Nigerian Research Journal of Engineering and Environmental Sciences 5(2) 2020 pp. 614-625

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Computer-Aided Assessment of Operations of Metal-Silo Storage Facilities in Nigeria

***[1]Olorunfemi, B.J. and [2]Kunle, O.K.**

[1]Department of Mechanical Engineering, Federal University Oye Ekiti, PMB 373, Oye Ekiti, Ekiti State, Nigeria.
[2]Department of Food Science and Technology, Federal University Oye Ekiti, PMB 373, Oye Ekiti, Nigeria.
*bayode.olorunfemi@fuoye.edu.ng

ARTICLE INFORMATION

Article history:
Received 05 Nov, 2020
Revised 19 Nov, 2020
Accepted 20 Nov, 2020
Available online 30 Dec, 2020

Keywords:
Computer-aided
Assessment
Grain
Storage
Losses

ABSTRACT

Assessment of the use of Metal silo storage facilities in Nigeria was carried out and problems associated with its uses in grain storage. This study identifies the bottlenecks and introduces the use of computer-aided system for managing storage facilities in the country. Questionnaires were administered to 50 metal-silo grain operators, government storage officials, grain merchants, grain farmers and silo managers. The data were analyzed quantitatively and qualitatively using the Statistical Package for the Social Sciences (SPSS) version 10.0. A software was developed to handle the maintenance procedures of all metal silo facilities. The software developed had three major sections: the user interface was developed using Dreamweaver 8, coding section was developed using Pre-Processor Hypertext Programme (PHP) higher programming language code, and Database was developed using MySQL. Results showed that problems reported varied from moulding (45%), insect infestation (33%), chemical contamination (34%), caking (20), rusting (20%), grain escape (16%), and electrical failure that occur in metal silos under review. Conditions of grains before storage affect its storage system. Coupled with poor management of grains in metal-silo have overall economic effect on the storage handling facilities Paired samples test showed probability level having significant difference (0.01 < 0.05) when the application of software was compared with previous procedures. The software provides a quick reminder when action is designed to take place. Losses was reduced from > 5% to a tolerable level of < 1% and a reduced maintenance cost. Computer-aided management will ensure efficient maintenance of installed grain equipment thereby saving cost.

© 2020 RJEES. All rights reserved.

1. INTRODUCTION

World population has been predicted to be more than 9.1 billion by year 2050, with the population of developing countries including Nigeria put at 8 billion (Mbata, 2013). In order to meet up with food requirement, production will have to increase by over 70% (Silva, 2018). In 2016, 36 percent of cereals produced globally was fed to animals. Substantially more cereal production will be needed to feed livestock in 2050 (Mbata, 2013). In spite of the huge agricultural potential, Nigeria, which used to be a major player in agriculture in the world, has lost its place in the global agricultural market. This was due majorly to field losses, and post-harvest losses as a result of inadequate storage and processing facilities (Adesina, 2013).

It is strongly believed that the major problem militating against food security in Nigeria is not the production but post- harvest operations (Odigboh, 2004; Mijinyawa, 2006). Small holder farmers and grain merchants are forced to sell their produce after they are harvested due to the lack of suitable storage structure and scarcity of storage management technologies (Hodges *et al.,* 2011). This would help them avoid post-harvest losses from storage pests and pathogens, and cannot use their harvest as collaterals to access credit, and ultimately their food security is undermined (Gustavan *et al.*, 2011). Consequently, farmers receive low market prices for any surplus grain they may produce. Ajisegiri and Obafisoye (2005) asserted that safe storage of grain at the on-farm level is important. This is because; it has great impacts on food and income security and prosperity for the small holder farmers (Admire and Tnashe, 2014).

Safe storage at the on-farm level (local government level) go hand-in-hand with food security particularly during scarcity. Food and Agriculture Organization (FAO) of United Nations recommended a food security programme which provides 20 kg of grains per capital for 28 days in the event of a natural disaster (FAO, 1994). The realization of this target in Nigeria implies a storage capacity of 4.4 million tons of grains for a population of over 200 million as against the total storage capacity of Federal grain storage reserves of 1.186 million available today (Olorunfemi and Kayode, 2018).

A lot of losses are recorded during the reception and release of grain out of the grain facility (Krishramurthy, 2005; Ileleji, 2010). Losses are recorded during the transportation of grains within the silo facility; from the point of weighing (intake pit), through the transverse conveyors, elevator, cleaner, dryer, and other facilities, and finally into the silo cells. These could be as a result of poor handlings and human factors during laboratory analysis, offloading, stock management, aeration, damages of storage facilities and other factors (Ileleji *et al.,* 2009; Olorunfemi *et al.,* 2015).

Grain crop farming is predominant in many parts of Nigeria, but the key grain producing states such as Kano, Kastina, and Kaduna have a much higher active population in grain farming. Hence, grain market in Nigeria is very dynamic because consumption is in excess of 20 million metric tons per annum and demand of 25 million metric tons per annum. This market in terms of supply and demand is expected to grow by 2.5-3% per annum (FMA&RD, 2016). Estimates for total annual grain production in Nigeria fall in the range of 20-25 million MT per annum over the last five years. It has been reported that, grain production is divided across four major grain crops: maize, sorghum, millet and rice, though there is a small production volume of wheat, barley and other grains (FMA&RD, 2016). The Nigeria's farm production efforts still have to be matched with adequate attention on storage, marketing and distribution. In this context, any effort at increasing agricultural production must be matched with equal if not greater effort at producing adequate and efficient storage facilities and good management in order to ensure availability of food material at relatively stable price throughout the year, both for domestic consumption and for export (Igbeka, 2013).

Storage facilities are systems designed for the appropriate receiving, cleaning, drying, storing, and dispatching of grains and legumes (Ajisegiri and Obafisoye, 2005). In order to perform these operations, several types of equipment and structures such as receiving pits, cleaners, dryers, conveyors, holding bins, bins, flat and dispatch bins need to be linked in a logical sequence. These systems should also be designed, operated, and managed in a way that product characteristics can be preserved and profits can be earned. Good maintenance of a grain handling and storage facility enhances its performance through prolonged working life, reduced downtime, and works at rated capacities thereby getting value for the capital investment. Proper maintenance helps prevent damage to grain which can result from defects in the machine or building structures. Further, a properly maintained facility ensures reduced risk of safety hazards and accidents to life, grain and the facility itself (Ajisegiri and Obafisoye, 2005). The maintenance activities include checking, inspection, servicing (including adjustments and lubrication), repairs (including painting) and replacement of worn out or broken-down parts or complete machines.

The aim of this research was to assess the operations of metal-silo storage facilities by identifying its common problems in Nigeria, and by introducing computer-aided approach as a tool for proper management of the installed storage facilities using the National strategic grains reserve storage complexes in Nigeria as basis for the study.

2. METHODOLOGY

2.1. Data Collection and Survey of Metal Silo Facilities

Visits were made to the 33 locations of the National Strategic Grain Reserves (NSGR) silo complexes of the Federal Ministry of Agriculture and Rural Development of Nigeria at all the six geo-political regions of country to obtain first-hand information about the prospects, problems and other essential challenges that are present. All the thirty-three Federal government storage centres were selected for the survey. These included Federal silos in Minna, Makurdi, Ezillo, Irrua, Lafiagi, Gaya, Jahun, Ibadan, Ilorin, Jos, and Akure. General problems were observed as well as peculiar problems associated with each location. Efforts were also made to obtain data at the headquarters of NSGR, Abuja, Nigeria. At the State level, observation was made to Ondo State metal-silo locations at Akure and Ondo towns, as well as to the Farm centres of Oyo State in Oyo and Iseyin. All the State-owned metal-silos have been abandoned. One of the visited metal-silo storage facilities is shown in Figure 1.

Figure 1: Metal silo storage complex, Akure, Nigeria

2.2. Assessment of Existing Metal Silo Grain Storage Facilities

Questionnaires were administered to assess the conditions of some available silo storage facilities in Nigeria. Primary data were collected to generate the necessary data needed for the analysis. Fifty (50) questionnaires with fifty questions were administered to metal silo operators and managers in the country. While the valid ones were used, the invalid ones were disregarded. The analytical tool used for the analysis of the questionnaire was descriptive statistics. The data was analysed with SPSS. The descriptive statistics used was frequency and ranking order. This in turn organized the data and identified the problems and development in metal-silo grain storage in Nigeria.

2.3. Parameters for Storage and Losses in Metal Silos

Parameters for storage and calculation of losses in metal silos were determined using Equations 1-6.

$$\text{Foreign matter \%} = \frac{\text{wt of foreign matter present in the sample}}{total\ wt\ of\ sample} \times 100 \tag{1}$$

$$\text{Insect damage \%} = \frac{wt\ of\ damaged\ grain\ by\ insect\ in\ sample}{total\ wt\ of\ sample} \times 100 \tag{2}$$

$$\text{Mould damage \%} = \frac{wt\ of\ mould\ damaged\ grain\ in\ sample}{total\ wt\ of\ sample} \times 100 \tag{3}$$

$$\text{Broken grain \%} = \frac{wt\ of\ broken\ grain\ in\ sample}{total\ wt\ of\ sample} \times 100 \tag{4}$$

$$\text{Hectoliter weight \%} = \frac{wt\ of\ grain\ in\ the\ cylinder}{volume\ of\ cylinder} \times 100 \tag{5}$$

$$\text{Weight loss \%} = \frac{M_i - M_f}{100 - M_f} \times 100 \tag{6}$$

Where, Mi = Initial moisture content (wet basis) Mf = Final moisture content (wet basis)

2.4. Development of Software for Silo Facilities' Maintenance

When programing a computer to manage a design work, it involves the development of set of program of instructions according to the design procedures, while the coding the instructions with high level language. A compiler is used to serve as interface between the computer and operators for the supply of imput data, while the compiler translates the written program to a machine-readable program (Adekunle *et al.,* 2014). The software was developed using PHP high language programming. It has three sections; the graphical user interface which the operators will be interacting with was developed using Dreamweaver 8. While the coding section was developed using Pre-Processor Hypertext higher programing codes, and the database was generated using structural Query Language (MySQL). The software was built to manage the day-to-day servicing and maintenance of the various grain equipment, of the metal silos. The maintenance activities included; checking, inspection, servicing (including adjustments and lubrication), repairs (including painting) and replacement of worn out or broken-down parts or complete machines**.**

3. RESULTS AND DISCUSSION

The first category of data generated were from the thirteen silo complexes constructed and commissioned from 1988 to 2006 (Table 1). These complexes have been in use for a significant period of time. Even though the award for the construction were made in 1987 (Talabi, 1996), years of completion varied from 1991 to 2006. By the end of December, 2014, the total quantity of grains in these Federal reserves was 46,886.09 MT. as against expected minimum stock of 352.8 million for a projected population of 176.4 million MT as recommended by FAO (1994). Also, as at this time, none of the metal-silo complex was in a perfect condition, they all needed one maintenance work or the order. Metal-silo requires adequate routine maintenance due to corrosion, wears, wind, and other environmental factors (Ajisegiri and Obafisoye, 2005; Alabadan, 2006). All of them are still in a serviceable condition (59-98%) as against expected 100% sound condition at the completion of the installation.

Table 2 shows the list of metal-silo complexes that the construction work had been completed, but not yet commissioned officially. This is in agreement with report of FMA&RD (2016). Even though these metal-silos were completed, each of them had technical problems that would not made them operational unless attended to. Sokoto metal-silo received paddy rice while Ilesha silo received 1,778.32 MT of maize for the test-running of the metal silo (Olorunfemi *et al.,* 2018).

Table 1: Operational metal-silo complexes in Nigeria

Silo location	State	Size (MT)	Year of completion	Grain stored (MT) (Balance stock as at Dec. 2014)	Metal silo Condition (1-100)
Akure	Ondo	25,000	1991	97.37	85%
Ezillo	Ebonyi	25,000	2012	-	87%
Gombe	Gombe	25.000	1988	10,057.00	89%
Ibadan	Oyo	25,000	2006	841.70	87%
Ilorin	Kwara	25,000	2006	1,855.88	64%
Irrua	Edo	25,000	1995	-	75%
Jahun	Jigawa	25,000	1998	3,920.98	91%
Jos	Plateau	25,000	2006	9,986.76	93%
Kaduna	Kaduna	25,000	2011	7,379.00	59%
Lafiagi	Kwara	11,000	1988	-	82%
Makurdi	Benue	25,000	1991	1,402.00	98%
Minna	Niger	25,000	1991	11,345.40	96%
Ogoja	Cross-River	25,000	1991	-	92%

Table 2: Constructed silo complexes

Silo location	State	Size (MT)	Year of completion	Grain stored (MT) (Bal. as at Jan. 2015)	Facilities condition (1-100)
Bulasa	Kebbi	100,000	2014	Unused	92%
Dutsin-Ma	Katsina	25,000	2014	Unused	87%
Ikenne	Ogun	25,000	N/A	Unused	92%
Ilesha	Osun	25,000	2012	Unused	95%
Kwali	FCT	100,000	2012	1,778.32	82%
Sokoto.	Sokoto	25,000	2013	10,738.5	94%

The third category (Table 3) of metal-silo complexes computed are under construction and at various stages of completion. The number of storage complexes that fall under this category are eleven. While they are all in varying state of completion, they require the installation of silo equipment that are essential for handling storage of grain. There would be need to review the contracts as exchange rate of Dollar to Naira has increased geometrically. One of the challenges of silo construction and maintenance is the high cost.

Table 3: Metal silo complexes under construction (Olorunfemi, 2018)

Silo location	State	Size (MT)	Grain Stored (MT) (Est. at Jan. 2016)	Facilities condition (1-100)
Ado-Ekiti	Ekiti	100,000	N/A	75%
Bauchi	Bauchi	25,000	N/A	60%
Gaya	Kano	25,000	N/A	85%
Gusau	Zamfara	100,000	N/A	85%
Igbariam	Anambra	25,000	N/A	0%
Jalingo	Taraba	25,000	N/A	10%
Lafia	Nasawara	25,000	N/A	15%
Lokoja	Kogi	25,000	N/A	15%
Okigwe	Imo	100,000	N/A	85%
Uyo	Akwa-Ibom	25,000	N/A	35%
Yola	Adamawa	25,000	N/A	80%

Storage parameters for different grains and cereals were used as standards for the design. Moisture content (≤ 12%), percentage of insect damage (≤ 1%), tolerable percentage of mould damage (1%), tolerable foreign

B.J. Olorunfemi and O.K. Kunle/ Nigerian Research Journal of Engineering and Environmental Sciences
5(2) 2020 pp. 614-625

matters content (≤ 1%), hectolitre weight (68-75kg/hl), colouration (normal), endosperm (viable and wholesome), percentage of broken grain (≤ 1%), and year or age of grain (not more than one year were considered. Appendix 2 shows the data generated on the metal-silos specifications These included the silo locations, size of storage bins, facilities installed, demand/level of usage of facilities, and size of silo cells.

Reports have shown that entry of moisture and rusting were the commonly problems associated with metal silos (Maier *et al.*, 2002). Moisture leakages from the roof was reported to be about 12% of occurrence, while rusting accounted for in 36% of the reported cases. Other problems are scored in Table 4. Two factors are responsible for these observations; one is poor workmanship and the other has to do with management (Roblodo, 2005). As a result of incompetent workmanship, the maintenance of metal silos is poorly handled, while on the side of management, inadequate monitoring, unavailability of spare parts, poor data management, manual data analysis, and inability to respond to maintenance as at when due to lack of funding (Olorunfemi and Kayode, 2018). During the field work, storage losses were obtained, and the results of quantity lost in the metal silos were documented as follows.

Utilization of metal-silo grain facilities varied across the country. All the facilities located in the south-west and south-east geo-political part of Nigeria are under-utilized, except Ibadan metal-silo complex that started receiving grains in 2006, while those that were located in the far north are efficiently utilised. The reason could be due to grain supply in the belt, consumption and demand for grains by end users (Table 5) Another challenge of storing grain in the metal-silo facilities in the south is the tropical climatic conditions. In more than half of the year, the relative humidity is high, and high rainfall (McNeill and Montross, 2003). All the government owned metal-silos are equipped with temperature sensors to monitor the temperature, and aeration fans are also installed for cooling of the grain mass when temperature reading exceed the threshold.

The paired sample test was carried out to compared the results obtained in metal-silos where the software was administered with where it was not used. Result showed that the probability level was 0.001. H_0: $\theta = \theta_0$ H_1: $\theta \neq \theta_0$ for at least one θ at $\alpha = 0.05$. The null hypothesis (H_0) indicated that the manual operations denoted as θ and the computer aided management denoted as θ_0 are equal or the same, while the alternative hypothesis (H_1) indicated that traditional metal silo maintenance are not equal. Since the probability level of 0.001 is less than the significance level 0.05, this led to the rejection of the null hypothesis. Hence there was a significant difference between the percentage losses recorded from the software package and the traditional metal-silo that is operated on preventive management technique (Figure 2).

A software was built to manage the day-to-day maintenance of all metal silos facilities. The software was developed using PHP programming language, an object-oriented programming language that is compatible with almost all popular internet platforms. The front-end is the user interface which the users interact with. This was developed using Dreamweaver 8, the coding section was developed using PHP code; and the database was generated using MySQL. Dreamweaver was used as the tool for creating the graphical objects that enhances the user friendliness, while Structured Query Language programme was used as the database facility. The database holds the parameter s for the software, stores all entries by users including the personal information of the individual users. Figure 3 is the landing page for the software while Figure 4 is the system login page of data and retrieving.

The landing interface is the welcome banner and the first interface that floats as soon as the package is launched. It contains basic information about the package, a few graphics that represent the general concept of silo grain management and its affiliates. Such information includes, metal-silo operation, goods and contacts. Since our interest is mainly on silo operations, click on metal-silo operation. The user’s access permit interface (system log in page), which is the log-in dialog box where the user is expected to log in with the administrative permit information that is, user name and password.

B.J. Olorunfemi and O.K. Kunle/ Nigerian Research Journal of Engineering and Environmental Sciences
5(2) 2020 pp. 614-625

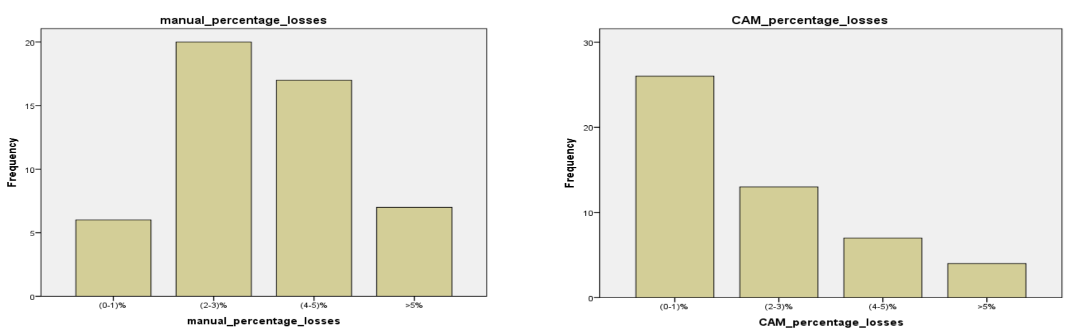
Table 4: Problems experienced with some metal-silo storage structures obtained through questionnaires and observation

Types of problems	No of occurrence (100)	Frequency	Remedial measures introduced
Rusting of cell inner wall	20	Regularly	• Sand-casting of affected areas • Re-painting with Aluminium coat • Replacement of worn-out components
Rusting of silo base	16	Regularly	• Application of bitumen • Prevention of water seepage
Water leakages	12	Higher in the south, but less in the north	• Ensure air-tight roof • Cover inspection window tightly • Weekly sampling analyses
Caking of grains	20	Regularly	• Avoid hot-spot • Regular aeration • Timely re-cycling
Moulding	45	Regularly	• Ensure good grain is stored • Treatment against insect infestation • Avoid water leakage
Insect infestation of stored grains	33	Regularly	• Apply Phostoxin at reception • Apply Coopex dust at the surface and through aeration fan
Dust explosion	2	Rarely	• Eliminating any one of the three main ingredients, i.e., air, or the dust cloud or the source of ignition • Ensure installation of good cleaner
Chemical contamination	34	Irregularly	• Avoiding personal contact during application • Always use PPE
Silo collapse	1	Rarely	• Rebuild silo cell
Electrical failure	18	Occasionally	• Apply rodenticide • Replace affected wires • Repair control panels
Structural deficiency	5	Rarely	• Minimising the height of the structure, good • Invite experts for rehabilitation
Ground water infiltration	4	Occasionally	• Chemical grouting • Application of sealants • Application of bitumen
Sweep auger/conveyor not removing dead grains	31	Occasionally	• Re-fix the Sweep auger/ • Remove clog grains manually • Replaced burnt electric motor
Grain escape at grain cleaner due to rusting of metal plates	16	Regularly	• Seal-up leaked areas • Replace worn out components • Replace cleaner mesh
Respiratory hazard	15	Regularly	• Wear PPE
Suffocation	3	Rarely	• `Do not enter metal silo during loading and in the afternoon
Arching or Bridged grain	13	Rarely	• Do not walk on stored grains • Avoid staying inside discharged grains

B.J. Olorunfemi and O.K. Kunle/ Nigerian Research Journal of Engineering and Environmental Sciences
5(2) 2020 pp. 614-625

Table 5: Grain economic activities in Nigeria (FMA&RD, 2016)

State	Silo location	Storage from Grain Supply			Grain demand		Profile
		Farmers	Storage	Prod. /Storage	Population	Fish/ Poultry	
Ekiti	Ado-Ekiti	30	24	27	24	29	Low
FCT	Kwali	29	1	29	30	26	Low
Osun	Besha	26	28	22	15	21	Low
Edo	Irrua	25	7	23	20	23	Low
Nasarawa	Lafia	21	9	16	29	22	Low
Akwa Ibom	Uyo	13	30	28	11	15	Low
Ebonyi	Ezilo	28	8	18	28	14	Low
Cross River	Ogoja	9	25	20	23	18	Low
Kwara	Lafiagi	22	17	4	25	24	Medium
Ogun	Ikenne	24	2	26	12	27	Medium
Kwara	Ilorin	22	17	12	16	24	Medium
Adamawa	Yola	8	14	17	22	30	Medium
Kogi	Lokoja	20	27	9	16	13	Medium
Ondo	Akure	19	13	15	14	20	Medium
Kebbi	Bulasa	12	20	24	19	5	Medium
Imo	Okigwe	5	26	30	10	9	Medium
Taraba	Jaingo	14	12	6	27	19	Medium
Gombe	Gombe	17	4	13	26	17	Medium
Anambra	Igbariam	16	15	25	8	12	Medium
Plateau	Jos	18	6	5	21	16	High
Zamfara	Gusau	10	11	21	18	6	High
Niger	Minna	27	19	3	9	3	High
Benue	Makurdi	11	5	10	7	28	High
Sokoto	Sokoto	6	22	11	13	8	High
Oyo	Ibadan	15	10	19	4	7	High
Jigawa	Jahun	7	16	14	6	10	High
Kaduna	Kaduna	3	29	1	2	4	High
Katsina	Dutsin	2	23	7	3	2	High
Bauchi	Bauchi	4	3	8	5	11	High
Kano	Gaya	1	21	2	1	1	High



(a) (b)

Figure 2: Bar chart of percentage losses in metal-silo (a) without computer-aided (b) with computer-aided

Figure 3: Landing page

Figure 4: System login page

Machines history card page (Figure 5) was created for regular updating of the conditions of the installed machines, servicing time and other maintenance activities. Interfaces were developed for all the installed silo equipment. This is necessary in order to monitor the maintenance of the machines. Proper machines maintenance includes cleanliness, lubrication, replacement. Monthly report can be generated through the report page.

Figure 5: Machine history card page

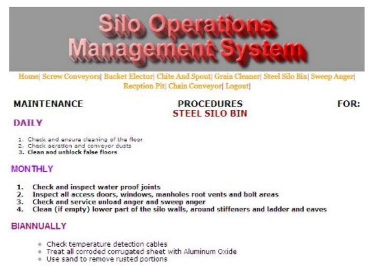


Figure 6: Steel silo maintenance page

Figure 7 shows the grain cleaners interface page. It reminds the users when to take actions for routine maintenance on daily, monthly and yearly basis. Necessary replacement must be made for the sieves in order to ensure no leakage of grain or escape of dust and chaff. While Figure 8 is the users software page for routine maintenance on screw conveyor on daily, monthly and yearly basis.

Figure 7: Grain cleaner page

Figure 8: Screw conveyor maintenance page

Other users page for maintenance activities of the following components of the metal-silo grain storage facility weere also developed. These include: Bucket elevator, Chute and Spout, Grain cleaner, driers, bagging plant, transverse conveyor, gear system, sweep augers, loading unit, discharge pit, weighbridge, auxiliary buildings, reception pit, control room, aeration fans, and so on. Their daily, weekly, monthly, bi-monthly, quarterly, bi-annual, and annual turn-around activities have been captured. The developed software comprised of a number of user's interface that allow the users to freely interact with the computer, select pages of interest among the grain handling equipment.

4. CONCLUSION

Storage parameters for different grains were analysed using descriptive statistics and there was a significant difference ($p<0.05$) between the values obtained from the package and the manually operating meta silo facilities. Deterioration of stored grain would be prevented if they are timely monitored in the metal silo thereby prevent quality, quantity and economic losses. Particular attention must be put into monitoring of grain mass in the silo against water infiltration, and temperature fluctuation. Regular grain analysis is required and weekly inspection. The most cost-effective method of limiting caking, moulding and other problems associated with metal silo is a proper temperature monitoring and aeration, rather cooling of the grain mass. Temperature cables can provide valuable information for isolated spots inside grain bins, especially where handheld grain/ temperature probes cannot collect samples or penetrate the grain stock This is achievable using computer aided management system. A well-managed grain storage facility has the potential to reduce substantial percentage of post-harvest losses. It affords the users a good management of their time for economic purpose. Good maintenance of a grain handling and storage facility enhances its performance through prolonged working life, reduced downtime, and works at rated capacities thereby getting value for the capital investment. Proper maintenance helps prevent damage to grain which can result from defects in the machine or metal-silo structures.

5. ACKNOWLEDGMENT

The authors wish to acknowledge the contributions of Department of Food Reserve and Storage, Federal Ministry of Agriculture and Rural Development, Nigeria in the area of data collection and in allowing us to use their facilities in carrying out the research work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Admire, M. T. and Tnashe, S. (2014). Efficacy of Traditional and Improved Granaries in Protecting Maize from *Prostephanus truncatusin* Small Holder Farming Storage System in Makonde District, Zimbabwe. *World Journal of Agricultural Research,* 2(2), pp. 53-69.

Ajisegiri, E. S. A and Obafisoye, J. O. (2005). Training manual for in-plant Training of Strategic Grain Reserve Technical Staff. Publication of Department of Strategic Grain Reserve, Federal Ministry of Agriculture and Rural Development, Nigeria.

Adesina, A. A. (2013). Unlocking Nigeria's Agricultural Potential to Create Wealth. Foundation day lecture, Federal University of Technology, Akure, Nigeria, pp. 6-13.

Alabadan, B.A. (2006). Evaluation of Wooden Silo during Storage of Maize (*Zea mays*) in Humid Tropical Climate. *Agricultural Engineering International: the CIGR E-journal.* VIII. February, 2006.

Adekunle, A. A., Olubo. and Olumide, A. (2014). Need for Computer Aided Design (CAD) Software Development for Chisel Plough. In: Proceedings, ASABE, Canada.

Food and Agriculture Organization (FAO) (1994). Grain Storage Techniques: Evolution and Trends in Developing Countries. Food and Agriculture Organization of the United Nations (FAO), Edited by D.L. Proctor, FAO Consultant, FAO Agricultural Services Bulletin No. 109, Rome, Italy.

Federal Ministry of Agriculture and Rural Development (FMA&RD) (2016). Private-Public Partnership Transaction for 33 Silo Complexes in Nigeria: Business case. Federal Ministry of Agriculture and Rural Development, Abuja. Lion's Head Global Partners LLP

Gustavan, J., Christel, C., Ulf, S., Robert van, O. and Alexandre, M. (2011). Global Food Losses: Extent, Causes and Prevention. Study conducted for the international congress 'SAVE FOOD' at Interpack 2011, Dusseldorf, Germany. Food and Agriculture Organization of United Nations, Rome, Italy.

Hodges, R. J., Buzby, J. C. and Bennett, B. (2011). Postharvest losses and waste in Developed and less Developed Countries: opportunities to improve resource use. *Journal of Agricultural Science,* 149: pp. 37-45.

Igbeka, J. C. (2013). Agricultural Processing and Storage Engineering (1st Ed.). Ibadan University Press. pp. 99-140.

Ileleji, K. E. (2010). Fundamental of Stored Grain Management. US-Nigerian Commodity Storage Workshop. Unpublished Training manual. Food Reserves and Storage Department, Federal Ministry of Agriculture and Rural Development, Nigeria. 1: 1-13.

Ileleji, K. E., McNeil, S. and Opit, G. (2009). Commodity Storage Assessment and Capacity Building needs in Nigeria. USDA-FAS.

Krishramurthy, K. (2005). Manual on storage of Food Grains. FAO Project on Improvement of Storage and Pest Management Procedures for Food Security. GCP/SUD/035/AUL, Wad Medani, Sudan.

Maier, D. E., Ileleji, K. E. and Woloshuk, C. P. N. (2002). Detection of a developing hot spot in Stored corn. Paper No 026075. Presented at the International Annual Meeting of the ASAE. St. Joseph, Michigan.

Mbata, G. N. (2013). Eradication of Global Hunger with Emphasis on Africa: Role in Post-Harvest Integrated Pest Management. Fulbright specialist lecture. The Federal University of Technology, Akure, Nigeria, pp. 3-17.

McNeill, S. G. and Montross, D. (2003). Harvesting, Drying and Storing Grain Sorghum. U.K Cooperative Extension service.). Agricultural Engineering Extension Publications. 9.

Mijinyawa, Y. (2006). Farm Structures: Roles and Challenges in meeting the need of the Nigerian Farmers. In: Proceedings of Nigerian Institution of Agricultural Engineers. 28. pp. 14-19.

Mushira, M. (2005). Manual on Grain Management and Equipment Maintenance in Silos. FAO Project UTF/NIR/O47/NIR: SPFS – Output 5 "Short Term Training to Produce Immediate Storage Management and Operational Support to the Strategic Grain Reserve Department of the Federal Ministry of Agriculture and Rural Development, Government of Nigeria

Odigboh, E. U. (2004). Status of Agro-processing in Nigeria. Invited lead paper. In: Proceedings of 5th International Conference of the Nigerian Institution of Agricultural Engineers. Kwara State Hotel, Ilorin. 28th Nov. – 3rd Dec., 2004, pp. 6 –15.

Olorunfemi, B. J., Adejuyigbe, S. B. and Adekunle, A. A. (2015). Development of Computer-aided Management for Grain Reception at grain storage silos in Nigeria. *International Journal of Engineering and Applied Sciences*, 2(7), pp. 45-49.

Olorunfemi, B. J. and Kayode, S. E. (2018). Computer - Aided Method: An Improved Procedure for Assessing Weight Loss in Stored Grains. *International Journal of Agricultural and Bio-systems Engineering*. 3(1), pp. 27-37.

Olorunfemi, B. J., Adejuyigbe, S. B., Ogbeide, S. O., Adeyemi, H. O., Adekunle, A. A. and Kayode, S. E. (2018). Development of Computer- Aided Management for Grain Storage in Nigeria. *Journal of Multidisciplinary Engineering Science and Technology,* 5(10), pp. 8747-8760.

Roblodo, E. R. (2005). Manual on Storage Management and Quality Control. United Nations Development Programme/ FAO Project, MLN/85/018.

Silva, G. (2018). Feeding the world in 2050 and beyond– Part 1: Productivity challenges. Michigan State University Extension

Talabi, A. E. (1996). Implementation of National Food security programme: experience so far. In: Proceedings of the national workshop on strategic grains reserve storage programme. pp. 82- 90.

APPENDIX

Table A1: Silo specifications

Silo complex		Size	Demand	Silo Bins	Size	Silo bin allocation				Weigh-bridge	Dry Intake	Wet Intake	Dryer	Cleaner	Bagging	Feed Mill
Location	State	MT	Level	No.	MT	Maize	Sorghum	Rice	Millet	MT/hr	MT/hr	MT/hr	MT/hr	MT/hr	MT/hr	(MT/hr)
Ado	Ekiti	100,000	Low	20	5,000	15	-	5	-	60	50	50	30	50	80	-
Akure	Ondo	25,000	Medium	10	2,500	8	-	2	-	50	30	30	15	30	24	18
Bauchi	Bauchi	25,000	High	10	2,500	4	3	1	2	59	44	30	30	30	39	-
Bulasa	Kebbi	100,000	Medium	20	5,000	4	8	3	5	60	50	50	50	50	60	-
Dutsin	Kasina	25,000	High	10	2,500	3	4	1	2	60	50	50	30	70	39	-
Ezillo	Ebonyi	25,000	Low	10	2,500	1	-	9		50	50	50	50	50	60	-
Gaya	Kano	25,000	High	10	2,500	3	4	2	1	80	50	50	30	70	39	18
Gombe	Gombe	25,000	Medium	10	2,500	3	3	2	2	50	50	50	34	50	30	-
Gusau	Zamfara	100,000	High	20	5,000	1	13	2	4	60	50	50	50	50	100	18
Ibadan	Oyo	25,000	High	10	2,500	7	1	2	-	50	30	30	12	30	70	-
Igbariam	Anambra	25,000	Medium	10	2,500	5	1	4	-	59	44	43	34	40	39	-
Ikenne	Ogun	100,000	Medium	20	5,000	18	-	2	-	60	50	50	50	50	60	-
Ilesha	Osun	25,000	Low	10	2,500	7	-	3	-	60	50	50	30	30	24	-
Ilorin	Kwara	25,000	Medium	10	2,500	3	2	4	1	50	30	30	30	30	20	18
Irrua	Edo	25,000	Low	10	2,500	6	-	4	-	50	50	50	12	59	30	
Jahun	Jigawa	25,000	High	10	2,500	1	4	1	4	50	40	40	40	40	30	18
Jalingo	Taraba	25,000	Medium	10	2,500	4	2	3	1	59	44	43	60	40	39	-
Jos	Plateau	25,000	High	10	2,500	5	3	1	1	60	50	50	45	50	60	-
Kadun	Kadun	25,000	High	10	2,500	4	3	2	1	50	30	30	30	30	40	-
Kwali	FCT Abuja	100,000	Low	20	5,000	5	4	8	3	60	50	50	50	50	200	-
Lafia	Nasarawa	25,000	Low	10	2,500	3	3	3	1	135	44	43	50	40	39	-
Lafiagi	Kwara	11,000	Medium	12	917	3	2	7	-	50	50	30	30	30	20	-
Lokoja	Kogi	25,000	Medium	10	2,500	4	1	4	1	59	44	43	50	40	39	-
Makurdi	Benue	25,000	High	10	2,500	2	2	5	1	60	60	60	34	15	30	18
Minna	Niger	25,000	High	10	2,500	4	3	2	1	60	30	30	30	30	60	18
Ogoja	Cross River	25,000	Low	10	2,500	7	-	3	-	50	50	50	30	50	30	18
Okigwe	Imo	100,000	Medium	20	5,000	16	-	4	-	60	52	50	46	50	100	-
Sokoto	Sokoto	25,000	High	10	2,500	1	4	1	4	50	50	50	50	50	30	-
Uyo	Akwa Ibom	25,000	Low	10	2,500	9	-	1	-	50	44	43	30	30	30	-
Yola	Adamawa	25,000	Medium	10	2,500	4	3	2	1	50	50	50	50	50	60	-