

Full Length Research Paper

Design, development and techniques for controlling grains post-harvest losses with metal silo for small and medium scale farmers

Babangida Lawal Yusuf* and Yong He

College of Biosystems Engineering and Food Science, Zhejiang University, Hangzhou 310058, China.

Accepted 15 September, 2011

There are many challenges facing small scale farmers especially in Africa and other developing countries that lead to grains post-harvest losses. Amongst these are inadequate storage facilities, rodents, insects and birds. It was predicted that the world's population will increase to about 9.1 billion people by the year 2050 and most of this increase will occur in developing countries. Hence, the need of investing much to the agricultural sector is necessary in order to produce more food to feed the world. Furthermore, increasing agricultural productivity must go hand-in-hand with improved storage in order to reduce post-harvest losses. Promoting small scale agriculture is the key to achieving food security in developing countries. In this work, metal silo technology for small and medium scale farming was developed for more comfortable and effective grains protection. Air-tightness of the silo was achieved by adding rubber stopper under grains-inlet and discharge lids. Locking points on grains inlet and discharge covers with padlock was designed. Larger size of this silo was modernized to be mobile facilitated with wheels-metal-frame stand for easy repositioning, which replaced the ordinary method of concrete stands and pallets. Cheaper methods of grains moisture control, cleaning and safe emptying of the silo were also provided. Metal silo can be fabricated as cylindrical, square or rectangular prism in shape, also in different sizes of 50 to 3,000 kg holding capacity of grain such as rice, maize, wheat, guinea-corn, millet and beans.

Key words: Metal silo, small scale farming, food security, post-harvest losses, developing countries, Africa.

INTRODUCTION

The challenges faced by small and medium scale farmers in Africa and other developing countries includes lack of good seedlings, lack of fertilizers, inadequate storage facilities, animals and insect pest. Agriculture has been estimated for up to 60% of gross domestic product in some Sub-Sahara African countries, employs 70 to 90% of the population, 60 to 70% of consumption expenditure and 10 to 50% of foreign exchange earnings. Regardless of its importance, agricultural sector especially in Sub-Sahara Africa is poorly funded and less productive compared to the rest of the world (IFC, 2010). The developing countries representing over 80% of the world's population is estimated to have about 500 million

small farms, supporting around two billion people. In developing countries, three out of every four poor people live in rural areas and most depend on agriculture for their daily livelihoods (Sonnino, 2010). Furthermore, global population is expected to increase from current 6.8 billion to about 9.1 billion people by the year 2050, and most of this increase will occur in developing countries (WPP, 2008).

On the other hand, post-harvest losses has been estimated up to 20 to 30% for staple food grains such as maize due to post harvest, insect pests, inadequate grains storage practices and absence of storage management technologies. These problems often force small farmers into selling their produce immediately after harvesting when prices are low, only to buy it back at an expensive price just a few months after harvest, thus causing them to fall in a poverty trap (FAO, 2009; Tefera et al., 2011). Consequently, farmers receive low market

*Corresponding author. E-mail: byingawa@yahoo.com. Tel: 0086-571-88982143, 86971143. Fax: 0086-571-86971143.

prices for any surplus grain they may produce. The maize weevil (*Sitophilus zeamais*) known in the United States as the greater rice weevil, is one of the most serious cosmopolitan pests of stored cereal grain. Infestation by this weevil commences in the field but most damage is done during storage (Yuya et al., 2009). The damaged grains have reduced nutritional values, low percentage germination, reduced weight and low market price. The aforementioned challenges therefore need to be addressed by investing much on the agricultural sector in order to produce more food to feed the world. Furthermore, increasing agricultural productivity must go hand-in-hand with improved storage (in order to reduced post-harvest losses), value addition marketing and distribution (FAO, 2009).

Storage is part of farming system and is necessary for keeping and maintaining grains to ensure household food supply. The practices of traditional grains storages made of grass, wood and mud in developing countries cannot guarantee protection against major storage pests such as rodents, insects and birds. Hence, the metal silos technology established since 1980's for safe store and the technology was introduced by Swiss Co-operation in Central America. More than 230,000 small metallic silos from a half to two tonnes of capacity were introduced to prevent food losses. Since then, this technology is being used in many countries as a valid option of small and medium scale farmers for protecting stored grains against pests (Tefera et al., 2011). However, there is still need to improve these small metallic silos for effective grains protections. In this work, metal silo has been developed to achieve hermetical sealing for effective fumigation, rodent and insect pest control. Padlocking facilities to protect grain from children's reach or stealing has been added. Also, easy repositioning technology, affordability, cleaning and safe emptying of the silo were all considered in this work.

The importance and objectives of this research is to describe common methods to the small scale farmers on preventing grains post-harvest losses using metal silo technology. As we all know, small scale agriculture in particular is the key to sustainable growth and equitable wealth generation in the developing world (IFC, 2010). This work provide the methods to enable farmers store their grains safely so that the quality of the grain will be maintained up to the time of sale, processing for consumption or sowing for next season. This work also serves as manual that would help extension workers provide the best advice, information and transfer knowledge of basic principles of good postharvest practice to the farmers.

MATERIALS AND METHODS

This research was written based on longtime practical knowledge of small scale agriculture challenges such as animal pest, insect pest and grains storage problems. Many books, published papers and

articles describing the hardship and situations of small scale agriculture in developing countries were read and cited in this work. We particularly looked at the grains storage problems and then developed the metal silo technology for effective grains protection and postharvest losses reduction. This paper presents a new dynamic model design of mobile metal silo with complete air-tight and padlocking abilities for small and medium scale farmers. This work will also contribute to the eradication of hunger and poverty alleviation in developing countries.

Metal silo structure and technology

The metal silo technology is an effective method of reducing grains post-harvest losses for small and medium scale farmers. This technology provides grains protection for both short and longtime storage against pathogen damage, animal and insect pest. Generally, metal silos are made of galvanized steel sheet of varying thickness and fabricated in different sizes as cylindrical, square or rectangular prism in shape. The Galvanized-steel is steel that has been coated with thin layers of zinc to prevent it from corrosion or rusting. Zinc act as a barrier against the environment and sacrificially corrode to provide cathodic protection (Simões et al., 2011). Moreover, metal silos can be aluminum painted for additional protection of the sheet against corrosion and improves silo's appearance.

However, without proper design and construction, improved storage technologies and methods cannot be achieved successfully. Table 1 shows the rice average losses in developing countries that have been estimated to be 4.5% of the world's rice production in the year 2000 and 2001, resulting from bad storage practices and causing a loss of around US\$20 billion (Mejia, 2003). The annual postharvest losses of maize calculated at Arusha, Tanzania in the year 2007 was up to 22.2%, of which 8.8 to 10.5% out of this estimate were caused by the storage. Table 2 shows the total percentage of grains post-harvest losses estimates for Eastern and Southern African countries from year 2003 to 2008. The grains lost include maize, barley, wheat, sorghum, millet, rice, teff, fonio, rye and oats. Also the types of postharvest losses include harvesting, field and platform drying, threshing and shelling, winnowing, transport to farm and home, transport to market, farm and market storage (Rembold et al., 2011).

Factories and Industrial grain silos especially in developed countries are already been organized with computer system, electrical loaders and dischargers, moisture sensors, grain level sensors, cameras, dryers and aerators (Isiker and Canbolat, 2009). Of course, small metallic silos too can be facilitated like that, but they will be very costly as poor or small scale farmers cannot afford it even though we noticed that our current metal silos for small scale farming needs to be improved due to some deficiencies in food protection. Areas needed to be improved include grain inlet and discharge covers for hermetical sealing ability, padlocking capabilities, safe emptying and moving silo from one place to another. This new metal silo has been designed to provide effective grains protection that people would benefit from, especially those in rural areas. This metal silo will also serve as another source of incomes, since it can be fabricated even *in-situ* by local tinsmiths or welder without many difficulties.

Design and development of metal silo

Mobility

Promoting small scale agriculture in developing countries is the key to achieving food security. Also provision of mobile storage is one of the solutions to grains postharvest losses problem (FAO/WB, 2010). Metal silo has been developed and designed to be mobile,

Table 1. Rice average losses in developing countries which was estimated to 4.5% of the world rice production year 2000 and 2001, resulting from bad storage practices and cause loss of around US\$20 billion.

Description	Estimate	Million-tons (Mt)
World rice production	100%	585
World rice production in developing countries	90%	526
World production by small and medium farmers (assuming 80% in developing countries)	80%	421
Expected world rice production without storage losses	100%	441
Expected world rice production	95.5%	421
Losses only during storage	4.5%	20
Economic losses as a result of poor storage	Assuming a cost of 100-US\$/t	US\$20 billion

Source: (Mejia, 2003).

Table 2. Estimated post-harvest losses of the total annual productions for cereals year 2003 to 2008 for East and Southern African countries, viz: Angola, Botswana, Burundi, DR Congo, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Rwanda, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

Year	2003	2004	2005	2006	2007	2008
Postharvest losses percentage (%)	17.0	14.4	14.3	14.8	15.1	17.4

Source: (Rembold et al., 2011).

provided with four wheels square metal frame-stand with supports of metal-angles, columns, bars and ring-beams. This replaced the local method of building fixed concrete stands, wooden or metal pallets supports for the flat bottom silos. Also, since the metal silo can last for more than 15 years if properly maintained, the wheels have been designed for repositioning the silo easily if the need arises, as demolishing and rebuilding concrete stands in order to adjust its position is not the economical method. Also in case of pallets, is not so easy to move the silo to another place whether it is empty or loaded with grain.

Figure 1 shows the side view diagram of cylindrical mobile metal silo for small scale farming. The given dimension can contain 600 kg of grains like rice, maize, wheat, guinea-corn, millet and beans. Metal silo can be produced in different sizes, 50 to 3,000 kg holding capacity of grains, although, this depends on the area and the people's needs (Mejia, 2003). Mobile metal silo has been provided with a hook as a dragging point or to be towed slowly by a vehicle. Wheels will be optional for smaller sizes of these silos, as they could have metal frame stand only. In order to avoid accident of falling down of the silo, it is better to construct mobile metal silo as "wider enough" than constructing it "very tall with small diameter" (Figure 1). The wheels frame and bottom of the silo should not be however, very high from the ground level. Also in order to avoid sinking in the ground, the wheels too will be as wider as possible depends on the size of the silo. If it seems or realizes that wheels are not so important, it could be on metal stand frame only.

Hoppers of the mobile metal silo

Top and bottom concentric hoppers of the cylindrical mobile metal silo are truncated cones in shape and they are of great importance. Silo with flat top may have the risk of getting downward deflection during grain loadings and if rainwater incidentally drops on top this may stay and further cause problem. Likewise silo's bottom hopper too with concentric discharge is very important while emptying, since the grain is being discharge by the pressure due to gravity (Isiker and Canbolat, 2009). Grain in the flat bottom metal silo

cannot be completely discharged without tilting or lifting one end of the silo, which may cause the silo to buckle, crack, twist, deflect or bent-in from the bottom. Figure 2 shows an example of redundant grain at an area X, Y and Z position in the silo. This grain may remain there even several when loading and discharging occurs, until silo is lifted to some angles at which point X move up to point X1 and point Z move down to point Z1.

The hopper angle should be between 15 to 30° from horizontal plane and the discharge point should be a pipe intersects with truncated cone at apex. Both grains inlet and discharge should be concentric with a silo center. The discharge point should not be directly vertically downward but inclined at an angle of 8 to 15° from horizontal plane, (Figure 1). The reason for inclination of the discharge point is to reduce grain pressure and have full control of grain during discharge (Pablo et al., 2005). While for square or rectangular prisms mobile metal silos the hoppers are going to be four sided pyramid frustum in shape. Also the grain inlet and discharge should be concentrically with silo center if possible.

Silo covers with rubber-stoppers

The small metallic silos for keeping grains mostly for home consumption, are fully welded sealed structures for protecting grain against rodent and insects pest attacks (Tefera et al., 2011). If silo is not properly sealed, losses of the stored grain can be very high. Technically, without rubber stopper under the covers, metal silo is not completely airtight because there must be a slight gap between the body of the silo and the lids, and through this gap the surrounding air may diffuse in and out of the silo which is dangerous to the stored grain. In order for the silo to provide perfect protection of grain against rodent and insects pest attacks, hermetic sealing is necessary. The cheaper and economical method for doing that is by adding rubber-stopper under the silo's grain inlet and discharge covers, which works perfectly during fumigation and longtime grain storage.

Figure 3 shows the sectioning view of rubber stopper compressed in-between the silo lid and silo top edge of the grain Inlet

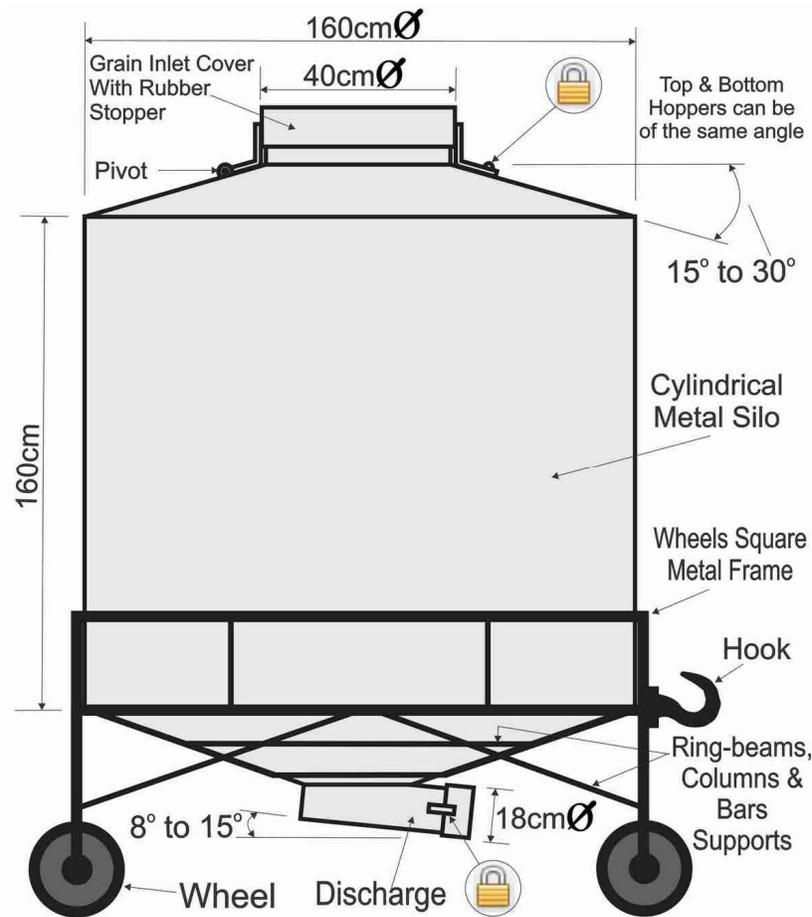


Figure 1. Side view of the cylindrical mobile metal silo.

opening for achieving hermetic sealing. The basic principle of hermetic grain storage is elimination of oxygen in conjunction with an increase in carbon dioxide within the storage atmosphere, thus disrupting the respiration of insects, fungi and grain. Therefore, all the insects will die when the air in the storage is reduced to 3% oxygen or less. Also the fungal development ceases when the oxygen level decreases to 1% (Quezada et al., 2006). Once this special airtight silo has been closed the grain is in confined and controlled atmosphere.

Padlocking the silo

Fastening facility with padlock at both grain-inlet and discharge has been designed in this metal silo development. This will improve the security and prevent the grain from children's reach or stealing. Figure 3 shows the silo cover which is design to turn on a pivot or hinge, while at the opposite side of the hinge is the locking point. The covers can be designed in different ways and shapes, but it is very important to have rubber stoppers under it and padlocking facilities.

Comparisons of silos

It is generally recommended to fabricate cylindrical silos than square and rectangular silos. It has been estimated that in terms of

structural cost per ton of storage, cylindrical silos are generally more economical than rectangular or square silos. Cylindrical silo has fewer joints compare to rectangular silos that have joints at all the corners between its sided walls including bottom and top. Hence, the risks of having holes, cracks or other welding or soldering defects in joints are less in cylindrical silos.

Grain exerts pressure on the body of the structure which contains it. Cylindrical silo will resist this pressure through the circumferential stress and development of hoop tension forces, which are very efficiently resisted. However, a rectangular silo must resist grain loads through the development of bending stresses that are less efficiently resisted than tensile loads, since both tensile and compressive forces have to be resisted. Hence, cylindrical silos resist more circumferential stresses than squares and rectangular silos (GASGA, 1994). The roof structure of a square or rectangular silo has to carry its loads in bending, compared to the roof structure of a cylindrical silo which can be designed as a shell (for example a cone), which carries its loads in direct compression and tension.

Moreover, in cylindrical silo with concentric grain-inlet and discharge on top and bottom hoppers respectively, grains are loaded and unloaded through the center, so the grain pressure balance is obtained on silo wall (Isiker and Canbolat, 2009). However, the circumferential loading of any mechanical body must be kept well below the yield strength of that material. The information on how to construct flat bottom cylindrical small metal silos, materials and tools needed were all provided by the AGST department of FAO of the United Nations (AGST, 2005).

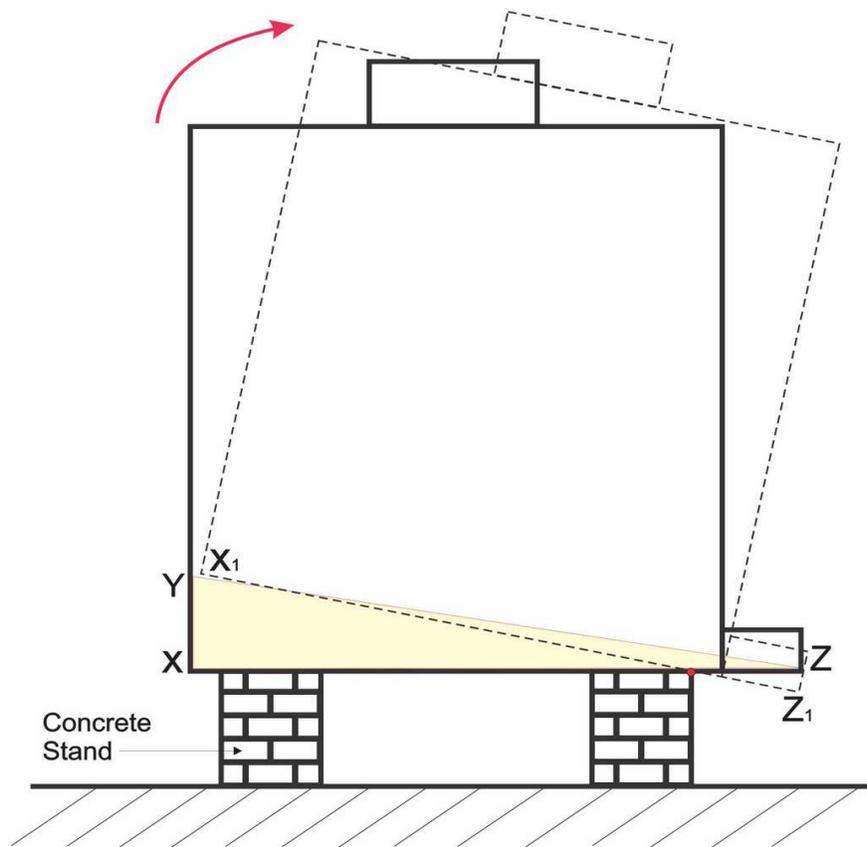


Figure 2. Lifting one end of the flat bottom metal silo for emptying; the dotted represent the silo's image when it is lifted.

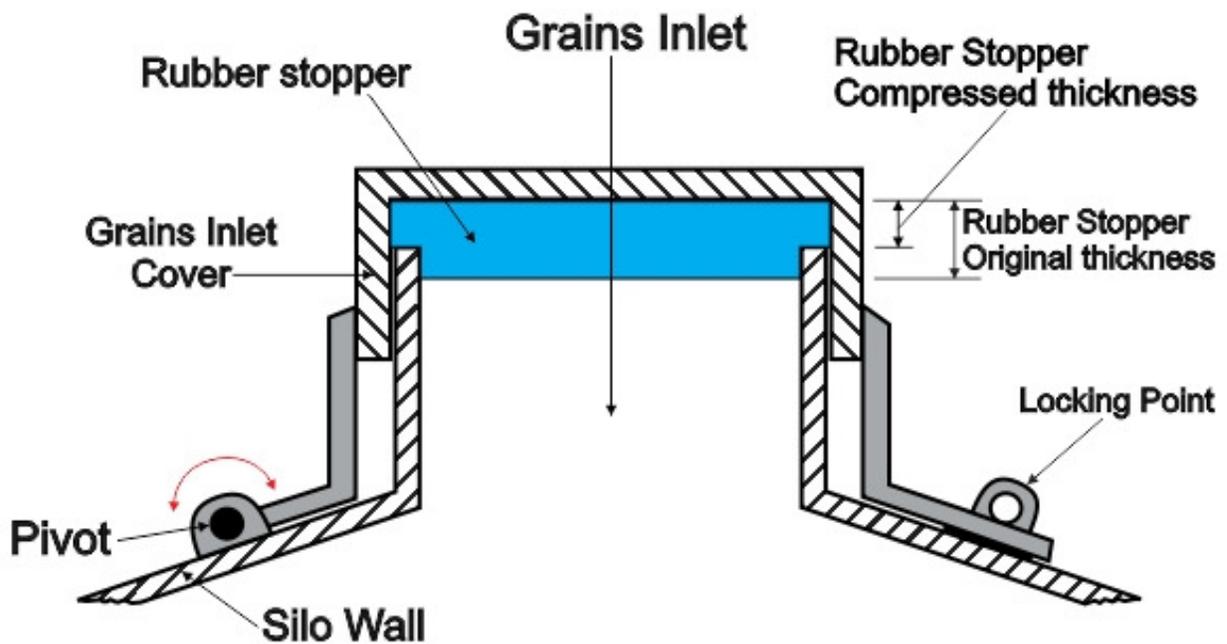


Figure 3. Section view of rubber stopper compressed in-between silo grain inlet cover and silo top edge of grain inlet opening. The same techniques can be applied to the discharge lid for achieving hermitical sealing.

Table 3. Household metal silo varying capacity and production cost in 11 selected countries under the FAO sponsored projects (in US\$). The cost includes materials, labour and depreciation of equipment only. The cost of utility, transportation of silo to destination and other costs are not included.

Country	120 (kg)	250 (kg)	500(kg)	900 (kg)	1800 (kg)
Afghanistan	-	28	70	-	92
Bolivia	20	35	60	-	-
Burkina Faso	26	29	42	56	70
Cambodia	12	20	30	-	50
Chad	-	66	97	128	187
Guinea	-	-	59	-	70
Madagascar	-	40	50	70	100
Malawi	-	22	45**	60***	-
Mozambique	20	34	54	75	-
Namibia	-	-	22*	-	-
Senegal	23	42	60	76	100

* A silo of 400 kilos, ** A silo of 700 kilos and *** A silo of 1000 kilos. Source: (AGST, 2008).

Cost of the mobile metal silo

The mobile metal silo may cost slightly more than the price of ordinary flat bottom metal silo or they may be the same. What has been added in mobile metal silo is the rubber-stopper under the grain covers, padlocking point and then changed the flat top and bottom to hoppers. The price increase due to these may even be neglected because it is very small. The wheels metal frame stand will not be included as the reason for cost increase, since it is the replacement of building concrete stands, wooden or metal pallet. The storage cost per kilo of grain falls as silo capacity increases. Table 3 shows the production costs of ordinary metal silos in the eleven selected countries under the FAO sponsored projects. The cost includes materials, labor and depreciation of equipment only; the cost of utility, transportation of silo to destination and other costs are not included. Although the costs vary according to the circumstances in each country or region, the prices are generally affordable (AGST, 2008).

Moisture control for safe storage

The condensation in metal silo can occur only if the air temperature drops below its dew point. It may likely be the that air in the top space above the grain level experience rapid change in temperature especially if there is large space, for example at the night time. As the grain itself being excellent heat insulator, temperatures within the grain mass will only change very slowly, and cooling rates can be rapid with steel surfaces. However, the air inside the silo will lose its heat mainly through convection which will be much slower and the change in grain moisture content will be very small. So, even if condensation will occur the amount of water that would be deposited would be extremely small and remains very low provided the silo is sealed perfectly (GASGA, 1994).

The experienced users of metal silos from Australia suggest that problems with condensation do not occur in fully-sealed stores. The condensation risk in sealed small metal silos is very limited compare to unsealed silos, as far as the grain stored is at safe storage moisture content level. The moisture contents are mostly below 14% for grain and preferably 12% or less for seed and extended storage period (Imoudu and Olufayo, 2000; Mejia, 2003).

Determination of the grain moisture level

Drying of the grain is the first step also necessary for effective and

successive storage. If drying is not properly done, losses can be as high as 100%. Sun drying of grain is the most common and cheapest drying method in developing countries. The drying period or drying time mostly depends on the grain type and weather conditions. The recommended grain moisture content level for safe storage must be less than 14% (Fields and Korunic, 2000). Mostly, in developing countries, farmers expose their grains at yard on concrete floor, tarpaulin or agricultural by-products mats for sun drying (Imoudu and Olufayo, 2000). Spreading grains on bare ground is however, not advisable because there is humidity in the soil, and also grain will be gathered with some foreign matters like gravels and dust. Most of small farmers in Africa depend on traditional methods of testing grain dryness by touching with hand, breaking some of the grains and observing it by their eyes.

There are cheap and new methods that will help small farmers to ascertain the dryness of their grain before storing. Among the methods includes grain moisture testers and using ordinary weighing scale to determine the perfect dryness of the grain. These methods are supposed to be introduced to small farmers through farmer's organizations, information centers if available or through heads of the villages at rural areas.

Grain moisture tester

There are many types of grain moisture testers in the market today like the digital and analog, operating on electricity, rechargeable battery or single-use size AA batteries, which are easy to replace even at rural areas. Some of those grain moisture testers are not so expensive and if explained once even an illiterate would be able to use it. Figure 4(a) shows an example of one of these grain moisture testers manufactured by International Rice Research Institute. It has analog needle-pointer and three different colors range readings.

The steps for using this moisture meter appropriately includes switching on the tester, pressing the reset button, putting some grain in the testing chamber of the tester and tightening the knob well by hand. If the needle-pointer is in the blue range, this means the grain is equal to or less than 12% moisture content which is safe for seed and longtime storage. When the needle-pointer is in the green range, this means the moisture content is between 12 to 14%, which is also safe for storage. However, if the needle-pointer is at red range or at end of the scale, this means the grain is too wet and needs to be dried before storing (IRRI, 2005). There are many types and models of grain moisture testers that could help and assist for safe storage, but many small farmers do not even

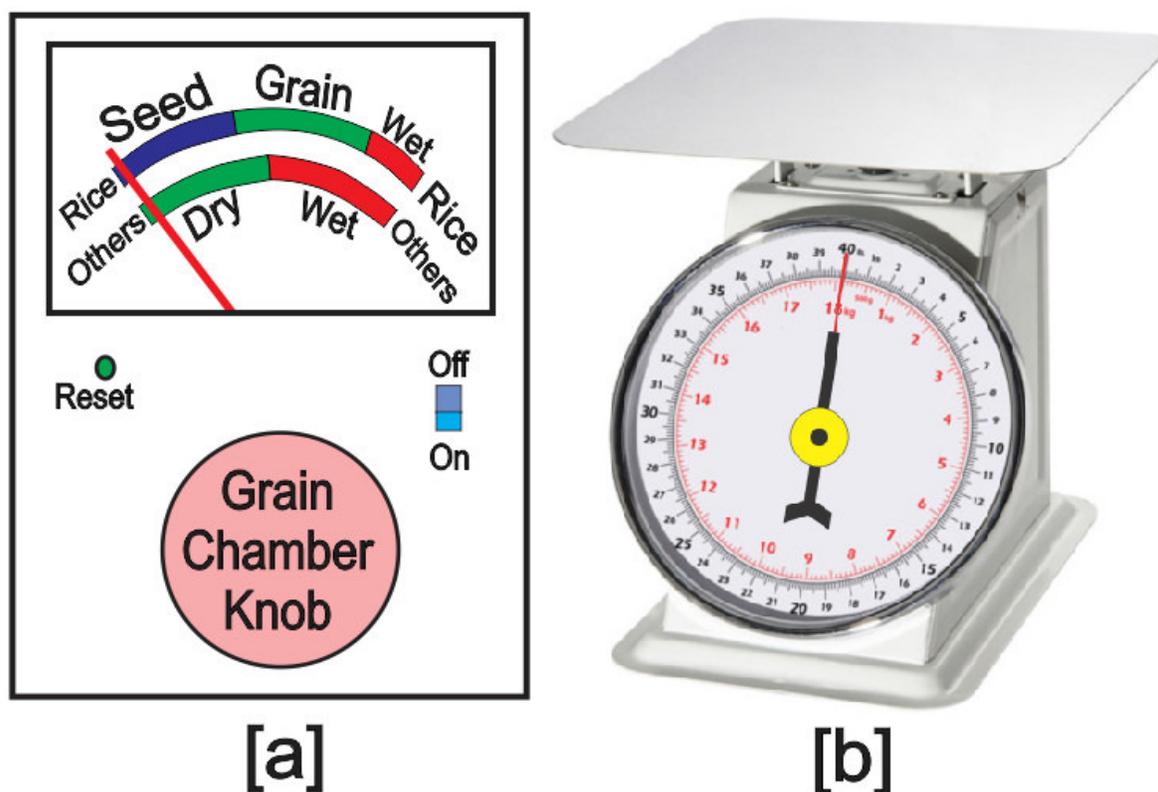


Figure 4. (a) Grains moisture tester diagram; If the needle-pointer is in the Blue range means the grain is $\leq 12\%$ moisture content. If the pointer is in the Green range, the grain is 12 to 14% moisture content, if the pointer is at Red range, the grain is too wet to store. (b) Table dial weighing scale for testing grain weight.

have information about them.

Weighing scale for testing dryness of the grain

Using digital weighing scale or ordinary dial weighing scale both table and suspended, is the easier and cheaper method of testing, determination and ensuring perfect dryness of the grain. Figure 4(b) shows an example of table dial weighing scale which is more available than grain moisture meters at rural areas especially in Africa. There are electrical weighing scale and batteries size AA operating ones, which is better for areas with no electricity or at drying yard. It is suggested to use digital weighing scale either electrical or those operated with batteries because the results can be in up to three significant figures, for example 3.574 kg. But if there is no digital weighing scale the dial one can be used; just make sure to take any larger and smaller readings accurately. Although, in this method we cannot know the exact percentage of the moisture content in grain as in the case of grain moisture meter.

In carrying out this procedure, the grain is first dried until expected; some part of it is then carried in a container as a sample for testing dryness and measured. The samples are then taken back to the drying place or drying yard and not mixed with rest of the grain, but rather spread at one side. This is continued drying until the following day or at any specific time, then samples weight are tested again and results written down as testing two. Compare the results, if it is the same as last test, this means the grain is well dried, but if it is less than that it means still the grain needs to continue drying. Drying and testing the weight of the same samples

will continue until the same results are achieved for the two-time test. This means that the grain is perfectly dried (all the water is out, no more loss in weight) and now is ready for storage.

Moreover, the following precautions should be noted; it is important to use 3 kg or more for grain samples in order to see clearly if there is any loss in weight. During testing and drying make sure that no adding or loss of even single grain from the samples, for the best result. Dry the samples at the same place with main grain. Don't spread some part of the main grain or samples under the shadow and some part of it in sunshine. Try to spread the samples at the same depth with the main grain approximately 2 to 5 cm, so that their dryness will be uniform. When sun drying the seed, grain should be turned more often and not exposed to temperatures above 42°C (Imodu and Olufayo, 2000), if high temperatures occur, the seed should be dried in the shade. Use the same weighing scale, the same nylon bag or container of the samples throughout the experimental tests.

Calculating moisture content of the grain

Moisture content (MC) is the weight of water contained in the grain expressed in percentage (%) and is usually referred to the wet basis, which is the total weight of the grain including the water (MC_{wb}). Also for the research, moisture content referred to the dry matter of the grain is sometimes used as (MC_{db}). Moisture content testing is very important in managing and marketing grains, and inaccurate tests leads to spoilage and losses. The following formulas were used:

Table 4. The amount of phosphine tablets to be used in fumigation, which is depends on the silo capacity not the amount of grain deposited inside the silo.

Silo capacity (kg)	180	225	360	800	1,360
Amount of tablets used	1	1	2	4	6

Source: (Postcosecha, 2007).

$$MC_{wb} = \frac{m_i - m_f}{m_i} * 100$$

and

$$MC_{db} = \frac{m_i - m_f}{m_f} * 100$$

Where, MC_{wb} is the moisture content wet basis (%); MC_{db} is the moisture content dry basis (%); m_i is the initial weight (g); m_f is the final weight (g)

Loading and safe keeping of the metal silo

The silo must be clean both inside and outside, check and make sure there is no any hole on the body of the silo before loading anything in to it, and loads only dried grains of the recommended moisture level (AGST, 2008). Silos must be placed under a roof or cover to protect it from the rain and solar heat radiation, which may cause grain quality degradation if exposed to the sun for the period of months or years. Metal silo is not supposed to be in contact with wall (especially mud walls during rainy). Also, heavy object is not supposed to be kept on top of the metal silo.

In case of mobile metal silo, it must be wedged properly while at stationary to avoid any accident that may happen from moving. When loading for the tall silo, it is better to climb on chair, table, stand-alone or dual ladder, than to lean the ladder on the body of the silo. However, silos should be loaded and unloaded through the center in order to obtain a balanced grain pressure on silo walls, hence Isiker and Canbolat (2009) thus recommends cylindrical metal silo with concentric grain inlet and grain discharge. It is advisable to give up or exchange the grain stored for the period of one to two years with new harvested one (Marks and Stroschine, 1995).

Fumigation

Fumigation is the application of a gas or smoke to something for the purpose of disinfecting it. Fumigating the metal silo immediately after loaded with perfectly dried grain is very important. The tablet or pills use for this process has many commercial names like aluminum phosphide, phosphine, phostoxin and detia (Rajendran and Muralidharan, 2001). In every silo capacity of 180 to 225 kg one tablet in an open container will be placed on top of the grain. The container can be tight or attached with a rope, which will make it easy to gather the dust after fumigation. Table 4 shows the amount of phosphine tablets to be used in fumigation, which is depends on the silo capacity not the amount of grain deposited inside the silo (AGST, 2008; Postcosecha, 2007).

Once the tablets or pills of phosphine are opened in the silo it produces gas known as phosphine or hydrogen phosphide and this

product must be used under hermetic conditions. Mostly, it takes 10 days time to achieve a concentration of the gas that is high enough to eliminate the weevils at all stages of development, then at day eleven the dust of the aluminum phosphide could be removed (Rajendran and Muralidharan, 2001; Tefera et al., 2011). Using rubber stoppers under the silo covers will help to achieve complete air-tightness, so that the fumigation gas will not escape. If silos do not have rubber stopper lids, quality nylons can be used to wraps the covers and then bicycle-tubes or adhesive tapes used to achieve air-tightness.

RESULTS

Small metallic silos technology has already been proven in many countries as effective solution and efficient method of reducing post-harvest grain losses. This technology helps strengthen food security in communities, as it provides daily livelihood and economic support for small scale farmers. It was estimated that more than two million people are currently being benefited with this technology in Central America. Also an FAO project in Bolivia on the prevention of food losses, introduced successfully more than 20,000 small metallic silos. Likewise, the FAO has successfully introduced 45,000 metal silos to 16 countries through Projects in the period of 1997 to 2007. The countries are Afghanistan, Bolivia, Burkina Faso, Cambodia, Chad, Ecuador, Guinea, Iraq, Madagascar, Mali, Malawi, Mozambique, Namibia, Panama, Senegal and East Timor (Tefera et al., 2011).

The most important advantages and benefits of metal silo include reducing losses to virtually nil in terms of storage, holding from 50 to 3,000 kg of grain, maintaining the quality of stored grains and avoiding the use of insecticides. Metal silo requires small space and can be placed in a home or at farm. This technology also affords the farmer protection from seasonal fluctuations in grains prices. The current development of metal silo in this work, made it mobile and completely airtight to permit effective non-residual fumigation, and to prevent rodents and other pests that can harm consumer health. Metal silo is inexpensive and can last for more than 15 years if properly maintained. Although, costs of metal silos vary according to the circumstances in each country or region, in general, the prices are reasonable and affordable. Table 5 shows the result of the interview with farmers in Bolivia on how they consider the price of the household metal silo, of which 59% of the participants consider it cheap (AGST, 2008). Even though, metal silos could be fabricated in mass quantities either by the governments or other organizational bodies, it will be cheaper as

Table 5. Result of the interview with farmers in Bolivia on how they consider the price of the household metal silo, of which 59% of the participants consider it cheap.

Cheap	Normal	Expensive	Quite expensive	No reply
59%	17%	14%	8%	2%

Source: (AGST, 2008).

everyone can use it.

The metal silo is a simple storage technology and is relatively easy to implement and helps preserve good quality grains and cereals. It is generally recommended to store grain for consumption in larger silos and seeds for sowing in small metal silos. This will allow the grain to retain its colour and germination capacity better than seed kept in jute or plastic bags (AGST, 2008). Good storage of seeds will help and contribute to have good crop next season. Also, healthy grain (non-cracked or broken grain) can be kept in the storage longer than the broken ones. The hard and dry seed-coat with no cracks or splits in it prevents molds and insects from getting into the kernel easily. Using metal silos will also reduce the conflicts between farmers and herders in Africa, which is sometimes due to cattle-herd destroys the farmer's local silos and eats up all the grains inside. In addition, postharvest loss reduction will increase grain supply and food security without wasting other resources such as land, labour, water and inputs. Also, this will create more employment and income opportunities through processing and marketing, as well as reducing labour costs in developing countries. If post-harvest losses are reduced, the world food supply can be increased by more than 30% without cultivating additional hectares of land or increasing any additional expenditure on seed, fertilizer, irrigation and plant protection measure to grow the crop (FAO/WB, 2010).

DISCUSSION

Growth in agriculture will make positive contribution to poverty reduction in developing countries since more than half of the populations in these countries live in rural areas where poverty is extreme. A large number of African farmers are illiterate and lives in areas where there is lack of basic infrastructure such as adequate electricity supply, telephone, tap water and good road network (Aina, 2007). In many agricultural systems of Sub-Saharan Africa, traditional land preparation and weeding are labour intensive. Indeed there is a general lack of support for small scale agriculture in much of sub-Saharan Africa, such that there are actually economic disincentives to investment in agriculture (Giller et al., 2009). Small scale farmers in developing countries are negatively affected by higher food prices because they buy more food than selling. Even those that can sell their surplus production are not able to take advantage of new

price incentives quickly enough, as they are often not well connected to markets. Also there is lack of financial and technical capacity to expand their production rapidly. It is therefore necessary to improve agriculture in developing countries including both conservation agriculture and natural resource management, as human population continues to increase rapidly especially in developing countries (WPP, 2008).

Small scale agriculture has the potential to contribute to food security in Africa and the rest of the developing countries. Reducing poverty and improving people's lives is by promoting rural economic policies, such as providing loans to small scale farmers' through farmers organizations or farmers groups and forming farmers information centers. Through these information centers, small and medium scale farmers can be informed with new farming technologies and share different experiences and ideas together. Although, every year there are efforts for giving out loans to farmers by governments and other international financial institutions that provides loans to developing countries, such as World-Bank and African Development Bank (AFDB), small scale farmers do not however benefit from these because the loans do not actually get to them.

Furthermore, modern farming methods and technologies such as using combine machine, global positioning system (GPS) and geographic information system (GIS) are supposed to be put into practice in all of the developing countries. There is therefore need for additional effort on awareness campaign at rural areas especially in Africa on modern farming technologies and procedures for keeping foods in easier methods, such as metal silos technology. If small farmers are able to produce large quantity of foods which will be enough for them to eat and also to sell out some to cover other costs like clothing, medicine and school fees for their children, definitely migration from rural areas to cities or even from developing to developed countries will be reduced. Consequently, foods will be cheaper in the cities, and even offences like robbery and terrorism that is happening in many parts of developing countries will be reduced.

Conclusion

Metal silo has the great potential impact on hunger eradication and poverty reduction since farmers who used to sell their surplus grain immediately after harvesting when

prices are low, are now able to store their produce until the market price is higher. Practically, hermetic grain storage offers the only hope for an effective, cost-efficient and chemical-free insect control especially at rural areas in developing countries. Small metallic silos also serve as another way of incomes, since it can be fabricated even *in-situ* by local tinsmiths and welders.

Acknowledgment

This study was supported by the Fundamental Research Funds for the Central Universities, Zhejiang Provincial Natural Science Foundation of China (Y3100205), Open Foundation of Zhejiang Key Lab of Exploitation and Preservation of Coastal Bio-resource (J2010001), and Natural Science Foundation of China (31072247).

REFERENCES

- AGST (2005). Technical Manual for the Construction of Small Metal Silos, by Agricultural and Food Engineering Technologies Service (AGST), FAO of the United Nations. <http://www.fao.org/fileadmin/templates/inpho/documents/ae616e.pdf> (accessed 09-Aug-2011).
- AGST (2008). Household metal silos, key allies in FAO's fight against hunger, by Agricultural and Food Engineering Technologies Service (AGST), FAO of the United Nations. Viale delle Terme di Caracalla 00153 Rome (Italy) http://typo3.fao.org/fileadmin/user_upload/ags/publications/silos_E_light.pdf (accessed 08-Aug-2011).
- Aina DLO (2007). Globalisation and Small-Scale Farming in Africa: What role for Information Centres? World Library and Information Congress: 73rd IFLA General Conference and Council, 19-23 August 2007, Durban, South Africa. <http://archive.ifla.org/IV/ifla73/papers/120-Aina-en.pdf> (accessed 12-Aug-2011).
- FAO (2009). FAO Main Message on Africa: Policy Options to Expedite Implementation. The Commission on Sustainable Development Seventeenth Session (CSD-17), Intergovernmental Preparatory Meeting for CSD-17, 23-27 February 2009, New York. http://www.un.org/esa/dsd/resources/res_pdfs/csd-17-ipm/26february/PM/FAO.pdf (accessed 05-Aug-2011).
- FAO/WB (2010). FAO/World Bank workshop on reducing post-harvest losses in grain supply chains in Africa, FAO Headquarters Rome, Italy 18-19 March 2010 http://www.fao.org/fileadmin/user_upload/ags/publications/FAO_WB_ph_web.pdf (accessed 05-Aug-2011).
- Fields P, Korunic Z (2000). The effect of grain moisture content and temperature on the efficacy of diatomaceous earths from different geographical locations against stored product beetles. *Stored Prod. Res. J.* 36(2000):1-13.
- GASGA (1994). Grain storage techniques, Evolution and trends in developing countries. Group For Assistance On Systems Relating to Grain After Harvest (GASGA), FAO of the United Nations Services Bulletin, Version 109, Job No. T1838, Rome, 1994. <http://www.fao.org/docrep/T1838E/T1838E00.htm> (accessed 09-Aug-2011).
- Giller KE, Witter E, Corbeels M, Tittonell P (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Res. j.* 114(1): 23-34.
- IFC (2010). Building sustainable small-scale agriculture in southern Africa, by International Finance Corporation of the World Bank group, Regional agriculture and food security forum, held in Livingstone, Zambia, April 6-9, 2010. [http://www.ifc.org/ifcext/africa.nsf/AttachmentsByTitle/IFC_Agriforum_Report/\\$FILE/IFC_Agriforum_Report.pdf](http://www.ifc.org/ifcext/africa.nsf/AttachmentsByTitle/IFC_Agriforum_Report/$FILE/IFC_Agriforum_Report.pdf) (accessed 04-Aug-2011).
- Imoudou PB, Olufayo AA (2000). The effect of sun-drying on milling yield and quality of rice. *Bioresour. Tech.* 74(2000): 267-269.
- IRRI (2005). Introducing the farmer-friendly moisture meter, by Agricultural Engineering Unit of International Rice Research Institute's (IRRI). http://beta.irri.org/networks15/index.php?option=com_content&view=article&id=128%3Aintroducing-the-farmer-friendly-moisture-meter&Itemid=160 (accessed 10-Aug-2011).
- Isiker H, Canbolat H (2009). Concept for a novel grain level measurement method in silos. *Compt. and Electr. in Agric.* 65(2): 258-267.
- Marks BP, Strohshine RL (1995). Effects of Previous Storage History, Hybrid and Drying Method on the Storability of Maize Grain (Corn). *J. Stored Prod. Res.* 31(4): 343-54.
- Mejia DJ (2003). An overview of rice post-harvest technology: use of small metallic silos for minimizing losses, FAO Proceedings of the 20th Session of the International Rice Commission Bangkok, Thailand, 23-26 July 2002. <http://www.fao.org/docrep/006/y4751e/y4751e00.htm> (accessed 05-Aug-2011).
- Pablo V, Manuel G, Francisco A (2005). Analysis of Dynamic Discharge Pressures in Cylindrical Slender Silos with a Flat Bottom or with a Hopper: Comparison with Eurocode 1. *Biosys. Engr.* 91(3): 335-348.
- Postcosecha (2007). Phosphine Fumigation of silo. POSTCOSECHA - Spanish for "post-harvest" programme. http://www.postharvest.ch/resources/sharewebResource_en_1180.pdf (accessed 12-Aug-2011).
- Quezada M, Moreno J, Vazquez M, Mendoza M, Mendezalbores A, Morenomartinez E (2006). Hermetic storage system preventing the proliferation of *Prostephanus truncatus* Horn and storage fungi in maize with different moisture contents. *Postharv. Biol. Tech.* 39(3): 321-326.
- Rajendran S, Muralidharan N (2001). Performance of phosphine in fumigation of bagged paddy rice in indoor and outdoor stores. *Stored Prod. Res. J.* 37(2001):351-358.
- Rembold F, Hodges R, Bernard M, Knipschild H, Léo O (2011). An innovative framework to analyse and compute quantitative postharvest losses for cereals under different farming and environmental conditions in East and Southern Africa, by African Postharvest Losses Information System (APHLIS). <http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/1/5877/1/lbna24712enc.pdf> (accessed 07-Aug-2011).
- Simões AMP, Carbonari RO, Di Sarli AR, del Amo B, Romagnoli R (2011). An environmentally acceptable primer for galvanized steel: Formulation and evaluation by SVET. *Corr. Sci.* 53(1): 464-472.
- Sonnino DA (2010). Global Food Security and the Possible Contribution of Agricultural Biotechnologies: Keynote address for REDBIO, FAO Rome, Italy, 1st November 2010. www.fao.org/biotech/docs/redbio2010e.pdf (accessed 04-Aug-2011).
- Tefera T, Kanampiu F, De Groote H, Hellin J, Mugo S, Kimenju S, Beyene Y, Boddupalli PM, Shiferaw B, Banziger M (2011). The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Prot.* 30(3): 240-245.
- WPP (2008). World Population Prospects: The 2008 Revision. UN Department of Economic and Social Affairs, Population Division. http://www.un.org/esa/population/publications/wpp2008/wpp2008_highlights.pdf (accessed 05-Aug-2011).
- Yuya A, Tadesse A, Azerefegne F, Tefera T (2009). Efficacy of combining Niger seed oil with malathion 5% dust formulation on maize against the maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae). *Stored Prod. Res. J.* 45(1): 67-70.