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Three and Half Decades of Research on Controlled Atmosphere Storage of Grains under Nitrogen and Recent Utilization of the Technology in Nigeria

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Abstract

A major breakthrough of Nigerian Stored Products Research Institute (NSPRI) is in the development of Inert Atmosphere Metal Silo (IAMS) in bulk grain storage for suitability of the climate, adoption and utilization in Nigeria. This technology uses nitrogen gas to achieve a controlled atmosphere (N2-CA) or environment for the control of stored products pests infestation and damage. Achieved 100% mortality of all life adults and immature stages of stored products insect pests; inhibited mould growth, maintained biochemical composition of stored grain and germinability (85% -91%) recorded at 12 months of storage. The system has been used to effectively store white maize, groundnut, Ife brown cowpea, wheat, paddy rice and yellow sorghum for periods of 12 – 48 months. The only system that has ability to store cowpea which cannot be stored in conventional silos. Research activities commenced from laboratory trials to pilot scale and later to medium and commercial levels. Shading the IAMS top against direct sun effect with palm fronds or hood for insulation prevented moisture migration and condensation, and maintained temperature below 30 °C in stored grain. A return per unit on investment of 0.44 was recorded when utilized for storage of wheat for a period of 48 months. IAMS has economic advantages over conventional silos which require frequency of pesticides application, turning of grains to prevent caking, food poisoning and high cost of labour. The recent utilization of this technology is due to increased awareness and demands for availability of grains for food safety, quality and nutrition. IAMS is being taken up by some entrepreneurs, marketers and Landmark University, Omu-Aru, Kwara state for grain storage in Nigeria. This technology is available for use at smallholder, medium, commercial and strategic grain reserve levels. Three and half decades of application of IAMS technology in grain storage in Nigeria is discussed.

Keywords: Inert atmosphere metal silo (IAMS), Nitrogen, grain storage and quality, control of pests, utilization.

1. Introduction

The Nigerian Stored Products Research Institute (NSPRI) is one of the National Agricultural Research Institutes (NARIs) in Nigeria, being supervised by Agricultural Research Council of Nigeria (ARCN) and a parastatal under Federal Ministry of Agriculture and Rural Development (FMARD). NSPRI has been conducting research in technology development suitable for postharvest handling, storage and preservation of grains for food safety and quality for over fifty years. Nigeria is the world largest producer of cowpea. Other cereal and pulses grains are produced in large quantities and consumption of safe and quality food for good nutrition and health is imperative. Research into use of phosphine and other conventional insecticides shoed that several insect pests have developed resistance ([1]). In late 1970s Nigerian Stored Products Research Institute (NSPRI) has developed improved warehouse, improved ventilated maize cribs and hermetic grains storage bags/containers ([2,3]). These technologies are not only effective in reduction of postharvest loss in cereals and pulses but reduce the impact of aflatoxin contaminations ([4]). However, handlers and operators are exposed to health hazards, poisoning and resistance to pesticides by stored products pests are developed ([5,6]). In 1980 the need for alternate pest control became imperative and the Institute in line with best global practices developed a non-chemical technique for storage of agricultural produce. Researches started with laboratory trials on susceptibility and insect infestations in mini IAMS of $0.65m^3$ and 4-ton volumetric capacity; to pilot scale of 45 ton volumetric capacity in Ibadan for storage of maize ([7,8,9,10,11,12]). Due to 2006 bean scare incident due to reckless misuse and abuse of pesticides for control of stored products pests by the farmers and grain aggregators in Nigeria, which resulted in accidental poisoning and deaths, NAFDAC one of the regulatory agencies banned importation and use of pesticides in stored products food ([13]). NSPRI seized the opportunity and stored cowpea under nitrogen in a 45-ton volumetric capacity Inert Atmosphere Metal Silo (IAMS) at NSPRI Ibadan. The release of the stored cowpea in 2008 attracted Federal government intervention in construction of other battery of 2 units of 50-ton volumetric capacity IAMS in Ilorin and Kano in 2010 and 2013 respectively. In 2015, some of Nigeria agricultural produce were rejected and cowpea was banned by the European Union countries due to misuse and abuse of pesticides on grains ([14]). By 2013 utilization of IAMS was introduced as there was increasing awareness on food safety and quality. NSPRI being the only Federal Government agency mandated by its Act of establishment to conduct research among other issues into the postharvest activities of agricultural crops in the country became part of the problem solving mechanism. By 2015 entrepreneurs, marketers, industrialists, university and other relevant stakeholders became interested in the utilization of IAMS due to increased awareness on grain availability for food safety and quality and the successful application of nitrogen controlled atmosphere in grain storage. Researches have proved use of N2-CA as safe alternative to synthetic pesticides for protection of grains from attack of stored products insect pests ([14,15]). Low temperature and controlled atmospheres (CA) are internationally standard recognized grain storage technologies. The two principal types of atmosphere that could be used for controlled atmosphere (CA) storage and disinfestations of grains are: low concentration of Oxygen (O_2) and high concentration of Carbon Dioxide (CO_2)([14]). The principles and operation of Nitrogen Controlled Atmosphere (N_2-CA) in grain storage involve maintenance of food safety and grain quality by control of storage pests, inhibiting storage fungi, prevention of re-infestation of storage insects, maintenance of viability and germinability of stored seeds and delaying deterioration of grain quality ([15]). The use of N_2 gas as a medium of modifying atmosphere is most preferable and suitable for grain storage in Nigeria. IAMS is therefore a promising alternative for appropriate storage of grains under nitrogen. This technology does not require use of any synthetic pesticides for control of stored products pests, no residues in stored grains and no food poisoning involved. Also resistance to pesticides and hazards to operators are eliminated ([5]).

The research in IAMS technology has moved from laboratory trials to pilot scale, to medium scale and finally to commercial and industrial levels. It is necessary to appraise the research efforts of this technology to further sensitize the public on the importance, relevance and benefit of the technology, as well as open up more research opportunities and collaboration for improvement studies. The research work carried out and development of IAMS technology for grain for the smallholder, medium, commercial and strategic reserve levels for storage in Nigeria are reviewed subsequently.

2. Materials and Methods:

Construction of Inert Atmosphere Metal Silo (IAMS)

In the laboratory trials, an airtight mini-silo of a battery of 2 units volumetric capacity 0.65m3, were constructed in NSPRI Ibadan and Kano respectively. The IAMS was installed under shade ([9]). The mini silo was provided with three sampling points located at the bottom, middle and top positions of the metal silo. A dial bi-metallic thermometer probe was fitted midway of the silo with sensing probe penetrating to the central axis. Nitrogen was supplied to the metal silo through a nitrogen distribution system consisting of a pressure cylinder and a gas flow instrument panel from the silo downward through the stored grain. A pressure relief valve was fitted at the base of the mini silo ([9]).

In the pilot trials, an airtight mini metal silo of a battery of 4 units volumetric capacity 4-ton were erected at the premises of NSPRI Ibadan supported by point load bearer concrete columns and structural bars, in such a way that they were fully exposed to varied effects of the sun, wind and rain throughout the experimental period. The mini silos were all painted white so as to increase the reflectivity of the surface and thus cause a cooler environment inside. The whole body and top of silo was insulated with 5 cm glass wool and galvanized sheets but not shaded; or top of silo was insulated with 5 cm glass wool but not shaded; or no part of silo was insulated or shaded; or silo not insulated but shaded on the top with palm fronds ([16]).

In the medium level, an airtight Inert Atmosphere Metal Silo of a battery of 2 units volumetric capacity 45-tons were constructed at the premises of NSPRI Ibadan in such a way that they were fully exposed to varied effects of the sun, wind and rain throughout the experimental period. The IAMS was made up of bin, plinth, gallery, gas supply network, monitoring devices and handling equipment. The bin is a cylindrical structure with conical top constructed of food grade coated steel plate. It has three outlets for loading, discharging and accessibility. The plinth is constructed of reinforced concrete and the basement supports the bin and the gallery. The gallery comprised of ladder and walkway designed for the silo accessibility. The gas supply system of the silo is responsible for nitrogen supply to the bin. The components of the system included gas cylinder, gas line, gas control valve and gas regulators. The gas line is supported with gas line tray and vertical support. The monitoring devices included pressure gauge and temperature probes. The pressure gauge is used to measure the pressure level in the silo especially during purging while the temperature probes are installed at different gradients in the silo to monitor the temperature at different levels of the grain mass in the silo. The handling equipment are accessories for operation of the silo include grain bunker, grain sampling probe, loading and unloading auger conveyors. The silo is also provided with a generator powered augur for mechanized loading with grains. The top of the silo shaded with palm fronds ([14,16,17]).

In the commercial level an airtight IAMS of a battery of 2 units of 50-tons capacity each were constructed at the premises of NSPRI Ilorin and Kano. Similar procedure as in medium levels was followed. While 4 units of 5-ton capacity was installed at Dawanu grain market in Kano.

At the Industrial level, NSPRI was commissioned by a private university, Landmark University, Omu-Aru, Kwara State, Nigeria, where it constructed and installed 2 units of 250-ton capacity IAMS.

Principles and operation of IAMS

IAMS is an airtight system with facilities to purge out the air content of the enclosure and replace it with nitrogen gas (N_2), thereby making the system inert and inhabitable for stored products insect pests.N_2 released into the silo eliminated O_2 in the process and created inert condition within the bin that could not support the growth or survival of any organism irrespective of its developmental stages. Operation of IAMS and maintenance of grains in the structure entail three major operations; loading of grain, purging of silo and unloading of grain from the bin.

Loading of grain: Dried grain stored at safe moisture content (≤ 13 % depending on the grain) determined with in-situ moisture test before the commencement of the loading operation were used. The grain bunker (for receiving the grains) and the bins were properly cleaned, dried and made free from dust and other extraneous materials. Thereafter, the air tightness was guaranteed to prevent gas leakage. All openings were properly sealed using bolts and nuts except the loading spout. Setting up of the loading conveyor preceded the conveyance of the grains into bin. After loading, the loading spout was properly sealed, and provision was made for appropriate insulation on the bins to reduce direct impact of the sun ([16,17]).

Purging of bin: This is a process of replacing the air content of the silo with N_2 gas. After loading the silo with grain, the interstitial atmosphere within the bulk was purged by introducing nitrogen at the bottom of the silo at a conveniently high rate. All valves that aided the supply of gas through the gas line were adequately opened to supply N_2 to the bin. The gas was allowed to fill the bin for some time after which the gas release valve was opened. The waiting time is a function of the size of the silo. It was 1h 30 mins for the 45-ton silo. The oxygen gas content of the bin was measured with the aid of oxygen analyser and less than 5%. Immediately this condition was achieved, the gas supply line was then switched off after the water in the purging container has bubbled for 5 minutes in case of silos of less than 2 tonnes and for 30 minutes for 50 tonnes capacity silo and for 1 - 2 hours for 250 tonnes silo and above. The O^2 concentration within the silo was checked once every week, and after every purge which followed sampling for analysis ([14,16,17]).

Sampling of grains from IAMS and quality assessment: Initial sample of different grains used for studies were drawn by opening IAMS top tight lid to sample at intervals of 6 month storage from the top, middle and bottom levels of the mini silo, 45-ton or 50-ton by means of silo sampling dip tool. The samples from the three different points were bulked and quartered for triplicate sampling 100 g each for assessment and quality parameters. Oxygen concentration within the silo was checked with the Taylor Servomex oxygen analyzer, type OA 272 forth nightly, and after every purge following grain sampling. The samples were subjected to the following tests: insect infestation count, insect damage kernel, mould count, proximate composition, viability and germinability, organoleptic evaluation according to standard methods ([8,9,11,14,16,17,18]).

Temperature fluctuations and relative humidity inside the silo: Each mini 4-ton silo was equipped with 5 temperature probes each containing 5 thermistors. Two of these were located axially while the other 3 were located radially round the silos so that temperatures can be measured axially and radially at the surface of the bins and at various depths in the stored grain. The temperature probes were led into a programmable electronic temperature recorder system, making it possible to record the temperatures at pre-set time intervals. Similar procedure for 45-ton and 50-ton IAMS ([16,19]).

Discharging of stored grains: After cleaning of the conveyor, the unloading spout of the bin was opened for grain discharge with aid of the unloading conveyor. The collected grains were later packaged in bags.

Research works carried out on IAMS by NSPRI for three and half decades

A battery of two units of 45 tons (in Ibadan) and a battery of two units of 50 tons capacity (in Ilorin and Kano) air tight metal silos were constructed at NSPRI offices located in different ecological zones in the country for bulk storage of grains. Apart from these capacities, there are laboratory and pilot scale capacities for experimental purposes only. Prominent among grains that have been successfully stored in the silos under nitrogen at the three locations were white maize, yellow maize, brown cowpea, wheat var. *Atilla gans atilla* and *Cetia*, paddy rice ‘Faro 2’ and yellow sorghum. The storage was carried out at different intervals spanning a total of 36 years. Series of research activities have been carried out on the aforementioned crops since inception of the technology.

Storage of maize: Experiments on storage of maize in inert atmosphere metal silo were carried out at five different levels and time. Six experiments were conducted in Ibadan in 1980, 1982, 1983 and 1984. The first experiment was on susceptibility of the life stages of *Sitophilus zeamais* and *Trogoderma granarium* larvae to nitrogen atmosphere in mini silos. This was carried out to determine how effective the technology was to control stored products insects attack in maize storage. The mini silos with capacity of 5 tons each were used for the experiment. The second was application of artificial controlled atmosphere in grain storage in Nigeria. The third experiment on maize storage was a laboratory examination of yellow maize stored under nitrogen in Nigeria. The fourth research was on microbiological studies on yellow maize stored in sealed mini-silo filled with nitrogen in two metal silos of $0.65m^3$. The fifth research on maize was on the effect of shading and insulation on maize stored under nitrogen in 4 mini-metal silos of 4-ton capacity each. The sixth storage of maize was in 45-ton silo at commercial level for 24 months.

Storage of rice and cocoa: The study was carried out in two airtight, stainless steel mini-silos labelled A and B of $0.65m^3$ capacity each erected under shade at the premises of NSPRI Ibadan in 1984 to determine the effects of nitrogen atmosphere on the adults and immature stages of some stored products insects: (eggs, larvae, pupae and adults of *Dinoderus porcellus* Lense, *Lasioderma serricorne* (F), *Callosobruchus maculatus* (F.), *Rhyzopertha dominica* (F.), *Dermestes maculatus* (DeGeer) and *Necrobia rufipes* Degeer) when used for storage of rice and cocoa.

Brown cowpea: Experiments on cowpea storage were carried out at Kano (North West) and Ibadan (South West). The Kano experiment which lasted 30 months was at the laboratory level to test the efficacy of the technology in controlling of insect pests in stored cowpea as well as its ability to maintain the quality of cowpea stored under the condition. Another study carried out on cowpea at the laboratory level was to establish the effect of insect infestation of cowpea stored under N_2 on biological evaluation of protein quality. The second stage of the experiment was at the commercial level. One of the 45-ton metal silos in Ibadan was used for storage of cowpea. A 45-ton metal silo was loaded with Ife brown cowpea variety for storage under nitrogen in NSPRI Ibadan. The IAMS was refurbished and purged with nitrogen to 0.05% level to remove O_2 and continuously maintained at regular intervals throughout the storage period. Sampling was done on monthly basis for evaluation of moisture content, microbial count, insect infestation, seed damage, aflatoxin level, germinability and organoleptic assessment which was carried out at the end of 24 months storage period.

Wheat seed: Two different wheat seeds (*Atila gan atila and Cetia*) were stored in silo facility located at the headquarters of NSPRI in Ilorin (North Central of Nigeria). An aspect of the study was to monitor temperature fluctuation in the silos, while the other two focused on maintenance of wheat seed germinability and nutritional quality. Another important area of the study was effect of the technology on mortality of insects at different developmental stages. The wheat was stored for 48 months (2010 to 2014). The germinability test was terminated after 12 months of storage, while the other parameters continued.

Paddy rice: The storage of paddy rice research was conducted in Ibadan at commercial level. The study was carried out to establish the potential of IAMS in preservation of the germinability and nutritional qualities of the paddy rice. The research work lasted for 24 months (2010 to 2012).

Yellow sorghum: This experiment was conducted in Kano for 30 months (2014 to 2016). The storage was at commercial level and was carried out to ascertain the effect of the storage conditions on nutritional qualities of sorghum.

Economic appraisal: The economic appraisal of the technology was conducted to establish how cost effective it is, and the expected return on investment. Different economic tools were jointly adopted to carry out the exercise. Such tools included budgetary analysis and profitability analysis in 1987 and 2015 ([20,21]).

Promotion and utilization: Series of steps have been taken to aid the adoption and utilization of the technology. The techniques adopted for this include training of grain stakeholders on importance and principles of operation of the silo and installation of smaller capacity at grain markets as government intervention in postharvest management of grains. The utilization component covers rentage of the facility to interested individual for storage of grains and installation for individual or corporate ownership. The Institute was commissioned by Landmark University, Omu-Aru, Kwara State, and a battery of 2 units of 250 tons IAMS were constructed on their Research Farm. In late

February 2018 loading of white and yellow maize harvested from their farm is ongoing. The loading is being carried out and supervised by Staff of NSPRI Postharvest Engineering Research Department.

3. Results

Construction of IAMS

Silo at NSPRI Headquarters is used as case study for all others. All the materials required for construction and installation of the functional IAMS were readily and locally available in the country. The silo consisted of two units of 50-ton inert atmosphere metal silo located at Headquarters, Ilorin. The geometry of the silo is shown below: Diameter and cylinder of cone = 4 m; Height of the cylinder = 5.4 m; Total height of silo = 6.4 m; Based on the geometry of the silo structure, the dimension of the cellular raft foundation base is as follows: Total width = 12 m; Total breadth = 6 m with top slab thickness = 300 mm; Width of the beam – 600 mm; Height of the beam = 1000 mm; Bottom raft thickness = 400 mm (Fig. 1) ([19]).

Impact of IAMS on insect control in stored grains

Results obtained by the authors showed that exposure time required to achieve 100% mortality at 28±2°C in inert atmosphere for adults and of larvae which developed internally varied from that required for the eggs stage. Adults of internally developing species such as *Sitophilus zeamais* Motsch, *Trogoderma granarium Dinoderus porcllus* Lense, *Callosobruchus maculatus* Fab..and *Rhyzopertha dominica* F. were more tolerant to N_2 gas than those of *Dermestes maculatus* DeGeer, *Lasioderma serricorne* F which develop externally. Susceptibility of these insects to the atmosphere varied both between species and the various stages of development within each insect species ([8,12]). White maize, brown cowpea, wheat, paddy rice and yellow sorghum under nitrogen in IAMS 45-ton or 50-ton capacity stored for 48, 24, 48, 24 and 30 months respectively and 100% mortality of all life stages of each insect species was recorded, inhibited zero mould growth and no re-infestation.

During the commercial utilization of the technology for cowpea storage, the quantity of N_2 gas used was 101.25m^3 for the 24 month period. It was observed that 40.7% of N_2 gas was used during the first month of storage. A greater quantity of N_2 is needed at the initial stage to establish complete purging of the silo, which in turn is required to maintain the IAMS. This decreased with length of storage period. The moisture content increased form initial 9% to 10.13% at the end of 24 months storage within safe moisture content limit.

Microbial load at the top of the silo ranged from 400-9000 colony (cfu/ml after 6 months), while at the bottom of the silo the value was below 300-4000 cfu/ml which are below safe limits ([23]).

Physical observation showed that the cowpea grains stored in IAMS were clean and without any mould growth. There was no insect infestation or seed damage. Percentage cowpea seed damage decreased from initial 13.64% to 12% after 24 months.

Nutritional quality of grains stored under N_2

Results of analyses carried out on grains stored under N_2 showed that the technology is not just efficient in insects control but also in maintenance of nutritional quality of grains. The outcome of the study carried out on brown cowpea showed that free fatty acid (FFA) contents increased from 2.60% to 6.51% under nitrogen, but increased rapidly to 58.60% in the control cowpea ([14]). Results of previous researchers carried out using the technology showed that crude protein content increase observed in grains stored as controls was not applicable to grains stored under nitrogen, this was attributed to excretory products of the insects that infested the control grains ([10]). Organoleptic tests carried out stored cowpea under N_2 after 24 months to assess the palatability of the stored cowpea and fresh cowpea by processing the cowpea into wet paste and made into bean cake showed no difference in taste and appearance in the fried “akara” balls.

Effects of IAMS on germinability of seeds

Seed germinability and grain quality were also maintained. Germinability of the stored paddy rice was maintained (≥85%) for 3 months in 45-ton IAMS at NSPRI Ibadan ([12]).The germinability of cowpea seeds stored in the inert atmosphere silo in 0.65m^3 at NSPRI Kano was maintained above 85% at 12 months of storage, which shows that the technology is effective for seeds storage ([14]). Germinability of Ife brown cowpea stored under N_2 in a 45-ton capacity IAMS at NSPRI Ibadan was maintained from initial 94% to 80% at 24 months. Also, the result of wheat seed variety *Atlila gans Atilla* stored under N_2 in a battery of 2 units 50-ton at NSPRI Ilorin showed that the technology was able to maintain the germinability 91 % at 12 month of storage.

Moisture migration and condensation in IAMS

Shading with palm fronds or hood to provide insulation for the silos prevented moisture migration and condensation that are peculiar to the conventional metal silos ([10, 11, 16]).The technology was able to maintain the temperature of the grain stored in the silo below 30 °C even when the ambient was as high as 36 °C during the hot season in Ilorin. The mean temperatures at the top, middle and the bottom of the inert atmosphere silos when used to store wheat in Ilorin were approximately 29.35 °C, 28.19 °C and 26.51 °C respectively. This depicts a temperature decrease from the top of grain bulk towards the floor of the inert atmosphere silos ([19]).The recorded temperatures in the silo used for storage of brown cowpea in NSPRI Kano, ranged from 21 °C (in the night) to 35 °C (in the day) with an average value of 28.5 °C; while the ambient temperature was in the range of 14 °C to 43 °C and an average temperature of 33.2 °C ([14]).

Cost benefit of IAMS

These economic advantages of IAMS over conventional silos were observed. The conventional silos require frequency of application of pesticides, turning of grains to prevent caking and high cost of labour. A cylinder of 50 kg N_2 gas used in storage of Ife brown cowpea in a 45-ton capacity IAMS at commercial level in NSPRI Ibadan, Oyo State cost N7014 and was used between 8 and 15 weeks. All indices of economic analysis adopted showed that the technology is economically viable for storage of grains with a return per unit of investment of 0.44 when utilized for storage of wheat for a period of 48 months in NSPRI Headquarters, Ilorin, Kwara State ([20,21,23]).The cost effectiveness has revealed that any investment in the facility is capable of huge economic return within short period of the investment.

Utilization of IAMS

The benefits of the technology coupled with the economic return on the storage structure have prompted the adoption of the technology. The beauty of the technology is that it could be used for storage at all levels (ranging from domestic storage to commercial/industrial grain storage). These are some of the factors that aided the decision of the management of Landmark University Farm to put up a battery of two units of 250 tonnes capacity of the structure for safe keeping of grains for production of feeds for the livestock arm of its commercial farm located in Omu-Aran, Kwara State. Aside from this, a number of individual grain farmers/handlers in the Northern part of the country have committed themselves to the adoption of the technology because of the huge benefits attached to it. In fact, this was referred to as a sustainable and reliable investment opportunity for retirees ([22]). The government of Nigeria through NSPRI was able to construct and install some units of 5 tonnes capacity IAMS for the benefit of stakeholders in the grain sector of agriculture as intervention and a means of popularizing the technology among the grain farmers and marketers. Four units of the silos were installed at Dawanu grain market (the largest grain market in West Africa) in Kano state of Nigeria.

One of the major factors responsible for the low adoption of the technology despite the enormous benefits attached to it, is the initial cost of construction and installation. Awareness has commenced on the rentage of the facilities for storage of grains for benefit of those that have interest and confidence in it but lack the initial capital require to put up such facility. Another means been adopted to propagate the technology is through training. IAMS was the main storage structure recommended aside from PICS bag for storage of sorghum in the training organised and facilitated by International Crop Research for the Semi-Arid Tropics (ICRISAT) and NSPRI respectively in six (6) states of the federation. Another capacity building workshop was organized by NSPRI on principles and operations of IAMS for grain merchants and industrialists across Nigeria.

4. Discussion

The practical application of N2-CA in stored grain showed that the effect of N2-CA control pests and closely related to the nitrogen concentration and processing time. The efficacy of nitrogen controlled atmosphere is closely related to the pest species, nitrogen concentration, grain temperature and exposure time. Only pure nitrogen eliminated those fungi, preserved grain and oil quality ([15]). Construction of new IAMS will engage fabricators and thereby creating more job opportunities and wealth for the people in the sector. The previous researches carried out by different researchers on different grains at different time and different locations within Nigeria have shown that the principle of operation of the silo is key to its functionality and efficiency. Irrespective of the capacity of the silo, once the principle is strictly adhered to, the efficiency and effectiveness of the structure in handling grains is guaranteed. Capacities of the silo range from 100 kg to thousands of tons. Construction of new IAMS will engage fabricators and thereby creating more job opportunities and wealth for the people in the sector.

Essentially, the adoption of any storage structure for grains is to protect the grains against insect pests attack. IAMS has proved its efficiency in dealing with stored products insects. The technology has potential to attack insect at its every developmental stages. The cost effectiveness has revealed that any investment in the facility is capable of huge economic return within short period of the investment.

One of the major factors responsible for the low adoption of the technology despite the enormous benefits attached to it, is the initial cost of construction and installation. Awareness has commenced on the rentage of the facilities for storage of grains for benefit of those that have interest and confidence in it but lack the initial capital required to put up such facility. Another means being adopted to promote the technology is through capacity building training. IAMS was the main storage structure recommended aside from PICS bag for storage of sorghum in the training organised and facilitated by International Crop Research for the Semi-Arid Tropics (ICRISAT) and NSPRI respectively in six (6) states of the federation. Another capacity building workshop was organized by NSPRI on principles and operations of IAMS for grain merchants and industrialists across Nigeria in October, 2017.

In conclusion, the recent achievement of the technology is that its utilization has been taken up by entrepreneurs, marketers and universities for grain storage in Nigeria due to the success of application, operating cost and increased awareness for availability of grains for food safety, grain quality and nutrition. Investment in this technology has economic benefits to the stakeholders in particular and the country. The technology is an advanced environmental friendly, and construction and operating cost and application is feasible all the agro-ecological zones of Nigeria. Apart from providing a green environment for the preservation of grains, it has the capacity to create jobs for those that will be involved in the management of the structure. IAMS application will encourage farmers to produce more grains as there is a technology that is effective and efficient for grain storage. The cumulative success recorded on different grains stored in IAMS is an evidence research input by NSPRI to ensure food safety and quality thereby meeting MDGs in food security. Finally, there is opportunity for collaborative research work to further strengthen the present achievement.

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Toxic effects of ozone on selected stored product insects and germ quality of germinating seeds

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Abstract

The merchant grain beetle (MGB), *Oryzaephilus mercator* (Fauvel), the cigarette beetle (CB) *Lasioderma serricorne* (F.) and the rice weevil, *Sitophilus oryzae* (L.) cause significant damage to stored grain, grain-based products, and other durable commodities. Ozone, a highly oxidative toxic gas, has the potent to kill insects, meantime degrades rapidly to oxygen, making it a potential alternative to phosphine, a fumigant to which insects are developing resistance. The adults of MGB and CB were exposed to ozone concentrations of 100 - 400 ppm at 50 ppm increments for one hour and at 100 ppm for 1-6 h. Adults of rice weevil buried at 5, 15 or 25 cm depths within a wheat mass placed in 10 cm diameter 30 cm high PVC pipes were exposed to ozone concentration of 200 ppm for six hours and then at 12-h increments up to 60 h. Adult survival was recorded at 0, 24, and 48 h post-treatment. Significantly fewer MGB or CB adults survived when exposed to higher ozone concentrations or when exposed to ozone in the absence of food. RW adult mortality at 5 cm depth were significantly higher than that of 15 or 25 cm depths. This paper further discusses about mortality of MGB, CB and RW adults at different exposure periods at various ozone concentrations and effect of ozone on wheat germination.

Keywords: Fumigants, germination, ozone, stored product insects, wheat

Introduction

The ban of methyl bromide, the most effective fumigant for the control of many stored product insect pests, has necessitated the search for other potential alternative management methods. One of the potential alternatives is ozone (O_3), a highly oxidative, environmentally safe gas that degrade into molecular oxygen (O_2) within 20-50 minutes. Ozone is formed by the excitation of molecular oxygen, into atomic oxygen (O), and then combination of three atomic oxygen to form ozone. The use of ozone against stored product insect pests has gained tremendous attention over the past decade (Mahroof el al., 2018).

There have been few studies (Hasan et al., 2012) on the effect of ozone on the merchant grain beetle, *Oryzaephilus mercator* (Fauvel), the cigarette beetle, *Lasioderma serricorne* (F.) and the rice weevil, *Sitophilus oryzae* (L.). Published studies did not investigate the effect of ozone when externally feeding insects are treated in the presence or absence of food. Therefore, the study described here was conducted using adults of *O. mercator*, *L. serricorne* and *S. oryzae* exposed to different concentrations of ozone for different durations. The objectives of this study were to evaluate the relative susceptibility of adults to different ozone concentrations, determining concentration-mortality and time-mortality relationships and to determine germination quality of wheat treated using ozone.

Materials and Methods

A bench-top ozone generating equipment that produces ozone in the range of 0-8000 ppm was used in the experiment. Detailed descriptions of the Ozone generator were provided in Mahroof et al. (2018).

Exposure of *O. mercator* and *L. serricorne* to different concentrations of ozone

Adults of *O. mercator* and *L. serricorne* were exposed to ozone concentrations beginning 100 ppm and then at 50 ppm increments up to 400 ppm for one hour. Ten jars with 20 adults were used for