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Hermetic Storage Technology: The Way forward in Solving Numerous Cereal Grains Storage Challenges in Developing Countries

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***Abstract*----This paper reviews the efficacy, diversity and potentials of hermetic storage (HS) technology and its ability to solve numerous storage related challenges abound, and prevalent in the tropics. Various types and diversity of hermetic storage structures, best practices in terms of use, capacity of best fit, and their consequent unique advantages/shortcomings in terms of cereal grains storage in the tropics were reviewed to aid farmers to make the right choices and achieve better results. The choice largely dependent on farmer's economic power, level of education, and the intended duration of storage, quantity to be stored and available facilities for storage. Major chemical based cereal grain storage related challenges, such as issue of pesticide residue/poisoning in stored grains, effect of storage chemicals on humans, animal, the environment, cost of storage chemicals and hazard associated with handling, insect developing resistance to chemicals, aflatoxins development, and loss of germinability were examined in details. Research results and theoretical data were also used to justify the ability of hermetic storage (HS) technology in solving these numerous challenges. Solutions were proffered with the approach of using different pesticide free airtight rigid and flexible storage structure to achieve a non-breathable atmosphere that will enhance disinfestation, eliminate all living organisms, as well as keeping the stored products in good condition.**

Keywords--- Hermetic Storage Technology, Non-Chemical Based Storage, Safe Storage, In The Tropics

I. INTRODUCTION

Over the years cereal grain storage remains the weak link in the generic cereal grain production value chain especially in the developing countries, apparently the area greatest concern due to percentage of cereal grains that are lost within an annual grain value chain or production circle. Though cereal grains storage is dated back to the prehistoric era, hitherto it is still associated with huge storage losses, which are estimated between 25%- 46%, in most developing countries and in Sub-Saharan Africa. This is due to inefficient and ineffective storage system, climatic factors, and agricultural practices used by farmers [1]. This situation often forces millions of rural peasant farmers/small producers of cereal grains to sell their grains at the time of harvest, with the disadvantage of low market prices, a situation which impoverishes them, and discourages youths from farming [2]. Among the numerous cereal grains storage challenges include the loss of enormous amount of harvested cereal grains yearly during storage to agents of deterioration and spoilage like insect/pests, microorganisms. Others are chemical based storage challenges created in a bid to solve insect/pest infestation problems. The issue of ineffective and inefficient storage system is largely due to the use of traditional or improved traditional storage structures which most lacks capacity, durability, efficiency and integrity, but is predominantly used by local farmers for cereal grain storage in the developing countries. The ability of these local farmers to adopt modern systems of storage either, which could take care of these shortcomings, remains a mirage due to cost, lack of adequate agricultural extension framework, and technological know-how in their various countries.

Enormous chemical based cereal grains storage challenges are also abound in developing countries. This is due to bad agricultural practices, weak legislations and lack of enforcement of related laws, farmer's low income, illiteracy and lack of technological advancement in these countries. Majority of the challenges arose from issues of dealing with the greatest enemy of cereal grain storage in the tropics which is insect/pest infestation. This include pesticide poisoning, the exorbitant cost of the pesticides, issue of high pesticide residue in stored and exported grains, the hazards related to the handling of these pesticides and its effect in the environment. However, there was tremendous achievement globally by the use of pesticides in controlling undesirable species of pests, micro organisms, and plant in the past, but its only in the developing countries where farmers' literacy rate, legislations and exposure are adequate, that they are done

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in accordance with World Health Organisation (WHO) approval for use in storage of food grain, which are regularly reviewed. In the developing countries, the situation is different. While illiterate farmers apply these chemicals most often at will, in a bid to solve the most critical problem in cereal grain storage in tropics which is insect infestation, they are ignorant of the side effect or the effect of over-application.

. This practice has not yielded positive results, due to the lack of knowledge on how this fumigants and insecticides are to be used for optimum and effective performance; rather it resulted to overdose-application by farmers in order to achieve results. This has left most stored grains in the tropics especially Nigeria, with huge amount of pesticide residue [3]. European Union banned importation of beans, sesame seed, melon seeds, dried fish, meat, grains, peanut and palm oil from Nigeria in 2015 [4]. The European Food safety Council in a statement reiterated, that they were bannered because most of the items contains as much as 0.3mg/kg to 4.6 mg/ of pesticide residue against the maximum limit of 0.01mg/kg. A research carried out in 2015 by a non-Governmental organisation in Northern Nigeria which is the grain hub of Nigeria, showed that about 80% of all the grains sold in consumer markets across the region contains high level of pesticide/extraneous residue far more than the Maximum Residue Limit (MRL) and the Extraneous Residue Limit (ERL) as recommended by Codex Alimentarius Commission [4]. There are incessant horrible stories where entire or part of a family is wiped out after consuming grains sprayed with enormous amount of insecticide. Many livestock farmers in Nigeria have lost their entire livestock after consumption of feed sprayed with over doses of insecticide/pesticides. Even when credible data is seriously lacking about the number victims from pesticide related poisoning in Nigeria, it is obvious that it is not a fairy tale as most neighborhoods and cities had experiences about this issue.

The handling of the insecticide among farmers the distributors or sellers' even posses more risk than when it is in form of residue in store grains. In many developed countries, especially Sub-Saharan Africa (SSA) insecticides are bought off shelves, even in open local markets. Some of the dealers even shelve it along with edible food items such as provisions, sachet water, palm oil and other edible foods as shown in plate.1, due to lack of legislations and enforcement of the existing laws in this regard by the relevant authorities. Poisoning due to handling had its own array of stories

Plate 1. Insecticides, palm oil and soft drinks sold in the same store in Minna, Niger state Nigeria

Among various modern storage types/system that could easily solve all these arrays of cereal grains storage related problems, and can be easily adopted in developing countries is hermetic system of storage. Its range and diversity of storage structures can carter for any category of farmer globally irrespective of diverse and varied climatic that exist worldwide.

II. HERMETIC STORAGE

Hermetic storage (HS) technology is a non chemical based system of storage. Its basic principle is the generation of oxygen depleted, carbon dioxide and or nitrogen enriched interstitial atmosphere caused by either the natural respiratory activities of living organisms in the bulk, or enhanced and accelerated by artificial means in an air tight storage structure [5]. A sufficiently low oxygen and elevated carbon dioxide or nitrogen could either be created through a natural internal metabolic process based on insect respiration and respiration of food material if they are living and other micro-flora in the bulk such as moulds, bacteria and fungi (Organic hermetic storage (OHS)). It could be achieved also by the deflating/sucking out of oxygen rich air from an air tight storage structure with the aid of a vacuum pump creating a partial pressure of air inside the structure that will lead to depletion of oxygen (Vacuum hermetic fumigation (VHF)), and through an artificial mechanism such as enriching the air tight storage structure with carbon dioxide or nitrogen by the use of pumps, generators and scrubbers (Gas hermetic fumigation (GHS)), These are the three major types of hermetic storage. When the sealed storage is enriched with carbon dioxide or nitrogen and oxygen is depleted, it will lead to the asphyxiation of the entire living organisms in the bulk, who are normally agent of deterioration, and the crops will store well and its quality preserved. The oxygen depleted atmosphere thus generated prevents the development of

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cancer causing mycotoxins and maintains the moisture level of the commodity regardless of the ambient humidity [6].

The process of disinfestation starts immediately after stocking of the grains inside the storage structure as well as the sealing. The air concealed inside the bulk which is composed of the natural air, mainly 78% nitrogen, 21% oxygen, 0.04% carbon dioxide will begin to undergo a process. At the beginning of the process, a modified atmosphere is automatically created with huge percentage of oxygen and less carbon-dioxide. As the modified atmospheric condition progresses, it will get to the middle of the process where equilibrium condition exists and as well the end where there will be complete oxygen depletion and carbon dioxide enrichment will lead to insect asphyxiation as shown in Figure. 1. This application has been successfully used for the storage of granular and milled grains, paddy crops, pulses, oil seeds, and varieties of food materials worldwide. Various other applications of hermetic technology includes the disinfestation of durable commodities during or before transportation, quarantine vacuum treatment for exported crops such as geophytes, onions, potatoes upon arrival or after acceptance [12]. Others are re-infestation prevention, by hermetic storage facilities, cold room storage, and manufacturing and packaging processes as well as seed preservation [7]. .

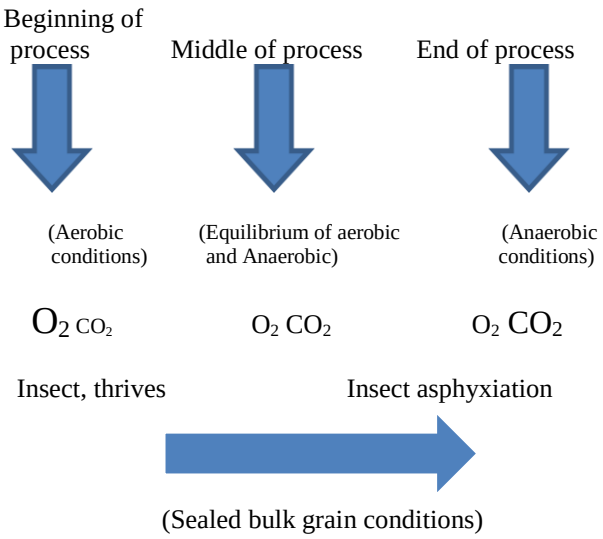

Fig.1. Process of oxygen depletion and carbon dioxide enrichment in hermetic micro-environment

Its major advantage is the prevention of hazards, enormous amount of resources spent on labour and fumigation of stored products using phosphine and Methyl Bromide (MB) and or pesticides /insecticides which may harm potential consumers. Laboratory data has confirmed that organic hermetic storage creates less than 1% oxygen environment after 15days if stored properly, and prevents the production of (FFA), which produces rancidity. Its potential in storage of crops with (FFA) will be a major breakthrough [8]. Its ability to maintain safe humidity level irrespective of the exterior environment was demonstrated by Ghana cocoa bud and laboratory studies in Israel in 2009. It was also discovered that 6 months hermetically stored beans preserve the same cooking time as fresh beans which otherwise usually doubles after long storage, [8]. The importance of hermetic storage as a modern alternative to traditional system of storage in developing countries especially (SSA) has been recognised and recommended by organizations such as International Rice Research Institute (IRRI), Forum for Agricultural research in Africa (FARA), International Institute for tropical Agriculture (IITA), and Food and Agriculture Organisation (FAO), for use in developing countries. In hot humid climates, insects, moulds and rodents can cause storage losses up to 25-50 percent.

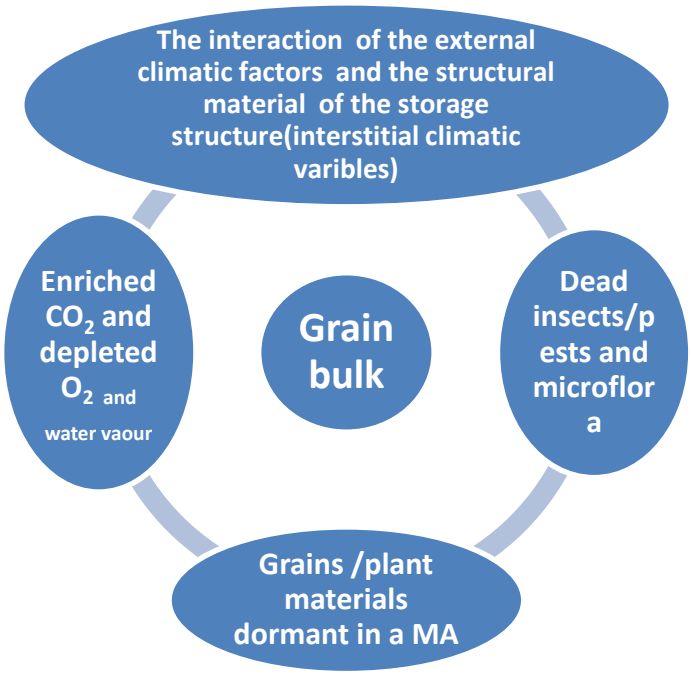

Fig 2. Stored grain ecosystem in a stable hermetic environment/modified atmosphere (MA)

The use of non sealed metallic silos works poorly due to moisture migration and condensation problems, so storing grains for long period could be a challenge. (HSS) is a unique type of storage that re-evolved at a time the issue of pesticide residue in stored food, animals and environment is becoming a serious issue especially in the developing countries. It has a wide range of storage structures and capacities that will be able to be adapted in any level and capacity of storage especially on- farm or domestic storage. However, the major challenge with the hermetic storage system is how to provide and sustain an air tight environment, as well as generating low O_2 and high CO_2, because sometimes it may be difficult to achieve 100% sealing. However time taken for total depletion of oxygen or enrichment of carbon dioxide in hermetic micro environment is a relative term. It differs from crop to crop and the storage conditions. It also depends on the initial grain condition and level of infestation; a highly infested

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grain is expected to deplete a given percentage of oxygen faster than non-infested grains because of the oxygen requirement of the sealed bulk.

However for efficient and effective hermetic storage of cereal grains, initial grain condition is vital. This includes the moisture content, hectolitre weight or bulk density, level of infestation and broken grains and cores and fines. Since grains cannot get better during storage, the need to store high quality grains with the right moisture levels as shown in Fig 3. is fundamental.

Table.1. Safe storage moisture content of some selected crops in the tropics

Grain	Max .MC%(wet basis)
Corn/maize	12.0
Sorghum	13.0
Groundnut	6.5
Rice	12.0
Millet	13.0

Hermetic systems of storage can be classified under the three different forms namely organic hermetic storage, (OHS) vacuum hermetic fumigation (VHF) and gas hermetic fumigation (GHS).

A. Organic Hermetic Storage (OHS)

Organic hermetic storage which is normally often referred to as (hermetic storage) is a type of sealed storage which relies on only the metabolic activities of insects, micro flora and the respiratory activities of the stored items if they are living, to generate a low oxygen and enriched carbon dioxide modified atmosphere that will lead to asphyxiation of the living organism in the bulk [9]. The metabolic activities is basically oxygen based, inform of respiration of insects, bacteria, fungi and moulds in the bulk. These will results in a consequent rise in the carbon dioxide concentration due to continuous aerobic respiration in the airtight storage structure. Moulds, yeasts, bacteria and fungi makes up the micro flora population in a stored commodity. An elevated humidity and temperature could contribute significantly to the respiration process. Most mould population is aerobic. Humidity requirement for rapid mould growth of aerobic micro flora are within the range of 65% to 85%. [8].

During storage using organic hermetic storage structures, grains must fill the storage structure, to the bream; no big volume of air should be entrapped. This will allow for easy disinfestation. However, if a big volume of air is entrapped, it could sustain the insects and the entire micro flora for so many days in which reasonable damage maybe done to stored crops. Organic hermetic structures could be rigid of flexible. It comes in a wide range of types such as the triple layer bags, aluminium metallic hermetic silos between 0.5 to 2 tonnes, grain storage cocoon, and a wide range of plastic and metallic containers. Most of the organic hermetic structure suits the lowest level of storage especially in sub Sahara Africa where peasant farmers produces little quantities but are responsible for the majority of the grains production and storage.

B. Vacuum hermetic fumigation (VHF)

This is the act of creating a very low pressure atmosphere to allow for an accelerated disinfestation of food commodities [8]. The creation of the low pressure could be achieved by the use of a vacuum pump through a one way vacuum line valve which does not allow air to go in a reverse direction, to suck out the entrapped air in the hermetic storage structure. This system is mostly used for flexible hermetic structures made of Poly vinyl chloride (PVC's) such as different types of grain cocoons. Research shows that mortality is caused mainly by the low partial pressure of oxygen that results in hypoxia and dehydration due to removal of water vapour under vacuum [7]. Until recently, the possibility of using low pressure at the large scale commercial level of storage to control insect infestation had been problematic due to the requirements for massive, rigid and expensive structures needed to withstand the pressure. However a new and innovative technology evolved whereby it is used in strong high density (PVC) to store durable commodities. The structure consists of flexible plastic containers with a high level of gas tightness that also enables treatment with control atmosphere or fumigants without significant gas loss. [7].

Vacuum hermetic fumigation is sophisticated type of hermetic storage which needs a level of technical knowledge than the organic hermetic system, due several gadget used in measurement of oxygen levels and the hurdle of setting it up correctly [5]. Its use by poor, illiterate and peasant farmers in developing countries is seriously limited by its sophistication. While the pump set up may be simple in some instance, the large commercial vacuum pump set may comprise of pressure gauge (transducers for pressure monitoring) and a generator for generation of the partial pressure. It is widely used in quarantine treatment of commodities that are packaged in bags, insect control treatments and quality assurance during storage and one of the most appropriate systems for commercial or middle level storage.

C. Gas Hermetic Fumigation (GHS)

Gas hermetic fumigation is the type of hermetic storage system where oxygen depleted and carbon dioxide or nitrogen enriched atmosphere is achieved by purging the air tight or sealed storage with carbon dioxide or nitrogen gas. It is mostly used in industrial and commercial scale, as the most sophisticated form of hermetic storage. Consequent disinfestation and the control atmosphere is achieved at an accelerated rate, since the control atmosphere is not bio-generated. It is mostly used for crushable commodities such as dried fruits prior to shipment. Highly fragile commodities are the most beneficiaries of this system because of the enormous damage insects can perpetuate in relatively short period. This method has been used for the storage of high valued commodities such as tobacco, coffee, fig, cocoa, peanut and a wide range of species in developed countries. In this case the modified gas composition usually produced artificially is maintained by additionally generating the desired (CO2 and N2) or by further purging the storage

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with these gases, supplied from pressurized cylinders. The gases are introduced when the desired level has dropped below recommended values. The (GHS) is designed to compensate for possible drop in concentration of the gases by probably leakages which are inevitable and can cause the increase of O2. The efficiency of the system amounts to regular monitoring and probable control involved. Another form of gas hermetic fumigation uses exothermic gas generators, catalytic oxygen converters in which case, the gases generated are located outside the storage container. The gases are pumped into the containers when desired catalytic oxygen converter burns propane or butane with catalytic conversion process without flames. Oxygen could also be removed from air by using various plant materials or wastes placed in an external generator. This system is the best fit for mega commercial storage activities and not for peasant farmers.

III. HERMETIC STORAGE STRUCTURES

Hermetic storage structures are air tight or sealed storage structures which maximize the modified atmosphere created in the sealed storage, for disinfestation and preservance of quality of stored items. They remain one of the oldest forms of storage structures ever used by man but its storage dynamics was not understood early enough. They are naturally made of different materials and are built or made to be air tight by man. Apart from being air tight, the functional requirements of an efficient crop storage structure must also be fulfilled to enhance its primordial functions An ideal hermetic storage structure should be able to eliminate or reduce the destructive effect of weathering, eliminate invasion of pests such as birds, rodents and insects, eliminate or reduce activities of microorganism, should have high integrity in terms of structural strength and should be air tight among others. The permeability of hermetic barrier materials differs from structures to structures depending on the product and type. Hermetic storage structure could be made from materials such as, plastic concrete metal (Ferro-cement) and metallic alloys, glass and flexible High Density (HD) materials provided they can be adapted to a convenient radius of curvature either construction or moulding. . Hermetic storage structures could be kept indoor or outdoor depending on choice available space and security considerations especially with flexible hermetic storage structures, but metallic containers performs excellently in that regards.

All the materials are characterized by individual intrinsic behaviours, and consequent advantages and disadvantages. Considering one of the fundamental expectations of hermetic storage structure which is air tight nature or reasonable impermeablity, all the material used for its construction are expected to guarantee such characteristics for effective storage. Metallic materials are synonymous with moisture problems such as condensation and migration especially in hot humid climates, but can guarantee high capacity smooth walls, and near 100% impermeablity, durability and can prevent rodent, birds and human pilferage. Concrete material are also efficient in protecting the grains against, rodents and human pilferage, moisture condensation, but it is expensive and often seepage challenges and sticking of grains on the walls are always issue of concern. Flexible structures greatest problem include high gas permeability problems, rodent attack, durability, human pilferage and wide fire. However it has high efficiency in the flexibility, ease of installation, and re-installation in another location. Other type of materials such as glass and plastic containers has high gas impermeablity efficiency, but capacity is its greatest challenge. They are very durable but exorbitant. However, according to research no material is absolutely satisfactory as a hermetic storage construction material over all others; they all have their advantages and disadvantages [10]. The choice of material is largely dependent on individual preference, available resources, prevalent climate, capacity of storage, the type of crop to be stored, and the duration of storage [11]. The array of sizes, varieties and types of hermetic storage structures are everywhere around us. Though most of the structures at domestic levels were not originally designed for this technology, but with understanding of hermetic technology dynamics many existing containers can be converted to hermetic structures by simple sealing.. It explain why almost all commodities and crops at all levels of storage and capacity of storage are catered for in this system of storage which is a perfect replacement to our existing traditional storage structures., especially at a time non –chemical storage is being championed worldwide. Hermetic storage structures can be classified into flexible and rigid hermetic storage structures

A. Flexible hermetic storage structures.

They are hermetic storage structure that are not rigid in nature, (they have no structural rigidity) but are made of semi-plastic polythene materials depending on the type. Most common flexible hermetic storage structures includes, triple layer grains storage bags , Poly vinyl chloride (PVC) envelops, grain storage cocoons and super grain bags.

The flexible hermetic silo materials are made of different types, gauge and strength polythene and poly propylene materials. However what is unique amongst them is their low permeability to ambient air and the prevention of interaction of the stored grain with the immediate atmosphere. A growing number of flexible storage structures are used in 81 countries of the world for storage of grains and other commodities [12]. The flexible hermetic storage structures comes in a wide range of capacity from 60kg to 2 tonnes portable bags mainly designed for household and domestic low level storage. The range of 5 to 12,500 tonnes capacity cocoons designed for middlemen grain merchants or large commercial purposes. Flexible hermetic storage structures was first introduced in 1970s and since then has appeared to be perfect replacement for past storage methods especially in hot humid climates [12]. Flexible hermetic structures, has a total flexibility both in handling, installation and use. It could be indoors or outdoors and different types of crops can be stored in the same storage structures provided they are bagged differently. Flexible storage structures has

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undergone improvement over the years especially its impermeablity to the ambient air. The new Super Grain pro hermetic storage bags for example, has improved oxygen impermeablity from 55cc/m2/day to 3cc/m2/day while maintaining the same permeability of water vapour which is 8g/m2/day [8]. The micro leakage around the seal has been eliminated by introduction of zip-lock like closure as shown in the plate 3. Flexible hermetic storage structure is characterized by little or no head space, if properly used, helps in accelerating disinfestation. Before now, flexible elastic liners supported with wire mesh frame made of butyl rubber were used. However under typical conditions and sub tropical climate, the liners deteriorated fast and gas permeability increased to a non-tolerant level; and liners was dumped [13]. In Israel the manufacturers of (PVC) liners that conformed to the prerequisite specifications of durability and climate, gas impermeabilities, and physical properties enabled the development of present PVC (PP) materials which has performed well [14].

- *Hermetic Bags*

Hermetic bags are form of hermetic storage structures designed to hold grain at the lowest level or the middle level storage. They are improved polyethylene and woven poly propylene bags designed to have high density and physical strength as well as high impermeablity of gases/ ambient air. It provides big alternative to most rigid hermetic storage structures which their initial cost of acquisition is high. The two basic component of hermetic bags are the inner bags made of high density transparent Polyethylene bags which may be double or single depending on design and make as shown in plate.2. The transparent inner bag is purely designed to guarantee high impermeablity of ambient atmosphere to create the desired sealed environment for a hermetic storage system. [5]. It is factual that more storage insect has the capacity to perforate bags, but it was dully considered during design in the inner bags. The outer bag is not transparent in nature but made woven polypropylene material basically designed for strength, due to handling problems and the weight of the grains that it will house. The impermeablity of the ambient air helps in maintaining safe constant moisture levels in stored grains regardless of ambient exterior relative humidity. Hermetic bags are made of plastic material which is not a good conductor of heat, unlike metallic materials. They are thermoplastic polymers of Polypropylene (PP) origin. During the 2008 and 2010 harvest season more than 33 million of grains were stored in plastic bags in Argentina [13]. In the recent years, there is a growing interest in the use of flexible hermetic structures such as Purdue Improved Crops Storage bags (PICS) super grains bags, cocoon and others which are con currently promoted as cheap and more effective ways to control storage insects in Asia and recently in Africa [15]. The triple layer bags consist of a double layer bag of High Density Poly-ethylene (HDPE) bags inside a standard polypropylene woven bags were shown to effectively protected cowpeas against bruchid beetles in West Africa [16]. However super grain bags consist of a single high density polythene bags and have been successfully disseminated in Asia [17]. Conflicting report from few researchers have reported perforation of bags by some species of insect, but it is function of so many factors such as, initial grain condition, level of infestation, type and species of insects, and the efficacy and integrity of the bags in question.

Plate.2. Flexible hermetic storage structures.

Hermetic bags are probably the most appropriate structure for seed preservation in developing countries due to its efficiency and affordability, provided is well protected from rodents.

- *Grain storage cocoon*

They are flexible hermetic storage structures made of big hermetic envelops called cocoon. Cocoon are basically made of poly propylene material like the grain bags but was designed for large scale storage ranging from 30-1,500 tonnes depending on the make. They are made of single layer density poly propylene thermo elastic material they are also known as volcanic tubes, mainly of high capacity could be assembled indoor or outdoor. Grain storage cocoon is a total enclave, which is highly flexible and can be folded to just a sample pad, but takes the shape of grains stored in it, if assembled. However, most available cocoons are either 0.83mm thick Poly Vinyl Chloride (PVC) as shown in Plate 2. with the oxygen permeability of $400ccm^2day^{-i}$ and to water vapour of $8gm^{-2}day^{-i}$ [18]. It's being widely used across the globe for storage of grains and pulses in places in places like the Philippines, China, Sri-lanka and Rwanda [18]. The commercially available super grains bags cocoons are currently used in 82 countries of the world [5]. The grains cocoon is basically made of two major component carefully sewed rectangular thick, blind (pp) material that can be attached or detached by a means of a plastic zippers designed on its outside surface for each component for the purpose of zipping/ sealing. The two basic (PP) components are the head and the tail. The both are normally joined with the male and female zippers attached to respective covers as shown in plate. 3.

It was designed with 2 holes that have plastics tight covers, one for oxygen and carbon dioxide sensors insertion point and the other is a one way in valve for sucking out of air

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from the cocoon during storage. After the tails has been spread on a clean well drained soft floor preferably on a sandy base, bagged grains in ordinary bags are stacked to take the shape of the sewed poly propylene cocoon. After stacking to the horizontal recommended length and width, it will be further stacked to the vertical length and width. While the tail is worn up the stacked grain, the top cover will be worn from the top and both will be attached together by means of a zipper and sealed.

After sealing of the zipper point, a vacuum pump is normally used to suck out the air trapped inside the cocoon to facilitate rapid disinfestation or it can be allowed to undergo the organic bio-generated form of disinfestation [13]. Grain cocoon is highly movable and easy to transport and set up in another location. It could last for 10-12 years if properly handled, and best fit for long term storage as far as hermetic structures are concern. Its shortcomings are largely centered on durability, cost and most importantly its security concerns. Material used for the manufacturing of cocoon, largely non bio-degradable. it is probably best suited for middle level or commercial storage. It can also be used at the lowest level by farmers who can afford its various capacities, or by farmer's co-operative societies.

Plate. 3. An assembled grain storage cocoon Minna, Nigeria

Countries who keep emergency stocks can also use them efficiently, since the grains are stored in bags and will be able to be evacuated to needed locations in a matter of hours. Major biological threats include rodents, weathering, pilferage, and protection against fire which can engulf it in a twinkle of an eye. However, its greatest attribute is the low storage losses recorded with hermetic cocoon storage. All the 3 types of hermetic storage namely (OHS, VHF, and GHF) can be practiced effectively in a grain storage cocoon. It is probably the only hermetic storage structure which the 3 different types of hermetic storage technology can be practiced. Capacity/space remains one of the impediments of Cocoon storage. It is like stacking grains in a warehouse where high altitude stacking may be difficult and a challenge. Space in between stacked grains makes it a space demanding type of storage. Aerial space utilization is poor unlike upright silo storage, while horizontal land surface utilization is high.

B. Rigid hermetic storage structures

These are hermetic storage structures that are made of non-flexible material. Materials those are rigid in nature such as concretes, metals, plastics and glass. Rigid hermetic storage structures are the fundamental hermetic storage structures used by man from cradle. History also revealed that the early humans stored grains in air tight and semi air tight pots and other rigid containers. Presently technological improvement has evolved much more modern rigid hermetic structure such as air tight metallic, plastics, glass containers of different shapes and capacities for different levels of storage. Rigid hermetic storage structures have proved to be efficient storage structures for any type of hermetic storage, affording an air tight environment with almost 100% impermeabllity to the ambient air [23].

The most critical problem associated with flexible hermetic storage structures such as rodent attack, human pilferage and deliberate piercing of holes by enemies or domestic animals is practically inexistent with rigid hermetic storage structures. However major issue associated with rigid hermetic storage structures includes improper sealing of the edges, loading and the unloading points. Various rigid hermetic structures have other problems ranging from moisture condensation, to high cost of hermetic storage structures. Individual materials used for the construction of hermetic storage structures, differs in reactions to external climatic conditions. Rigid hermetic storage structures made of metallic materials is bound to have condensation problem which are also expected in plastic but not in glass containers, but glass and plastic containers are relatively expensive especially high volumes, and as such that peasant farmers many not be able to afford them. However, according to research, if storage structures are kept under a shade or roof during storage, better results will be achieved [23],[18]. With advance technology, pressure decay test (PDT) are always conducted on the structures to ensure that hermetic conductions are guaranteed or more common test is to fill the storage structure with water, and check for leakages, especially if the material of construction is not water absorbent.

Rigid hermetic storage structures are easy to handle or use as its rigid body provides a lot of physical protection against, rodents, birds, insects, and generally makes handling safer and easier. However, available data on successful application is mainly with movable rigid structures, but recently many existing silos and ware house have been modified to enhance hermetic sealing especially in Australia [18]. Transportability is one of the major considerations that further determine the choice of rigid hermetic storage structures. (FAO) through its outreach had upheld rigid hermetic storage structures for use by local farmers in the developing countries. In Kenya the grain value chains had received a big boost due to the introduction of metallic containers [18]. Its recommendation is not far from the ability of any category of farmer to use rigid hermetic storage structures efficiently. There is not much to it, than to fill your dried

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grains to its bream and seal accordingly. By virtue of peasant farmer's low income and standard of living, the handing, pest control, availability of safety condition and enough space for flexible hermetic storage structures is always an issue, but rigid hermetic storage structures are devoid of those issues. Apart from performing better in terms of impermeablity of the ambient air and physical protection of the grains, rigid hermetic storage structures are durable and forms the basis of an effective and efficient hermetic storage structures for present farmers in the tropics and subtropics where there individual grain output is relatively less compared to the developed countries. . Most of the storage systems practiced in developed countries remained alien to the peasant farmers largely due to the technological concerns and cost. However, with the re-evolution of hermetic storage, most of the problems will be non-existent. An illiterate farmer can use triple layer hermetic bags of plastic and metallic containers easily. They are affordable, amidst the wide range of alternatives in the array of structures that exist.

- *Metallic containers*

Hermetic metallic containers are rigid storage structures made of metallic or metallic alloy materials as shown in Plate.4. Metallic containers which were not naturally made for hermetic storage, but guaranteed air tight conditions were the first type of hermetic structures used for this purpose. As one of the first ever known type of hermetic storage structure used by man, it affords farmers a great advantage going into storage especially, if the structures are kept under a roof or shade.

Plate .4. 300kg Aluminiun hermetic containers set under a shade for storage.

Recent technological developments have evolved different type of metallic structure purposely designed for hermetic storage with good loading and unloading points [18].

However its shortcomings ranges from its high thermal conductivity which predisposes grains in storage to local or internal heating given rise to browning and mustiness of grains, loss of moisture content and moisture condensation inside the storage structures. Metallic containers comes in variety of shapes and sizes depending on the choice of individual .The most common types are empty metallic drums, and other container that were originally meant for liquid and solid granular materials, as either for packaging or storage purposes. Devoured of basic design, the use is opposed to problems due to absence of loading and unloading points. Others are metallic containers, designed and built specifically for the purpose of hermetic storage crop storage such 0.5 to 5.0 tonnes metallic containers. The most popular is the aluminiun metallic containers that is presently seriously being championed by (FAO) as a possible replacement of the traditional storage structures used in developing countries

Metallic containers are mostly used organic hermetic storage structures. The few exception are different types of control atmospheric stores and other metallic containers used for vacuum hermetic fumigation and bunker grain storage, in which it disinfestation are accelerated by the means of external gases. While metallic silos are very effective they are expensive. Half of the initial cost comes from the cost of the metal sheets. However the cost per kg of grain stored decreases with increase in the volume of the container, therefore economic analysis is needed to determine the sizes at which metallic silos becomes economical under deferent price condition [19]. Metallic silos are particularly successful in EL-Salvador and in Asia where farmers use approximately up to 65,000 numbers I ton metallic silos in the respective countries [19]. In Central America, at inception of storage in metallic silos, brands of methyl bromide fumigant are used to accelerate disinfestation [20]. In Africa especially in Sub-Saharan Africa, metallic silos are yet to get its place in all levels of storage except little achievement in Kenya recently. The effort of (FAO) in 2009 in Nigeria did not achieve its desired result.

- *Plastic and glass containers*

These are rigid hermetic structures made form plastic or glass materials respectively. Plastic hermetic structures and made thermo plastic polypropylene materials using extrusion blow moulding machines. They are mainly produced from High Density Polypropylene (HDPP). Others are made of polyvinyl chloride (PVC). As a very durable and long lasting construction material, is can be used in the production of either rigid or flexible hermetic storage structures along with other additives. The greatest quality is the provision of the hermetic environment needed as impermeably is high and largely depending on the ability of the farmer to seal the loading and the unloading points. Physical strength of the structures is guaranteed, and susceptibility to rodent attack, human pilferage, birds and other pest are not prominent with the use of plastic hermetic structures. However, the issue of moisture condensation is very prominent with plastic rigid hermetic storage materials coupled with its high cost of procurement [10]. Like in metallic hermetic structures, majority of the available plastic containers were not originally designed for hermetic storage but were converted and as a result also lacked basic loading and unloading facilities. The originally designed structures are almost inexistence in developing countries due to the cost of importing a blow mould and as well as financing the production. Lack of potential market possibilities would have likely

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discouraged entrepreneurs. However there arrays of relatively plastic containers of different capacities, which farmers can use at the lowest level of storage or at household level that will serve this purpose but requiring little or no sealing as shown in plate.5.

Glass hermetic storage structures are containers made of quality glass material normally transparent or translucent, designed for the hermetic storage of commodities. Glass jars are basically made of sand, soda ash, limestone and other ingredients such as iron and carbon which provides colour. It undergoes the same process as in the production of plastics when the raw materials recipe are mixed in specific percentage and melted in a high temperature, and later blow moulded to form the shape of its mould before cooling. The self cleansing natures of glass hermetic containers are one of its greatest attributes. Its low thermal conductivity and, the ability to maintain a 100% sealed environment without interaction with the ambient air is an added advantage. Climatic variable has no significant effect on glass hermetic storage structures. However its greatest shortcoming is its breakable nature, its initial cost, transportation or relocation of structures which are also problematic. Glass hermetic structures are seldom used for grain storage, especially in respect to big capacity storage. Most of the popular glass containers are used for domestic storage unlike other hermetic structures which has a wide range of sizes and capacity. In sub-Saharan Africa most plastic and glass containers used for hermetic storage are not naturally designed for such but for packaging of other materials are later converted to such purpose. However in developed countries there are various sizes of glass containers specifically designed for hermetic storage structures, such containers are designed with the kind of covers that will enhance easy sealing, loading and unloading of grains. Locally available glass, plastic bottles, jerry cans are the most common universally available hermetic storage structures and one of the most effective of all kinds of hermetic storage structures.

Plate .5. Plastic hermetic storage structures

- *Transafeliners*

They are hermetic storage containers which uses both flexible and rigid hermetic structures together. They are not commonly used hermetic storage structures as the major use is for transportation of high valuable crop meant for export. Crops like coffee, tobacco, fig, could deteriorate rapidly in an open storage system and would lead to colossal loss resources especially in the tropics and sub-tropics. Transafeliners are metallic containers which are designed with inner high density polyethylene bags. Which the metallic container guarantees mechanical protection of the grains, the inside is always lined to avoid damage to the poly ethylene material as shown in Plate. 6. The inner bag is highly impermeable to the ambient air, thereby guarantying the hermetic environment needed for disinfestation. While the high density polyethylene are well twisted and tied before closing [9]. The inner flexible component functions in a way that even if the container gets in contact with water there will be no ingress. Thousands of shipping containers travel across the oceans each day to deliver agricultural commodities. Temperature and relative humidity flocculation and changes in climate plays a crucial role in the conditions of the commodities being shipped. Poor fumigation practice at origin, especially commodities with high level of infestation will definitely lead to additional expenses, trade dispute or rejection at final destinations [8]. However the development of condensation of moisture inside shipping containers still remains a serious problem to importation and exportation. The poor air movement does not help matters either, as condensation encourages mould growth, insect infestation and damage commodities. The use of transafeliners conveniently takes care of the entire problem mentioned above [13]. Made form multi layered film, transafeliners is specially designed ultra hermetic liner with superior gas and moisture barrier properties.

Plate. 6. Transafeliners (Grain pro.com, 2015)

It effectively isolates the commodity from the ambient conditions thereby minimizing condensation. It is specially designed for disinfestation before departure. Carbon dioxide or nitrogen can be flushed through an expansion piece with an integrated air to air duct at the top of the liner to allow oxygen to escape [13] [8]. This type of foundation is safe and environment friendly due to the inert characteristics of carbon dioxide and nitrogen gases and the gas tightness of the inner liner inside the container. This system is mostly used to prepare delicate commodities for exportation. Transfer liner, has performed effectively, stopping mould growth, eliminating insets at all life stages while on transits without residues of heedful chemical that could lead to rejection at the destination port and point [8].

- *Hermetic bunker storage*

It is a sound and convenient inexpensive hermetic storage structures used for storage of wide range of agricultural commodities. It is used for short, medium and long term storage of grains. It has been used in different ways in counters such as Australia, USA, Turkey, Brazil, Israel and

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Cyprus. Bunker storage has given excellent results for long term storage of wheat and barley [21]. The term bunker storage is used to describe large bulk of grain stored on the ground, in the open, surrounded by low retaining walls and protected from weather with plastic sheets. The advantage of bunker storage is that it is based on high level of sealing using plastic liners that enclose the grain under hermetic conditions without any form of chemical treatment.

Low density polyethylene sheets are used as floor covering to seal the grain from beneath. Specially developed liners are also used to cover the top. However, bunker storage will be most convenient and is only recommended were the harvest period coincides with the dry season, since loading of grains may take days during which the grains are highly exposed. The bunker storage must be located in a well-drained area with very low water table the bunker floor can be made of concrete, asphalt as repeated use is possible [21]. Site preparation may be influenced by loading and unloading system to be used. It can be loaded by a means of screw auger. Access to the bunker must also be considered for evacuation. Bunker type and dimension depends on the capacity of grain. Proper drainage of runoff water is essential thus surrounding ground should be lower than the bunker floor and sloping away from the bunker [21] . However the bunker over liners does not protect the grains from pilferage, free roaming animals in the vicinity. Fencing should be provided to secure the bunker. Bunker could be loaded as big as 15,000 tonnes of grains. Careful removal of the cover of the bunker makes it reusable. Bunker orientation should be such that the direction of the prevailing wind should be in longitudinal axis with the bunker, otherwise bunker orientation should be North – South to provide uniformity of exposure of the over liner and grain bulk to solar radiation.

- *Control atmospheric stores*

They are air tight storage structures used for control atmospheric system of storage. Mainly used for commercial storage, the hermetic store may not be necessarily metallic, but should guarantee the hermetic environment required for disinfestation. The ambient air contains 20.9% of oxygen and 78.1% nitrogen and carbon dioxide. The control atmosphere (CA) fumigation system lowers oxygen concentration leaving high nitrogen to create an anaerobic system. The basic ingredient in this system of storage and storage structures is the ability to monition conditions inside the store as well as effecting control if need be.

Plate.7.Control atmospheric store Source:(www.insecttreatment.com).

The (CA) store could be a room, container made of any material, silo, tent, bag, provided they are air tight in nature as shown plate .7. There are wide range of equipment used for monitoring and control of condition inside a (CA) store such as leak detectors, nitrogen and ethylene generators, pressure release valves, standard, sensors, and refrigerating units, oxygen filtering equipment, infra gas analyzers, scrubbers, humidifiers and dehumidifiers, and a central computer unit for easy reading of results and control. All the various equipment con function differently and also in a few combination largely dependent of the type of commodity to be stored, the quantity, and the intended duration of storage. When used for storage and disinfestation of cereal grains, a few of the equipment may be required. A scrubber called (zero, ox) system can filter the air inside the hermetic structure, removing oxygen and enriching nitrogen in a matter of minutes depending on the capacity of the storage structure. This will initiate a serious disinfestation that can take the gains for month, if properly sealed [13].

However the main difficulty associated with control atmospheric storage and structures are the head space. Since most of the storage structures are rigid, stacking commodities up to its roof is always difficult, therefore leaving a lot of void for ambient air and oxygen. In a situation where the stores are so big up to the size of mini warehouse, the problem will even be more. The tendencies for leakage in big stores are more pronounced. Hence arrays of equipment are always needed to monitoring the condition inside the stores. However each equipment work in conjunction with others in a bid to maintain the desired atmospheric condition needed for the preservation of quality, and disinfestation of the commodities.

However, no two storage situation can be the same, different commodities have different needs and conditions for its preservance, though few specialized applications require rapid disinfestation as low as in two days such as dry figs. It is a highly technical form of storage. The material of construction of the stores is of importance in storage; however most of the stores are double walled with a border insulating materials in between the double wall. This enables the store to be independent in terms of temperature, humidity, moisture sorption and desorption in maintaining the moisture content of the commodities in storage. A typical (CA) store is characterized by a lot of (PVC) pipes going in and out, a lot of sensors in and outside the stores for reading and comparison of parameters, but the most important aspect is the ability of the control atmosphere store to be sealed and maintenance of its sealed conditions for a long time.

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IV. CONCLUSION

Numerous cereal grain storage challenges in the developing countries needs urgent attention and commitment, by both the farmers and Government. With the all the arrays of structures abound and potentials of hermetic storage technology, there is no doubt that it has the capability to solve the present storage problems as far as cereal grain storage in the tropics and developing countries are concerned.

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