International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Factors Affecting Quality of Grain Stored in Ethiopian Traditional Storage Structures and Opportunities for Improvement

Dubale Befikadu[a*]

[a]*Jimma Agricultural Mechanization Research Center, P.o.Box 358, Jimma, Ethiopia*
[a]*E-mail: dubebefikadu@gmail.com*

Abstract

In Ethiopia, like in other developing countries post harvest losses, including storage losses is estimated at 5-26%. Damages or loss of grains vary generally and are a function of crop variety, pest and insects, climate, system of harvesting, system of processing, storage, handling and marketing. Interrelated factors that greatly affect quality of stored grain are grain moisture content, grain temperature, initial condition of the grain, insects and pest and molds. The main objective of grain storage is to maintain quality of the produce for a long period of time and the basic requirements of every grain storage structure or systems are to protect the grains from insects, rodents and prevent deterioration of the grains by the activities of micro-organisms. Safe storage is one that minimizes quantity loss and maintains grain quality characteristics that may be expressed in terms of germination, malting quality, baking quality, color, oil composition, and many others. This means protecting it from weather, molds and other micro-organisms, addition of moisture, destructively high temperatures, insects, rodents, and birds, objectionable odors and contamination, and from un authorized distribution. Common storage structure used by most of Ethiopian farmers is traditional ones with poor construction that exposes the stored grains to different deterioration agents or conditions and to which appropriate management and monitoring of all the influencing factors hasn't been considered.

----

*Corresponding Author
E-mail address dubebefikadu@gmail.com

Though there had been promotion of improved storage structures, stored grain deterioration problem could not be solved. Since deterioration of stored grains results from the interactions among the physical, chemical and biological variables existing in the system, it is therefore important to understand the inter-relations and interactions of these variables in order to design an effective control and management of these factors for safe storage. Focus should also be given to storage through cost-effective and sustainable improvement of the traditional systems and the introduction of alternative sustainable and cost effective systems.

Keywords: Storage structures; Quality; Stored Grain

1. Introduction

Estimates suggest that the magnitude of post-harvest loss in Ethiopia was tremendous ranging from 5% to 26% for different crops [1]. This figure is quite large especially for Ethiopia where a great majority of people are food insecure. Post-harvest grain loss is the loss of grains (quality and/or quantity) between the moments of harvest and consumption. Grain storage is the practice of keeping grain in store houses, heaps, bulks and bags in such a way that seeds should retain both food and seedling value, provided with certain conditions like ventilation, fumigation and optimum temperature and humidity. Whereas, the purpose of storing seeds is to preserve planting stocks from one season until the next. Crop losses occur at all stages of the post-harvest handling, including pre-processing, transportation, storage, processing and packaging and marketing. Grain losses could arise either from poor post-harvest handling or from production over and above the capacity of the available stores, or both. It is therefore important to recognize that post-harvest grain management (PHGM) practices and capacities (and not just production and marketing) are important for many reasons including the achievement of food security objective [2].

Grain quality is a nebulous term that means different things to different people. It largely depends on the grain type and its end use. It includes a range of properties that can be defined in terms of physical (moisture content, test weight, kernel size, total damaged kernels, heat damage, broken kernels, stress cracking, breakage susceptibility), sanitary (fungi and mycotoxin count, insects and insect fragments, rodent excrements, foreign material, toxic seeds, pesticide residue, odor, dust), and intrinsic (milling yield, oil content, protein content, hardness, density, starch content, feed value, viability, storability) quality characteristics. The quality properties of a grain are affected by its genetic traits, the growing period, timing of harvest, grain harvesting and handling equipment, drying system, storage management practices, and transportation procedures. Only a few of these quality factors are usually used for grading grains. Often contracts between processors and producers will specify specific varieties, quantities, and quality criteria. Some processors offer premium for high quality grain as a function of how far within the maximum or minimum specifications farmers deliver their crops. Thus, it is important to understand how these quality characteristics are affected so that producers can maintain and deliver these grain quality attributes, and receive deserved premiums.

Grain quality losses are due to the proliferation of storage insects (moisture content of less than 12% can reduce their multiplication), rodents that can cause high quality losses in stored grain by contaminating the grain with urine and hair as they consume part of it. The other cause of storage losses is the multiplication of fungi due to excessive humidity in particular *Aspergillus spp.* which produces dangerous toxins (Aflatoxins) which make grain unfit for human consumption. Aflatoxins, even in lower concentration are carcinogenic and at higher concentration are acute toxic [3]. Grain quality is not solely a varietal characteristic but also depends on the crop production environment, harvesting, processing and handling systems. Therefore, maintaining good grain quality is the concern of all disciplines such as breeding, agronomy, entomology, chemistry and engineering.

1.1 Statement of the problem

Rural farmers face the most challenging problem on their produce in terms of storage service life due to termites weakening the wooden stand. Pests are also common agents for the stored grain deterioration. Usually the seriously affected crop is maize. Maize is easily susceptible for weevils attack though this is common problem for other cereals and pulses. Farmers also indicated that there is a great shortage of chemical supply to be used for controlling weevils. The other important agent for deterioration of the stored grain is rat [4]. The poor storage construction allows vertebrate loss agents (rats, mice, birds and monkeys, apes) to easily attack the stored grain forcing the farmers to store their crops in partitioned room inside the living house with sack or bag. While mentioning the extent of the storage problem, farmers repeatedly respond that they are equally sharing the stored crops with the vertebrate animals and rodents especially with rats.

Common storage structure used by most of Ethiopian farmers are traditional ones with poor construction that expose the stored grains to different quality and quantity deterioration agents or conditions and in which appropriate management of all the influencing factors hasn’t been addressed [4]. Survey results of a selected major grain producing areas of Ethiopia indicate that farmers perceived post-harvest grain loss as an imminent risk, and that instant sales of grains after harvest are triggered by temporary but immediate liquidity preferences to meet various obligations in the absence of or limited sources of cash other than crops sales, and by an impending risk of post-harvest grain loss and the limited capacity to prevent it [2].

Study conducted on the underground storage pits in Hararghe indicates that, grain storage in traditional underground pits for long periods does lead to grain deterioration and the use of improved above-ground bins and/or modified underground pits rather maintains the grain quality and nutritional value of sorghum for a reasonably long storage period [5]. According to result of survey conducted in southwestern Ethiopia to investigate farmers’ perceptions and management practices of insect pests on traditionally stored sorghum, most farmers estimated sorghum yield losses of up to 50% due to insect damage during storage. It was also noticed that only about 32% of the farmers had access to chemical insecticides for the control of stored sorghum insect pests, while the majority of them used cultural practices and locally available plant materials as storage protectants [6].

On the underground pits lined with fired clay or cement promoted among Borana pastoralists by CARE Borana (Ethiopia), an international NGO, up to 16% losses due to mold were recorded [7]. Studies in South Somalia in the frame of the EC funded Integrated Pest Management Project have shown that grains stored in underground pits lose some of their qualities but are still fit for human consumption after 1 year [3]. Consequences of post-harvest and storage losses for food security and health of people are therefore quite important. The economic importance of such losses is therefore better to be grasped. Experiences by farmers in Bay Region of Somalia to line the walls with plastic sheets proved to be ineffective in case of heavy rainfall and flash floods. Research conducted in Bay Region by GTZ indicated that in all tested pits moisture and temperature were conducive for fungal development and therefore grains were potentially contaminated by aflatoxins. Although no data could be found on the incidence and impact of aflatoxins in the storage pit in specific areas studied like in S. Somalia's storage pits, there is evidence that the post-harvest and storage conditions in underground pits are conducive for its development [3]. People consuming a stored grain in such structure are therefore at great risk of regularly eating aflatoxins contaminated foods. There is, therefore, need to better identify its occurrence in traditional storage pits and in minimizing the risk of occurrence by improving grain drying and storage conditions. Aflatoxin contamination of foods is especially severe after long-term crop storage because of excessive heat, humidity and insect and rodent damage result in proliferation and spread of fungi. Cereals are particularly exposed. Rural populations are therefore exposed to high aflatoxin throughout life. Data from several West African countries show that more than 98% of children and adults have detectable amounts of aflatoxin in their blood. Exposures are orders of magnitude higher than those allowed by regulation in Europe, the USA and other parts of the developed world [3].

It should be emphasized that underground pits can allow hermetic storage conditions where the decrease of oxygen and the increase of carbon dioxide concentration due to grain respiration make insects and rodents inactive. There are several methods, with different costs and impact that need to be tested and introduced to improve their efficiency. This includes the lining of the pit walls with maize/sorghum sticks or plastic sheets, the digging of drainage systems around the pits, the establishment of pits in elevated position.

1.2 General objective

- To review factors that affect quality of the stored grain

1.3 Specific objectives

- To review factors that influence quality of grains stored in the traditional storage structures
- To review advances and recent trends on the improvement of traditional grain storage practices

From the review to recommend suitable grain storage conditions (storage structures and stored grain quality management practices)

2. Literature Review

2.1 Grain storage

Grain storage involves more than just placing grain in a suitably sized receptacle until it is needed. The grain is a major asset in which the grower has invested preparation, sowing and harvesting costs. The asset must be protected because while grain is in storage its quality, and thus its value, deteriorates.

2.2 Grain storage principles

High temperature and high moisture are the most significant factors affecting grain quality in storage. Each can cause rapid decline in germination, malting quality, baking quality, color, oil composition, and many other quality characteristics [8]. Insects and molds impair the quality of grain directly by their feeding and development, and indirectly through generation of heat and moisture. High temperatures and moistures favors development of insects and molds. Development of insects is limited by temperatures below 15°C, and by moistures below 9% in cereal grains. Development of molds is limited by temperatures below 10°C, and by moistures below 13% in cereal grains [8]. Spraying with insecticides or fumigating minimizes insect problems but leaves chemical residues in grain, which break down with time. Presence of residues, and their concentration, affects acceptability of the grain to markets [8]. Some markets prefer grain without residues. Grain buyers will not knowingly accept grain treated at rates higher than those specified on the label, or within the specified withholding period.

2.3 Ethiopian traditional grain storage methods

The traditional grain storage structures in different part of Ethiopia are made of various locally available materials to store grains either in threshed or un threshed forms. Usually, the type of locally available materials indicates the type of structures and differs from region to region. Each of the storage methods has their own advantages and disadvantages. Traditional storage structure found in this country includes: earthenware pots and gourds, bark, baskets, sacks/bags, basket silos, roof storage, maize cribs, underground pits, small store houses, earthen silos, *Gombisa* which is made from split or whole bamboo poles or other tree sticks and its roof thatched either by dry grass/hay or corrugated iron sheet [4,9].

2.4 Factors affecting quality of the stored grain

Once the last grain has been put into the storage and the hatches closed, there is often a tendency to forget about what is needed to maintain the grain at a high level of quality. However, without proper management, that grain can rapidly deteriorate, becoming a worthless mass [10]. Grain spoilage is usually the cumulative result of several different handling and management operations and decisions. Thus, the better the overall management program, the better the chance for maintaining grain quality. Four factors which greatly affect grain storability are grain moisture content, grain temperature, initial condition of the grain and insects and molds [10]. These factors are also all interrelated.

2.5 Stored grain deterioration by biotic and abiotic factors

2.5.1 Abiotic factors

Moisture Content

If grain moisture content is too high, even the best aeration equipment and monitoring management will not keep the grain from spoiling - it only delays the inevitable. All micro-organisms, including molds, require moisture to survive and multiply. If the moisture content in a product going in to store is too low, micro-organisms will be unable to grow provided that the moisture in the store is also kept low. Moisture should therefore be prevented from entering the store. The moisture content below which micro-organisms cannot grow is referred to as the safe moisture content [9]. Table 1 lists the safe moisture content levels for cereals and pulses, valid for temperatures up to 27^{o}C. Slight variations in safe moisture contents arise, depending upon the variety.

In general, it is essential that all food stuffs are below their safe moisture content before they enter the store. The safe moisture content is to some extent related to the storage time. Moisture levels above safe moisture content can be tolerated if only short times are required. The sitting and ventilation of the store are important. Condensation of moisture can cause storage problems. If the walls of a store are cooled below their dew point by low night temperature, condensation can occur and increase the moisture in the layers of the stored grain near the edge of the store. It is important to remember that the stored grains are alive and respiring giving off moisture as well as heat.

Table.1 Safe moisture content levels for cereals and pulses stored below 27^{o}C

Product	**Safe moisture content (%)**
Cereals: maize flour	11.5
Maize shelled	13.5
Millet	16.0
Rice (milled)	13.0
Rice	15.0
Sorghum	13.5
Wheat	13.5
Wheat flour	12.0
Pulses: broad bean, cow pea	15.0
Lentil, pea	14.0

Source: [9].

Going into storage at the proper moisture content does not guarantee grain will remain at that moisture. Grain may be rewet as a result of storage roof or sidewall leaks. Moisture can also enter through downspouts from a bucket elevator or through hatches that have been left open. Moisture condensation can also cause localized increases in grain moisture content. Condensation, particularly on storage roofs and sidewalls, is common when warm grain (10^{o} C or above) is cooled during cold weather (-1^{o}C or less), or when hot grain from a dryer is cooled in a storage [10]. Condensation can also be minimized by providing adequate exhaust vents in the cooling storage [10]. Due to excessive humidity, multiplication of fungi particularly *Aspergillus spp*., which produce dangerous toxins (Aflatoxins), will make grain unfit for human consumption [3].

Grain Temperature

The temperature within a store is affected by sun, the cooling effect of radiation from the store, outside air temperatures, heat generated by the respiration of both the grain in the store and any insects present [9]. With a few exceptions, micro organisms thrive in environments with temperature between 10 and 60^{o}C. As stores in most parts of Ethiopia have temperatures between 25 and 35^{0}C, the effect of both micro organisms and insects are obviously important. Direct temperature control of small stores is not usually a technical or economic possibility. So other measures, particularly reducing the moisture content of the stored produce, are necessary.

Whether holding wet grain for a short period of time or storing dry grain for longer periods, it is important that grain temperatures be controlled by moving air through the grain mass. Because both wet grain and molds respire and give off heat, aeration is needed to keep the grain cool and to slow mold growth. Properly aerated grain can generally be safely held about four times longer than non-aerated grain. Aeration is needed, even if grain is dry and cool when placed in storage, to keep the grain mass at the desired temperature and to keep temperatures equalized. Differences in grain temperatures create convection currents which can move and concentrate moisture in the top center of the storage. Problems caused by this moisture movement, or moisture migration, often become obvious in the spring (when outside air temperatures begin to warm). The first indication of trouble is usually damp or tacky feeling kernels at the grain surface, followed by the formation of a crust. Moisture migration is more of a problem in a peaked storage because the moisture is concentrated in a smaller volume of grain. Moisture also moves by vapor diffusion from warmer to cooler areas in the storage. If grain is not properly cooled, there is a tendency for moisture to move to the cool grain along the sidewall, causing spoilage. Moisture movement problems can be prevented or minimized by keeping grain mass temperatures equalized and within -12 to -9^{o}C of the average outside air temperature.

Initial Grain Condition

Grain quality will not improve during storage. At best, initial quality can only be maintained. To help assure that only high quality grain goes into storage, the following is recommended:

- Clean around the storage site. Remove any old grain, grass, weeds, and other debris.
- Remove all traces of old grain from the storage and harvesting and handling equipment.
- Properly adjust the combine (harvesting, threshing and handling equipment) to minimize grain damage.
- Clean the grain as it is put into the storage, preferably using a rotating grain cleaner.
- Cool the grain to the prevailing outside air temperature (that most usually occurs) as soon as it is put into the storage.

2.5.2 Biotic factors

Damages of grains or loss of grains vary generally and are a function of crop variety, pest and insects, climate, system of harvesting, system of processing, storage, handling and marketing [11]. The main agents causing deterioration of stored grains are micro organisms (fungi, bacteria, and yeast/mold), insects and mites, rodents, birds, and metabolic activities.

Fungi

They belong to plant kingdom with no chlorophyll and are therefore, unable to manufacture their own food by photosynthesis. They live on other living things or bodies as parasite, or inactively alive or dead bodies as saprophytes. Parasitic fungi may cause disease in the host body, while saprophytic fungus degrade or destroy the body on which they feed. Saprophytic fungi are more important in relation to stored durable crops.

Bacteria

Bacteria prevalence to the stored durable crops may be low. They may, however, invade already damaged portion of the crop products during storage and their multiplications.

Insects

Many species of insect are found in stored products. But few causes damage and losses. Some of them even are beneficial because they attack insects and pests. Among several insects that attack stored products, weevils are very important:

- *Sitophilus oryzae* L. (Rice weevil). They attack cereals like rice and cereal products such as paste, flour and biscuits
- *Sitophilus zeamais* (Maize weevil). They attack maize, sorghum and other cereals

Insects are the major causes of post harvest grain losses. They penetrate the kernels and feeding on the surfaces and the endosperm. They remove selectively the nutritious part of the food and encourage the development of bacteria and increase the moisture content of the food [11]. Insect infestation will eventually lead to other storage problems. They give off moisture which can cause grain moisture contents to increase enough to create a mold problem. Mold activity will in turn raise temperatures and result in an increased rate of insect reproduction. Greater numbers of insects create more moisture, and the cycle is repeated at an ever increasing rate. Insects also cause quality deterioration through their excreta as they consume. Insects are generally not a problem in grain stored for less than 10 months or a year if the grain is at its safe moisture and low temperature of storage. However, if grain is to be stored for longer than this, or if storage has had an insect problem in the past, special precautions should be taken. These include:

- Spray the inside of the storage with protective insecticides 2 to 3 weeks before new grain is added.

- Treat the grain with an approved insecticide as the storage is filled.
- Top-dress the grain with an approved insecticide after the storage has been filled and the grain surface has been leveled.

Controlling insects with insecticides, including fumigants, rather than using preventative methods incurs great cost. In addition, infestation generally results in dissatisfied customers and related marketing problems that develop from a poor reputation in marketing channels. The most unfortunate consequence of not managing grain properly is the loss of money, time, and effort to produce the grain (seed, fertilizer, field pest management, harvesting, threshing costs). Store preparation, drying and cooling are the main ways to protect against grain storage pests. Changing temperatures and increasing moisture contents at the surface of grain bulks may allow residual infestations to develop. Occasional control failures due to poor management may require remedy. Most storage insects carry over from previously stored grain, so it is important to detect any residual infestations. Chemical grain treatment may be justified if persistent infestations cannot be controlled by drying and/or cooling.

Protectants include:

• Liquid pesticides which may be applied to store fabric or grain itself to kill insects and mites.
• Fumigants which eliminate infestations within a few days.
• Smoke generators (not fumigants), primarily used to control flying insects.
• Diatomaceous earth (DE) which is not regarded as a pesticide.

Rodents

Three species of rodents are major pest of stored products:

- *Rattus rattus* (Black rat)
- *Rattus norvegieus* (Brown rat)
- *Mus musculus* (House mouse)

Rodents consume cereal crops and damage sacks and building structures. They contaminate much great portion of the grain with their urine and droppings than they consume. Rodents can daily consume about 10% of their body weight. Poisoning and preventing their access to stored commodities can control them. Biological control also applied to stop rat damages. Generally, rats transmit diseases (typhus, rabies, trichomaisis) and destroy and damage building structures [11]. Regardless of storage period, grain pest can invade the stored grain and affect the quantity and its quality.

Birds

Like rodents, birds also consume some grain foods but also contaminate a greater quantity with droppings. Losses caused by birds can be avoided by preventing their access to the stored commodities.

Metabolic activities

Cereal grains are living materials and their normal chemical reactions produce heat and chemical reactions by products [11]. Heat is also generated by insects, mites and micro organisms, which if presented in large number may lead to a significant rise in temperature of stored products. Under aerobic condition the complete combustion of a typical carbohydrate can be represented by the following equation:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 677.2Kcal$$

There are two types of losses during metabolic processes:

a. The loss due to grain being converted by micro organism to carbon dioxide and water.

b. The other loss occurs when the grain (entirely or as individual kernels) rejected.

2.6 Conditions of safe storage

Safe storage must maintain grain quality and quantity. This means protecting it from weather, molds and other micro-organisms, addition of moisture, destructively high temperatures, insects, rodents, and birds, objectionable odors and contamination, and from un authorized distribution. From the moment of harvest to the moment of its use in processing for human food or animal feed, grain should be stored so as to prevent quality deterioration. The grain, together with microorganisms and foreign material, make a system of living organisms, also called an artificial ecosystem of grain in bulk. Any quality deterioration of such a system is a result of simultaneous biological, physical and chemical processes.

The following quantities and factors can be distinguished that characterize these processes or influence them: temperature, moisture content, carbon dioxide (CO_2), oxygen (O_2), as well as biological state of the grain, microorganisms especially molds (Figure 1), insects and mites at the moment of harvest. Moreover, rodents, birds, climatic conditions, transport and cleaning, and the applied technology of ventilation, drying, cooling and storing all have their influence. The ecosystem of stored grain should be properly protected against all risks that can reduce quality or lead to spoilage (Figure 1.).

Post-harvest preservation of grain tries to inhibit those biological processes in the ecosystem of the grain bulk that are a cause of quality deterioration. The largest influence on these bio-processes arises from the moisture content and temperature of kernels, as well as the air humidity in the inter-granular spaces.

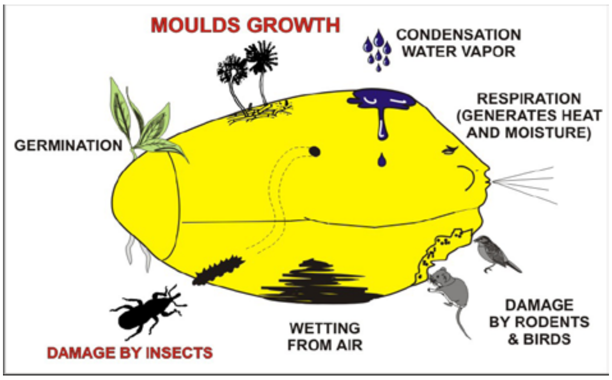

Fig 1. Various risks of quality deterioration in the ecosystem of bulk grain.

Grain entering a storage structure should be cool and dry. Grain harvested later in the season during cool weather will store longer. In addition, grain temperatures will vary -7 to 4°C throughout the day. Temperatures of grain placed into storage should be within 10 to -9°C for each load to prevent moisture movement due to temperature gradients. If at all possible cool the grain to 10°C or below before placing in storage. The maximum moisture content of any load should not exceed the recommended safe storage moisture content for a particular grain. Normally, these values are 13, 14 and 15.5 percent moisture (wet basis) for soybeans, grain sorghum, and corn, respectively. The grain should be placed in the storage at less than 14 percent moisture, wet basis, and preferably 13 percent for greater safety.

2.7 Management and control of the stored grain

2.7.1 How to maintain quality of grain in storage

Moisture

High moisture grain should not be stored long-term. Accepted moisture limits for trading and storage of grains (Table 2) are generally below the limits at which molds develop. Moisture moves around inside a silo. Daily and seasonal temperature changes near the silo walls set up air movements that carry moisture to the coolest parts of the grain. Pockets of high moisture grain (e.g. grain harvested early in the season, late at night, early in the morning, or soon after rain) or inclusion of green leaf material with the grain can affect quality of all the grain in storage because of moisture movement.

Table 2. Maximum moisture limits for trading and storage of grains, based on National Agricultural Commodities Marketing Association standards (Queensland, Australia).

Grain	Moisture limit (% dry weight)
Sunflower	9
Barley (malting), faba beans, mungbean, oats	12
Barley (feed), wheat	12.5
Chickpea, pigeon pea, soybean	13
Sorghum	13.5
Maize	14

Aeration will slow the rate of deterioration of high moisture grain, but if the moisture is more than two or three percent above the limits (Table 2), it should be dried before long term storage. Early harvesting of grain at higher moisture produces higher quality and higher yield of grain, but those advantages are lost unless aeration and drying are used to minimize losses in storage. Hot-air drying is necessary to maintain the quality of high moisture grain. However, holding grain at too high a temperature for too long in the dryer will reduce grain quality. Operate the equipment according to specifications of the dryer manufacturer. Using higher airflow rates is a safer way to speed up drying than increasing temperature. Selling grain at a moisture content below that allowed by market results in economic loss. Grain loses approximately 1.2% of its weight for every 1% of moisture content reduction. For example, selling grain with 9% moisture content when up to 12% is allowed means a loss of about 3.6% of the value [13].

Temperature

Aeration will markedly reduce grain temperature, and so minimize the deterioration of grain quality. Aeration will also even out temperature differences that result in moisture migration from warmer to cooler patches in the grain. A white finish on the silo will also contribute to a reduction in temperature [10].

Insects and chemical residues

Good hygiene is an essential component of insect control in stored grain. Other options for insect control include:

- Cooling grain with aeration
- Treating storages and equipment with inert dusts or residual chemicals
- Treating grain with inert dusts or residual chemicals
- Treating infested grain with dichlorvos (an insecticide)
- Fumigation (bombing) with phosphine, or
- Controlled atmosphere treatment (e.g. Carbon dioxide).

Good hygiene combined with automatically controlled aeration is sufficient for some growers to maintain grain quality without using any residual treatment. Fumigation with phosphine leaves minimal residues, provided tablet formulations are not mixed with the grain. It needs to be checked with buyers before spraying grain with insecticides [10].

Inspect grain frequently during storage: Stored grain should be inspected frequently. Insect or mold activity gives a distinct odor to air moved through the grain. By operating the aeration system and smelling the air coming through the grain, storage problems can be detected. Any 'hot spots' should be cooled as soon as possible by aeration. If the problem is due to insect activity, the grain should be fumigated.

Aeration system management: The primary objectives of aeration are to keep the grain at a seasonally cool temperature and to maintain uniform grain temperatures - preferably no more than a -12^{o}C difference in temperature from one part of the storage to another. These objectives can be achieved by keeping grain temperatures within -12 to -9^{o}C of the average ambient air temperature. Thus, seasonal temperature changes require changes in aeration fan operation. There are a number of fan operation schedules that can be used to maintain the quality of stored grain. Following the management procedure will help assure that basic aeration requirements are met. It has to be adapted as necessary to meet individual needs and conditions.

Monitoring grain condition: Following the aeration schedule will help maintain grain quality. However, grain condition needs to be monitored to verify that the desired temperature control is being achieved. Further, a regular checking schedule is essential if mold and insect activity are to be detected and controlled in a timely fashion. The method and frequency of checking will vary with time of year, initial condition of the grain, and aeration procedure. Generally grain should be inspected at least once a month during the cold season and every two weeks over the warmer and hottest seasons.

Grain checking is extremely important during the warmest season because grain is being held at higher temperatures and aeration conditions are less favorable than during the rest of the year. Grain temperatures need to be checked and recorded on a regular basis. Without temperature records, it is difficult to tell whether elevated grain temperatures are caused by normally occurring outside temperatures or by heating due to mold activity. The grain needs to be probed to locate any moisture pockets where molds will develop rapidly as temperatures warm. Insect activity is also at a peak during the warm season, and frequent checking is required if infestations are to be controlled before they develop into major problems. Failure to monitor grain condition throughout the entire storage period is a frequent mistake. A small area which starts to heat or otherwise "go out of condition" can quickly get out of control and spread within the storage. Think of the grain as being cash in the storage, and consider how frequently it would get checked if that were the case.

Some areas and conditions to check when monitoring grain quality include:

- Grain surface for condensation, crusting, wet areas, molds, and insects.
- Storage roof for condensation and leaks.
- Grain mass for non-uniform temperatures, high moisture pockets or layers, molds, and insects.
- Exhaust air for any off-odors.

If problems are detected, they need to be evaluated and corrected as soon as possible. This may include cooling with aeration, further drying, or fumigation for insect control.

2.8 Improved storage techniques recommended for grain storage and preservation in Ethiopia

2.8.1 Plastic bags

Plastic bags are widely used for storage in Ethiopia. The product has to be dried well because, during storage, further drying is impossible as there is no air circulation. When plastic bags are closed well, air tight storage results, with all its advantages and disadvantages. Plastic bags do not offer much protection against rodents, and they can be pierced by sharp seeds during transport and penetrated by insects. This can be reduced by putting bag of tightly woven cotton inside the plastic bag. Plastic becomes weak or brittle after continued exposure to the sun and therefore no plastic package will last indefinitely. An advantage of transparent plastic is that the product remains visible, which makes control more simple. Although the product may look good from the outside, however, it may have become musty within. Fertilizer bags cannot be used unless they have been very thoroughly cleaned. Suitable for: sowing seed, cereals, pulses, ground nuts, copra [9].

2.8.2. 45-Gallon metal drums

Small drums and water tanks are often available and can be used for storing crops, provided they have been well cleaned. When being used for storage, they should not be placed in full sun light, but protected, preferably under a good roof, and insulated with a layer of straw to prevent large temperature changes. A tightly closed drum prevents the entry of insects. Grain should be well dried before filling. Suitable for: cereals, pulses and seeds [9].

2.8.3. The pusa bin

The Indian pusa bin is essentially a square double-walled silo. Both the floor and the roof structure are also double walled. The space between the two walls contains a layer of plastic sheeting to minimize the passage of water in to the store. Provided the filling and emptying openings are well closed the store is extremely well sealed. In general, the walls are made from mud blocks but they can be made using a mixture of mud mixed with a small amount (10%) of cement or made from fired bricks or concrete blocks. Grain should be well dried before storage. Suitable for: cereals and pulses [9].

2.8.4. Metal silos

Metal silos are suitable for cereals and pulses. A whole range of small metal silo designs exists, with silo capacities up to about 5 tones. Some skill in welding is required to make the structure airtight. Silos can be made with overlapping sheets, bolted or riveted together. The silo has two openings, one for filling at the top and one for emptying at the bottom. As in the case of metal drums, metal silos should not be placed in full sun light, but sheltered to prevent dramatic temperature changes. Some small silo designs incorporate a ventilation system operated by natural airflow. A rotating fan-like structure is placed on top of the silo and, when the flaps are open, the grain is ventilated by fresh cool air. Metal silos tend to be expensive.

2.8.5. The brick and ferro-cement silos

Silos of this type are suitable for use in dry and wet tropical areas, but they should be protected from rain by a roof, and the base should be made from reinforced concrete or fired bricks. These silos are comparatively airtight and watertight, particularly when painted with rubber-based paints, coal tar or bitumen. A whole range of sizes and styles are possible. Three common types are brick, cement-stave and Thai ferro-cement silos.

The brick silos: The brick silos are suitable for both cereals and pulses. As the name implies, this silo is made from bricks, placed on reinforced foundation and covered by a concrete plate, with a manhole for filling and emptying. Brick silos are relatively easy to build and can store several tones of grain.

The cement staves silos: The cement-stave silos are suitable for cereals and pulses. The cement-stave silo is more durable than the brick silo but also somewhat more expensive. It does not cost less, however, than a metal silo of the same size. Cement-stave silos are often raised off of concrete.

The Thai ferro-cement silos: Ferro-cement is made of wire mesh (for example chicken wire), sand and cement and it is strong and durable. Ferro-cement silos can be made in almost any shape. The Thai ferro-cement silo has a conical shape and is water proof and airtight. The base is saucer-shaped and is made of two layers of reinforced concrete with a layer of bitumen, asphalt paper, plastic or metal foil in between. The frame of the walls is made from water pipes or bamboo poles and reinforcing rods, which support an inside and outside layer of wire mesh. The mesh structure is filled and smeared with mortar of a paste-like consistency: 1 part of standard cement 1.75 part sand with the optional addition of a plasticizer to improve the workability. Suitable for: cereals and pulses [9].

2.8.6. Storage in ventilated huts

The aim of this type of storage is to offer protection against rodents, sun, rain and ground water and, by providing ventilation, to prevent fungus growth and rotting. As this method offers hardly any protection against insects, it is less suitable for long term storage of cereals and pulses. This storage method is very suitable for the storage of root crops. For construction, locally available materials should be used: bamboo, planks, woven mats in a wooden frame. For protection against rats and termites, the huts can be built on poles, at least 75 cm in height, with rat baffles fixed on them. If the walls are made of plank they should overlap like roof tiles with some space between them so that sun light cannot enter but ventilation is still possible. The roof of wood or thatch should be overhanging for protection against sun and rain. Inside the hut, the products should be piled in boxes or on shelves or racks along the wall, in such a way that air can move freely between them. Regular inspection of stored products is necessary. Suitable for: cereals, pulses [9].

2.8.7. Improved pit storage

Roofing

The roofing of a pit can be made of metal sheet, sealed with mud/dung or bitumen, or polythene sheet. A temporary shelter over the pit site gives protection from rain but should be removed in the dry season to ensure drying by evaporation, because a shelter does not prevent lateral movement of water in to the pit.

Improving pit linings

- Coating the walls of the pit with mud/dung/ straw mixture: the grain remains much drier than in unimproved pits
- The product is put into well-sealed plastic bags, which are placed in the pit: this allows part of the product to be removed without letting air and moisture in to the rest of it.
- Plastic lining: the pit is lined with a plastic sheet or cut-open plastic bags, which are sealed together. The disadvantage is that the plastic lining can be damaged easily.
- Ferro-cement lining: a pit can be made airtight and watertight by using ferro-cement to line the pit two layers of mortar (cement: sand 1:3 with as little water as possible to make a paste), 2.5-3cm thick, with a chicken wire reinforcement between the layers. A water barrier can be achieved by incorporating a

bitumen layer between the two mortar layers or by applying a cement/bitumen emulsion layer as a final lining. Suitable for: cereals, pulses and root crops.

2.9 Alternative and supplementary control measures

2.9.1 Physical measures

The effects of various physical factors upon insect development and control have been discussed already. The particular measures that are important as supplements to other insect control procedures are cleaning and drying. Those which may provide alternatives to other forms of control are cooled grain storage, hermetic storage, thermal disinfestations and, in some circumstances, mechanical disturbance.

The cleaning and drying of grain for storage are essential measures. Practical difficulties in achieving the desired freedom from excess moisture and foreign matter are frequently encountered. There can be no doubt that failures to overcome such difficulties do occur and that these lead to increased insect infestation. The rate of insect development may be somewhat accelerated and, more importantly, the spectrum of infestation will be greatly increased. Practical recommendations take account of this when they acknowledge the difficulties that may occur but emphasize the need for cleaning and drying to be done as thoroughly as possible, especially when grain is to be stored for a long period. The longer the expected storage period, the greater the need for efficient cleaning and drying.

Techniques for the storage of damp grain, in hermetic conditions, under controlled atmospheres or with mold-suppressant treatments, have been developed but these are regarded as unsuited to the storage of grain for use as human food [14]. However, the practical value of ventilated cribs for the storage of maize on the cob and other grains on the head or in the pod, when insufficiently dry for sealed storage, should not be overlooked. Advice on optimum design for maize cribs, with particular reference to the humid tropics where the restriction of crib width to facilitate drying is important, is given in FAO Agricultural Services Bulletin No.40 [15].

The development of other temporary storage procedures, especially for under dried rough rice, has received much attention in countries where the introduction of new cultivars has led to massive production increases and, sometimes, to the regular harvesting of grain in wet weather. Limited applications of mold-suppressant chemicals, such as propionic acid, have been found effective and may be acceptable for short holding periods (5-7 days) prior to proper drying [16]. The use of admixed desiccants, such as common salt (sodium chloride) or wood ash, may also be of limited usefulness.

Aeration and cooling, by natural aeration in small, ventilated stores (e.g. maize cribs), or by forced aeration in larger stores, can significantly retard the development of insect infestation. Where it is possible to reduce the temperature of a grain mass to 17°C or less the infestation will be effectively suppressed although not eliminated. The suppression could be achieved, by selective aeration, in many parts of the tropics where early morning temperatures are of this order. More attention should perhaps be given to this [13; 18]. The particular importance of maintaining relatively cool storage conditions for seed grain stored in tropical climates is well known [14].

Small-scale of hermetic storage applications in the tropics are not uncommonly reported and attempts have been made to encourage the use of this technique in many parts of the tropics. However, it can only be cost-effective, in practice, where the storage management objectives will accommodate the principle and where suitable containers are available at a reasonable price. It is best regarded as a technique for selective application to particular commodities or to particular stocks clearly identified as reserves for protracted storage. Large-scale applications are likely to be handicapped by the cost of maintaining air tightness in large structures and by the common commercial requirement that grain stocks should be renewed at regular intervals [17]. However, considerable interest in the technique remains [18].

Thermal disinfestation techniques include simple exposure to the heat of the sun, a traditional procedure that can achieve disinfestation in thin layers of exposed grain but which may often, in practice, do no more than drive off any adult insects or free-moving larvae. At the other extreme is the sophisticated technique, based on fluid-bed grain drying systems [19].Between these extremes lie opportunities for using solar drying equipment for grain disinfestation [20].and the occasional use of conventional hot-air grain dryers for this purpose in the reconditioning of infested grain. All of these techniques need careful management to ensure an effective kill of all stages of the insects in the grain without causing physical (thermal-stress cracking) or physiological (germinability loss) damage to the grain. Thermal disinfestation (like fumigation) provides no ongoing protection against re-infestation and, moreover, if heated grain is put into storage without sufficient cooling any subsequent infestation may develop very rapidly.

Mechanical disinfestation techniques also show a range of refinement from the simple turning of grain through bulk-handling systems [21]. to the use of sophisticated percussion machines (entoleters) in flour mills. As with thermal disinfestation, the treatment provides no ongoing protection and may cause physical damage to the grain which, if it is returned to storage, may therefore be made susceptible to infestation by a greater range of insect species.

2.9.2 Traditional grain protectants

The occasional use of abrasive mineral dusts, natural desiccants like wood ash and various plant materials with repellent or insecticidal properties is well known and documented [22].

Other works have identified various commonly available cooking oils, notably palm oil but also groundnut oil and coconut oil, as being particularly effective (and used in some countries) for the protection of pulses against bruchid beetles. The oil obtainable from the seeds of the widely-grown neem tree (*Azadirachta inidca*) has also been found effective but comprehensive evaluations of its economic acceptability are less easily identifiable. [23] gives a good account of laboratory investigations and field trials in Nigeria that tested other materials from the neem tree, including water-based leaf extracts, for the protection of cowpeas and maize. The results showed good protection of cowpeas (against C. maculates) for five months but only moderate protection of maize and found that seed extracts were more effective than leaf extracts.

2.9.3 Modern biological methods

Irradiation techniques and controlled atmosphere storage can be considered, although they may also be regarded respectively as physical and chemical techniques, because their use depends upon radical interference with biological systems or processes.

Insect resistant packaging of grain or grain products, immediately prior to irradiation, would seem the most logical adjunct in countries where socio-economic circumstances favor the adoption of this sophisticated and relatively expensive control technique. The indirect applications of irradiation, to achieve the suppression of pest populations through the release of sterilized males of the pest species, appear unlikely to prove economically attractive for the widespread control of grain storage insects.

Controlled atmosphere (CA) storage has become an important addition to the available options for stored-grain pest control.

Conventional biological control techniques for possible application in stored-grain pest control, including control by the use of predators, parasites, insect diseases and sterile males, the use of pheromones for pest monitoring, mating disruption or enhanced mass trapping, and the use of resistant crop varieties can be mentioned. It should be noted that control by the use of a resistant variety will generally retard the increase of infestation and grain damage, thereby prolonging the period in which damage remains relatively low, while control by predators or parasites can be expected to suppress the pest population and the consequent grain damage but is unlikely to restrict insect numbers or grain damage to a low level.

2.10 Current possibilities for integrated pest management

2.10.1 Farm level improvements

As suggested by [24] and many other authors the development and use of improved grain cultivars, with resistance to storage insects as well as to pre-harvest pests, could provide the key element in IPM for stored grains. This would be of particular importance for loss reduction at farm level because, if the improved cultivars were both agronomically suitable and acceptable in all other respects to farm-level users, the adoption of this lPM (Integrated pest management) strategy by farmers should be quite straightforward and would require no change in their traditional approach to grain storage. It would permit the renewed realization of traditional concepts of safe storage, for a substantial period, by good husbandry alone. It must be understood that this would not, in most circumstances, reduce on-farm storage losses to less than the customary level generally accepted by farmers storing their own preferred varieties. However, it would reverse the trend towards increased losses which has been observed in those areas where farmers have been encouraged to plant high-yielding varieties which, typically, are more susceptible to damage by storage insects. Moreover, there should be a net gain provided that improved resistance to storage insects can be coupled successfully with high yield characteristics.

Tactical opportunities for supplementary improvements in grain storage by small-holder farmers are indicated and discussed by [22] with particular reference to maize grain but considerable relevance to most other grains. They include realistic modifications to traditional storage structures to enhance their performance or to adapt performance to seasonal climatic change. The relative efficacies of various grain protectants, including some of the common traditional materials, are also considered. It is clear that several of these do have some value as a means of further extending the safe storage period but it remains true that reliable formulations of suitable contact insecticides, where these are available to the farmer at a reasonable price, are likely to prove more cost-effective so long as they are properly applied and judiciously recommended. Recommendations for widespread use, without regard to the particular storage objectives of individual farmers, are unlikely to be generally adopted.

A need for improved grain stores, modeled on larger-scale bulk storage bins suited to more sophisticated management, is a popular idea that should be treated with considerable caution. There are examples of such developments that have proved successful but a great many more have failed because the real needs and management capabilities of small-scale farmers have not been perceived.

2.10.2 Improvements in large-scale storage

The advantages and disadvantages of bulk storage, with particular reference to its use in the humid tropics, need considerations. The choice amongst the technical options to develop cost-effective packages of measures for well-integrated pest control cannot be made without reference to particular situations. It is the storage management objectives, together with the technical and financial constraints, that must be identified and analyzed in each case. However, it is of interest that recent decades have seen a marked swing towards the use of physical barriers against re-infestation in combination with improved conventional fumigation or the introduction of controlled atmosphere storage techniques [25].

The attainment of fully integrated pest management in large-scale storage will depend largely upon the development and adoption of improved pest-monitoring procedures, with increased capability for measuring pest population levels as a parameter of grain damage and quality loss, so as to ensure as far as possible the most cost-effective timing of pest control actions. Here again, in developing countries, recent advances in this direction have been particularly concerned with milled rice storage [26].

Increased attention to the monitoring of re-infestation pressure is noted as a requirement for the more cost-effective use of admixed insecticidal protectants [27]. It is recommended here also that judicious use of grain cooling techniques to achieve a net enhancement of insecticidal efficacy in such treatments. Even for those insecticides which show a positive correlation between temperature and toxicity to insects the increase in chemical persistence, at lower temperature, outweighed the reduction in toxicity.

These several lines of research exemplify the possible refinements of established insect control procedures that are required for improved storage pest management. Such approaches are likely to prove more beneficial than attempts to devise complex packages of control measures, including as many as possible of the various available options, with the mistaken idea that IPM necessarily calls for such complexity.

2.11 General precautionary measures for safe storage

- Maintain high standard of cleanliness.
- The grains to be stored should be sound, healthy and free of trash.
- Store house should be at such a place where grain remains safe from insect pests, rats and humidity changes that favors more moisture.
- The proper ventilation for air crossing should be maintained in store houses.
- The seed must be dried before storage in the store houses must be kept dry and well aerated (it means the seed and storage area should be kept dry) before use.
- The moisture content of seed should be minimized up to 8-12% or below, for safe storage purposes.
- The storage area should be safe from rain.
- Pest control must be ensured at adequate level in the storage area.
- Use rodent and bird proof stores having controlled ventilation, leakage free floors, doors and windows.
- The old bags must be avoided and new ones should be dried before use.
- If old gunny bags, cloth bags and containers are required to be used to store seed, the same should be fumigated.
- The fumigation in storehouses needs air tight arrangements.
- The wheat grains stored in bins and bags should be added with neem leaves as natural repellant, which must be dried first under shade before use.
- The storage area should not be heat trap. The temperature should be low if necessary to keep the storage as cool as possible.
- The periodical inspection of the grain should be carried out and control measures must be taken to minimize losses.
- The measures for keeping in and taking out grain, easy access and inspection of grain in the store houses and control over incidence of fire should be properly managed.

3. Summary and Conclusion

Nothing can be done to improve grain quality once it is lost so it's important to maintain the quality possessed when ready to be stored. The two biggest factors affecting grain quality are mold and insects. The two most important management practices are: Managing moisture content and managing grain temperature. It is therefore critical to carefully manage stored grain to prevent its deterioration and possible serious economic loss. This management should include:

A well-designed and properly-operated storage system with adequate aeration capacity, storing only clean grain at the proper moisture content and temperature, checking the grain condition regularly and correcting problems before they get out of hand. Since deterioration of stored grains results from the interactions among the physical, chemical and biological variables existing in the system, it is important to understand the inter-relations and interactions of these variables in order to design an effective control and management of these factors for safe storage. Focus should also be given to storage through cost-effective and sustainable improvement of the traditional systems and the introduction of alternative sustainable and cost effective systems.

4. Recommendations

- Use of an integrated management, monitoring, and precautionary measures of the stored grain throughout the storage period.
- Selection and promotion of alternative, cost-effective / appropriate storage structures considering suitability to local conditions, cost and sustainability.

5. Scope of Future Work

- Assessing and testing grain quality deterioration causes of the existing traditional storage systems and filling the gaps along with the overall improvement and promotion of the improved storage systems.
- Determining safe moisture limit for storing teff grain, a cereal grain indigenous to Ethiopia
- Assessing the existing traditional management practices of stored grain so as to take corrective measures

Acknowledgements

The author would like to thank Professor Geremew Bultosa for his advice and information during the preparation of this review paper. My gratitude goes to Dr. Solomon Abera (Dr. Eng) for his constructive information and material support. I am also very thankful to Mr. Abdulahi Umer who provided me with useful information.

References

[1] Dereje, A. ‘’The Utilization and Conditions of Postharvest Concept in Ethiopia’’. In *EARO. Postharvest Food Preparation and Storage, and Research and Extension on Agricultural by-products Utilization Technologies*, Amharic Version, Ethiopia, 2000.

[2] Abebe, H.G and Bekele, H. ‘’*Farmers' post-harvest grain management choices under liquidity constraints and impending risks: Implications for achieving food security objectives in Ethiopia*’’. Poster paper prepared for presentation at international association of Agricultural Economists conference, Gold coast, Australia August 12-8, 2006.

[3] Turner, P. C. *Reduction in exposure to carcinogenetic aflatoxins by post-harvest interventions in west-Africa: a community-based intervention study*. Lancet, 2005.

[4] Kemeru, D. ‘’*Farm Level Survey on Farm Tools and Implements in Jimma and Iluababor Zones. Agricultural mechanization for productivity and sustainable use of the natural resource*’’. Proceedings of the first agricultural mechanization post harvest and food science research completed research forum, 5-7 June 2007, Addis Ababa, Ethiopia. Pp 171-180.

[5] Mashila, D. ''*Grain Storage Methods and Their Effects on Sorghum Grain Quality in Hararghe, Ethiopia*''. Doctoral Thesis. Swedish University of Agricultural Sciences, Uppsala, 2004.

[6] Chemeda, A, Abush, T, Zekarias, S, and Habte J. ''Survey on farmers' perceptions and management practices of insect pests on traditionally stored sorghum in southwestern Ethiopia''. *Crop Protection*, 26, 1817-1825, 2007.

[7] Hodgson, R. J. *The Southern Sidamo Rangelands Project 1985-1988: Perspectives on Development Interventions and Extension*.Unpublished monograph, 1990.

[8] Ken, B. *Grain storage basic design principles*. Toowoomba, DPI & F Client Service Center, 2005.

[9] Tilahun, S. ''Grain based Ethiopian traditional common foods processing science and technology''. In *Training module for center of research on grain quality, processing and technology transfer,* Haramaya University, Ethiopia, 2007.

[10] David, P.S and David, D.J. *Management - The key to maintaining stored grain quality*. http://lancaster.unl.edu/ag/crops/inservice-i98.html, Jun 10, 1998 [Jan 18, 2010].

[11] Fekadu, L. ''Fundamentals science and technology of food grain drying, cleaning and storage practices''. *In Training module for center of research on grain quality, processing and technology transfer,* Haramaya University, Ethiopia, 2007.

[12] Ryniecki, A. (2006). Drying and Cooling Grain in Bulk: Handbook. (Vol 1). [On-line]. 1. Available: http://books.google.com.et/books?id=gPjWPgAACAAJ [Sept 06, 2014].

[13] Gough, M.C. and McFarlane, J. A. Aeration of stored grains: some psychrometric considerations. *Tropical Stored Products Information*, 50, 32-35, 1984.

[14] Christensen, C.M. *Storage of cereal grains and their products*. American Association of Cereal Chemists Inc., St Paul, Minnesota, USA, 3rd edition, 544 pp, 1982.

[15] Anon. *On-farm maize drying and storage in the humid tropics*. Rome, FAO Agricultural Services Bulletin , 9 (40), 60 pp, 1984.

[16] Kamari, A and Yon, R.M. ''Temporary storage of wet paddy. Pp 114-118'' in: *Grain Quality Improvement, Proceedings of the 3rd Annual Workshop on Grains Postharvest Technology*, Kuala Lumpur, Malaysia, 29-31 January, 1980.

[17] Hyde, M.B, Baker, A.A, Ross, A.C and Lopez, C. O. *Air tight grain storage*. Rome , FAO Agricultural Services Bulletin, 5 (17), 71 pp, 1973.

[18] Calderon, M., Donahaye, E., Navarro, S. and Davis, R. ‘’Wheat storage in a semidesert region’’. *Tropical Science*, 29, 9 l - 11 0, 1989.

[19] Dermott, T. and Evans, D.E. ‘’An evaluation of fluidized-bed heating as a means of disinfesting wheat’’. *Journal of Stored Products Research*, 14, 1-12, 1978.

[20] McFarlane, J.A. *Guidelines for pest management research to reduce stored food losses caused by insects and mites*. Overseas Development Natural Resources Institute Bulletin, 98 (22), 62pp, 1989.

[21] Joffe, A. ‘’The effect of physical disturbance or 'turning' of stored maize on the development of insect infestation’’. *South African Journal of Agricultural Science*, 6(1), 5564, 1963.

[22] Golob, P. ‘’Improvements in maize storage for the small-holder farmer’’. *Tropical Stored Products Information*, (50), 14-19, 1984.

[23] Makanjuola, W.A. ‘’Evaluation of extracts of neem (Azadirachta indica A. Juss) for the control of some stored product pests’’. *Journal of Stored Product Research*, 25(4), 231-237, 1989.

[24] Dobie, P. ‘’The use of resistant varieties. II. Integrated control: the role of biological methods’’ In: Biological methods for integrated control of insects and mites in tropical stored products; ed. J. A. McFarlane. *Tropical Stored Products Information*, 48, 4-8 and 37-45, 1984.

[25] Annis, P.C, Banks, H.J and Sukardi. *Insect control in stacks of bagged milled rice using carbon dioxide treatment and an experimental PVC-membrane enclosure*. CSIRO Australia, Division of Entomology Technical Paper, 22, 1-38, 1984.

[26] Haines, C.P, Rees, D, Ryder, K, Sistyanto, S and Cahyana, Y. ‘’Brown-rice bait bags for monitoring insect pest populations in bag stacks of milled rice as an aid to pest control decision-making’’ In: Proceedings of the Fifth International Working Conference on Stored Product Protection, Bordeaux, France, September 9-14, pp 1351-1358, 1990.

[27] Desmarchelier, J.M. ‘’Selective treatments, including combinations of pyrethroid and organophosphorus insecticides, for control of stored product Coleoptera at two temperatures’’. *Journal of Stored Product Research,* 13(3), 129-137, 1977.