PRCATICAL APPLICATIONS OF NEEM AGAINST PESTS OF STORED PRODUCTS

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Abstract: It has been an age-old practice to mix neem materials in stored products for protection against insect pests in countries where neem abounds. Recognition of this bio-dynamism of neem materials and the protection it offered to stored products was experience driven rather than being based on knowledge of neem's bioactive chemical constituents. Little consideration was given to large quantities of neem materials used because of the ubiquity of neem trees in villages and homesteads. The characteristic garlicky odor of neem materials permeating in closed storage environment presumably repelled insects and the bitter components present in neem materials mixed with the stored grains deterred feeding. Recent researches have revealed how the neem materials, whether raw, enriched, or purified, including bioactive compounds such as azadirachtin, affect insect pest behavior, growth and development, and survival and reproduction. The sensitivity of stored product insect pests to neem materials may vary, but nearly all are susceptible to neem. As seed damage is not always reduced by neem materials at par with synthetic insecticides, there has been some loss of faith in neem as a stored products protectant. However, the use of neem can confer significant economic advantage and service to rural areas in tropical developing countries if reliable recommendations can be made and given to farmers for the protection of stored commodities. This paper reviews the practical applications of neem based on actual field testing against pests affecting grains, such as legumes, sorghum and corn, wheat, rice, and potato tubers.

Key words: Azadirachta indica, stored grain protectant, neem.

Introduction

Although agriculture began about 10,000 years ago, the practice of storing food grains began about 4,500 years ago as a safeguard against poor harvests and famines due to adverse weather conditions and/ or pest attacks. There is evidence that several species of storage insect pest attacked granaries and other food structures in ancient times, e.g. in ancient Egypt (Levinson and Levinson 1985). Even today, storage losses remain notoriously high. According to an FAO study, world-wide loss in store approximates 10% of all stored grain., i.e., 13 million tons of grain lost due to insects or 100 million tons to failure to store properly (Wolpert 1967).

Insect pests cause heavy food grain losses in storage, particularly at the farm level in tropical countries. Food grain losses in India during storage at the farm level approximate 10% of the production (Lal 1988). In Sub-Saharan Africa, food grain losses during storage at farm level can reach as high as 25-40% (Dichter 1976). Such high levels of food grain losses generally result from inadequate post-harvest management practices and poorly designed storage structures (Anon. 1989). In a survey conducted in the Nyanza district in Kenya, it was found that 20% of corncobs were already infested with weevils at the time of harvest (Nyambo

1993). In Togo, corncobs stored in cribs suffered much higher pest damage than when stored in granaries (Richter *et al.* 1997).

Although improved storage structures and modern chemical and physical control techniques are now employed for the safe storage of produce, in many countries 70-90% of food grain is still stored for 6 months to a year at farmer's level in traditional storage structures made of locally available material, such as paddy straw, split bamboos, reeds, mud, bricks, etc., which are not insect-proof (Semple 1990). In some countries, grains are sometimes mixed with sand, limestone, or ash to provide physical obstacles to movement of insects through the grain and reduce deposition of eggs. In Nigeria, both local herbs and smoke from small fires have also been used as insect repellents and fumigants to deter insect establishment in stored food grain (Ezueh 1983).

The size of on-farm storage may range from a few hundred kilograms to a few tons. Gunny bag storage, as practised widely in some countries, is not the most efficient way of storing food grains and is vulnerable to pest attacks. Prophylactic chemical and physical treatments, such as aeration, radiation, refrigeration, heating, or hermetic storage in controlled nitrogen or carbon dioxide gaseous environments, are not only prohibitively expensive but not always feasible, because in villages the food grain is generally stored within the confines of human dwellings. Also, widespread resistance to insecticides, including the juvenoid methoprene, among populations of major post-harvest insect pest species (Benezet and Helms 1994, Champ and Dyte 1976, Muggleton 1987) and concerns about health hazards associated with the use of chemicals are other limitations of chemical control at village levels. Although methyl bromide has been used as a fumigant for more than 70 years for controlling insect pests in durable and perishable commodities, concerns of its role in ozone depletion indicate that it will eventually be removed from the list of few remaining products capable of preventing the damage in food and other commodities (Taylor 1994). This situation demands alternative control measures that reduce the dependence on contact insecticides.

Over the past three decades, neem, *Azadirachta indica* (A. Juss.), a botanical cousin of mahogany, has come under close scientific scrutiny as a source of natural pest control materials (Schmutterer 2002). The tropical tree is widespread in Asia and Africa and has long been known to be free from pests and diseases. The scientific name of neem is derived from *"azad dirakht-i-hind,"* which in Persian language means the "free or noble tree of India." Here, the traditional uses and the possible practical applications of neem materials for averting losses in food grains and other commodities caused by stored products insect pests are reviewed and evaluated on scientific bases.

Traditional Uses

It has been an age-old practice in India to mix dried neem leaves with grains meant for storage. The practice of mixing neem materials with stored products became rooted as part of traditional wisdom and culture. Pruthi and Singh (1944) recorded that neem leaves were spread in 5-7 inches thick layers in grains and neem fruits were crushed on the inner surfaces of grain containers. Mixing of neem leaves (2-5%) with wheat, rice, or other grains is even now practised in many villages in India and Pakistan. Other common practices include mixing of neem leaf paste with the mud that is used for making earthen bins and overnight soaking of gunny bags in boiled neem leaf extract (2-10%), which are then used for storing grain.

The traditional uses of neem may differ in different regions or with farmers of different cultural backgrounds. For example in southern Sind, Pakistan, farmers mix dried neem leaves with grains stored in jute sacks, or they apply crushed neem leaves on the inner surfaces of mud bins before filling them with grains (Jilani and Amir 1987). In central Sind, where *"palli"* (a giant basket) made of plant materials is a common storage structure, crushed neem leaves mixed with mud are used as plaster for its inner sidewalls and top. In southern Punjab, Pakistan, neem leaf extract is sprinkled on wheat straw packed at the bottom of *"palli"* 2 to 3 days before filling with grain. A survey of various types of on-farm storage practices revealed that a combination of two or three control measures, including the use of neem leaves, was used by 29% of the farmers in Punjab and 47% of the farmers in Sind (Borsdorf *et al.* 1983). In Sri Lanka, farmers burn neem leaves to generate smoke for fumigation against insect pests that attack stored paddy and pulses (Ranasinghe 1984). Also, chopped green leaves are kept over the heap of paddy in a container; as leaves dry up, they are replaced periodically.

Ahmed and Koppel (1987) conducted a survey of post-harvest control practices of 145 farmers in 11 districts of six provinces in India. They found that 30-60% of the farmers who stored wheat, rice, sorghum, and millet, used 4-10% neem leaves (wt/wt) for protection. The grain was stored in large, open straw baskets or in jute bags.

In Ghana, cacao beans mixed with 8% neem leaves remained free from attack by *Ephestia cautella* up to 9 months in storage (Fry 1938). In Nigeria, the traditional use of neem for protecting stored grains is well-documented (Bugundu 1970, Giles 1964, Prevett 1962).

The traditional use of neem materials simply emerged from experience and understanding that relatively less damage occurred in the treated stored commodity than when stored without neem. Little consideration was given to the large quantities of neem material needed for affording protection because of the ubiquity of neem tree in villages and on homesteads. The characteristic garlicky odor of neem materials permeating the closed storage environment presumably repelled insects and bitter compounds in neem materials mixed with the stored grain discouraged insect feeding. Probably, the oil present in neem seed or kernel also discouraged egg deposition on grains, particularly on leguminous seeds. There could also be other less visible but significant effects of neem on behavior and physiology of stored product pests.

Scientific Basis for Effectiveness of Neem Materials

How neem materials, whether raw, enriched, or purified, including biactive compounds, such as azadirachtin, affect behavior, growth and development, and survival and reproduction of stored product insects has been reviewed (Jacobson 1986, Jotwani and Srivastava 1981, Mordue (Luntz) and Blackwell 1993, Pascual *et al.* 1990, Saxena *et al.* 1989, Schmutterer 1988, Singh 1993). Although the sensitivity of stored product insect pests to neem materials varies, almost all the species are sensitive to neem. There are a few exceptions, such as *Oryzaephilus surinamensis* (Sarup and Srivastava 1971) and *O. acuminatus* (Thomas and Woodruff 1983), which can infest old neem seed kernels.

Although seed damage is not always reduced by neem materials at par with synthetic insecticides (Sehgal and Ujagar 19990), the advantage of neem treatment is that it does not impair the germination of stored seed (Gupta *et al.* 1989). In fact, rice seedlings raised from seed treated with 2.5% neem seed kernel extract or with 2% neem cake were more vigorous and had higher root and shoot growth indices and dry weights than those germinated from untreated seed (Abdul Kareem *et al.* 1989).

Practical Applications

Since the advent and popularization of broad-spectrum synthetic insecticides, there has been some loss of faith in neem as a protectant for stored products. However, the use of neem can confer significant economic advantage and service to rural areas in tropical developing countries, if reliable recommendations can be made and given to farmers for the protection of stored commodities, especially food grains, animal feed, and seed, from insects. This approach requires on the spot production and field testing of neem-based grain protectants as well as revalidation of previous reports. Some of these are reviewed here with respect to legumes, sorghum and corn, wheat, rice and paddy, and potato.

Legumes. In India, green gram, chick pea, cowpea, and pea could be protected from damage by the pulse beetles, *Callosobruchus* spp., for 8-11 months by mixing powdered neem kernel with grains at 1 or 2 to 100 parts (Jotwani and Sircar 1967). Neem kernel protected the legumes against *C. chinensis* and *C. maculatus* and stopped the development of progeny even 12 months after *C. chinensis* was released on treated lentil seed (Yadav 1973). Likewise, chick pea and pigeon pea seeds remained undamaged up to 12 months after treatment with 2g neem kernel powder per 100 g seed. Application of 1 to 3 parts of neem oil per 100 parts of Bengal gram rendered complete protection against *C. chinensis* for at least 135 days, without impairing seed germination.

Ketkar (1976) tested the efficacy of neem kernel and oil for protecting bagged leguminous seeds (peas, Bengal gram, *Phaseolus*, and *Vigna* spp.) from pulse beetles during 8 months storage in warehouse trials conducted in Pune, India. Neem oil treatment at 8 ml to 1 kg of grains reduced the infestation to almost zero in Bengal gram and *Phaseolus* (*vs*. 14% in untreated Bengal gram and 26% in untreated *Phaseolus*), and by 50 to 70% in treated peas and *Vigna*; treatment with kernel was less effective. Neem oil did not affect seed viability and unused seeds were fit for animal and even human consumption. Ali *et al*. (1983) reported that neem oil at 1 ml/100 g seed killed all the pulse beetle grubs and adults, and no eggs were laid on treated seed. On cowpea and bambara groundnut, neem oil at 8 ml/kg seed not only reduced oviposition, but also killed larvae; the activity persisted more than 90 days on cowpea and for 180 days on bambara groundnuts (Pereira 1983). Green gram was completely protected against *Callosobruchus* spp. when soaked for 20 minutes in a 1% solution of neem oil extractive (Attri and Prasad 1980).

In a warehouse trial conducted in Togo, white cowpea treated with 0.5% neem oil was protected from *C. maculatus* for up to 6 months of storage and even after 10 months of storage only 18% of the initial weight was lost (Zehrer 1984). In contrast, fumigation with aluminum phosphide (‘Phostoxin’) initially killed all storage pests, but re-infestation occurred after 6 months and 4 months later all cowpeas were destroyed. Untreated cowpea lost 50% of its initial weight after 10 months of storage, which was near total loss as far as human consumption was concerned. The neem oil-treated cowpea had good texture, but tasted slightly bitter. However, the influence of taste was mattered little compared with the overall nutrient value and acceptability. Probably, eating quality could have been improved further by thorough rinsing or by removing the seed coat prior to cooking. Neem oil was found to be highly suitable for cowpea preservation and well adapted to the life styles of subsistence farmers, as it was inexpensive and its application did not need any tools.

In Ghana, Tanzubil (1987) demonstrated that cowpea treated with neem oil at 0.5%, or mixed with powdered fruit at 10% remained undamaged by *C. maculatus* over a 16 week storage period; mixing neem leaf dust in the grain was less effective, while untreated cowpea had 90% grain damage.

Sorghum and corn. In India, sorghum seed mixed with powdered neem kernel in a proportion of 100 to $\geq$ 1.5 (wt/wt) remained protected from damage by *Sitophilus oryzae* (Deshpande 1967). Corn seed soaked for 20 minutes in a 1% solution of neem oil extractive was resistant to attack by *S. oryzae* (Attri and Prasad 1980). In Togo, Adhikary (1981) found that neem treatment of corn stored in sacks or unpeeled corn cobs held in bins was quite simple and effective against *S. zeamais*, *Tribolium* spp., *Rhyzopertha dominica,* and *Cathartus* spp.

Wheat. Jotwani and Sircar (1965) in India were the first to demonstrate that powdered neem kernel when mixed with wheat seed at a proportion of 1-2 to 100 (wt/wt) parts satisfactorily protected against *S. oryzae, R. dominica,* and *Trogoderma granarium* for 270, 320, and 380 days, respectively. Rahim (1997) found that an ethanolic neem kernel extract, containing azadirachtin, at 75mg/ kg protected stored wheat against *R. dominica* for up to 48 weeks. In warehouse trials, wheat grain treated with neem oil at a proportion of 8 ml to 1 kg grain, prior to storing for 8 months in gunny bags, had 50 to 70% less infestation by *S. oryzae, R. dominica*, *T. castaneum*, and *Cryptolestes* spp. (Ketkar 1976). Application of neem oil at a low concentration of 0.1% (wt/wt) to wheat grain reduced egg laying by *Sitotroga cerealella* as effectively as a 5% malathion dust treatment (Verma *et al.* 1985).

In commercial trials conducted in Pakistan, it was demonstrated that paper or cloth grain storage bags treated with water extract of neem leaves at 20% (wt/vol) or water extract of neem seed at 5% (wt/vol) checked the penetration of stored grain pests into the bags for 6 months during storage (Malik et al. 1976, Jilani 1981). In an on-farm trial conducted in Sind, Pakistan for 13 months, the application of ethanolic neem seed extract (600 $\mu g/cm^2$) to storage bags or directly to wheat grain controlled more than 80% of the population of *Tribolium castaneum*, *R. dominica*, *S. oryzae*, and *S. cerealella* and prevented grain damage up to 6 months (Jilani and Amir 1987). The treatments remained effective up to 13 months, providing more than 70% protection; insect infestation and the percentage of weevil attacked grains was much lower than in the untreated control.

Rice and paddy. In Malaysia, mixing neem leaves with paddy grain in a proportion of 2 to 100 parts (wt/wt), bag treatment with 2% neem leaf water extract (wt/wt), or placing barriers of neem leaves between bags and storage floor, significantly reduced the infestation by *S. oryzae* and *R. dominica* and damage to paddy grain stored in 40 kg jute bags for 3 months (Muda 1984). Although it was not clear which treatment was superior, but all treatments had potential for adoption in rural areas.

In a warehouse trial conducted in the Philippines, Jilani and Saxena (1988) evaluated the effectiveness of neem oil alone or in combination with fumigation against five species of major stored grain pests infesting rice and paddy grains. Rice grain treated with 0.05 to 0.1% neem oil or treated with neem oil after fumigation with 'Phostoxin', and stored for 8 months contained significantly less *T. castaneum* adults than in the untreated control (Table 1). Both kinds of neem treatments were as effective as the bag treatment with 'Actellic' (primiphos-methyl 20 EC) at 25 µg/cm^2 or grain treatment with 'Actellic' at 0.0005%, and suppressed the pest population by about 60%. The pest population build-up also was reduced when either fumigated or non-fumigated rice was stored in bags treated with neem oil at $\geq$1 mg/cm^2. Other pest species, *R. dominica*, *S. oryzae*, *O. surinamensis*, and *Corcyra cephalonica* were similarly affected by neem treatments alone or in combination with prior grain fumigation. Fumigation with 'Phostoxin' was effective only for a period of about 2 months against *R. dominica*, and for up to 6 months against other pest species. In contrast, neem oil treatments were effective up to 8 months. Compared with the pest damage to untreated or fumigated rice, neem oil treatments significantly reduced the damage to rice grain. At 8 months after storage, weevil attacked grains in neem treatments were 50% of those in the fumigated rice and 25% of those in the untreated rice.

Paddy grain that had been fumigated and then treated with neem oil or, after fumigation, stored in neem oil-treated bags, also had fewer adults of *T. castaneum*, *R. dominica*, *S. oryzae*, and *O. surinamensis*, as compared with the fumigated or the untreated paddy grain (Table 2). *C. cephalonica* infestation was found in the stored paddy only after 4 months and remained low throughout the trial in treated as well as untreated paddy.

Table 1. *Tribolium castaneum* (TC), *Rhyzopertha dominica* (RD), *Sitophilus oryzae* (SO), *Oryzaephilus surinamensis* (OS), and *Coryra cephalonica* (CC) adults and weevil-attacked grains found in samples taken from rice stored for 8 months in neem oil (NO)- or Actellic-treated bags or in rice treated with phosphine gas (1g/m^3), phosphine gas and NO, NO alone, or with 'Actellic' prior to bagging and storing in a warehouse in the Philippines (adapted from Jilani and Saxena 1988)[a]

Treatment	Conc.	Adult insects and weevil-attacked grains in 250g samples[b]					
		TC (no.)	*RD* (no.)	*SO* (no.)	*OS* (no.)	*CC* (no.)	Weevil-attacked grains (%)
NO-treated bag	(1mg/cm^2)	2.0a	5.0a	3.1a	2.4bc	2.7a	3.1a
NO-treated bag	(4mg/cm^2)	3.0abc	5.0a	3.5ab	2.1abc	2.7a	3.3a
Fumigation+NO-treated bag	(1mg/cm^2)	3.0abc	4.0a	3.1a	2.4bc	4.7abc	2.8a
Fumigation+NO-treated bag	(4mg/cm^2)	2.7ab	4.0a	3.1a	2.4bc	4.0ab	3.2a
NO-treated rice	(0.05%)	2.3ab	5.3a	3.9ab	2.4bc	2.3a	2.8a
NO-treated rice	(0.1%)	1.7a	3.3a	3.5ab	2.4bc	2.7a	2.9a
Fumigation+NO-treated rice	(0.05%)	2.3ab	3.7a	3.5ab	1.2a	3.0a	3.1a
Fumigation+NO-treated rice	(0.1%)	1.7a	4.3a	3.1a	1.8ab	2.7a	2.8a
Actellic-treated bag	(25ug/cm^2)	1.7a	3.7a	3.1a	2.1abc	2.3a	2.8a
Actellic-treated rice	(0.0005%)	3.0abc	3.0a	2.4a	1.2a	3.0a	3.3a
Phosphine fumigation	(1g/m^3)	4.0bc	9.7b	5.3b	2.7bc	6.3bc	5.9b
Control	(untreated)	5.0c	10.0b	5.7b	3.5c	8.3c	10.6c

[a] Pest infestation was low (0 to 0.7 adult per species per sample) and weevil attacked grains were few (0.2 to 0.4%) in rice grains sampled initially at one month after storage.
[b] In a column, means followed by the same letter are not significantly different at the 5% level by Duncan's (1951) multiple range test (DMRT); averages of three replications per treatment.

Neem treatments also decreased the per cent weevil attacked grains by about 70% or more. Compared with fumigation, which was effective for only 2 months, neem treatments conferred protection against the stored grain pests for up to 8 months, after which the trial was terminated.

Table 2. *T. castaneum* (TC), *R. dominica* (RD), *S. oryzae* (SO), *O. surinamensis* (OS), and *C. cephalonica* (CC) adults and weevil-attacked grains found in samples taken from paddy stored for 8 months in neem oil (NO)-treated or actellic-treated bags, and in paddy treated with phosphine gas (1 g/m^3), phosphine gas and NO, NO alone, or with 'Actellic' prior to bagging and storing in a warehouse in the Philippines (adapted from Jilani and Saxena 1988)[a]

Treatment	Concn.	Adult insects and weevil-attacked grains in 250g samples[b]					
		TC (no.)	*RD* (no.)	*SO* (no.)	*OS* (no.)	*CC* (no.)	Weevil-attacked grains (%)
NO-treated bag	(1mg/cm^2)	1.3a	6.7bcd	4.3abc	2.1abc	0.7a	4.3ab
NO-treated bag	(4mg/cm^2)	1.7ab	5.0abc	3.1a	1.2a	1.0a	3.3a
Fumigation+NO-treated bag	(1mg/cm^2)	3.0b	3.3ab	3.5ab	2.4bc	1.0a	3.6ab
Fumigation+NO-treated bag	(4mg/cm^2)	1.7ab	3.7ab	3.1a	1.8ab	1.0a	3.1a
NO-treated paddy	(0.05%)	2.3b	4.7abc	4.3abc	2.1abc	0.7a	3.3a
NO-treated paddy	(0.1%)	2.3b	6.0a-d	3.5ab	1.0a	1.0a	3.3a
Fumigation+NO-treated paddy	(0.05%)	1.0a	3.3ab	3.1a	3.1bc	0.7a	3.4a
Fumigation+NO-treated paddy	(0.1%)	1.3a	3.7ab	3.1a	2.4bc	1.0a	3.3a
Actellic-treated bag	(25ug/cm^2)	1.0a	3.7ab	3.9ab	2.1abc	0.7a	3.1a
Actellic-treated paddy	(0.0005%)	2.7b	3.3ab	6.8cd	1.8ab	0.7a	3.7ab
Phosphine fumigation	(1g/m^3)	3.3b	7.0cd	9.1d	2.7bc	1.3a	5.9b
Control	(untreated)	1.9ab	9.3d	5.7bc	3.5c	1.3a	13.3c

[a] Pest infestation was low (0 to 0.7 adult per species per sample) and weevil attacked grains were few (0.2 to 0.6%) in paddy grains sampled initially at one month after storage.
[b] In a column, means followed by the same letter are not significantly different at the 5% level by DMRT; averages of three replications per treatment.

The efficacy of neem oil against some species of stored grain pests was confirmed in laboratory bioassays. In a choice test, filter paper strips treated with $\geq$200µg/cm^2 of neem oil repelled *T. castaneum* adults and in a food preference chamber fewer adults settled in grains treated with >100 ppm of neem oil (Jilani *et al.* 1988). *T. castaneum* adults fed wheat flour, which had been treated with 200 ppm of neem oil, produced fewer and underweight larvae, pupae, and adults, compared with the control. Likewise, in choice tests, *R. dominica* adults were strongly repelled by filter paper strips treated with neem oil or 'Margosan-O,' a neem-based insecticide, at $\geq$200µg/cm^2 (Jilani and Saxena 1990). The borer made significantly smaller feeding punctures in filter paper disks treated with neem oil or 'Margosan-O' at $\geq$100µg/cm^2 than in untreated control disks. The effects of neem oil and 'Margosan-O' persisted long enough to give a satisfactory result, as generally seen in field trials.

Potato tubers. Neem can also be applied in reducing damage due to the potato tuber moth, *Phthorimaea operculella,* during storage. In India, in simulated storage trials as well as in actual storage trials conducted in a warehouse, a 4 month protection was achieved against the pest when harvested potato and the covering material was sprayed with 5 and 10%

'enriched' neem seed extract (Sharma *et al.* 1984). Serious potato tuberworm damage to stored potato was averted also in the Sudan by spraying potato with a 2.5% neem leaf or seed extract prior to bagging (Siddig 1987).

Future Considerations and Conclusion

Although the use of synthetic pesticides, including fumigants, continues to be the chief method of controlling stored products pests, neem materials, such as leaves, seed or kernel powder, and oil can be used economically to achieve acceptable levels of pest control in villages and rural areas in developing countries, where neem is widespread. Neem materials, having insect repellent, antifeedant, and insect growth and development inhibitory properties, offer a time-tested, novel approach to the management of stored products pests. This approach can be quite practical and preferable over other methods, such as fumigation, which lose effectiveness after some time, leaving the stored commodity vulnerable to reinfestation. A promising method for preserving stored products in villages and rural areas, which do not have access to modern storage facilities, will be through encouraging the use of neem-treated storage bags or bins. And, if grain fumigation is practiced, then the problem of reinfestation during long-term storage can be overcome by integrating fumigation with bag treatment or grain treatment with neem oil, extract, or powder. Such treatments are safe and suited for grain protection by resource-limited farmers in developing countries.

The use of dried neem leaves or leaf powder would not need any standardization, except probably ensuring the minimum effective quantity required for mixing with grain. However, appropriate machinery, *e.g.* decorticator, seed/kernel crusher, pulverizer, will be needed for village level processing plants (Sivakumar *et al.* 1996) for producing quality seed/kernel powder and oil. Also, as azadirachtin, the principal bioactive ingredient in neem, is heat sensitive, cold processing technology for neem seed would be needed. Neem oil obtained by cold processing of seed is light in color and can be rich in azadirachtin ($\geq$2,000 ppm) (Ramakrishna *et al.* 1993). Oil, thus obtained, could be standardized for chemical properties and ingredients, biological activity, and its efficacy stabilized and further enhanced by the addition of stabilizers, antioxidants, synergists, compatible plant products with pest control properties (*e.g.* pyrethrins), or even synthetic insecticides. Also, improved methods of application, *e.g.*, mechanical mixers for uniform and bulk coating of oil on grain, use of slow release dispensers/sachets which could be placed at different depths in storage structures, bins or bags, could be devised for ensuring and enhancing efficacy.

Beside the excellent track record of neem seed as non-toxic, non-hazardous pest control material, especially suited for post-harvest management, the use of neem has other fringe benefits such as the inhibition of production of aflatoxins, which can grow in some food. Zeringue and Bhatnagar (1993) reported that nonvolatile, somewhat heat labile constituents in neem leaf extract, when added to fungal growth medium before inoculation, blocked aflatoxin biosynthesis in *Aspergillus flavus* and *A. parasiticus*. Practical applications of this finding may eliminate pre-harvest contamination of crops with aflatoxins.

Definitely, neem treatments, comprising the use of leaves, seed/kernel powder, extracts, and even bioactive principles, cannot replace completely chemical pesticides used in stored products preservation, but the amounts of pesticide needed could be reduced, thereby decreasing the pesticide load in food grains. Neem materials, in spite of possessing broad-spectrum activity against pests of stored products, are generally not hazardous to beneficial organisms, such as predators and parasitoids, and, with proper timing and innovative methods of application, their use could be integrated in stored product pest management. With increased interest in the biological control of stored product pests, this aspect merits investigation and evaluation.

The neem tree thrives on waste and marginal lands. Unlike pyrethrum (which requires careful cultivation), neem, once established, becomes a perennial source of pest control materials and other useful products.

Despite the setback to the traditional pest control uses of neem due to the advent and popularization of synthetic insecticides, new interest in the pest control potential of neem has grown worldwide since the past decade. However, if full benefits are to be achieved, then further patronage is needed from governments, policy makers, administrators, public and private organizations, national and international programs, and the donor community. Collecting and processing of neem seed and foliage will have to be undertaken on an organized scale. For example, in India, in spite of the growing demand, neem seed collection is barely 25% of the total produce. Also, more trees will have to be grown to ensure availability around the year of the raw material.

The complexity of the azadirachtin molecule will preclude its economic synthesis in the near future. So, neem seed will be the basic material needed for the production of neem-based pesticides, enriched formulations, or plain seed powder or oil.

There is every reason to believe that the use of neem materials for pest control will increase both in developing as well as developed countries. But as far as stored product pests are concerned, with increased use of neem materials the possibility of selection of tolerant pest species or strains cannot be negated. Already, species such as *O. surinamensis* and *O. acuminatus* have been reported to survive on old neem kernels (Sarup and Srivastava 1971). Studies of averting such a possibility would prolong the useful life of neem materials in stored product management.

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