CHAPTER 10

ADVANCES AND INNOVATIONS IN SUSTAINABLE MANAGEMENT OF MAIZE STORAGE PESTS TO SUPPLY SAFE FOOD AND FEED

Advances and Innovations in Sustainable Management of Maize Storage Pests to Supply Safe Food and Feed

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Abstract Maize is one of the most important cereal crops in Sri Lanka and the world. With the increase of the world population, demand for maize keeps on increasing, which is accelerated by the increasing demand for poultry feed, for which maize is the main energy source. The loss of grain in quantity and the deterioration of quality by storage pests remain a main concern. The preservation of maize during storage needs to be done sustainably. Considering the drawbacks of the traditional storage methods, farmers shifted to chemical pesticides to preserve stored grain. The public awareness of environmental safety, toxicity to humans and animals, and the increasing demand for pesticide-free food have created pressure on the research community to develop alternative measures for the management of stored products insect pests. The research findings indicate that the resistant traits in maize can be improved by identifying the resistance against storage pests in local varieties and through hybridization. The progress in the research, development, and application of biopesticides shows the potential for the use of local resources to produce biopesticides for managing the stored products pests. The alternative storage pest management strategies are considered simple, economical, effective, and environmentally friendly. It is recommended to formulate policies to invest more in IPM research, development, and implementation, which also include development and cultivation of resistant maize varieties and development and application of biopesticides against storage pests to ensure a sustainable and safe supply of maize grain for food and feed.

Keywords: Food security, Grain storage, Postharvest losses, Insect pests

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Magnitude of the Problem

Maize (*Zea mays* (L.)) is a major cereal crop due to its various uses as a food, feed, and raw material for industries [1]. Maize is the most widely used grain in the diets of intensive poultry production in the world [2]. The demand for maize in the developing world will be increased by two-folds by 2050 [2]. Consuming maize is one of the most important ways for the human body to acquire nutrients that are necessary for its normal functioning [3]. On the other hand, maize is considered to have a relatively high nutritional value for poultry, where the contribution of maize is around 65% of the metabolizable energy and 20% of the protein requirements in a broiler starter diet [4].

Maize is the second major cereal crop in terms of the extent of cultivation and productivity in Sri Lanka. As shown by Premarathne and Samarasinghe [5], the major user of maize in Sri Lanka is the feed manufacturers. Maize grain is also used for "Thriposha", which is a processed food for feeding mothers and infants. Part of the harvested green corn is directly used for human consumption, while another portion of the local production is used in the feed industry. According to [5], the gap between local supply and demand for maize has been widening since 2014, mainly due to higher demand for poultry feed formulation that paved the way for maize imports [6].The storage of maize grain to be used during the off-cultivation season is a common practice. According to Kumari et al. [7], 3.3%–33.6% of maize is stored after harvesting in the Anuradhapura district. The storage statistics of Sri Lankan maize have been hard to estimate. However, estimates suggest that 44,000MT of maize grain may be stored annually from local production. Kumari et al. [7] stated that the percentage of loss during storage was 5%-13%. According to Wasala et al. [8], insect infestation accounts for 4–6% of grain losses in tropical countries such as Sri Lanka during warehouse storage. In the Sub-Saharan Africa region, maize weevils (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus* (Horn)), moths, and red rust flour beetle (*Tribolium castaneum* (Herbst)) are the major insect pests [9]. These pests can incur 100% grain loss within months if they are not controlled.

According to Manandhar et al. [10] and Otieno and Alwenge [9], the use of chemical pesticides, such as phosphine, actellic super, shumba dust, and super grain dust to manage maize storage is common in developing countries. The authors' preliminary observations found that actellic compounds are mainly used to control maize storage pests indiscriminately. The use of chemical pesticides in protecting food and food products is found to have a deleterious effect on human health [11]. A study on rabbit feed formulated with maize contaminated with higher concentrations of actellic dust resulted in toxicity symptoms and sometimes death in growing rabbits (Omoyakhi et al., [12].

The usage of chemical pesticides to manage storage pests is a common practice and the subsequent multi-faceted effects have been documented elsewhere [13], [14]. The extensive use of chemical insecticides for the management of stored pests has become a global issue due to the environmental hazards associated with the development of resistance to the chemicals, bioaccumulation in the food chains, broad-spectrum of actions on non-target organisms, and the exorbitant cost of the chemicals [15].

The public's understanding of environmental safety, toxicity to humans, and the increasing demand for pesticide-free food have compelled the world research community to focus on the development of alternative mechanisms like the use of resistant maize varieties and biopesticides against the storage pests. Therefore, it is necessary to look for an eco-friendly solution to manage the store products pests which is non-toxic to non-target organisms and easily biodegradable and could be produced from locally available raw materials while minimizing the use of synthetic pesticides to sustain the supply of safe food and feed.

Insect Pests Associated with Maize Grain

The insects that cause damage to the maize in storage, affecting the quantity and quality, have already been identified by several research studies. Insects that affect healthy grains like maize and inflict losses on grains are referred to as primary pests. Secondary pests, on the other hand, are those that target already damaged grains and inflict more harm [16]. Table 1 summarizes the insect pests that damage the maize grains.

Due to their feeding activities, insects increase the temperature of the product, resulting in "hot patches' that can reach up to 57 °C [23]. These patches cause a concentration of dampness within the product, promoting grain degradation and more fungal growth. The influence of quality can be significantly damaged by a secondary infection from a variety of fungal species. Fungal contamination causes changes in color, taste, and odor, as well as a decrease in nutritional value, an increase in free fatty acids, and a decrease in germination capacity [4]. Mycotoxins are metabolites generated by this fungus that can cause a variety of health issues. Aflatoxin produced by *Aspergillus* spp. has particular concern over its significant carcinogenic qualities, which has restricted global trade [23].

Table 1: Common maize storage pests

Common name	Scientific name	Type of pest	Reference
Maize weevil	*Sitophilus zeamais*	Primary Pest	[17], [18]
Granary weevil	*Sitophilus granarius* (L.)	Primary Pest	[17], [19]
Rice weevil	*Sitophilus oryzae* (L.)	Primary Pest	[20], [18]
Red rust flour beetle	*Tribolium castaneum* (Herbst)	Primary Pest, Secondary Pest	[17], [18]
Confused flour beetle	*Tribolium confusum* (Jacquelin du Val)	Primary Pest, Secondary Pest	[20], [17]
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)	Primary Pest	[20], [19]
Larger grain borer	*Prostephanus truncates* (Horn)	Primary Pest	[21], [17]
Saw toothed grain beetle	*Oryzaephilus surinamensis* (L.)	Secondary Pest	[21], [22]
Yellow mealworm beetle	*Tenebrio molitor* (L.)	Secondary Pest	[21], [17]
Flat grain beetle	*Cryptolestes pusillus* (Schonherr)	Secondary Pest	[18], [17]
Rusty grain beetle	*Cryptolestes ferrugineus*	Secondary Pest	[17], [20]
Merchant grain beetle	*Oryzaephilus mercator* (Fauvel)	Secondary Pest	[17]
Square-necked flour beetle	*Cathartus quadricollis*	Secondary Pest	[17]
Indian meal moth	*Plodia interpunctella* (Hubner)	Secondary Pest	[18], [22]
Rice moth	*Corcyra cephalonica* (Stainton)		[18]
Maize grain moth	*Sitotroga cerealella* (Olivier)	Primary Pest	[17], [18]
Tropical warehouse moth/ Almond moth	*Ephestia cautella* (Walker)	Secondary Pest	[17], [18], [20]

Further, because of contamination with dead insects, waste materials, frass, and dust due to insect activity, the grain loses its economic value and earns a poor grade [25]. A pest infestation can also increase the amount of fatty acids in the grain and leave large amounts of uric acid, which causes grain rancidity [6]. Contamination of the embryo of seeds by Eurotium fungus can result in a 50–100% diminution in germination, lower levels of amino acids in the grain, and loss of the unique grain odour and flavour [24]. The natural odour of grain

bulk is changed into a musty or mouldy odour in extensively infected grain bulk. Several *Aspergillus* and *Penicillium* species are linked to mycotoxins (orchratoxin A in maize) that can cause serious health problems in humans and animals [24]. Consumer demand for safe and hygienic food free of pests and chemical residues has increased over the years. Even though exporting countries strive to keep their grain consignments 'insect-free', sometimes, as a result of phytosanitary measures failing, when live insects are spotted at importing terminals, the entire shipment of grain may be rejected, or a demurrage fee, as well as disinfestation fees, may be imposed [23].

The intake of contaminated feed by animals is the most common route for pesticide/insecticide contamination of animal origin food [27]. Hamid et al. [28] reported that, chlorinated pesticide residues were observed in the body tissues and eggs of chickens i.e., Bifenthrin and difenoconazole were found in egg samples. Because of the lipophilic nature of the organochlorine pesticides, they congregate in fatty tissues and bioaccumulate throughout the food chain [29]. As a result, these chemicals are present in larger amounts in fatty foods, and organochlorine pesticide exposure can also occur through low-level food contamination. Eggs have a high fat content and will acquire long-lasting organic contaminants such as polychlorinated biphenyls (PCBs), dioxins, and pesticides [28]. As shown by [30], the Endosulfan pesticide caused lower egg-hatchability and sterility in hens. The following insecticides are frequently used in maize storage to eliminate pest damage by local farmers.

Actellic Super (Pirimiphos methyl)

Actellic super is a frequently used insecticide in Sri Lanka to prevent storage pests during the storage of maize grains by the local farmers [31]. The active component in Actellic super dust is O-2-diethylamino-6-methylpyrimidin-4-yl-O, O-methyl phosphorothioate, also known as pirimiphos-methyl [12]. Actellic super is a broad-spectrum organophosphorous non-cumulative insecticide and acaricide with the mode of action of contact and fumigant [12]. After exposure for 14 days, pirimiphos-methyl causes an elevated level of death to immature larvae of around 60% in maize storage [32]. Likewise, pirimiphos-methyl controlled four psocid (Psocoptera) species on maize by 100% [33]. Another study based on pirimiphos-methyl was found to be successful in controlling twelve populations of *Sitophilus granarius* [34]. The average residues of pirimiphos-methyl found in the food products were frequently in the range of 40 -60% of the nominal dose [12].Mahugija et al. [35], found that pirimiphos methyl was detected at different levels in kidney, liver, and muscle samples of the chickens in Tanzania. A study conducted in Egypt also revealed that pirimiphos methyl was found in chicken samples [36]. Pirimiphosmethyl is a relatively cheaper pesticide that is extensively used to preserve food from pests across the globe, notably in the African region. Pirimiphos-methyl is a non-cumulative insecticide that causes the hydrolysis of body choline esters, including acetylcholine, at cholinergic synapses [37]. Inhibiting aforesaid enzymes will result in both nicotinic and muscarinic actions in the body, such as muscular contraction and secretion in numerous glands.

Storage Methods Used to Store Maize Grains

Storage methods are mainly divided into traditional, conventional, and modern, which are further subdivided based on either construction techniques or both construction techniques and principles used (Figure 1). Traditional grain storage management practices have losses ranging from 20% to 50% [38]. Traditional grain storage buildings are offered to farmers in order to conserve and propagate them for future use. Apart from being environment-friendly, these structures are cheaper, and locally accessible, preserve the stored grains and do not pose any health risks [39]. However, farmers moved away from traditional and conventional methods and began using synthetic chemical preservatives due to the inefficiency of traditional and conventional methods [40]. It was found that the initial investment and the related technology are the main obstacles in adopting modern storage methods by smallholder farmers in developing countries [41].

Development of Resistant Maize Varieties

Several research studies conclude that the development of resistant maize varieties against grain stored product pests is possible and can be encouraged for field and commercial cultivation. Table 2 summarizes resistant maize varieties identified or developed against stored product pests and corresponding recommendations by various research studies in various regions of the world. According to Zunjare et al. [49], the developed resistant varieties would be a sustainable and economically viable solution to post-harvest loss of grains during storage.

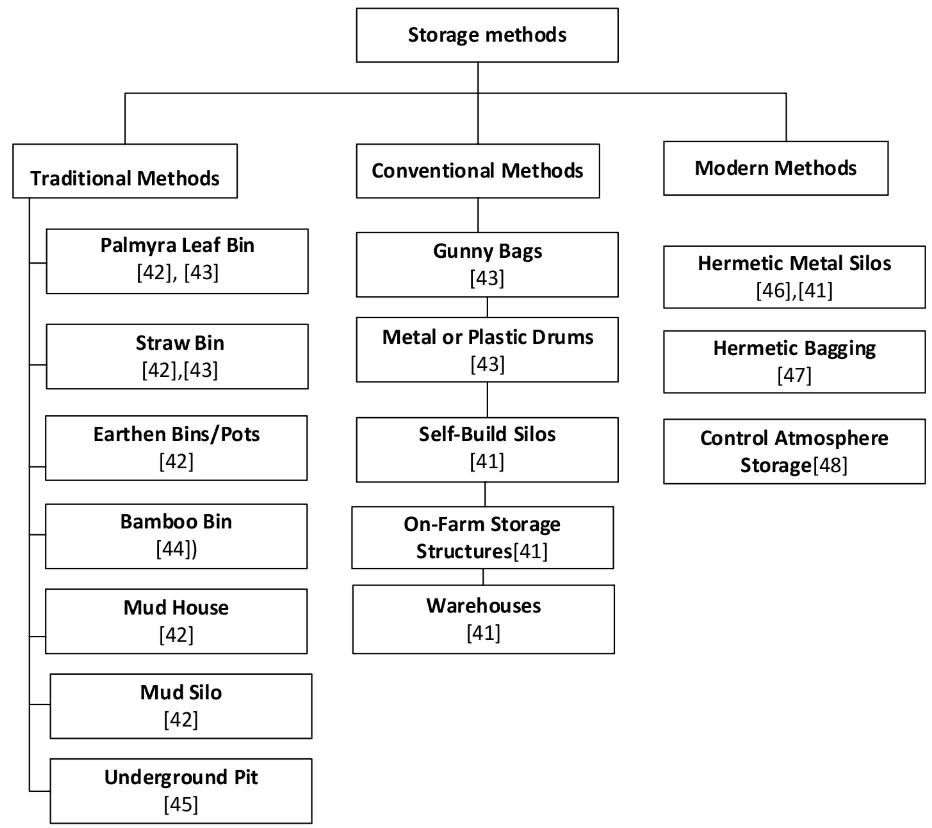

Figure 1: Traditional, conventional and modern methods used to store maize grain

Table 2: Resistant varieties identified against maize storage pest

Resistant varieties and recommendations	Target pest	Reference
2000SYNEE-WSTRand TZBRELD3C5. Can be used singly or best in an integrated pest management process.	*Sitophilus zeamais* (maize weevil)	[50]
ZM421 and ZM521 highly tolerant maize varieties. Need to breed ZM521 and ZM421 maize varieties in breeding programs for weevil resistance.	*Sitophilus zeamais* (maize weevil)	[51]
2000SYNEE-WSTR and TZBRELD3C5. Can be used to control grain damage in maize storage.	*Sitophilus zeamais* (maize weevil)	[52]
The variety SR52 under the laboratory CTH and the stock room ATH conditions is considered as resistant. Resistance to can be developed to minimize the grain loss.	*Sitophilus zeamais* (maize weevil)	[53]
BHQP-542' can be used in storage management	*Sitophilus zeamais* (maize weevil)	[54]
Pertiwi 3 are resistant ones. Bisi 19, Bisma, Bisi 18, Pioneer 21 and Pioneer 29 are moderately resistant in Indonesia. Can be used to reduce grain losses during storage.	*Sitophilus zeamais* (maize weevil)	[55]
Early-Thaï, DMR-ES and Tzee-Yellow Can be used to reduce the maize postharvest losses.	*Prostephanus truncatus* (Horn) (larger grain Borer)	[56]
BHQP-542 is the resistant maize variety. Promoted for stored pest management in eco-friendly manner for small scale farmers in the tropics.	*Sitophilus zeamais* (maize weevil)	[57]
Transgenic avidin maize, Avidin when present in maize at levels of ≥100 ppm toxic to and prevents development of insects which cause damage to grains during storage.	*Sitophilus zeamais* (maize weevil) and many other species of stored-product pests	[58]

The term "insect resistance" refers to "the relative amount of heritable qualities possessed by a plant or its materials (for example, its seeds) that influence the ultimate degree of damage done by insects." [59]. For stored grains, resistance represents the ability of a certain crop variety to produce grains that maintain better quality than commonly cultivated varieties following long storage under similar insect populations" [60].

The host plant resistance (HPR) is found in the seeds that are readily available to farmers for cultivation. After seeding them, farmers do not require more effort in order to manage post-harvest pests of maize. HPR to post-harvest insects is an inherent characteristic that has been demonstrated as antibiosis, antixenosis, and tolerance [61]. Antibiosis is the negative impact of the host-plant on the biology of the insects and their progeny (survival, development, and reproduction). Antixenosis is when the plant and the seed are not desirable as a host and the pests and post-harvest pests look for other hosts. Tolerance refers to a situation where the plant is able to withstand or recover from stem borer damage [62].

Nwosu [63] concluded that the variation in resistance levels of the elite maize varieties is a measure of the intrinsic ability to resist *S. zeamais* attack. The antibiosis effect of the resistant elite maize varieties significantly affects the survival and development of *S. zeamais*. The combined effect of antixenosis (non-preference) and antibiosis due to the presence of a higher level of crude fiber in grain, phenolic acid, and trypsin inhibitor is responsible for resistance to *S. zeamais* infestation. On the other hand, higher levels of protein, starch, and minerals cause the elite varieties to become susceptible. Further, Nwosu [63] suggested that the testing of protein, starch, and minerals are needed for impairment for a maize breeding program which will help against the infestation by *S. zeamais* in stored maize. However, it is important that this does not lead to substantial nutritional losses in the amount required by human beings and livestock.

Lopez-Castillo et al. [20] demonstrated that the understanding of resistance mechanisms is the basis for the development of new effective and resistant varieties for a sustainable measure for developing countries. The mechanisms of resistance (anatomical, biochemical, and genetic) and underlying factors for each resistance type and their implications for different storage pests are comprehensively investigated and documented.

Nwosu [63] indicates that the integration of the resistant chemical properties into other maize varieties is necessary to increase their resistance to *S. zeamais*. Several studies indicate that physical properties have been shown to be a basis for resistance to the attack of *S. zeamais* and some other insect pests of stored maize [64]. The existing literature clearly indicates that resistant traits in maize can be improved by identifying the resistance against storage pests in existing local varieties and through hybridization. The development of resistance varieties is considered the easiest, most economical, effective, and environmentally friendly way of managing insect pests on stored grains. Further, there is no specific technology that can be used by the farming community and they need to invest only in seeds. It is also important to note that the method can be easily incorporated with IPM since it is highly compatible with other pest management methods in grain storage.

Use of Biopesticides for Maize Grain

Researchers found the various aspect of stored grain pest management techniques including design of storage structure with different capabilities for manipulation of the environment, application of chemical and biopesticides, mechanical and traditional pest control methods and factors to prevent the infestation in the stored grains. Plant essential oils and their components with fumigant actions are used as biopesticides since the use of plant sources with the benefit over traditional fumigants in regards to low mammalian noxiousness, rapid decaying, and readily available in the local environment. Several plant species have been recognized with fumigant properties to control insects of stored grain during the last four decades (Table 3) . It has been evident that most of the plant extracts can control the feeding and breeding of stored grain insects or even kill them swiftly to chemical fumigants [65]. For example Sharma [66] found that neem-based products with recommended concentrations protected maize against *S. oryzae*, *S. cerealella*, *R. dominica*, and *T. castaneum* over five months. Neem has also been demonstrated to be effective against maize storage insects in several investigations [67].

Table 3: Plant parts used for insecticidal activities against storage insects of maize

Scientific name	Common name	Plant part used	Target pests	Reference
Acorus calamus (L.)	Sweet Flag	Rhizome	*Sitophilus oryzae, Tribolium castaneum*	[68]
Anethum graveolens (L.)	Dill	Seed	*T. castaneum*	[69]
Annona squamosa (L.)	Bullock's Heart	Leaf and stem	*S. oryzae*	[70]
Artemisia annua (L.)	Mugwort	Stem and leaf	*T. castaneum*	[71]
A.capillaris	Chinese wormwood	Stem and leaf	*Sitophilus zeamais*	[72]
Carum carvi (L.)	Caraway	Fruit	*S. zeamais, T. castaneum*	[73]
Eucalyptus globulus	Blue Gum	Leaf	*S. oryzae, T. castaneum*	[74]
Hyptis spicigera	Black Sesame	Whole plant	*S. zeamais*	[75]
Lavandula angustifolia	Lavender	Whole plant	*S. oryzae, R. dominica, T. castaneum*	[76]
Momordica charantia (L.)	Bitter Gourd	Leaf and seed	*S. oryzae, T. castaneum*	[77]
Cinnamomum aromaticum	Cassia	Bark	*T. castaneum, S. zeamais*	[78]
Psidium guajava (L.)	Guava	Leaf	*S. oryzae*	[79]
Mentha citrate	Peppermint	Aerial part	*T. castaneum, C. maculatus*	[80]
Z. officinale	Ginger	Rhizome	*T. castaneum*	[81]
Convolvulus arvensis (L.)	Bind weed	leaves	*R. dominica, S. oryzae*	[82]
Colocasia esculenta var. esculenta (L.)	Cocoyam	Rhizome	*S. oryzae, T. castaneum, C. chinensis*	[83]
Pimenta racemosa	Bay rum tree	leaves	*S. zeamais*	[81]
Lantana camara (L.)	Shrub verbena	Leaves	*S. oryzae, T. castaneum, R. dominica*	[84]
Tagetes filifolia	Irish lase	Aerial parts	*T. castaneum*	[85]
Vitex negundo (L.)	Nirgundi	Leaf	*S. oryzae*	[86]
Eucalyptus spp.	Gum tree	leaf	*S. oryzae*	[82]

The subject of biopesticides has developed excellent application prospects during the last ten years, with numerous social and economic benefits. Biopesticide research and use have progressed to the point where hazardous pesticides are being replaced in the market, resulting in a decrease in chemical pesticide manufacturing by 2% each year in recent years [87]. Application of biopesticides is considered an eco-friendly method to reduce the effect of pests on stored products while also reducing the hazards to the environment and also humans and animals. At present, improving the quality of stored products is a challenge due to the storage pest attack. It is necessary to improve quality and quantity while improving the range of commodities, keeping quality with scientific-technical advancements in line with the demand of the country. Further, the preservation quality and quantity would ensure better nutrition for a mass of the population who suffer from malnutrition.

Conclusions

This chapter evaluated the literature on challenges caused by insect pests in storage of maize, storage methods used, chemical pesticides used to manage storage pests, research and developments on resistant maize varieties which produce grains that are less susceptible to storage pest damage; and advances made on biopesticide applications. The purpose was to explore the progress in innovations and developments in storing and supplying maize grain sustainably that are safe for human consumption and animal feed formulation. A significant portion of maize grain loss by insect pests takes place during the storage, which is, however, dependent on the environmental conditions, micro-climatic conditions of the storage, maize variety, nutrient composition of the grain and the methods used to manage the pests. The traditional methods used to store maize grains are ineffective in controlling the storage pests. Certain conventional and modern methods used are not affordable for small-holder farmers. Though chemical pesticides significantly reduce grain loss, environmental threats, chemical resistance development, the availability of harmful residual effects in food, a broad spectrum of actions on non-focal organisms, and the high cost of the chemicals are major concerns. Mazie variety identification and hibrydization in different parts of the world indicate the high potential for the development of resistant varieties to produce less susceptible grain to maize storage pest attack. The progress made with regard to biopesticide application indicates the potential for local innovations through research and development using local resources.

Advances and Innovations in Sustainable....

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References

[1] H.S. Gupta, F. Hossain, V. Muthusamy, "Biofortifcation of maize: An Indian perspective," Indian Journal of Genetics and Plant Breeding, vol. 75, issue 1, pp. 1-22, Feb 2015. http://dx.doi.org/10.5958/0975-6906.2015.00001.2

[2] M.R. Rosegrant, C. Ringler, T. B. Sulser, M. Ewing, A. Palazzo, T. Zhu. G.C. Nelson, J. Koo, R. Robertson, S. Msangi, and M. Batka, Agriculture and food security under global change: Prospects for 2025/2050. International Food Policy Research Institute, Washington, DC, pp.145-178. 2009.

[3] S. Qamar, M. Aslam, M.A. Javed, "Determination of proximate chemical composition and detection of inorganic nutrients in maize (Zea mays L.)," In Materials Today: Proceedings, vol. 3, issue 2, pp. 715-718. Mar 2016.

[4] A. J. Cowieson, Factors that affect the nutritional value of maize for broilers. Animal Feed Science and Technology, vol. 119 issue. 4, pp. 293-305, 2005

[5] S. Premarathne and K. Samarasinghe, "Animal Feed Production in Sri Lanka: Past Present and Future" in Agricultural Research for Sustainable Food Systems in Sri Lanka, Springer, Singapore. pp. 277-301.

[6] FAO "FAOSTAT, statistical database of FAO". Food and Agriculture Organization of the United Nations, Rome. 2018.

[7] J. M.P. Kumari, L.K.W. Wijayaratne, N.W.I.A. Jayawardena, and W.C.P. Egodawatta, "Quantitative and qualitative losses in paddy, maize and green gram stored under household conditions in Anuradhapura district of Sri Lanka". Sri Lankan J. Agri. Ecosys, vol. 2, pp. 99-106, 2020.

[8] W.M.C.B. Wasala, C.A.K. Dissanayake, C.R. Gunawardhane, R.M.N.A. Wijewardhane, D.M. C.C. Gunathilake, B. M.K.S. Thilakarathne, "Efficacy of insecticide incorporated bags against major insect pests of stored paddy in Sri Lanka," Procedia Food Science, vol. 6, pp. 164-169. Mar 2016.

[9] H.M. Otieno and B. A. "Alwenge. A mini-review of potential toxicity, efficacy and residues management of actellic-based grain preservatives" Fundamental and Applied Agriculture. Vol. 5(4), pp. 491–499: 2020.

[10] Manandhar, P. Milindi, A. Shah, "An overview of the post-harvest grain storage practices of smallholder farmers in developing countries," Agriculture, vol. 8, issue 4, pp.57. Apr 2018.

[11] L.C. Nwosuand and U.I. Nwosu. Assessment of maize cob powder for the control of weevils in stored maize grain in Nigeria. Journal of Entomological Research, vol. 36, issue, 3, pp. 195-199, 2012

[12] J.M. Omoyakhi, A.M. Orheruata, and O.A. Osinowo. "Actellic 2% dust as pesticide

in feed ingredients: Effects on haematological and serum metabolites in growing rabbits". African Journal of Biotechnology, vol. 7, issue, 3, 2008.

[13] S. Lee, C.J. Peterson, J.R. Coats, "Fumigation toxicity of monoterpenoids to several stored product insects," Journal of Stored Products Research, vol. 39, issue 1, pp. 77–85, March 2003.

[14] T. Tefera, "Post-harvest losses in African maize in the face of increasing food shortage," Food Security, vol 4, pp. 267–277. Apr 2012. http://dx.doi.org/10.1007/s12571-012-0182-3

[15] L.C. Nwosu, "Maize and the maize weevil: advances and innovations in postharvest control of the pest," Food Quality and Safety, vol. 2, issue 3, pp. 145-152, Jul 2018.

[16] E. Getu and T. Abate, "Management of maize stem borer using sowing date at Arsi-Negele," Pest Management Journal of Ethiopia, vol. 3, issue (1&2), pp. 47-51, 1999.

[17] D. Rees "Insects of stored products". CSIRO publishing. 2004.

[18] M.J. Alam, K.S. Ahmed, B. Hossen, H. Mozammel, and A.B.M.Z. Hoque. "Storage pests of maize and their status in Bangladesh". Journal of Bioscience and Agriculture Research, 20(02), 1724-1730, 2019.

[19] V. Stejskal, R. Aulicky, and Z. Kucerova, "Pest control strategies and damage potential of seed-infesting pests in the Czech stores-a review". Plant Protection Science, vol. 50, issue. 4, 165-173. 2014.

[20] L.M. López-Castillo, S.E. Silva-Fernández, R. Winkler, D.J. Bergvinson, J.T. Arnason, and S. García-Lara. "Postharvest insect resistance in maize". Journal of Stored Products Research, vol. 77, pp. 66-76, 2018.

[21] W. Sori and A. Ayana, "Storage pests of maize and their status in Jimma Zone, Ethiopia," African Journal of Agricultural Research, vol. 7, issue 28, pp. 4056-4060. May 2012.

[22] K.S. Banga, S. Kumar, N. Kotwaliwale, D. Mohapatra, "Major insects of stored food grains," International Journal of Chemical Studies, vol. 8, issue 1, pp. 2380-2384. Dec 2020.

[23] M.K. Nayak and G.J. Daglish, "Importance of stored product insects" in Recent advances in stored product protection, Springer, Berlin, Heidelberg, 2018, pp. 1-17.

[24] D.B. Sauer, R.A. Meronuck, C.M. Christensen, "Microflora" in Storage of cereal grains and their products, Sauer DB and St. Paul, MN (ed), American Association of cereal Chemists, 1992, pp 313–340.

[25] F. Fleurat-Lessard, "Qualitative reasoning and integrated management of the quality of stored grain: a promising new approach," Journal of Stored Products Research, vol. 38, issue 3, pp. 191-218. Jan 2002.

[26] L.J. Mason and M. McDonald, "Biology, behaviour and ecology of stored grain and legume insects" in stored product protection, Hagstrum DW, Phillips TW, Cuperus G (eds.). Agricultural Experiment Station and Cooperative Extension Service, Kansas State University. Manhattan, KS, 2012, pp. 7–20.

[27] M. Ledoux, "Analytical methods applied to the determination of pesticide

residues in foods of animal origin: A review of the past two decades," Journal of Chromatography A. vol. 1218, issue 8, pp. 1021-1036, Feb 2011.

[28] G. Hamid, S.R. Yaqub, N. Ahmed, N. Aziz, "Assessment of human health risk associated with the presence of pesticides in chicken eggs," Food Science and Technology, vol.37, pp. 378-382. 2017.

[29] R.P. Singh, Y.P. Sahni, R.K. Sharma, K. Shrman, V. Gautam, S. Bharti, "UHPLC determination of residues of chlorpyrifos insecticide in chicken meat," The Pharma Innovation Journal, vol 7, issue 6, pp.107-110, May 2018.

[30] S.M. Naqvi and C. Vaishnavi, "Bioaccumulative potential and toxicity of endosulfan insecticide to non-target animals," Comparative Biochemistry and Physiology Part C: Comparative Pharmacology, vol. 105, issue 3, pp. 347-361. 1993.

[31] S. Karunakaran, and V. Arulnandhy, "Insecticidal activity of selected botanicals on maize weevil, Sitophilus zeamais L., in stored maize grains". AGRIEAST: J. Agric. Sci, vol. 12, issue,1, pp. 1-6,2018

[32] N.G. Kavallieratos, E.J. Michail, M.C. Boukouvala, E.P. Nika, and A. Skourti. "Efficacy of pirimiphos-methyl, deltamethrin, spinosad and silicoSec against adults and larvae of Tenebrio molitor L. on wheat, barley and maize" Journal of Stored Products Research, issue, 83, pp. 161-167, 2019.

[33] C.G. Athanassiou, F. H. Arthur, and J.E. Throne, "Efficacy of grain protectants against four psocid species on maize, rice and wheat". Pest Management Science: formerly Pesticide Science, vol. 65, issue, 10, pp. 1140-1146, 2009.

[34] P. Kljajić, and I. Perić, "Susceptibility to contact insecticides of granary weevil Sitophilus granarius (L.) (Coleoptera: Curculionidae) originating from different locations in the former Yugoslavia" Journal of Stored Products Research, vol. 4, issue, 22), pp. 149-161. 2006.

[35] J.A. Mahugija, P.E. Chibura, and E.H. Lugwisha, "Residues of pesticides and metabolites in chicken kidney, liver and muscle samples from poultry farms in Dar es Salaam and Pwani, Tanzania". Chemosphere, issue, 193, pp. 869-874. 2018.

[36] A.M. Aboul-Enein, F.N. Abou Elella, and E.S. Abdullah. "Monitoring of some organochlorines and organophosphorus residues in imported and locally raised chicken and bovine muscles in Egypt". J Appl Sci Res, vol. 6, issue, 6, pp. 600-608. 2010.

[37] F. Ngoula, P. Watcho, C. Dongmo, A. Kenfack, P. Kamtchouing, and J. Tchoumboué. Effects of pirimiphos-methyl (an organophosphate insecticide) on the fertility of adult male rats. African health sciences, vol. 7, issue, 1, p. 3. 2007.

[38] A.E. Talabi, "Appropriate Storage Facilities for Promoting Economic Growth and Food Security," Bulletin of Nigerian Institute of Food Science and Technology, pp. 17- 31, 1996.

[39] M. Shaila and N. Begum, "Ancient farming methods of seed storage and pest management practices in India-a review," Plant Archives, vol. 21, issue 1, pp. 499-509. 2021.

[40] D. Kumar and P. Kalita P, "Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries, Foods, vol.6, pp. 8,

2017. doi: 10.3390/foods6010008.
[41] A. Manandhar, P. Milindi, and A. Shah, "An overview of the post-harvest grain storage practices of smallholder farmers in developing countries". Agriculture, vol. 8, issue,4, p. 57, 2018.
[42] S. Kiruba, S. Sam Manohar Das, S. Papadopoulou, "Prospects of traditional seed storage strategies against insect infestation adopted by two ethnic communities of Tamil Nadu, southern peninsular India," Bulletin of Insectology, vol. 59, issue 2, pp. 129-134, Oct 2006.
[43] A.J. Mobolade, N. Bunindro, D. Sahoo, Y. Rajashekar, "Traditional methods of food grains preservation and storage in Nigeria and India, Annals of Agricultural Sciences, vol. 64, issue 2, pp. 196-205. Dec 2019.
[44] C.Karthikeyen, D. Veeraragavathatham, D. Karpagam, S.A. Firdouse, "Indigenous storage structures," pp. 225-229, Apr 2009.
[45] B.J. Olorunfemi and S.E. Kayode, "Post-Harvest Loss and Grain Storage Technology-A Review," Turkish Journal of Agriculture-Food Science and Technology, vol. 9 issue 1, pp. 75-83. 2021.
[46] D. Bbosa, T.J. Brumm, C.J. Bern, K.A. Rosentrater and D.R. Raman, "Evaluation of Hermetic Maize Storage in 208 Liter (55 Gal) Steel Barrels for Smallholder Farmers," Transactions of the ASABE, vol. 60, issue 3, pp. 981-987, 2012.
[47] T. De Bruin, P. Villers, A. Wagh and S. Navarro, "Worldwide use of hermetic storage for the preservation of agricultural products". In Proceedings of the 9th International Controlled Atmosphere and Fumigation Conference, Antalya, Turkey, 2012, pp. 450-458.
[48] H. Navarro, S. Navarro and, S. Finkelman. "Hermetic and modified atmosphere storage of shelled peanuts to prevent free fatty acid and aflatoxin formation" Integr Prot Stored Prod IOBC-WPRS Bull, vol. 81, pp. 183-192. 2012.
[49] R. Zunjare, F. Hossain, V. Muthusamy, S.K. Jha, P. Kumar, J.C. Sekhar, S.K. Guleria, N.K. Singh, N. Thirunavukkarasu and H.S. Gupta "Genetics of resistance to stored grain weevil (Sitophilus oryzae L.) in maize," Cogent Food Agric., vol. 1, no. 1, 2015, doi: 10.1080/23311932.2015.1075934.
[50] L.C. Nwosu, "Chemical bases for maize grain resistance to infestation and damage by the maize weevil, Sitophilus zeamais Motschulsky," J. Stored Prod. Res., vol. 69, pp. 41–50, 2016.
[51] S. Muzemu, J. Chitamba, and S. Goto, "Screening of Stored Maize (Zea mays L.) Varieties Grain for Tolerance Against Maize Weevil, Sitophilus zeamais (Motsch.)," Int. J. Plant Res., vol. 2013, no. 3, pp. 17–22, 2013, doi: 10.5923/j.plant.20130303.01.
[52] L.C. Nwosu, C. Olukayode Adedire, E. Oludele Ogunwolu, "Screening for new sources of resistance to Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae) infestation in stored maize genotypes," Journal of Crop Protection, vol. 4, issue 3, pp. 277-290. June 2015.
[53] A. John Derera, V. Kevin, B. Pixley, P. Denash, and C. Giga, Itai Makanda., Resistance of maize to the maize weevil: III. Grain weight loss assessment and implications

Advances and Innovations in
Sustainable....

for breeding. Journal of Stored Products Research vol., 59 pp. 24-35, 2014.
[54] F. Abebe, T. Tefera, S. Mugo, Y. Beyene, and Vidal, S., Resistance of maize varieties to the maize weevil Sitophilus zeamais (Motsch.)(Coleoptera: Curculionidae). African Journal of Biotechnology, vol., 8, (21). 2009.
[55] L.P. Astuti, S.M. Yahya, M.S. Hadi, "Susceptibility of six corn varieties (Zea mays L.) to Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae)," International Journal of Plant Biology, vol. 10, issue 1, 7441, Jun 2019.
[56] D. Ngom, M.L. Fauconnier, P. Malumba, C.A.K.M. Dia, C. Thiaw, M. Sembène, "Varietal susceptibility of maize to larger grain borer, Prostephanus truncatus (Horn)(Coleoptera; Bostrichidae) based on grain physicochemical parameters," PloS one, vol. 15, issue 4, e0232164, Apr 2020.https://doi.org/10.1371/journal.pone.0232164.
[57] T. Keba and W. Sori. "Diffential resistance of maize varieties to maize weevil (Sitophilus zeamais Motschulsky) (Coleoptera: Curculionidae) under laboratory conditions" J. Entomol. 10: pp. 1-12, 2013.
[58] K. Kramer, T. Morgan, J. Throne, et al., "Transgenic avidin maize is resistant to storage insect pests," Nat Biotechnology, vol. 18, pp. 670–674, Jun 2000. https://doi.org/10.1038/76531
[59] G.N. Mbata, "Non–insecticidal protection of stored grain legumes now and in the future. In: Anonymous (ed.). Integrating Biological Control and host plant resistance," Proceedings of a CTA/IAR/IIBC Seminar. Addis–Ababa, Ethiopia, 1997. pp. 99-106.
[60] G.N. Mbata, "Studies on the susceptibility of varieties of groundnuts to infestation by Plodia interpunctella (Hb.) (Lepidoptera: Pyralidae)," Journal of Stored Products Research, vol. 23, issue 1, pp. 57–63. Feb 1987.
[61] V.K. Kumar, H.C. Sharma, K.D. Reddy, "Antibiosis mechanism of resistance to spotted stem borer, Chilo partellus in sorghum, Sorghum bicolor," Crop Protection, vol. 25, issue 1, pp. 66–72. Jan 2006.
[62] Tefera, T., Mugo, S., Beyene, Y., 2016. "Developing and deploying insect resistant maize varieties to reduce pre-and post-harvest food losses in Africa". Food Secur. 8, 211e220. https://doi.org/10.1007/s12571-015-0537-7
[63] L.C. Nwosu, "Chemical bases for maize grain resistance to infestation and damage by the maize weevil, Sitophilus zeamais Motschulsky," Journal of Stored Products Research, vol. 69, pp. 41-50, Oct 2016.
[64] JK, Mwololo, and Munyiri SW. "Evaluation of traits of resistance to postharvest insect pests in tropical maize." 2013.
[65] R.P. Singh, Y.P. Sahni, R.K. Sharma, K. Shrman, V. Gautam and S. Bharti, "UHPLC determination of residues of chlorpyrifos insecticide in chicken meat," The Pharma Innovation Journal, vol 7, issue 6, pp.107-110, May 2018.
[66] R.K. Sharma. "Efficacy of neem products against storage pests in maize". Annals of Agricultural Research, vol. 20(2), pp.198-201.1999.
[67] F. Chebet, A.L Deng, J.O. Ogendo, A.W. Kamau and P.K. Bett, Bioactivity of selected plant powders against Prostephanus truncatus (Coleoptera: Bostrichidae) in

stored maize grains. Plant Protection Science, vol. 49, issue, 1, pp. 34-43. 2013.

[68] H. Chander, S.G. Kulkarni and S.K. Berry. "Acorus calamus rhizome as a protectant of milled rice against Sitophilus oryzae and Tribolium castaneun" Journal of Food Science and Technology, India 1990; vol. 27, issue,3, pp. 171-174.

[69] M.K. Chaubey, "Insecticidal activity of Trachyspermum ammi (Umbelliferae), Anethum graveolens (Umbelliferae) and Nigella sativa (Ranunculaceae) essential oils against stored-product beetle Tribolium castaneum Herbst (Coleoptera: Tenebrionidae)" African Journal of Agricultural Research, vol. 2, issue,11, pp. 596-600, 2007.

[70] J. A. Kumar, T. Rekha, S.S. Devi, M. Kannan, A. Jaswanth and V. Gopal. "Insecticidal Activity of Ethanolic Extract of Leaves of Annona squamosa", J. Chem. Pharm. Res., vol. 2, issue, 5, pp. 177-180, 2010.

[71] A.K. Tripathi, V. Prajapati, K.K., Aggarwal, S.P.S. Khanuja. and S. Kumar. "Repellency and toxicity of oil from Artemisia annua to certain stored-product beetles". Journal of economic entomology, vol. 93, issue, 1, pp. 43-47, 2000.

[72] Z.L. Liu, S.S., Chu, and Q.R. Liu. "Chemical composition and insecticidal activity against Sitophilus zeamais of the essential oils of Artemisia capillaris and Artemisia mongolica". Molecules, vol. 15, issue, 4, pp. 2600-2608, 2010.

[73] R. Fang, C.H. Jiang, X.Y., Wang, H.M., Zhang, Z.L. Liu, L., Zhou, and Deng, Z. W. "Insecticidal activity of essential oil of Carum carvi fruits from China and its main components against two grain storage insects". Molecules, vol. 15, issue, 12, pp. 9391-9402, 2010.

[74] B.B. Mishra, S.P. Tripathi, and C.P.M. Tripathi, (2012). Repellent effect of leaves essential oils from Eucalyptus globulus (Mirtaceae) and Ocimum basilicum (Lamiaceae) against two major stored grain insect pests of Coleopterons. Nature and Science, 10(2), 50-54.

[75] I. Wekesa, L.A. Onek, A.L. Deng, A. Hasanali, and J.O. Othira, Toxicity and repellant potency of Hyptis spicigera extracts on Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae). Journal of Stored Products and Postharvest Research, vol. 2, issue, 6, pp. 113-119,2011.

[76] V. Rozman, I. Kalinovic, and Z. Korunic, "Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored-product insects" Journal of stored products research, vol. 43, issue, 4, pp. 349-355, 2007.

[77] P.U. Rani, and P. Devananda," Efficiency of different plant foliar extracts on grain protection and seed germination in maize" Research Journal of Seed Science, vol. 4, issue, 1, pp. 1-14, 2011.

[78] F. Huang. "Resistance of the fall armyworm, Spodoptera frugiperda, to transgenic Bacillus thuringiensis Cry1F corn in the Americas: lessons and implications for Bt corn IRM in China" Insect Science, vol. 28, issue, 3, pp.574-589. 2021.

[79] N. Akhtar. "Temporal regulation of somatic embryogenesis in guava (Psidium guajava L.)" The Journal of Horticultural Science and Biotechnology, vol. 88, issue, 1, pp. 93-102, 2013.

[80] D. Singh, M.S. Siddiqui and S. Sharma, "Reproduction retardant and fumigant

properties in essential oils against rice weevil (Coleoptera: Curculionidae) in stored wheat" Journal of Economic Entomology, vol. 82, issue, 3, pp. 727-732, 1989.

[81] V.D. Brito, F. Achimón, R.P. Pizzolitto, A.R., Sánchez, E.A.G. Torres, J.A. Zygadlo, and M.P. Zunino. "An alternative to reduce the use of the synthetic insecticide against the maize weevil Sitophilus zeamais through the synergistic action of Pimenta racemosa and Citrus sinensis essential oils with chlorpyrifos" Journal of Pest Science, vol. 94, issue, 2, pp. 409-421. 2021.

[82] B.H. Lee, P.C. Annis, and W.S. Choi. "Fumigant toxicity of essential oils from the Myrtaceae family and 1, 8-cineole against 3 major stored-grain insects". Journal of Stored Products Research, vol. 40, issue 5), pp. 553-564. 2004.

[83] Y. Rajashekar, N. Tonsing, T. Shantibala, and J.R. Manjunath. "2, 3-Dimethylmaleic anhydride (3, 4-Dimethyl-2, 5-furandione): A plant derived insecticidal molecule from Colocasia esculenta var. esculenta (L.) Schott". Scientific reports, vol. 6, issue, 1, pp. 1-7. 2016.

[84] Y. Rajashekar, H.V. Kumar, K.V. Ravindra, and N. Bakthavatsalam, "Isolation and characterization of biofumigant from leaves of Lantana camara for control of stored grain insect pests" Industrial Crops and Products, vol. 51, pp. 224-228, 2013.

[85] R.H. Olmedo, E. Lucini, J.M. Herrera, M.P Zunino, R.P. Pizzolitto, J.S. Dambolena, and J.A. Zygadlo, Fumigant toxicity of Tagetes filifolia Lag essential oil and its main compounds against Tribolium castaneum Herbs and its relation to lipid peroxidation. vol. 32, no. 2, pp. 113-121, 2015.

[86] S. Rana, and K.K.Rana, "Review on medicinal usefulness of Vitex negundo Linn" Open Access Library Journal, vol. 1, issue, 3, pp. 1-13. 2014.

[87] X.L, Cheng, C.J Liu, J.W. Yao "The Current Status, Development Trend and Strategy of the Bio-pesticide Industry in China". Hubei Agric. Sci. vol,49, pp. 2287-2290, 2010.