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Traditional methods of food grains preservation and storage in Nigeria and India

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ABSTRACT

Efficient post-harvest handling storage can tremendously contribute to socio-economic empowerment in developing nations. Farmers use traditional storage containers for storing food grains for their own need. These storage structures are comparatively cheap, eco-friendly and impart high shelf life to the stored commodities. These traditional storage systems could be applied in modern storage areas with minor modification, could save food commodities that would be damaged by insects. Although chemical methods of management of stored produce pests are highly successful, they leave behind toxic residues. The traditional wisdom and methods of storage can protect commodities from insect infestation for substantially longer periods.

1. Introduction

Cereals and legumes generally known as grains constitute the most vital diet component for the majority of people in the world (Duranti, 2006; Rajashekar et al., 2016) providing the calories and proteins consumed by the resource-poor and provide the rural folks with employment and sustainable source of income. Food grains are the most commonly stored durable food commodities in the tropic and subtropics usually stored to provide food and feed reserves as well as seed for planting. The major grain crops cultivated in tropics and subtropical nations are maize, rice, wheat, sorghum, cowpea, soybean, pigeon pea, kidney bean, mung bean, black gram, and lentil (Asif et al., 2013). According to Biam and Okorie (2012), Nigeria produces 1.09% and 2.85% of world production of cereals and legumes respectively. In India, food grain production is by far the major agricultural activity with 80% of arable land put into its cultivation.

Postharvest losses are a major cause of concern worldwide where below 5% research funding has been allocated (Rajashekar et al., 2012). The food problem in Nigeria and India is largely due to the inability to preserve food surpluses during the short harvest periods rather than to low production. Grain production plays minimal role in the economies of developed and developing nations because agricultural production is seasonal while the demands for agricultural commodities are more evenly spread throughout the year (Rajashekar et al., 2014; Swinnen and Maertens, 2007). In this circumstance, there is a need to meet average demand by storing excess supply during the harvesting season for gradual release to the market during the off-season period. For regular availability of agricultural outputs or stabilizing the economy of any country, it is required that quality food grains must be supplied to the consumers for making different products and marketing, as well as to the farmers for sowing and growing healthy grains (Wright and Cafiero, 2011). In order to satisfy the demand for a plentiful supply of cereals and legumes, grains must be stored throughout the year.

A substantial amount of food grains is being damaged after harvest due to lack of adequate storage and processing facilities. Moreover, significant agricultural production could be impacted due to variations in periodicity and intensity of climatic events like floods and droughts, temperature and rainfall patterns (Arun et al., 2017). FAO estimates of worldwide annual losses in stored produce have been given as 10% of all stored grain (Parfitt et al., 2010). In Sub-Saharan Africa, 25–40% of food grain losses occur during storage at the farm level. Rajashekar et al. (2012) stated that, post-harvest losses in India were 12 to 16 million metric tons of food grains per year, an amount that the World Bank stipulates could feed one-third of poor Indians. In India, the estimated post-harvest losses account for 9.5% of total pulses production. Among the post-harvest operations, storage is responsible for the maximum loss (7.5%). Among storage losses, pulses are most susceptible to damage due to insects (5%) compared to wheat (2.5%), Paddy

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(2%) and maize (3.5%) (Deshpande and Singh, 2001). This generally results from inadequate post-harvest management practices and imperfectly designed storage structure.

Post-harvest facilities or appropriate storage technology has been the major problem of India and Nigeria and other developing nations for a long time. This has resulted in a considerable waste of agricultural output and hence considerable loss to the economy. The average proportion of food grains retained by farmers for their own (not for sale) is usually assumed to be 60–70% in indigenous storage structures (Kanwar and Sharma, 2003). Farmers usually keep such food grains in storage structures mainly for household consumption. The surplus grains, on the other hand, may be sold within two or three months of harvest. After harvest, the grains may be stored temporarily in bulk or in bags for a month or two before being transferred to a structure. It is observed that different localities in Nigeria and India have peculiar storage methods depending on the types of crop grown and farmers attain a varying degree of success in applying the basic principles involved in the safe storage of food grains.

Storage practices differ and there are small or big storehouses, indoor or outdoor, temporary or permanent and individual or community storage design. These structures have open storage system, semi-open storage system and closed storage system (Gwinner et al., 1990). These traditional approaches have been used for many years with little or no modification and are successful because of the application of scientific values, though accidentally. The choice of a traditional storage system is often relevant to climate, but regional natural resources and customs also influence the choice of the storage methods (Hall, 1970).

Traditional methods of storage are a type of knowledge, which has evolved into the community and has been passed on from one generation to another generation (Natarajan and Santha, 2006). Certain traditional methods of grains storage practices are unique to the culture of society and vary among countries, villages, locals and even communities. These indigenous practices originate from the cultural connection with specific environmental conditions and are based on traditional societies having intimate consciousness of their environment. It is estimated that 60–70% of food grains produced in developing nations are stored at home level in traditional structures either in threshed or unthreshed forms. In order to reduce the losses incurred after harvesting, farmers take measures such as sufficiently drying maize before storage, using storage structures which are moisture proof and are adequately aired (Nduku et al., 2013). Most of the structures are constructed at the beginning of the harvesting season and harvesting time varies with the agro-climatologically zones. In Nigeria, the prominent structures found in the three different climatic zones are; granaries, mud rhombus, thatched rhombus, platforms, cribs, earthen pots or baskets, domestic or indoor storage such as plastic containers, gourds, earthen pots and metal containers. Other storage structures include bags, which could be made of jute, hessian, polyethylene or plant fiber. In addition to the use of traditional storage structures, farmers use other coping strategies aimed at reducing these postharvest losses such as the use of traditional knowledge. These include the use of herbs such as the Mexican marigold and hot pepper in storage, selling grain soon after the harvest and cleaning or dusting the storage structure with pesticide thoroughly before depositing the maize or by acquiring the new maize storage technologies.

The fundamental requirements of every grain storage methods or structures are to secure the grains from insect, rodents and prevent spoilage of the grains by the activities of the microorganisms (Hall, 1970). It is also essential to keep the grains cools and dry during storage. The various natural resources associated with the adoption of synthetic insecticides have necessitated the search for safe and affordable storage structures, which do not have an adverse effect on secondary consumables and the environment. Therefore, this review was conducted to re-examine the various traditional storage practices adopted by resource-poor farmers in Nigeria and India to store food grains product in order to maintain food security.

2. Purpose of food grains storage

Food grain storage plays a crucial role in the economies of developed and developing countries. Quality food grains must be supplied to the consumers for making different products and marketing, as well as to the farmers for sowing and growing healthy cereals and pulse grains. These required regular availabilities of agricultural outputs which will stabilize the economy of any country. In order to satisfy the demand for a plentiful supply, the grains must be stored throughout the year and gradually released to the market during off-season periods, which also stabilizes seasonal prices (Adejumo and Raji, 2007; Ellis et al., 1992). The traditional methods of grains storage and preservation date back to since time immemorial which were developed in the communities and passed on from generation to generation (Natarajan and Santha, 2006). One fourth of developing countries, farmers keep their products at the village level. The traditional storage system is considered to be effective or give satisfaction in which they continue improving so as to sustain grains from damage. The percentage of total food crop yield retained at the farm-level and the period of storage is largely a function of farm size and yield per acre, marketing pattern, consumption pattern, form of labor payment, credit availability and future crop expectations. Grains can be stored indoors, outdoor or at the underground level in structures ranging from those of mud to modern bins. The storage containers are built from a variety of locally available materials differing in design, shape, size, and functions (Channal et al., 2004; Kanwar and Sharma, 2003).

3. Traditional grains storage practices and methods

3.1. Solarization

The process of heating grain in the sun to kill insects is called solarization. It is an old age practice by farmers before storing the grains and pulses in regions where the outdoor temperature reaches 20 °C or higher (Chua and Chou, 2003). The solarisation time is varied based on the products, the dried grains are chewed to determine whether the grains are dried to satisfactory level. It also normally applies to grain being kept for food rather than for seed as it may reduce seed viability. The stored grains have been sun-dried by the farmers involves spreading the food grains on the bare grounds, on spread polythene or on tarpaulin, bamboo mat, roadsides or on rooftops to reduce the moisture content and killed most infestive agents (Fig. 1). If the grain is placed in an insect-proof container, then it will remain free of infestation (Ofor, 2011). Kiruba et al. (2008) found that exposure to the sun (in different colored polyethylene bags) for 24 h killed *Callosobruchus*

Fig. 1. Solarisation.

chinensis eggs and grubs found in infested green gram and complete egg mortality was recorded in colored bags and complete grub mortality in black colored bags.

3.2. Open fire place

In most rural farming communities, the majority of the farmers stored food grains near the kitchen where the heat and smoke of burning firewood penetrate to keep the food grains free from insect pest infestation (Sarangi et al., 2009). In the instance where large quantities are required to be stored, specially raised barns are constructed; a slow burning fire is lit and hot air is controlled to allow grains to remain dry (De Lima, 1982; Sarangi et al., 2009). While smallholder farmers usually store food grain crops above the kitchen fire in the farm hut or in open where the high temperature due to direct solar radiation may also kill the developing larvae in the seeds.

3.3. Open air/aerial storage

Unshelled maize cobs and other unthreshed cereals are suspended in bunches or sheaves, using rope or plant material, under eaves, from the branches of trees or the top poles driven into the ground (Ofor, 2011). The grain dries in the air and the sun until it is needed by the farmer for consumption or marketing. When the grains are stored in the open air, the farmers always ensure to protect the grains being from rainfall by covering with polyethene. The disadvantage of open-air storage is that the grain is exposed to the environment and pests.

The farmers do also hold the unthreshed food grains tied in more hands under cross ventilated shade away from rainfall. The unthreshed cereals grains are commonly stored under the roof of dwellings, hanging from the roof timbers or spread out on a grid in the ceiling where high temperature due to direct solar radiation heats up the grains to reduce the moisture content and may also kill the developing larvae in the seeds thus preventing insect infestation.

3.4. Storage with diatomitzed earth

Diatomitzed earth (DE) is a dust formed from fossilized diatoms; consisting of entirely amorphous silicon in which the particle size ranges from 3 μm to more than 1 mm. DE is used as a natural insecticide for the protection of stored agricultural products. The most susceptible stored grain insects to least against DE are *Cryptolestes ferrugineus*, *Oryzaephilus surinamensis*, *Sitophilus oryzae*, *Sitophilus granarius*, *Ryzoperthe dominica*, *Tribolium castaneum*, and *Prostephanus truncates*. The particles of Diatomaceous adheres to the insect body, damage the insect cuticle by hydrocarbon absorption and to a lesser degree by abrasion resulting is the death of the insects due to dehydration (Korunic, 2013).

3.5. Gourds

Gourds are made from the hard dried outer skins of fruits from the members of squash or Cucurbitaceae family generally found in tropics and subtropics (Wehner and Maynard, 2003). Gourds are used for storing small quantities of food grains (5–30 kg) required for home consumption or planting for a duration of six months to one year (Bodholt and Diop, 1987; Proctor, 1994). Gourds are normally kept indoor or under shelter and above the kitchen or places where they are not prone to insect infestation. Gourds used for grains storage are treated with varnish, paint or linseed oil and once the grains are poured in, the lid is covered mud or cow dung to make an airtight storage condition (Fig. 2). Gourds are placed on a platform to save the grains from moisture absorption. The benefit of using gourd is that it's economical, stores grain much better than unlined pits and it's easy for farmers for checking for insect's infestation (Makalle, 2012).

Fig. 2. Gourds.

3.6. Palmyra leaf (Broassus labellifer L.) bin

B. labellifer leaves are double woven in a shape of the cylindrical basket for more durable grains storage and are closely superimposed preventing the entry of insects. Palmyra leaf bin is designed to meet the storage needs of individual farmer's household and used for a short-term grain storage ranging from 500 kg–10 kg. The normal size of the bin is 2.5–3 m height, 1 m width, and 2 m length, and the dimensions of the small sized bins are 0.5 m height, 0.25 m length, and 0.25 m width. The dried Palmyra leaves used for making this storage system are seasoned to make them hard enough to resist the bite of mandibulate insects and insect larvae that may hatch out from the eggs laid on the external surface. The bin has a top cover or lid made of the same material; optionally before grains are placed in the bins, leaves of the plant such as *Psidium guajava*, *Vitex negundo* etc., are used as inner lining of the bin (Kiruba et al., 2006). These plant leaves has been reported to possess insecticidal activity.

3.7. Crib

The Crib is an improvement on platform structure, which is a rectangular shaped enclosed structure elevated between 0.5 and 1 m above ground, supported on columns and has well-ventilated sides made of straw, palm leaves, bamboo or wire netting (Fig. 3). The entire storage structure could be constructed with wood, bamboo, metal or wire mesh and roofed with thatch straw or iron sheet and faced in such a way that the prevailing winds blow perpendicular to the length. The legs are fitted with rat-proof device to prevent rodent infestation. The Crib is designed in such a shape that the drying process continues during storage because of the free flow of air over the stored produce due to natural ventilation. Traditionally, the crib was used for unthreshed maize cobs storage but presently its use has been extended to include virtually many other crops. This type of storage unit is easy and cheap to make, but offers very little protection against insect pest and storage losses due to insects and rodents are often as high as 40%. Maize varieties with husk are protected reasonably well for 3–6 months without the use of insecticides (Mijinyawa, 2002).

3.8. Straw bin

Paddy straw is used for building this type of storage structure. It is dried properly, specially prepared, kept straight and the dried straw is woven to form rope concentrically arranged over a large area with the bark of *Erythrina indica* and *E. variegate* placed along with the straw. For grains to be stored in this structure, they are mixed with sifted ash

Fig. 3. Cribs (adapted from USAID, 2011).

before being placed in the straw bin, thereafter the straw ropes are folded over the grains. This storage structure is usually suspended from the roof rafters (Jain et al., 2004). This type of design is used because of being inexpensive and easy management through locally available materials and low-temperature variation keeping the grain cool. Seed viability of grains stored in the straw bin can last for two years.

3.9. Nahu

Nahu is a traditional storage structure commonly used by the resource-poor farmers in the West Siang district of Arunachal Pradesh, India for the storage of food grains such as rice, maize, millet, etc. The storage capacity of Nahu ranges from 5.0–8.0 t and can hold 0.20–0.24 t/nahu for seed purpose and the structure lasts for 20 years. These storage structures are constructed close to residential areas in the village, and in the cluster apart to avoid a fire outbreak. The structure in appearance looks like a crib but is divided vertically into 3 compartments; the lowest compartment for firewood, middle compartment remains empty, while the grains are stored after thoroughly drying by making airtight compartments at the top, made up of bamboo mats and *Livistona jenkensiana* leaves. Finely woven bamboo mats are tightly set on the ground and the walls to create an airtight compartment for storing of grains. After the grains are added to the store, it is covered tightly with a bamboo mat by keeping stones over it, so that there is no space left for rodent entry. *L. jenkensiana* used for roofing are changed every 5 years (Sarangi et al., 2009).

3.10. Metal or plastic drums

Plastic or metal used for the organic solvents, petroleum products, vegetable or palm oil storage and transportation or water storage tanks are other materials used to provide hermetic storage of food grains in both countries after thorough washing in case the new one is not being used. Grains meant for storage are first sun dried to reduce the moisture content to 12% or less, thereafter the drums are filled with the grains (threshed or unthreshed) and sealed with the grease screw cap for easy opening later. The filled drums are kept on a pallet under shade insulated with a layer of straw or in a storehouse away from direct solar radiation to avoid the grains from becoming caked due to the moisture change and heating of the stored grains. If the drums are closed air tight, the grains can be stored for a year or more without using insecticides. One major disadvantage of grain storage in a drum is that the drum must remain sealed for it to be effective because the insect is prone to resume physiological activity at the slightest inlet of oxygen when opened indiscriminately (Hall, 1980; Murdock et al., 1997; Makalle, 2012).

3.11. Earthen bins/pots

Farmers across; have used the various agroecological zones of India and Nigeria used earthen bins/pots made of burnt clay mixed with or without straw as the binding material to provide strength for storing threshed food grains such as cowpea, maize sorghum, paddy, black gram and millet ranging from 5 to 1500 kg for short to long duration of time (Bodholt and Diop, 1987). These storage structures differ in shape and sizes depending upon locality; it has a unique shape with a smaller base and a broader top with a constricted mouth for grain pouring. Grains to be stored in bin or pot are generally sun-dried to 12% or less moisture content and filled into the bin/pot and placed on a concrete platform or pallet so that the stored grains do not absorb moisture (Gupta, 2013; Gwinner et al., 1990). The mouth is covered by an earthen plate that fits into the opening and the lid is sealed with mud. It is a common practice among some rural farmers to top up the bin or pot with dried leaves of *Pongamia pinnata* and *Azadirachta indica* (Adejumo and Raji, 2007; Dhaliwal and Singh, 2010; Jeeva et al., 2006; Kiruba et al., 2006, 2008). The grains stored in these structure are mostly used for planting. The majority of the farmers used earthen bins because of their low cost and easy construction through locally available materials followed by low-temperature variation that keeps the grains cool, easy to fill and discharge of grain and can be airtight to control insect (Chattha et al., 2013).

3.12. Bamboo bin

The Bamboo bins are made from bamboo splits, straw, raffia palm/palm fronds closely intertwined or wooden planks to form a narrow opening at the top in the conical shape similar to the pyramid in a structure erected in any open space (Fig. 4). The base on which the structure is erected is made up of bricks or stones 2–3 ft above the ground level. Straw and thatch are fixed on the wooden skeleton using ropes. The top of the structure is covered with ginger grass (*Cymbopogon* spp.) straw mat and thatch to prevent rainwater from damaging the structure and stored grains. The structure is plastered with mud or clay to make it somewhat air tight and provide an impervious coating that will deny even small insect pests access to the stored grains; the exterior can also be fortified with cow dung (Kiruba et al., 2006). The underlying principle of grains storage in this structure is that the ginger grass used in the top cover has insect deterrent action which prevents insects from settling down on the structure and the sterilizing effect of UV in solar radiation (Saravanan, 2010). The Bamboo bin storage structure is commonly used by farmers in the northern parts of Nigeria and Southern parts of India.

3.13. Storage bags

Short duration storage of food grains in sacks is widely used in farms, villages and commercial storage centers. Sacks made of woven jute, sisal, local grass, cotton and depend on the materials that are available in the area. These were earlier used widely in both Nigeria and India until the introduction of the polypropylene bags, however; farmers still use jute or sisal bags. They usually come in different sizes ranging from 25 kg bags to 100 kg bags. Polyethylene storage bags create a highly efficient, hermetic storage environment for all crops. Polyethylene bag is placed inside ordinary storage bags for an additional layer of protection to form multi-layer polyethylene storage bags to ensure water resistant and completely air tight storage condition (Mutungi et al., 2015; Ng'ang'a et al., 2016).

Fig. 4. Bamboo bin (based on Kiruba et al., 2006).

Storage of grains in sacks has some advantages for small-scale farmers; bags of grains may be piled under any convenient shelter away from weather and predators. Bags can be transported and handled without special equipment; above all these sacks allow for gaseous exchange and insect control using fumigants in a closed storehouse or underneath a plastic sheet covering the sack is made possible (Hall, 1980). Farmers stack the sacks on pallets or platforms raised off the floor; this keeps stacked grain from absorbing moisture from the floor. The raised platform is better than plastic because it allows air to flow under the sacked grains (David, 1998).

3.14. Earthen pot-pile

Earthen pot-pile is a variant of earthen bin/pot made from clay and is used for storage of small quantities of threshed food grains ranging from 10 to 50 kg depending on the capacity of the pots (Fuseini, 2003; Ofor, 2011). The earthen pot-pile structure is cylindrical in shape and made up of different sizes or capacities usually arranged over one another at the corner region of the house. The pots fit exactly one over another in such a way there is no gap left to allow for insect gaining entry into the stored grains, with the smallest being at the top, covered by an earthen lid sealed with thick cloth, mud or clay and cow dung to ensure proper alignment into the opening (Boxall and Gillett, 1984; Kiruba et al., 2006; Oakley and Momsen, 2007). Food grains to be stored are first sun-dried and properly cleaned before being been stored in the different pots (Fig. 5). In some cases, grains stored in earthen pots are mixed with crushed *Azadirachta indica* leaves or crushed dry capsicum pepper fruits to ensure they are preserved for the next season and for the market (Ofor, 2011). Meanwhile, before grain storage, circular ring-like structures made of straw, dried banana leaves or rags are placed on the floor and the pots filled grains are placed above those rings. The reason for doing this is to prevent the pots from absorbing moisture from the floor. The use of pots for food grains storage cut

Fig. 5. Earthen pot.

across the different ethnic backgrounds in the various agroecological zones of Nigeria and India and can help against storage pest infestation for up to 6 months and thereafter the grains needs to be sun dried again and restored in the pots.

3.15. Storage with table salt

Rural farmers in developing nations utilized table salt for the short term duration storage of *Cajanus cajan* and *Phaseolus vulgaris* for 6–8 months. About 200 g of table salt is thoroughly mixed with 1 kg of *C. cajan* and *P. vulgaris* and sealed in jute bags. The underlying principle of this practice is that due to the abrasive action of the salt which prevents insect movement inside the storage container, insect infestation and population build-up is suppressed (Jeeva et al., 2006).

3.16. Platform storage

The Traditional raised platform is used for stored grains to reduce moisture, larvae killing, and to discourage insects or other pests. It is built in the open space with strong or hard-forked sticks about 1 m high, crossed with split bamboo and other hard sticks. In some instances, straw mats, bamboo mats or raffia mats are spread on the platform. The legs of the raised platform are shielded with rodent proof. There are two types of the raised platform: open raised platform and shaded platform. The unthreshed food grains are sometimes spread evenly or heaped on the platform and this also allows air to pass over the grain and help it dry better. The high temperature due to direct solar radiation continually heat up the grains which reduce the moisture content and may also kill the developing larvae in the seeds thus prevents insect infestation. In some places, fires may be lit under upright platforms, to reduce the moisture content of the produce and discourage insects or other pests under humid condition. While in use, the farmer covers the stored grains with polythene, tarpaulin or mats at sunset against moisture in form of rainfall or dew. Under this storage method, shading, ventilation, and regular inspection are essential. Open platform storage is discontinued when the rainy season begins (FAO, 1998; David, 1998;

Fig. 6. Underground pit (based on Gronenborn, 1997).

Fig. 7. Mud house.

Ofor, 2011).

3.17. Use of camphor

Camphor is used for short-term storage of grains required for next season planting. The shelled grains or paddy are stored in bags or pots after being sun-dried and camphor is placed inside the storage bags or container. The mode of action of camphor used in such grains storage could be either fumigant, repellent or antifeedant attributed to pungent odor emanating from the camphor (Karthikeyan et al., 2009a).

3.18. Underground pit

Underground grain storage is carried out by farmers in an agro-ecological zone with low water table for long duration storage of large quantities of threshed grains such as cowpea, millet, and sorghum ranging from 1000 kg to 200 tons (Fig. 6). The underground pit is dug between 1–3 m deep and 1–3 m diameter in a round or square form and insulated or lined with the straw mat or corn husk (Gilman and Boxall, 1974). Storage pits may be of two different types. Firstly, the distinguished: bell-shaped ones with a pronounced storage chamber and a small entrance. Secondly, cylindrical ones with a wide opening and walls supported with mats. Bell-shaped storage pits are constructed outside of villages on clay soils. Such types of pits can be traced back to the beginning of farming in the area (Gronenborn, 1997).

Before filling, the sides and bottom are packed with straw and husk; threshed grains are filled with bags and loaded into the pit and after loading, wooden planks are placed to cover the pit and thereafter covered with polyethylene or iron sheet. Then a layer of husk and heap of sand are used to conceal the pit or by a stone sealed with mud or by placing thorns around the pit as a protection from animals. Grains stored in this structure are protected against insect infestation due to reduced oxygen level; because of the pit depth it keeps the grain cool and storage duration could be between 1 and 5 years without opening and usually once opened; all the stored grains must be emptied. Main advantages of underground pits are the high efficiency of protection against insects, fire, mites, and theft, furthermore low construction and operational costs (Bodholt and Diop, 1987). However, main disadvantages are: increased moisture content of the grain with time of storage, that leads to mould damage, lower grain quality and reduction of viability and some nutritional value (Bakheit, 1997); operational difficulties such as manual work for filling and emptying the pits and rainwater damage occurring to the pit cap and its immediate environment (Abdalla et al., 1998).

3.19. Mud house storage

Mud houses are used to store large quantities of food grains from 1000 kg to 2500 kg or above. The size depends on the farmer needs, but an average size dimension is 4 m × 4 m × 3 m to give a storage capacity of 2500 kg (Fig. 7). Mud houses are made up of either mud alone or the walls are made of mud mixed with paddy straw and plastered over the bamboo splitted framework and the top is covered with tin roof. The entire structure along with the covered wooden planks is coated with clay and cow dung, allowed to dry and thereafter lime-washed (Karthikeyan et al., 2009b; Kiruba et al., 2006).

3.20. Silo

Silo is usually used for storing threshed food grains and paddy in most countries due to its long lifespan and insects and pest resistance. There are different types of silo: metal, mud, concrete, and plastic, though none has proved to be absolutely satisfactory as a constructional material over others (Adejumo, 2013; Mijinyawa, 1999). Storage time in silo varies between 6 months to a couple of few years and storage capacities also varies with the size of the silo, sometime between 0.5 to several million of metric tons (Omobowale et al., 2015). The silo should be placed on a foundation consisting of a loose coarse gravel embankment, resting on the ground level, in the way; it is insulated from moisture meteoric water (Barbari et al., 2014).

3.21. Mud silo

Mud silo is used for short duration food grains storage. The structure is spherical in shape and normally built of three or four stones that serve as a base. The carrying capacity of the structure is between 1 and

Fig. 8. Typical Mud silo with corrugated roof (based on Jujufilms, 2014).

4 tons. It is normally constructed from termite mound soil or clay soil (Fig. 8). The mud silo needs protection against rain. A simple and inexpensive method of protection is to construct a thatch cone in the shape of an inverted "V" and put it on the silo. If the cone hangs over and down, it will also protect against the sun's rays, also the mud silo exterior could be plastered with cow dung or slightly with cement (David, 1998).

3.22. Thatch silo

This is a cylindrical structure built on stones of about 0.5 m above the ground. The structure is cladded with straw mats woven from grass or palm leaves and sticks as reinforcement. It is usually about 2 m high with the carrying capacity depending on the size and crop to be stored. Apart from cowpea grains, this structure can also be used to preserve unshelled maize, unthreshed sorghum and groundnut pods (Fuseini, 2003).

3.23. Metal silo

Metal silos made from galvanized iron and recycled oil drums have emerged as efficient and low-cost storage containers for long-term storage of cereal grains and pulses in a water resistant and hermetic condition. Food grains stored in the metal silo are inaccessible by rodents, efficient against insects, sealed against entry of water, therefore, metal silos are excellent grain storage containers. However, they should be guarded against direct sunshine and other sources of heat to avoid condensation, they should be located in shaded and well-ventilated places (Adejumo, 2013).

3.24. Plastic silo

Plastic PVC water storage tank is also being used for food grain storage in most developing nation with some minor adjustments to provide an effective hermetic storage environment. The tanks come in different size and shapes. Plastic containers dedicated as a silo for grains storage are kept under shade or indoors, away from direct solar radiation on a raised platform above ground level to allow for an easy discharge of the stored grains (Ochandio et al., 2010).

Fig. 9. Bamboo house.

3.25. Bamboo house

Bamboo house is a variant of mud house and made up of bamboo splits joined by carpentry work. It is used for storing large quantities of food grains. The walls made up of bamboo splits are closely fitted with no gap existing between the bamboo frameworks (Fig. 9). The walls can be coated with cow dung or sprinkled with cow urine to prevent insects and rodents from gaining entry to the product stored therein. The house can be constructed in rectangular or square shape with 4 m × 4 m × 3 m dimension to give a storage capacity of 1000 kg or above and the top is covered with tin roof. After loading with grains, locally available medicinal plants with insecticidal properties such as *Artemisia vulgaris*, dried chilli, etc., are placed on the corner to prevent insect infestations (Karthikeyan et al., 2009b).

3.26. Mud rhombus

Mud rhombus is cylindrical, spherical or circular-shaped storage bin built from a mixture of dried straw and mud or clay resting on large stones covered with a thatched roof for storage of food grains between 2 and 5 years or more (Fig. 10). Loading of grain into the storage structure is through the roof, the thatched roof is removed and the unthreshed millet and sorghum tied in bundles with ropes are stacked in the rhombus (Mahai et al., 2015). Minimum of four men are required to manually load the grains depending on the size and height of the rhombus. The first person stays on the ground, loosens the bundles and passes it to the second person who is on top of the bin or on a ladder. The third person is inside the structure or on another ladder inside the rhombus collects the grains heads and the fourth person arranges it in the rhombus. To offload the stored grains, part of the bin may be broken to create an opening for easy offloading, the created opening is later sealed after the complete evacuation of the stored grains.

The major disadvantage of this storage method is that the structure is not airtight, moisture and rodent proof. Damage often results from rodent pest or insect infestation, structural failure and termite infestation (Adejumo and Raji, 2007).

Fig. 10. Mud Rhombus (based on Joost, 1996).

3.27. Obeh

Obeh is a traditional storage structure mostly used by the resource-poor farmer in the Senapati district of Manipur, India for the storage of unthreshed rice. Obeh has a storage capacity ranges from 5.0–10.0 t. These storage structures are made from bamboo sticks interwoven tightly to create an airtight compartment for storing of grains. The structure in appearance looks like an oval shaped storage platform in which the lower portion is in the form of square and tapers on the top (Fig. 11). Loading and offloading of the unthreshed rice is through the removable roof.

Fig. 11. Obeh.

3.28. Room type structure/local warehouse storage

The room type or warehouse structure is masonry constructed using burnt bricks, mud or cement blocks with aluminum or iron roofing sheets used for storing unthreshed and threshed grains. It has walls, floor, roof, windows, doors, and ventilators (Appert, 1987). The unthreshed grains are sometimes tied in bundles and heaped on the floor of the store room. While threshed grains stored in bags are stacked on pallets on the floor or on dunnage with space to circulate air around the bags. However, stored grains are treated with synthetic insecticide dust to prevent insect infestation.

In a rural farming community, where smallholder farmers are financially constraint to put up own stores or warehouse, have limitations of land availability or lack the technical know-how to store commodity for a long duration of time. Such farmers organize themselves into groups to construct communal stores as bulking center to consolidate their stocks ready for the market where large traders come and pickup truck loads of commodity at one time.

3.29. Storage of grains with natural products/botanicals

The practice of admixing of natural products or botanicals for the storage of food grains dates back to the very earliest periods of known history, well before the advent of synthetic insecticides/fumigants. The practice is common in Africa and Asia, with the increasing development of resistance and the negative impact of these synthetic insecticides on human health and environments (Isman, 2008). There is renewed interest in the utilization of these products for the management and preservation of stored grains from insect infestation. Being cheap and readily available, resources-poor farmers perceive that natural products possessed repellence, anti-feeding and ovipositional deterrence, fumigant or contact activity, growth inhibition etc., and uses them against storage insect pest than relying on the expensive, adulterated and not readily available synthetic insecticides to prevent storage pest from attacking their produce (Rajashekar et al., 2012).

In this practice farmers mix pulverized plant parts with the grains in the storage container(s), the irritating odor emanating from these products repelled insect from infesting the produce. At times, famers place the leaves of the plants believed to possess insecticidal properties as layers in between the gunny bags arranged one above other in the store room. Using the natural products/botanicals grains could be stored up to a year.

There are empirical reports or findings on the utilization of *Acorus calamus*, *A. indica*, *Pongamia glabra*, *Artemisia* species, *Citrus aurantium*, *Curcuma longa*, *Khya senegalensis*, *Caspicum* species, etc., for the management of stored grains insect pest.

3.30. Storage with cow dung

Seeds meant for next season sowing are stored with cow dung after the seeds must have been ascertained to be properly dried. Rural farmers believe that cow dung possess pesticidal properties to protect such seeds from insect infestation, they equally believe that cow dung immunostimulant properties increased seed viability (Karthikeyan et al., 2009). For seeds to be stored in cow dung, farmer collect fresh cow dung and made it to a plate-like round shape and the seeds are embedded into the cow dung and then sun dried for 2–3 days depending on the intensity of the sunlight. In the process of sun drying, the seeds get stuck onto the cow dung and then stored in open or inside a wooden box. Seeds treated this way can be stored for up to a year.

4. Conclusion

Food grains are the main source of human calorific requirements and animal feed worldwide and more so in developing countries. The spoilage of grains at the time of storage has resulted in the starvation of million people worldwide, including people who suffer from undernourishment. All the storage practices and methods review in this study are comparatively cheap and constructed with readily available local materials, eco-friendly, impart considerable high shelf life to stored food grains by effectively reduced or suppressed insect infestation. These traditional food grains storage and preservation practices can be improved upon or modified where necessary for effective grains storage to ensure the full realization of agricultural potential to meet the world's increasing food and energy needs.

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