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Neem (*Azadirachta indica*) and other botanical plant's grain protectant: A review

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Abstract: Smallholder farmers in underdeveloped countries, such as Nepal, frequently experience substantial grain storage losses, which contribute significantly to food insecurity. Wheat is one of the necessary needs of humans, these crops are particularly grown in the winter season. Humans preserve grains throughout the year. Approximately 10-20% of grain is lost to pests (insects, rats), and diseases (rotten) cobs in Nepal. As a preventative measure, farmers often used botanical insecticides in the past, which are now being replaced by modern chemical fumigants. These fumigants residue is highly toxic and causes health hazards to humans when used continuously and indiscriminately.

Thus, the objective of this review is to assess the traditional plant-based grain storage practices for smallholder farmers in developing countries and highlight their most promising features and drawbacks. Research studies on neem and other botanical plants, their constituents as fumigants i.e., compounds acting on target insects against stored-grain crops insects have been reviewed. Azadirachta indica, commonly known as neem, has attracted worldwide prominence in recent years, owing to its wide range of botanical insecticides. This plant's fruit, seeds, oil, leaves, roots, and bark are used for pest management, insecticidal properties, insect repellents, pesticides properties, have antiretroviral, antifungal, antibacterial, and medicinal properties for grain crops. Neem extracts can be used against over 250 pests including whiteflies, aphids, mealybugs, mites, and termites. This review summaries the wide range of botanical activities of the neem along with other botanical plants as a grain protectant.

Keywords- **Storage, Grain, pest, Azadirachta indica, insecticides, Neem, preserve.**

I. INTRODUCTION

Cereals are the edible seeds and grains of the Gramineae family, which include rye, oats, barley, maize, triticale, millet, and sorghum. Worldwide, wheat and rice account for over 50% of the world's cereal production. (McKevith, 2004).

Wheat (T. aestivum) grains are a stable and valuable crop that serves as a good source of protein (Gairhe et al., 2017). In Nepal, Wheat is the third most important crop after rice and maize and is cultivated on 762373 hectares, with national productivity of 2.55 tons per hectare. So far, 43 improved varieties of wheat have been released by the government of Nepal, out of which 13 varieties have been de-notified (Timsina et al., 2019). Nepal, being a landlocked country, Wheat grains are cultivated only during the winter season in the terai, the mid-hills, and the high hills (Devkota and Phuyal, 2015). Produced food and trade commodities such as cereals, oilseeds, pulses, spices, dried fruits, and tree nuts are hindered by insect pest infestations, resulting in economic and quality loss (Rajendran, 2001).

Over 20,000 species of field and storage pests destroy about one-third of the global food production annually, valued at over $100 billion, with the highest losses (43%) occurring in developing Asian nations (Singh, 2017). However, in recent years many countries are now focusing on plant-based products for medicinal purposes to solve global problems in agriculture, the environment, and public health (Lokanadhan et al., 2012).

2. PURPOSE OF FOOD GRAIN STORAGE

The storage of food grain is a crucial part of the economy of developed and developing countries. Quality food grains must be provided to customers for use in various goods and marketing, as well as to farmers for planting and growing nutritious cereals and pulse grains. These necessitate consistent agricultural production, which will help to stabilize any country's economy. So, it is essential to store grains all year and gradually release them to the market during off-season months to ensure a plentiful supply, keeping pricing stable during those months. (Ellis et al., 1991; Adejumo and Raji, 2007; Adesina et al., 2019).

Insect infestations are a big problem in grain storage and other food products around the world. A worldwide report in 1989 revealed that 9% of post-harvest losses were caused by insect and mite infestations, indicating the need for a comprehensive effort to reduce these losses. Other than insects, rodents and molds are also responsible for stored food grain losses. Consequently, during the storage season, it is important to control and reduce grain losses (Miyata, 1989; Pree et al., 1989; Haq et al., 2005).

There are many other reasons for storing grain, such as the time of production is not the same as the point of consumption and the production is not the same as the consumption. There is a risk that stored grain will lose quality and quantity as a result of insect, mite, rodent, bird, and microorganism infestations. These infestations cause crop losses in both quality and quantity and can contaminate the grain with their metabolic by-products. As a result of their metabolic activities, produce heat and moisture that promote microflora growth and hotspots in grains. (Neethirajan et al., 2007).

To prevent such loss, various types of storage techniques including metal bins, plastic bags, jute bags, and natural medicinal plants were utilized to preserve grains' physicochemical properties. (Kandel et al., 2021).

3. LOSSES FROM INSECT PESTS ON STORED GRAINS

With the growing population, it is difficult to protect and store cereal grains from insects such as weevils, beetles, moths, and rodents and quickly degrade due to fluctuations in temperature, moisture, chemicals preservatives, and the types of storage methods used (Devkota et al., 2015; Mishra et al., 2012). According to the Paneru et al., 2018 survey in Nepal's central and far-western mid-hills, pests (insects, rats) and diseased (rotten) cobs caused 19.5% *12.5% of crop losses. Food loss is a serious threat both to food security and environmental welfare. It is most often the waste of viable food products in developed countries that causes food losses, while in developing countries, it is more likely to be post-harvest losses or in-field losses (Bailey, 2015). Although, crop suffers from severe post-harvest losses due to different factors. In Nepal, 10-20% of cereal grains are lost post-harvest (Bhandari et al., 2015).

Sharma, 2016 reports that 70% to 90% of food grain is stored for six months to a year at the farmer's level in structures made from locally accessible materials such as paddy straw, split bamboo, reeds, mud, bricks, and other materials, which are not insect-proof.

In ancient times, granaries and other food structures were attacked by several species of storage insect pests (Levinson and Levinson 1984). According to an FAO study, global grain losses amount to about 10% of all stored grain, i.e., 13 million tons of grain lost due to insects or 100 million tons due to improper storage (Saxena, 2009).

According to Utono, 2013 insect pest infestations in grain storage were a crucial problem, threatening the livelihood of small-scale farmers and producing the worst infestations and infestation levels in various types of grain warehouses.

The insects are not controlled, losses can range from 20 to 80 percent within a few months of harvest. Insects such as the lesser grain borer (Rhyzopertha dominica), maize weevil (Sitophilus zeamais), and red flour beetle can damage and consume stored grain (Tribolium castaneum) (Rembold et al., 2011; Dowell and Dowell, 2017).

In many parts of the world, insects and diseases consume or damage a fifth or more of stored food grains each year, and the impact of such varieties could be dramatic in developing countries, where grain infestations are most common and harmful. In (a less developed country), where tropical conditions allow insects and disease agents to reproduce quickly and colonize unprotected grain, such damage is commonly responsible for losses of more than 20% of the grain harvested (David, 2004)

Grain is frequently stored for fewer than eight months across Africa, particularly in Ethiopia, due to poor storage practices and insufficient insect and pest management systems, resulting in qualitative and quantitative losses during storage. There is an estimated 10-30% grain loss due to insect pests in Ethiopia (Demiscoasie et al., 2008; Tefera et al., 2016; Tadesse, 2005; Tadesse and Ali, 2021).

Rice weevils (Sitophilus oryzae L.) are one of the most serious pests of cereal grains Mainly Soft wheat grain varieties are preferred by the pest (Zakladnoi and Ratanova, 1987; Baloch, 1992; Oryzae et al., 2006).

Ward et al., 1970 report that the Greenbug, Schizaphis gram mum (Rondani), has destructive effects on wheat, barley, and oats during the winter and spring seasons in North America. This aphid is considered the most destructive of the small grain aphids.

Farmers face major postharvest issues when the grain is attacked by weevils, primarily during the storage phase, causing the grain to become less marketable, resulting in financial loss for the producers and poor quality for the customers. Due to these problems, many farmers prefer to sell their crops immediately after harvesting to avoid losses from weevil infestations. An estimated 15–20% of Ethiopia's stored grain agricultural product is lost every year as a result of weevil infestation resulting in weight loss and quality deterioration (Adane, 2020).

Mason and McDonough, 2012 reported that, Insect infestation and mold and microbial deterioration are common problems with stored grains and legumes. The United States believes that the average minimum overall loss from biological degradation in industrialized countries is 10% (National Research Council 1978), whereas in developing countries is 20%.

Food grain losses during storage due to numerous insect infestations are a severe problem. According to a survey of 27 states and provinces in the United States and Canada, stored-product pests contaminated 20-26 percent of stored wheat In India, insect damage accounted for 6.5 percent of stored grain losses in which rice weevil, Sitophilus oryzae (L.), is the world's most common storage pest of raw cereals (White et al. 1985; Raju 1984; Talukder, 2009)

During the storage period, most of the cereals and legumes cultivated in sub-Sahelian West Africa, such as maize, millet, rice, sorghum, soybeans, cowpea, and groundnuts, are damaged by pests such as Stitophilus oryzea Linn., Oryzeaphilus surinamensis Linn., Coreyra cephalonica Saint, Ephestia cautella Wlk., Sitotrog (Fatope et al., 1995).

4. ADVERSE EFFECTS OF FUMIGANTS AS GRAIN PROTECTANTS

It has been common practice since the 1960s to use a variety of pesticides and fumigants to control stored grain pests and insects. In addition, the accumulation of toxic residues on food grains has resulted in health hazards to humans due to their uninterrupted and indiscriminate use. At present, modern agricultural methods and costly insecticides and insecticides are broadly used to control pest attacks on crops during storage; In addition to being expensive, these pesticides and residues are released and are hazardous to human health. (Adejumo et al., 2014) However, in many developing countries, about 70-90% of food grains are stored in conventional storage structures to control pests and insects, using the hazardous and chemical fumigant (methyl bromide) during the storage of grains for more than 70 years (Saxena, 2009).

Currently, methyl bromide and phosphine are the most commonly used fumigants to protect cereals from insects and other pests. It is estimated that 1900 and 8500 tons of these fumigants are used annually by the world's agriculture and non-agricultural sectors (Banks, 1994; MBTOC, 2002; Rajendran and Sriranjin 2008). In recent years, technological advances in fumigation have faced threats/constrictions due to regulatory concerns and the development of resistance (Banks, 1994). Therefore, several fumigants were discontinued due to health concerns, cost, carcinogenicity, and other factors.

Many developed nations have banned employing methyl bromide because it is responsible for depleting the ozone layer; health concerns, cost, carcinogenicity, and other factors: have restricted its use by 20 percent in 2005 and phased it out in 2015. (Rajendran, 2001; Singh, 2017).

5. ALTERNATIVES TO SYNTHETIC CHEMICAL COMPOUNDS: PLANT PRODUCTS

To solve the problem of synthetic chemical hazards, utilizing natural products such as powdered vegetable/fruit peels and leaves of medicinal plants is one of the best control measures against the beetles (Coleoptera) and moths that damage the food grains. (Haq et al., 2005; Adejumo et al., 2014). The popularity of plant-based products is increasing day by day due to low economic cost, the least toxic, easy availability, and biodegradability (Debashri and Tamal 2012). Also, to overcome such an issue, Neem (Azadirachta indica) is one of the most active and promising natural compounds whose antifungal, antiviral, insecticidal, and antibacterial properties have been known for many years. (Debashri and Tamal 2012).

6. Traditional Uses (Neem)

Figure 1 (a) Showing the Neem tree

Neem (Azadirachta indica) is a flowering plant belonging to the family (Meliaceae) that includes about 50 genera and 550 species grown in tropical and subtropical regions and other Southeast countries. This plant's fruit, seeds, oil, leaves, roots, and bark are used for medicine and have antiretroviral, anti-ulcer antiviral, anti-inflammatory, antifungal, antibacterial, antiplasmodial, antiseptic, antiplasmodial, antipyretic, and anti-diabetic properties. (Prashanth and Krishnaiah 2014).

Table 1.1 a Taxonomic position of neem tree is as follows: (Eid et al., 2017).

Order	Rutales
Suborder	Rutinae
Family	Meliaceae
Subfamily	Melioideae
Tribe	Melieae
Genus	Azadirachta
Species	Indica

This plant can grow up to 18 m high and 30m wide, and its leaves contain an array of biologically active compounds. These include triterpenoids, alkaloids, phenolic compounds, flavonoids, carotenoids, ketones, and steroids (Eid et al., 2017).

In addition, the leaves of neem offer excellent therapeutic properties, contain high amounts of calcium, magnesium, fair amount of protein, and are valuable raw materials for making traditional and modern medicines (Bhowmik et al., 2008).

"Arishtha", also known as Neem (Azadirachta indica), has been used for centuries as a remedy for sickness and has antimicrobial effects on bacteria, viruses, and pathogens (Susmitha et al., 2013).

The extract obtained from the neem plant acts as protection against over 250 pests including aphids, mites, whiteflies, mealybugs, and termites. Neem extracts can be used against over 250 pests including whiteflies, aphids, mealybugs, mites, and termites. Neem is considered a magical tree because of its active biological compounds that act as insect growth regulators (IGR), preventing insects such as nematodes, fungi, and insects (Singh et al., 2014).

7. Chemical constituents

The neem leaf is a 'storehouse' that, apart from containing a variety of organic compounds, also contains 0.13 percent essential oil, which gives the leaves their smell and prevents pests from spoiling during storage. It has a chemical compound known as terpenoids in most parts of the plant used as neem pesticide, neem insecticide neem pest fumigant, neem manure neem fertilizer, neem urea coating agent, neem compost, and neem soil conditioner without any toxic reagent during crop production and storage. Many countries like Bangladesh, India, and Nepal use neem and its by-products for medicinal purposes and as industrial by-products for their economy (Bhowmik et al., 2008).

Table 1.2.a. Principle Constituents of Neem tree.

During the offseason of wheat production, we visited a few of the local wheat milling industries and the local markets of my village we found that the quality of wheat grains is thrashed by pests, weevils, beetles, and rodents and also using spray fumigants and chemical powder during the storage of crop grains which are highly hazardous to the human health. Therefore, the study aims to reveal the beneficial properties of the magical neem plant and its leaves, which are used as an insecticide, pesticide having an aromatic scent that prevents pests and other insects from damaging the grains for a longer period without any toxic (Subapriya and Nagini, 2005).

Parts of neem plant	Benefits	References
Neem kernel oil	• Seed storage 20ml of neem oil used for 1kg of pulses seed by simply coating the seeds. • Act as pest management and retard the growth of insect regulator • Neem oil has insecticidal and medicinal properties due to which it has been used in pest control in rice cultivation.	Karrhikeyan et al., 2009; Mondal and Chakraborty, 2016; Lokanadhan et al., 2012
Neem kernel powder	• Used to control storage pests of some cereal grains such as rice, maize, and beans. • Used as pest management widely used in agriculture. • Antiviral, Antiretroviral, Anti-inflammatory.	Onu et al., 2015; Mondal and Chakraborty, 2016; Prashanth and Krishnaiah 2014
Neem leaves	• As repellents and feeding inhibitors against various stored-grain insects • Neem leaves are used as green leaf manure and also storage of grains. • Medicinal properties (Antifungal, Antibacterial, and so on). • Used as insecticide and pesticide for crops. • Storage of rice and grain from weevil	Jilani and Su, 1983; Lokanadhan et al., 2012; Subapriya and Nagini, 2005, Bhowmik et al., 2008; Ahmad et al., 2017; Puri, 1999; Khanal et al., 2021
Neem steam, roots	• Used as insecticidal properties. • Have medicinal properties the powdered form is used to control fleas & sucking pests in rice cultivation	Mondal and Chakraborty, 2016; lokanadhan et al., 2012

Figure 2 (b) Before storage of grain with leaves and Figure 3 (c) is showing after storage of grain with neem leaves

8. Other plant products as grain protectants:

The leaves of Ocimum grattissimum L (Labiatae) are a popular vegetable in Nigeria, and they are used to deal with stomachaches and as a pre-harvest treatment in the eastern parts of the country. Asawalam et al., 2008 investigated the effect of the essential oil of O. grattissimum leaves on the maize weevil was found to be moderately repellant and caused high mortality in the weevils. Also, significantly reduced in grains treated with the essential oil.

The primary chemical present in carrot oil, carol, a sesquiterpenoid, was subjected to column chromatography to obtain nonpolar and polar fractions and found that the oil's nonpolar and polar components had an antifeedant effect and repellant effects against T. castaneum (Kaur et al., 2016) found that carrot seed essential oil could be utilized to protect stored grains from T. castaneum.

According to Bhavya et al., 2021 the essential oils in plants have low mammalian toxicity, selectivity, rapid degradation, and low environmental impact and are used to control various stored product insects because of their bioactive compounds.

Furthermore, numerous plant species in powdered form showed protection against pulse beetle with toxic, antifeeding, ovicidal, repellence, larvicidal, and growth-inhibiting activities (Isman 2000; Nenaah 2014; Kedia et al. 2015).

As per Sharma and Chahal, (2012), the essential oil of Tagetes erecta fresh flowers extracted by steam distillation is highly effective as an insecticide, with the non-polar fraction showing effective potential.

Haq et al., 2005 discovered that a blend of plant components offered very efficient protection against insecticides. It is widely recognized internationally as being nontoxic to nontargeted creatures or the environment during grain storage.

Suthisut et al., 2011 stated that essential oils from the Alpinia conchigera and Zingiber species have antifungal and antibacterial properties, anti-inflammatory properties, antibacterial properties, and antitumor properties. Similarly, turmeric (Curcuma longa L.) rhizome has long been utilized in Southeast Asian cuisine and as traditional medicine. (Yamada et al. 1992; Gilani et al. 2005; Huang et al., 2005; Singh et al., 2005; Chien et al., 2008).

According to Tapondjou et al., 2002 there was an annual loss of 25% of pulses in Nigeria and 12-44% of maize in the western highlands of Cameroon during the first six months of storage because of the common pulse weevil Callosobruchus maculatus (F.) Chenopodium ambrosioides plants have leaves that are aromatic, hairy, and annual or perennial, although dry ground leaves of C. ambrosioides were proven to have an antifeedant effect, the extracted essential oil was found to be more harmful to the insects than the dry ground leaves.

In the study of Zoubiri and Baaliouamer, 2010 that Coriandrum sativum L is widely dispersed and cultivated heavily for seed production. Linalool, the monoterpene component of the essential oil, has been demonstrated to possess antibacterial, antioxidant, antidiabetic, anticancer, and antimutagenic properties (Msaada et al., 2007; Eikani, Golmohammad, and Rowshanzamir, 2007).

Ukeh et al., 2012 state that the maize weevil, Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae) is one of the major economic and primary pests of stored maize. It causes yield losses of over 30% in West Africa, with losses of 20% in Ghana and (12-44% in the western highlands of Cameroon after a few months of storage. Besides weight loss, larvae and adults of S zeamais result in reduced aesthetic and market value, germination, and nutritional value of maize grown in this region. Among the two plant species found in Southeast Nigeria, alligator pepper, Aframomum melegueta, and ginger, Zingiber officinale, can control stored grain insect pests. A melegueta seed and Z Officinale rhizomes were directly repellent to adult S zeamais, even in the presence of maize seeds (Ofuya, 1990; Kossou and Bosque Berez, 1990; Bouda et al., 2001; Obeng-Ofori and Amiteye, 2005; Rees, 2004; Ukeh, 2008)

Asawalam and Anaeto, 2014 report that storage losses for stored cowpea have ranged between 20 and 50% due to attacks by the cowpea weevil, Callosobruchus maculatus F, and sometimes the losses are complete with a 100% loss. The use of plant-derived materials (botanical insecticides) is more readily biodegradable, readily available, cheap, less toxic to mammals, and more selective in action. It also significantly reduced oviposition and adult emergence rates of bruchids (Rahman and Talukder, 2006; Asante et al., 2001; Udo and Harry, 2013).

Weevils such as Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae), Rhyzopertha dominica (Fabricius) (Coleoptera: Bostrichidae) and Sitotroga cerealella (Olivier) (Lepidoptera: Gelechiidae) are a problem for grain and grain products. As per Jembere et al., 1995 that azadirachtin, derived from the leaves and fruits of the neem tree, Azadirachta indica, is the most well-known of this class of insecticides. The perennial shrub Ocimum kilimandscharicum (Labiatae) is widely used in East Africa as a grain protectant (Saxena et al., 2018)

The invasion of insects results in crop losses, storage losses, and damage to trees and plants causing significant economic losses. Their consumption of food causes massive losses of stored grain as well as contamination with insect fragments and feces, as wheat is a staple food for many parts of the world. According to Abid and Butt, 2015 that Punica granatum and Murraya koenigii leaves proved to protect grains. Higher concentration led to greater action against Tribolium castaneum. These effects are strong enough to replace hazardous chemical pesticides in grain storage. (Nirjara et al., 2010; Sheaffer and Moncada, 2012; Herren, 2004; Haq et al., 2005).

Rice weevils, Sitophilus oryzae L., are among the most common insect pests of stored grains, especially cereals, and they contribute significantly to the deterioration of the physical and nutritional quality of stored grains. As per Devi and Devi, (2013) Powders of 18 spices were tested including mace, pepper, nutmeg, cloves, cinnamon, star anise, fennel (saunf), fennel (Lucknow saunf), ajowan, cumin (jeera), caraway (shah jeera), turmeric, ginger, bay leaves, red chili, cappers and found that the spices used as insecticidal, antifeedant, and antiovipositional potential against S oryzae infested wheat during the storage of grains (MS et al., 2009; George et al. 1999; Rajendran and Sriranjini 2008; Rajashekar et al., 2010).

Conclusion:

As a developing country, more than 65 % of Nepalese people rely on agriculture for their living. The Nepalese grow grains in different seasons and consume them throughout the year, so their preservation must be done in a healthy way. Otherwise, insects not only destroy the grains but also cause significant losses in storage and contaminate grains with insect fragments and feces, lessening their quality and decreasing their economic value. In Nepal, many large and small-scale companies, and even retailers, shopkeepers, and farmers continue to use expensive chemical fumigants and insecticides that later left toxic residue on food grains during the storage period, which posed health hazards for humans due to because unrestricted and indiscriminate usage. Numerous laboratory research conducted on plant products as fumigants against insect pests of stored products; However, many places of Nepal are unable to utilize botanical insecticides because of a lack of awareness of their benefits against pest management during grain storage, many are unaware of their benefits.

To protect grain from losses, a global search is currently underway for non-toxic, safe, and highly effective plant products that overcome the modern chemical fumigant approaches and techniques. one such natural insecticides plant is "Arishtha", also known as Neem (Azadirachta indica), which has been used for centuries and the extract obtained from the neem plant acts as protection against over 250 pests including aphids, mites, whiteflies, mealybugs, and termites during the storage of grains. Neem-based materials are compatible with integrated pest management (IPM). In addition, different parts of neem and other botanical plants including essential oil of Tagetes erecta flowers, essential oils of Alpinia conchigera and Zingiber species, Chenopodium ambrosioides, Coriandrum sativum L many more have been found to be safe, cheap, and eco-friendly pesticides, insecticides, parasiticides, and agrochemicals in grain storage.

The above discussion has shown that this Divine tree deserves special attention and interest from the world community due to its unique properties and applications in various areas of social need.

References:

1. Abid, R. A. M. S. H. A., & Butt, S. A. B. A. (2015). Repellent activity of cardamom, ginger and nutmeg against certain insect pests. *Int. J. Zool*, *5*(6), 1-6.
2. Adejumo, B. A., & Raji, A. O. (2007). Technical appraisal of grain storage systems in the Nigerian Sudan Savanna.
3. Adejumo, O. A., Ojoko, E. A., & Yusuf, S. A. (2014). Factors influencing choice of pesticides used by grain farmers in Southwest Nigeria. *Journal of Biology, Agriculture and Healthcare*, *4*(28), 31-38.
4. Asante, S. K., Tamo, M., & Jackai, L. E. N. (2001). Integrated management of cowpea insect pests using elite cultivars, date of planting and minimum insecticide application. *African crop science journal*, *9*(4), 655-665.
5. Asawalam, E. F., & Anaeto, C. G. (2014). Laboratory evaluation of five botanicals as protectants against cowpea bruchid Callosobruchus maculatus F.(Coleoptera: Bruchidae) on stored cowpea. *Advancement in Medicinal Plant Research*, *2*(2), 41-46.
6. Asawalam, E. F., Emosairue, S. O., & Hassanali, A. (2008). Essential oil of Ocimum grattissimum (Labiatae) as Sitophilus zeamais (Coleoptera: Curculionidae) protectant. *African Journal of Biotechnology*, *7*(20).
7. Ayalew, A. A. (2020). Insecticidal activity of Lantana camara extract oil on controlling maize grain weevils. *Toxicology Research and Application*, *4*, 2397847320906491.
8. Bailey, A., (2015). A grain moisture meter in Nepal. AGR 1100.
9. Baloch, U. K. (1992). Integrated pest management in foodgrains.
10. Banks, H. J. (1984). Fumigation and the properties of gases.
11. Bergvinson, D., & García-Lara, S. (2004). Genetic approaches to reducing losses of stored grain to insects and diseases. *Current Opinion in Plant Biology*, *7*(4), 480-485.
12. Bhandari, G., Achhami, B. B., Karki, T. B., Bhandari, B., & Bhandari, G. (2015). Survey on maize post-harvest losses and its management practices in the western hills of Nepal. *Journal of Maize Research and Development*, *1*(1), 98-105.
13. Bhavya, M. L., Obulaxmi, S., & Devi, S. S. (2021). Efficacy of Ocimum tenuiflorum essential oil as grain protectant against coleopteran beetle, infesting stored pulses. *Journal of Food Science and Technology*, *58*(4), 1611-1616.
14. Bhowmik, S., Chowdhury, S. D., Kabir, M. H., & Ali, M. A. (2008). Chemical composition of some medicinal plant products of indigenous origin. *Bangladesh Veterinarian*, *25*(1), 32-39.
15. Bouda, H., Tapondjou, L. A., Fontem, D. A., & Gumedzoe, M. Y. D. (2001). Effect of essential oils from leaves of Ageratum conyzoides, Lantana camara and Chromolaena odorata on the mortality of Sitophilus zeamais (Coleoptera, Curculionidae). *Journal of Stored Products Research*, *37*(2), 103-109.
16. Chien, T. Y., Chen, L. G., Lee, C. J., Lee, F. Y., & Wang, C. C. (2008). Anti-inflammatory constituents of Zingiber zerumbet. *Food Chemistry*, *110*(3), 584-589.
17. Debashri, M., & Tamal, M. (2012). A Review on efficacy of Azadirachta indica A. Juss based biopesticides: An Indian perspective. *Res. J. Recent Sci*, *2277*, 2502.
18. Demissie, G., Tefera, T., & Tadesse, A. (2008). Efficacy of Silicosec, filter cake and wood ash against the maize weevil, Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae) on three maize genotypes. *Journal of Stored Products Research*, *44*(3), 227-231.
19. Devi, K. C., & Devi, S. S. (2013). Insecticidal and oviposition deterrent properties of some spices against coleopteran beetle, Sitophilus oryzae. *Journal of Food Science and Technology*, *50*(3), 600-604.
20. Devkota, N., & Phuyal, R. K. (2015). Climatic impact on wheat production in Terai of Nepal. *Journal of Development and Administrative Studies*, *23*(1-2), 1-22.
21. Dowell, F. E., & Dowell, C. N. (2017). Reducing grain storage losses in developing countries. *Quality Assurance and Safety of Crops & Foods*, *9*(1), 93-100.
22. Eid, A., Jaradat, N., & Elmarzugi, N. (2017). A Review of chemical constituents and traditional usage of Neem plant (Azadirachta Indica). *Palestinian Medical and Pharmaceutical Journal (Pal. Med. Pharm. J.)*, *2*(2), 75-81.
23. Eikani, M. H., Golmohammad, F., & Rowshanzamir, S. (2007). Subcritical water extraction of essential oils from coriander seeds (Coriandrum sativum L.). *Journal of Food Engineering*, *80*(2), 735-740.
24. Ellis, R. H., Hong, T. D., & Roberts, E. H. (1992). The low-moisture-content limit to the negative logarithmic relation between seed longevity and moisture content in three subspecies of rice. *Annals of Botany*, *69*(1), 53-58.
25. Fatope, M. O., Nuhu, A. M., Mann, A., & Takeda, Y. (1995). Cowpea weevil bioassay: a simple prescreen for plants with grain protectant effects. *International Journal of Pest Management*, *41*(2), 84-86.
26. Gairhe, S., Karki, T. B., Upadhyay, N., & Sapkota, S. (2017). Trend analysis of wheat area, production and productivity in Nepal: An overview. In *Proceedings of 30th National Winter Crops Workshop* (Vol. 15, p. 495).
27. George, J., Ravishankar, G. A., Pereira, J., & Divakar, S. (1999). Bioinsecticide from swallowroot (Decalepis hamiltonii) Wight & Arn protects food grains against insect infestation. *Current Science*, *77*(4), 501-502.
28. Gilani, A. H., Shah, A. J., Ghayur, M. N., & Majeed, K. (2005). Pharmacological basis for the use of turmeric in gastrointestinal and respiratory disorders. *Life sciences*, *76*(26), 3089-3105.
29. Haq, T., Usmani, N. F., & Abbas, T. (2005). Screening of plant leaves as grain protectants against Tribolium castaneum during storage. *Pakistan Journal of Botany*, *37*(1), 149-153.
30. Herren, R. V. (2011). *The science of agriculture: A biological approach*. Cengage Learning.
31. Huang, G. C., Chien, T. Y., Chen, L. G., & Wang, C. C. (2005). Antitumor effects of zerumbone from Zingiber zerumbet in P-388D1 cells in vitro and in vivo. *Planta Medica*, *71*(03), 219-224.
32. Isman, M. B. (2000). Plant essential oils for pest and disease management. *Crop protection*, *19*(8-10), 603-608.
33. Jembere, B., Obeng-Ofori, D., Hassanali, A., & Nyamasyo, G. N. N. (1995). Products derived from the leaves of Ocimum kilimandscharicum (Labiatae) as post-harvest grain protectants against the infestation of three major stored product insect pests. *Bulletin of Entomological Research*, *85*(3), 361-367.

34. Jilani, G., & Su, H. C. (1983). Laboratory studies on several plant materials as insect repellants for protection of cereal grains. *Journal of economic entomology*, *76*(1), 154-157.
35. Kandel, P., Kharel, K., Njoroge, A., Smith, B. W., Díaz-Valderrama, J. R., Timilsina, R. H., ... & Baributsa, D. (2021). On-farm grain storage and challenges in Bagmati Province, Nepal. *Sustainability*, *13*(14), 7959.
36. Karthikeyan, C., Veeraragavathatham, D., Karpagam, D., & Firdouse, S. A. (2009). Traditional storage practices.
37. Kaur, P., Chahal, K. K., Kaur, R., & Kataria, D. (2016). Carrot seed essential oil as stored grain protectant against rust red flour beetle, Tribolium castaneum. *Pesticide Research Journal*, *28*(1), 76-83.
38. Kedia, A., Prakash, B., Mishra, P. K., Singh, P., & Dubey, N. K. (2015). Botanicals as eco-friendly biorational alternatives of synthetic pesticides against Callosobruchus spp.(Coleoptera: Bruchidae)—a review. *Journal of Food Science and Technology*, *52*(3), 1239-1257.
39. Khanal, D., Neupane, S. B., Bhattarai, A., Khatri-Chhetri, S., Nakarmi, N., Sapkota, S., ... & Sharma, V. (2021). Evaluation of botanical powders for the management of rice weevil (Sitophilus oryzae L. Coleoptera: Curculionidae) in Rupandehi, Nepal. *Advances in Agriculture*, *2021*.
40. Kossou, D. K., & Bosque-Perez, N. A. (1990). *Insect pests of maize in storage: biology and control; Research Guide No. 32*. IITA.
41. Levinson, H. Z., & Levinson, A. R. (1985). Storage and insect species of stored grain and tombs in ancient Egypt. *Zeitschrift für angewandte Entomologie*, *100*(1‐5), 321-339.
42. Lokanadhan, S., Muthukrishnan, P., & Jeyaraman, S. (2012). Neem products and their agricultural applications. *Journal of Biopesticides*, *5*, 72.
43. Mason, L. J., & McDonough, M. (2012). Biology, behavior, and ecology of stored grain and legume insects. *Stored product protection*, *1*(7).
44. McKevith, B. (2004). Nutritional aspects of cereals. *Nutrition Bulletin*, *29*(2), 111-142.
45. Mishra, A., Prabuthas, P., & Mishra, H. N. (2012). Grain storage: methods and measurements. *Quality Assurance and Safety of Crops & Foods*, *4*(3), 144-144.
46. Miyata, T. (1989). Problems in the control of insecticide‐resistant rice plant‐and leafhoppers. *Pesticide science*, *26*(3), 261-269.
47. Mobolade, A. J., Bunindro, N., Sahoo, D., & Rajashekar, Y. (2019). Traditional methods of food grains preservation and storage in Nigeria and India. *Annals of Agricultural Sciences*, *64*(2), 196-205.
48. Mondal, E., & Chakraborty, K. (2016). Azadirachta indica-A tree with multifaceted applications: An overview. *Journal of Pharmaceutical Sciences and Research*, *8*(5), 299.
49. MS, O., MO, O., & VA, I. (2009). BIOACTIVITY OF THREE PLANT DERIVED ESSENTIAL OILS AGIANST THE MAIZE WEEVILS SITOPHILUS ZEAMAIS (MOTSCHULSKY) AND COWPEA WEEVILS CALLOSOBRUCHUS MACULATUS (FABRICIUS). *Electronic Journal of Environmental, Agricultural & Food Chemistry*, *8*(9).
50. Msaada, K., Hosni, K., Taarit, M. B., Chahed, T., Kchouk, M. E., & Marzouk, B. (2007). Changes on essential oil composition of coriander (Coriandrum sativum L.) fruits during three stages of maturity. *Food chemistry*, *102*(4), 1131-1134.
51. Neethiranirjan, S., Karunakaran, C., Jayas, D. S., & White, N. D. G. (2007). Detection techniques for stored-product insects in grain. *Food control*, *18*(2), 157-162.
52. Nenaah, G. E. (2014). Bioactivity of powders and essential oils of three Asteraceae plants as post-harvest grain protectants against three major coleopteran pests. *Journal of Asia-Pacific Entomology*, *17*(4), 701-709.
53. Nirjara, G., Sujatha, P., & Prabhudas, P. (2010). Efficacy of pulverized Punica granatum (Lythraceae) and Murraya koenigii (Rutaceae) leaves against stored grain pest Tribolium castaneum (Coleoptera: Tenebrionidae). *International Journal of Agriculture and Biology*, *12*(4), 616-620.
54. Obeng-Ofori, D., & Amiteye, S. (2005). Efficacy of mixing vegetable oils with pirimiphos-methyl against the maize weevil, Sitophilus zeamais Motschulsky in stored maize. *Journal of Stored Products Research*, *41*(1), 57-66.
55. Ofuya, T. I. (1990). Oviposition deterrence and ovicidal properties of some plant powders against Callosobruchus maculatus in stored cowpea (Vigna unguiculata) seeds. *The Journal of Agricultural Science*, *115*(3), 343-345.
56. Onu, F. M., Ogu, E., & Ikehi, M. E. (2015). Use of Neem and Garlic Dried Plant Powders for Controlling some Stored Grains Pests. *Egyptian Journal of Biological Pest Control*, *25*(2).
57. ORYZAE, S. (2006). Effects of six plant extracts on rice weevil Sitophilus oryzae L. in the stored wheat grains. *Journal of Agricultural and Biological Science*, *1*(4).
58. Paneru, R. B., Paudel, G., & Thapa, R. B. (2018). Determinants of post-harvest maize losses by pests in mid hills of Nepal. *International Journal of Agriculture, Environment and Bioresearch*, *3*(1), 110-118.
59. Prashanth, G. K., & Krishnaiah, G. M. (2014). Chemical composition of the leaves of Azadirachta indica Linn (Neem). *International Journal of Advancement in Engineering and Technology, Management and Applied Science*, *1*(3), 21-31.
60. Pree, D. J., Archibald, D. E., & Morrison, R. K. (1989). Resistance to insecticides in the common green lacewing Chrysoperla carnea (Neuroptera: Chrysopidae) in southern Ontario. *Journal of economic Entomology*, *82*(1), 29-34.
61. Puri, H. S. (1999). *Neem: the divine tree Azadirachta indica*. CRC Press.
62. Rahman, A., & Talukder, F. A. (2006). Bioefficacy of some plant derivatives that protect grain against the pulse beetle, Callosobruchus maculatus. *Journal of Insect Science*, *6*(1).
63. Rajashekar, Y., Gunasekaran, N., & Shivanandappa, T. (2010). Insecticidal activity of the root extract of Decalepis hamiltonii against stored-product insect pests and its application in grain protection. *Journal of food science and technology*, *47*(3), 310-314.
64. Rajendran, S. (2001). Alternatives to methyl bromide as fumigants for stored food commodities. *Pesticide Outlook*, *12*(6), 249-253.
65. Rajendran, S., & Sriranjini, V. (2008). Plant products as fumigants for stored-product insect control. *Journal of stored products Research*, *44*(2), 126-135.

66. Raju, P. (1984). The staggering storage losses-causes and extent. *Pesticides*, *18*(1), 35-37.
67. Rees, D. (2004). *Insects of stored products*. CSIRO publishing.
68. Rembold, F., Hodges, R., Bernard, M., Knipschild, H., & Léo, O. (2011). The African postharvest losses information system (APHLIS). *European Union, Luxembourg*.
69. Saxena, R. C. (2009). Practical applications of neem against pests of stored products. In *Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, Florida, USA* (pp. 110-114).
70. Saxena, R. C., Jilani, G., & Kareem, A. A. (2018). Effects of neem on stored grain insects. In *1988 Focus on Phytochemical Pesticides* (pp. 97-112). CRC Press.
71. SHARMA, D. (2016). Storage of wheat (Triticum aestivum) in jute (Corchorus sp.) bags: An Indian storage system case study.
72. Sharma, N., & Chahal, K. K. (2012). Protectant potential of Marigold oil (Tagetes erecta L.) and its fractions against Tribolium castaneum (Herbst). *Annals of Plant Protection Sciences*, *20*(2), 294-297.
73. Sheaffer, C. C., & Moncada, K. M. (2012). *Introduction to agronomy: Food, crops, and environment*. Cengage Learning.
74. Singh, G., Maurya, S., Catalan, C., & De Lampasona, M. P. (2005). Studies on essential oils, Part 42: chemical, antifungal, antioxidant and sprout suppressant studies on ginger essential oil and its oleoresin. *Flavour and fragrance journal*, *20*(1), 1-6.
75. Singh, O., Khanam, Z., & Ahmad, J. (2011). Neem (Azadirachta indica) in Context of Intellectual Property Rights (IPR). *Recent Research in Science and Technology*, *3*(6).
76. Singh, S. (2017). Natural plant products-As protectant during grain storage: A review. *Journal of Entomology and Zoology Studies*, *5*(3), 1873-1885.
77. Subapriya, R., & Nagini, S. (2005). Medicinal properties of neem leaves: a review. *Current Medicinal Chemistry-Anti-Cancer Agents*, *5*(2), 149-156.
78. Susmitha, S., Vidyamol, K. K., Ranganayaki, P., & Vijayaragavan, R. (2013). Phytochemical extraction and antimicrobial properties of Azadirachta indica (Neem). *Global journal of pharmacology*, *7*(3), 316-320.
79. Suthisut, D., Fields, P. G., & Chandrapatya, A. (2011). Contact toxicity, feeding reduction, and repellency of essential oils from three plants from the ginger family (Zingiberaceae) and their major components against Sitophilus zeamais and Tribolium castaneum. *Journal of economic entomology*, *104*(4), 1445-1454.
80. Tadesse, A. (2005, June). Crop losses due to pre-and post-harvest pests and its attribution to food security. In *workshop on prevention and disposal of obsolete pesticide stocks in Ethiopia–Phase II* (pp. 23-24)..
81. Tadesse, M., & Ali, M. J. (2021). Assessing Storage Insect Pests and Faecal dropping of Rodent in Stored Grains in two districts of Southwestern Ethiopia.
82. Talukder, F. (2009). Pesticide resistance in stored-product insects and alternative biorational management: a brief review. *Journal of Agricultural and Marine Sciences [JAMS]*, *14*, 9-15.
83. Tapondjou, L. A., Adler, C. L. A. C., Bouda, H., & Fontem, D. A. (2002). Efficacy of powder and essential oil from Chenopodium ambrosioides leaves as post-harvest grain protectants against six-stored product beetles. *Journal of stored products research*, *38*(4), 395-402.
84. Tefera, T. (2016). Reducing post-harvest losses and increasing food availability. *Post-harvest Pest Management Research, Education and Extension in*.
85. Timsina, K. P., Gairhe, S., Koirala, P., & Shrestha, J. (2019). Investment on wheat research and its effect: A case of Nepal. *Agriculture Science and Technology*, *11*(2), 138-143.
86. Udo, I. O., & Harry, G. I. (2013). Effect of groundnut oil in protecting stored cowpea (Vigna unguiculata) from attack by cowpea weevil (Callosobruchus maculatus). *J Biol Agric Healthc*, *3*, 89-93.
87. Ukeh, D. A. (2008). *The identification and use of semiochemicals for the control of the maize weevil, Sitophilus zeamais (Motschulsky) in Nigeria* (Doctoral dissertation, University of Aberdeen).
88. Ukeh, D. A., Umoetok, S. B., Bowman, A. S., Mordue, A. J., Pickett, J. A., & Birkett, M. A. (2012). Alligator pepper, Aframomum melegueta, and ginger, Zingiber officinale, reduce stored maize infestation by the maize weevil, Sitophilus zeamais in traditional African granaries. *Crop protection*, *32*, 99-103.
89. Utono, I. M. (2013). *A novel approach to control stored sorghum beetle Tribolium castaneum (Coleoptera: Tenebrionidae) in small-scale farmers' storerooms in Kebbi-Nigeria* (Doctoral dissertation, University of Greenwich).
90. Ward, C. R., Huddleston, E. W., Ashdown, D., Owens, J. C., & Polk, K. L. (1970). Greenbug control on grain sorghum and the effects of tested insecticides on other insects. *Journal of Economic Entomology*, *63*(6), 1929-1933.
91. White, N. D. G., Harein, P. K., & Sinha, R. N. (1985). Current status of insecticide recommendations for managing stored grain in Canada and the United States.
92. Yamada, Y. (1992). Identification of antimicrobial gingerols from ginger (Zinglber officinale Roscoe). *J. Antibact. Antifung. Agent*, *20*, 309-311.
93. Zakladnoi, G. A., & Ratanova, V. F. (1987). Stored-grain pests and their control. *Stored-1967grain pests and their control.*
94. Zoubiri, S., & Baaliouamer, A. (2010). Essential oil composition of Coriandrum sativum seed cultivated in Algeria as food grains protectant. *Food chemistry*, *122*(4), 1226-1228.