrust

No systematic work has been undertaken on the neem tree which has numerous qualities and usage and is truly called as "wonder tree". It is therefore; felt that the workers engaged in research on neem may consider the following thrust areas for high-quality neem production:

1. It is now important to establish a Field Gene Bank of neem cultivars found within the country and abroad at a suitable location. There is a need for genetic improvement of the neem of local species and for generating more information on various uses, production, and suitability systems.
2. An integrated process of cleaning, decortications, and crushing of neem seed for extracting neem oil needs to be developed.
3. It is imperative to have an international neem improvement programme network. The long-term objectives of the network comprise improvement of genetic quality and adaptability of neem and its utilization worldwide as pesticides, medicine, *etc.*
4. Increasing awareness of eco-friendly technologies and efforts to enhance the economic value of neem and its products which are likely to provide much-desired impetus and sustainability to their utilization. Therefore, it is imperative that effective formulations of high biological activity of neem are developed in order to minimize the use of chemical formulations.
5. Standardization and development of neem-coated urea-based fertilizer for their low nutrient release properties are required to be expedited.
6. Sustainable IPM programmes having neem as one of the important components, need to be standardized and implemented at a large scale.

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