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CURRENT STATUS OF CONTROLLED ATMOSPHERE STORAGE IN NIGERIA

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ABSTRACT

Controlled atmosphere (CA) storage of food crops was introduced to Nigeria in 1978 in a cooperative agreement between Snamprogetti/Assoreni of Italy and the Nigerian Stored Products Research Institute (NSPRI). Collaborative research between Assoreni and NSPRI from 1979-1981, and by NSPRI from 1982 to date on experimental, pilot, and commercial scales has shown that this technology, using nitrogen (N_2), gives excellent results in preserving quality of dry grains during long-term storage under Nigeria's ambient conditions. Special features observed included the considerable reduction in moisture condensation (that leads to large-scale losses when conventional metal silos are used for grain storage in the humid tropics where there are wide diurnal fluctuations in temperature), protection of operators from hazards of toxic chemicals, absence of residues in stored crops, control of insects, reduction of fungal load, longer retention of seed viability than in normal ambient storage, longer retention of biochemical quality, and maintenance of organoleptic characteristics of the grains during storage. Yellow maize, sorghum, rice, and cowpea retained their quality after storage of over four years. The technology was also shown to be effective in preserving the quality of cocoa, an oilseed and major cash crop in Nigeria. Its possible application for groundnuts has also been initiated. Controlled atmosphere technology has now been developed to a level where it can be used commercially for long-term grain storage in Nigeria.

INTRODUCTION

Modern trends in stored-product pest management place increasing emphasis on preventive control measures that will avoid the use of traditional pesticides. International objection to the use of toxic chemicals in food is growing as a result of increasing evidence of the hazards that these chemicals pose to human health, the environment, wild life, and even to agriculture. Resistance of pests to several long-standing pesticides has become widespread world-wide. There is, therefore, a pressing need to introduce pest control measures that will not require the use of toxic chemicals. The controlled atmosphere (CA) technique is one that has been studied very closely over the past few decades and promises to play an increasingly important role for pest control in crop storage in the years to come. Because it has few adverse effects on the commodity, the environment, or the consumer, its use for crop storage is accepted internationally.

CA storage was introduced to Nigeria in the late seventies. After years of fruitful research, it has been found that it provides an excellent method for maintaining the quality of dry grains during long-term storage. However, several problems have outweighed its adoption for grain storage even until the present time. The current status of this technology and its usage in Nigeria are reviewed in this paper.

THE ATTRIBUTES OF A CONTROLLED ATMOSPHERE

The atmosphere surrounding any commodity can be altered by different manipulations to create an atmosphere that is lethal to pests of the commodity. There are at least three methods of bringing about these changes. The atmosphere can be changed or modified by the commodity itself. In this commodity-modified atmosphere, respiration and basic metabolism of the components of the commodity in general lead to a reduction in oxygen (O_2) and increase in carbon dioxide (CO_2) concentrations in the enclosed system. In the hermetic storage technology, the atmospheric composition is altered either by insects or microflora, while the commodity itself contributes little. The hermetic storage technology is a very good example of commodity-modified atmosphere storage for grains. Also, substantial modification in storage atmosphere is brought about by respiration of the commodity in the case of fresh fruits and vegetables.

The second method of changing the storage atmosphere is by the introduction of toxic gases, referred to as fumigants. The most widely used fumigants today are methyl bromide and phosphine gas. The third method of changing the storage atmosphere is by the introduction of non-toxic gases such as CO_2 and nitrogen (N_2) into the storage atmosphere at specific concentrations. Atmospheres produced by artificial modification of the storage environment surrounding a commodity are known as modified atmospheres (MA) or controlled atmospheres (CA). Where the concentrations of the component atmospheric gases are controlled accurately, the resulting mixture is rightly called a controlled atmosphere. Where the concentrations of the constituent gases are not really controlled, the atmosphere can be regarded merely as a modified atmosphere.

CAs or MAs may be referred to by their active components e.g. "oxygen-deficient", "low-oxygen", "high-carbon dioxide", "nitrogen" or "hermetic storage". An oxygen-deficient atmosphere can be provided by the addition of N_2, CO_2, helium or exhaust gases. In practice, N_2 and CO_2 are the common gases used in CA storage worldwide. CA storage employs only the major gaseous components of the earth's atmosphere and exclude the introduction of any gases or vapours normally considered to leave toxic residues.

Some of the advantages of using the oxygen-deficient CA for crop storage are listed below:

1. It has the potential to kill all animals including insects (all stages), mites, rodents, and birds without the use of toxic chemicals.
2. It inhibits the growth of microorganisms, particularly aerobic fungi, thereby reducing the production of mycotoxins.
3. Toxic chemicals are excluded, thereby eliminating hazards to operators and toxic chemical residues on crops.
4. It reduces grain respiration.
5. It reduces oxidative degradation.
6. By nature of the structures used generally in CA storage, protection is offered against external reinfestation from insects, rodents, and birds.
7. It has minimal adverse effect on either the commodity or the environment since the constituents of CA are present normally in the storage atmosphere and in the environment. This suits modern philosophies of safety to man and the environment.

Another great advantage of CA for pest control is that there is little chance of development of resistance to low-oxygen CA (Shejbal, 1978).

However, CA storage has a number of disadvantages, some of which are mentioned below:

i. Initial capital costs of the technology are high.
ii. The process of disinfestation is rather slow, as compared with the use of toxic chemicals.
iii. Generally, a high level of airtightness is required for successful storage.
iv. There is inadequate information about its reliability as a technology for crop storage, especially in the developing countries.

The hazards of pesticides to man and the environment are recognized fully. But it is a fact that pests are still very much present in food and the environment. Indeed, a major problem of harvested crops is the destruction caused by various pests during storage. Since dependence on the use of toxic chemicals for crop storage is no longer desirable, the introduction of alternative control measures is inevitable. Therefore, the use of CAs for crop storage is assured of becoming increasingly important as one of the alternative control strategies.

USE OF CONTROLLED ATMOSPHERE FOR CROP STORAGE

CA technology is used to some extent in industrialised countries for the storage of some fresh fruits and vegetables, especially apples and pears, making it possible to market these fruits all the year round (Dervey *et al.*, 1969; Smock, 1979; Brecht, 1980; and Kader, 1980).

CA storage technology is not used widely for the storage of fresh fruits and vegetables in developing countries of the world. Nevertheless small-scale storage of some climacteric fruits, notably bananas and plantains, is carried out using commodity-modified atmosphere, rather than sophisticated CA technology (Ndubizu 1976; Opadokun and Onwuzulu, 1984).

By far the most widespread use of CA in crop storage is in the storage of grains. CA storage of grains has been reported in many parts of the world, including Italy (Shejbal, 1980), Australia (Banks *et al.*, 1980), China (Rånnfelt, 1980), Japan (Mitsuda and Yamamoto, 1980) and Nigeria (Adesuyi *et al.*, 1980).

CONTROLLED ATMOSPHERE STORAGE WORK IN NIGERIA

CA storage technology for grains was introduced into Nigeria when Snamprogetti/Assoreni, Rome, signed a cooperative agreement with the Nigerian Stored Products Research Institute (NSPRI) in 1979. Collaborative research carried out in NSPRI, Ibadan, from 1979-1981 by Assoreni and NSPRI is summarised below. The programme was divided into three phases:

Phase I: storage of maize, cowpeas, rice, and cocoa in minisilos

The two minisilos used in this part of the study were made of stainless steel and were supplied by Assoreni from Italy. They were cylindrical in shape, 0.5 m in diameter, and 2.30 m in height plus a conical hopper at the bottom giving a useful volume of 0.6 m^3. They were situated in complete shade. The minisilos were fitted with 3 sampling points for gas and grain analysis, an insect cage introduction point, and a pressure relief valve to prevent excessive pressure build-up. The gas distribution system had gastight valves fitted on each gas line and fittings that enabled direct readings of pressure, O_2 and CO_2 concentrations.

(a) *Maize*

Yellow maize of 12.7% moisture content (m.c.) was loaded into the silos. The silos were then sealed and purged with N_2 until the residual O_2 concentration was approximately 0.10%, after which a constant over-pressure was maintained in the silos throughout the storage period of 10 weeks. The initial m.c. was maintained at 12.7% throughout the storage period and no moisture migration was recorded. The mean grain storage temperature was 28.5°C. All insects present in the grain including *Trogoderma granarium* larvae were killed within 6 days of purging with N_2. Mould counts showed that mouldiness of the grains did not increase during storage. A decrease in mould count was even recorded in one of the silos. Chemical parameters, including crude protein, fat, ash, reducing and non-reducing sugar contents, remained unchanged throughout the storage period. Although viability was reduced at the end of the storage period, it was substantially higher than the viability of similar maize stored out in the open.

(b) *Cowpea*

Both white and brown cowpea varieties (*Vigna* sp.) at 8.2% and 9.7% m.c., respectively, were stored separately in two minisilos under conditions similar to those described above for maize. The mean storage temperature of the cowpeas was 28.5°C. Storage lasted 12 months. Viability of both varieties of cowpea was maintained during storage, whereas insect damage did not increase. At the end of storage total mould count decreased as compared with the initial count. Organoleptic characteristics of the stored cowpeas compared favourably with those of fresh cowpeas.

(c) *White rice*

Fair quality white rice, already infested with *Sitophilus* sp. and at 14.2% m.c., was stored in a minisilo for 45 weeks under conditions similar to those described above for maize. At the end of the storage period, no live insects were observed in the rice. Mould counts were found to decrease with storage. There were no changes in the chemical parameters of quality although non-reducing sugar content was found to have decreased slightly during the latter part of the storage period. Samples of the stored rice taken from the study and cooked were rated fair by a taste panel, just as they were at the beginning.

(d) *Cocoa*

High quality cocoa, insect free and at 4.3% m.c., was loaded into the minisilo and stored under N_2 for 44 weeks under conditions similar to those described above for maize. No changes were observed in the chemical and entomological parameters analysed at the end of the storage period. However, the cocoa sample drawn at the end of the storage trial had slightly increased microbial counts and the chocolate prepared from it rated slightly poorer than at 25 weeks' storage. This latter observation was not consistent with later findings at a pilot-scale level, and was explained as probably due to mould contamination of the sample after it had been drawn from the silo rather than to changes during storage.

Phase II: storage of maize, cowpeas, and cocoa beans in pilot scale silos

The four experimental pilot-scale silos used in Phase II of the study were built and installed in Ibadan in an unshaded area having a North - South (N-S) alignment. The silos were cylindrical in shape and each had a diameter of 1.50 m, a height of 2 m, and a conical hopper at the base giving a storage volume of 4 m^3. Various devices were used to protect the silos from solar radiation. One bin was fully insulated with 5 cm rock-wool and galvanised steel sheets, another was insulated similarly, but only on the roof. The third bin was painted white while the fourth bin, in addition to being painted white, was also shaded at the top by a thatch of palm leaves.

It was observed that diurnal temperature fluctuations of the exposed metal surface of the roofs in the unshaded bins were rather large, the greatest being in the headspace of the unprotected bin, while smaller fluctuations were observed in the completely insulated bin and the bin with an insulated roof. The best protection was obtained by suitable shading of the top of the bin, in this case, with palm leaves. Consequently, after this preliminary observation, the two insulated silos were stripped of their insulation, painted white, and protected by shading with palm leaf thatches.

(a) *Yellow maize*

Grade 1 yellow maize of 13.3% m.c. was loaded into the four pilot-scale silos leaving a head space of 10 cm between the grain and the flat roof of the silos. After sealing, the silos were purged with N_2 to a residual O_2 concentration of less than 0.5%, and the maize was stored for up to 22 months.

At the end of the storage period, no live insects were observed in any silo. Mould counts were found to decrease during storage. There were slight increases in free fatty acid and sugar contents attributed mainly to the rather high temperatures of storage. Maize stored for either 10 months or 22 months rated well in organoleptic evaluation. Although prolonged storage resulted in a reduction in germination capacity, it was observed that the viability of the maize was not high from the start and was infested rather heavily with insects (5% insect damage). The viability was still higher than that of similar quality maize stored in ambient air.

(b) *White cowpea*

Rather low-grade white cowpeas having from 15-25% insect damage were stored for 9 months at commodity temperatures ranging from 16.2-32.2°C in the silos, that, after sealing, were purged by N_2 to obtain a residual O_2 content of less than 0.5%. It was found that no insect survived the treatment. Mould counts remained virtually unchanged during storage. Viability was retained substantially while chemical parameters of quality remained unchanged.

(c) *Cocoa*

Grade 1 cocoa was stored in the silo after purging with N_2 to a residual O_2 concentration of 0.35%. Storage lasted 44 weeks under environmental conditions similar to those used for cowpeas above. No significant changes were observed in the chemical, microbiological, and organoleptic parameters analysed at the end of storage. The cocoa remained free of insects during the storage period.

Phase IIII : storage of maize and sorghum in demonstration silos

The two demonstration silos were cylindrical steel storage bins with flat bottoms and conical roofs. Each cylinder had a diameter of 3.50 m, height of 5 m, and a conical hopper, giving each bin a useful volume of 52 m^3. These bins were built in Ibadan. The bins were fitted with openings for sampling at the top, centre, and bottom, and with a manhole permitting inspection and cleaning after unloading. Openings for gas emission and gas sampling were provided. The silos were painted white and their roofs were shaded with palm leaf thatches. Maize and sorghum were stored in these demonstration silos.

(a) *Maize*

Thirty-nine tons of high-quality white maize were loaded mechanically into one of the demonstration silos. The m.c. and storage temperatures of the maize were 7.7% and 32°C, respectively. After sealing, the silo was purged with 30 m^3 N_2 for 10 hr, reducing the O_2 level at the roof gas outlet to 5%. Because of the unavailability of compressed N_2 to complete the purge entirely, the silo was kept on hold for two months. The interstitial O_2 concentration was found to have decreased to only 2.75% in two months, a level too high for safe storage of the grains. The silos were then purged with a further 40m^3 N_2 over a 5 hr period to obtain a residual O_2 concentration of 0.45%. The O_2 level was maintained at 0.15%-0.20% throughout the subsequent storage period of seven months. At the end of the storage period, no significant changes were observed in the quality parameters analysed. No live insects were found at the end of the storage period, although light insect infestation was observed before loading. Total mould count was found to have decreased as compared with the initial mould count. The main problem during the trial was difficulty in maintaining a low O_2 concentration in the interstitial atmosphere because of problems of N_2 supply.

(b) *Sorghum*

Forty-one tons of fair-quality sorghum were loaded mechanically into a demonstration silo and stored for 7 months as described above for the storage of maize. The initial m.c. was 8.3% decreasing to 7.6% at the end of 7 months; the temperature was 32°C. The same problem of availability of N_2 for purging affected this study. The first purge with 27 m^3 N_2 resulted in a residual O_2 concentration of 2.5%, that decreased within 2 months to 1.75%. The second purge with 32 m^3 N_2 reduced the O_2 concentration of the interstitial atmosphere to 0.05%. At the end of the 7-month storage, the O_2 concentration at the bottom of the silo was 0.2%.

No changes in qualitative parameters were detected after seven months of storage. Although insect infestation (composed of *Tribolium castaneum*, *Rhyzopertha dominica*, *Cryptolestes pusillus*, and *Lasioderma serricorne*) at loading was relatively high (13 adults per 500 kg), no live insects were found in the samples drawn from the bottom of the silo after 7 months storage. It was concluded that storage of low-moisture sorghum in a demonstration silo was successful, with full control of insect and mould damage and maintenance of other quality parameters.

SPECIAL STUDIES CONDUCTED UNDER THE COLLABORATIVE RESEARCH PROGRAMME

(a) Susceptibility of various life stages of some storage insects to N_2 atmospheres in minisilos

The main aim of the study was to determine the exposure periods necessary to kill 100% of some important insect pests of food crops in Nigeria. The insects studied were *Sitophilus zeamais*, *Trogoderma granarium*, *Callosobruchus maculatus*, *R. dominica*, *L. serricorne*, *Dinoderus purcellus*, *Dermestes maculatus*, and *Necrobia rufipes*. The mean temperature was 28°C and mean r.h. 70%. It was observed that the larval stages of all the insects tested were more susceptible to N_2 than were the adult, egg or pupal stages. *D. purcellus* and *R. dominica* were found to be the least susceptible of the insects to N_2. Adults of these two species were observed to be paralysed temporarily when exposed to N_2 for periods not long enough to kill them. It was also observed that there was delayed hatching of eggs of *C. maculatus* when exposed to N_2 for periods less than those required for kill. Exposure periods needed to achieve 100% kill of the insects tested varied from 48-78 hr. Details of the study were reported fully by Shejbal and Agboola (1982).

In another study, Williams *et al.*, (1980) found that durations of exposure required to kill the eggs, larvae, pupae, and adults of maize weevils were 4.0, 7.5, 8.0, and 3.0 days, respectively, while 5 days' exposure to N_2 killed all the larvae of the khapra beetle.

(b) **Study of the consumption of nitrogen gas**

(i) *Minisilos*

For the minisilos, 700-800 litres N_2 was used to purge each silo containing the commodities to obtain a residual O_2 concentration of less than 0.05%. The purge rate was 1.17-1.33 m^3 N_2/m^3 maize. However, this rate of N_2 consumption is by no means indicative of consumption for larger structures.

(ii) *Pilot-scale silos*

Gas consumption for purging ranged from 3.0-3.8m^3, depending on the type of commodity and the filling rate of the silos. After the initial problems of increased gas consumption due to frequent sampling and some technical problems were overcome, mean N_2 consumption for both pilot-scale silos was less than 10 1/day or less than 300 1/month. It was found that protection against direct solar radiation on the silos reduced gas consumption considerably. Full insulation followed by simple shading reduced gas consumption appreciably. As full insulation of the metal silos would be very costly, simple shading is advocated for protection of the silos against solar radiation and consequent increased gas consumption.

(iii) *Demonstration silos*

The unavailability of N_2 after incomplete purging of the demonstration silos made it difficult to give reliable values for the quantity of gas needed for purging. Mean consumption of N_2 for pressure maintenance was 0.178 m^3/day or 3.4 1 N_2/m^3 commodity/day for maize and sorghum. This would give a consumption level of 1.62 m^3/ton/year. Mean N_2 consumption for the shaded demonstration silos was 0.813 m^3/ton/year.

CONCLUSIONS FROM THE COLLABORATIVE STUDY

Studies carried out using the minisilos, experimental pilot-scale silos, and the demonstration silos showed conclusively that the CA technique for grain storage is fully applicable in the humid tropics (see Table 1.) This technology, that makes use of non-toxic, non-contaminating gases, ensures complete insect and mould control, a no-loss medium, and long-term storage (Shejbal and Agboola, 1982), is definitely an attractive technology for crop storage. These findings are consistent with findings in other parts of the world which were reported earlier.

Table 1: Storage of dry grains in nitrogen in metal silos.

Silo Type	Source	Useful Volume (m^3)	Crop Stored	Initial Quality	Initial Moisture Content (%)	Final Moisture Content (%)	Storage Period (months)
Minisilo	Assoreni, Rome	0.6	Yellow Maize	Just Fair	12.7	12.7	2.5
"	" "	0.6	Yellow Maize				
"	" "	0.6	White Cowpea	Good	8.2	10.2	6
"	" "	0.6	White Cowpea	Good	8.2	10.4	12
"	" "	0.6	Brown Cowpea	Good	9.7	8.7	6
"	" "	0.6	Brown Cowpea	Good	9.7	9.0	12
"	" "	0.6	Rice	Fair	14.2	14.0	6
"	" "	0.6	Rice	Fair	14.2	14.3	11
"	" "	0.6	Cocoa	Good	4.3	5.5	6
"	" "	0.6	Cocoa	Good	4.3	5.2	11
Pilot-scale silo	Ibadan	4	Yellow Maize	Good	12.9	12.8	10
" " "	"	4	Yellow Maize	Good	12.9	12.0	22
" " "	"	4	White Maize	Low Grade	8.3	9.6	9
" " "	"	4	Cocoa	Good	4.3	5.4	6
" " "	"	4	Cocoa	Good	4.3	5.1	11
Demonstration Silo	Ibadan	52	White Maize	High	7.6*	7.7	7
" "	"	52	Sorghum	Fair	8.3**	7.6	7

* Unusually low moisture content for the region in which the trials were conducted, though if purchased from the north during the dry season, these m.c.s are not exceptional.

** Sorghum is grown largely in the north of Nigeria, where if purchased during a dry period, the grains may reach this low moisture content.

STUDIES CARRIED OUT AFTER 1981 IN NSPRI

Several studies have been conducted since the collaborative studies between Snamprogetti and NSPRI ended in 1981. Some of the studies carried out are mentioned briefly below.

(a) Biochemical changes in yellow maize stored over a three-month period under N_2 were observed by Sowunmi *et al.,* (1982). Proximate constituents, carbohydrate fractions, free fatty acid, peroxide value, and N_2 solubility were found to be relatively unchanged at the end of the study, whereas significant changes were observed in the quality of similar maize stored under ambient conditions.

(b) The chemical quality of maize and sorghum stored in N_2 in demonstration silos were examined after four years of storage by Opadokun and Sowunmi (1985). Their observations confirm that this technology preserves the chemical quality of these grains excellently for at least four years.

(c) An attempt was made to store wet maize in the minisilos and monitor the quality. Initial m.c was 21% and this increased to 30% at the end of the storage period. Although the grains appeared to have kept well for the first 6 months, rapid deterioration later set in, with the grains becoming discoloured and emitting an offensive, fermenting odour. The silo had to be evacuated. The poor initial quality of the wet maize may have contributed to this rapid spoilage. No further attempt was made to store wet maize.

SCIENTIFIC/TECHNICAL FACTORS TO CONSIDER IN ADOPTION OF CONTROLLED ATMOSPHERE FOR GRAIN STORAGE

The decision to adopt CA technology for the storage of grains will be influenced by availability of satisfactory solutions to some or all of the problems surrounding this technology, namely, the type of grain, the moisture level of the grain, the climate at the storage facility, the type of CA used, and technical capabilities. NSPRI experience as a result of the collaborative study with Assoreni has provided answers to these basic questions.

(a) *Type of grain*

Three different cereal grains, namely, maize, sorghum, and rice of varying qualities were stored satisfactorily under N_2 for periods exceeding 48 months. The principal food grain legume in Nigeria, cowpea, both white and brown varieties, were stored successfully in N_2 with good retention of quality for 24 months. Cocoa, an oilseed and major cash crop of Nigeria, was also stored successfully in N_2.

Groundnut was also successfully stored in the minisilo. Thus, it can be concluded that in Nigeria, all major dry food grains can be stored successfully under N_2 atmosphere.

(b) *Moisture content of the grain*

All grain samples that had m.c. equal to or below the levels considered "safe" for storage (13.0% m.c. for cereal grains) stored well under N_2. Samples of wet maize stored in the minisilo were of very poor quality at the end of the storage period, revealing extensive mould damage and high aflatoxin B1 content. Although the poor quality of the wet maize was probably due to its poor initial quality and the delay in loading it into the silos, no further attempt was made to store wet maize.

(c)*Climate at the storage facility*

Studies on CA storage of grains in Nigeria were conducted in Ibadan whose climate can rightly be described as humid and tropical. The hot, humid parts of the country such as Ibadan are noted generally for faster deterioration of stored grains than in the drier north. It is anticipated that CA technology will be even more successful in the drier north than in the more humid south, provided that the silo top is shaded adequately. Preliminary studies carried out in Kano (dry north) confirm that cowpeas and groundnuts stored successfully under N_2 atmosphere in minisilos, with excellent retention of quality.

(d)*Type of CA used*

Although either N_2 or CO_2 can be used in CA storage technology, NSPRI and Assoreni decided to use N_2 for the studies for a number of reasons. ASSORENI's past experience as observed by Shejbal (1980) suggests that CO_2 at high concentrations (above 60%) causes adverse organoleptic changes in dry grains stored over long periods. With wet grains, the organoleptic and quality changes will be even more acute. A second reason is that CO_2 is not truly inert and can support the growth of some microorganisms (Hocking, 1989).Thirdly, in Nigeria, N_2 is more readily available commercially than is CO_2.

(e)*Technical capabilities*

For effectiveness, CA storage technology needs gastight containers, and requires highly trained people to fabricate, install, and operate the silos and basic equipment correctly. CA storage technology also requires trained personnel to handle and monitor the quality of the produce during storage. The expertise required for these is now available in the country. Key officers of the NSPRI have been trained in this technology.

ADOPTION OF CONTROLLED ATMOSPHERE TECHNOLOGY FOR GRAIN STORAGE IN NIGERIA

Results of the studies carried out on CA storage technology (usually referred to as "Inert Atmosphere" storage technology) by NSPRI and Assoreni have been widely publicised in Nigeria over the past eleven years. At the official launching of this technology in Ibadan (Nigeria) in 1981, Agboola (1981) expressed optimism that this technology would be adopted immediately and widely by large scale farmers, industrialists and government organisations, and hopefully extended eventually to rural areas as well. Every available forum has been used since then to popularize the technology: at agricultural shows, national science exhibitions, and trade fairs etc. Several industrialists have made contacts with the Institute for possible adoption of this technology for grain storage. Regrettably, there is very little evidence that any major farmer, industrialist, or government organisation is using or is planning to use the technology in the immediate future. Some reasons are given for this state of affairs.

(i) *High cost of the technology*

The most important constraint in the use of CA technology in Nigeria is probably the high initial capital cost of constructing CA storage silos and the fittings required to operate the silos effectively. Even in advanced countries of the world, initial capital costs have been shown to be the major constraint preventing the adoption of this technology for grain storage (Annis, 1986; Banks, 1989; Quan, 1989).

As for operating (maintenance) costs, it has been observed that provided sealed storage can be guaranteed and provided the silo is not opened frequently, gas consumption and, therefore, maintenance costs for the use of CA technology for the storage of dry grains can be very low, as compared with conventional storage. Shejbal (1980) and Tranchino (1980) estimated that the storage costs for one year preservation is either lower or of the order of a single fumigation by chemicals and that operating costs decrease with increase of storage facility capacity. Based on an in-depth economic analysis in Indonesia, it was calculated by Conway *et al.* (1989) that although initial capital costs for CA technology are high, maintenance costs are lower as compared with the use of conventional pesticides for storage.

Adesida (1985) calculated that for Nigeria, it will take 6 years to pay back the initial cost of installing the CA storage silo for a 270-ton capacity silo before an annual rate of return on investment of 15% can be expected.

(ii) *Problem of supply of gas*

CA storage technology requires a source of pure or food-grade N_2 for initial purging and a constant supply of gas after purging to maintain the required low level of O_2 in the system. This is generally delivered in compressed form in heavy metal gas cylinders. Where problem of gas supply arises, as it did during the last phase of the collaborative study of NSPRI and Assoreni, pest control may be impossible resulting in spoilage of the grain being stored. While N_2 is now generally available in urban centres in Nigeria, the same cannot be said of rural areas in the country. Thus, availability of N_2 may be a limiting factor in the adoption of this technology for grain storage outside urban centres.

A nitrogen generator to be installed at the storage site has been suggested as an alternative to having to convey heavy nitrogen cylinders to storage sites. Attractive as this suggestion may seem, initial cost and the maintenance of such generators may create additional problems.

(iii) *Non-familiarity with the technology*

It is a fact that despite the Institute's effort to popularise the CA technology for grain storage it is not well-known in Nigeria . One reason is that this is not a technology that can be demonstrated to people just anywhere. Demonstration has to be performed at sites where the CA silos have been erected. Regrettably, there are only two of these in Nigeria at present, in Ibadan and Kano. Very few people can be persuaded to adopt technologies with which they are not familiar and that have not been shown conclusively to work and to be economical.

For those who know, CA technology is still considered rather sophisticated and expensive. Very few organisations other than NSPRI have worked on, or are still carrying out, meaningful research on CA technology. While NSPRI itself has done a considerable amount of work on this technology, a lot still remains to be done to provide answers to some technical and economic problems affecting the technology.

(iv) *Nature of agricultural system in Nigeria*

It is estimated that about 80% of Nigerian food crops are produced by peasant farmers in Nigeria in rural areas, who store a substantial part of their harvested crops often in rather small quantities. For such farmers, CA storage technology at this time appears unfeasible for reasons of cost, availability of materials, familiarity with the technology, and the small quantity of produce they store.

The large-scale farmers who can afford to pay the high initial capital costs cannot wait 6 years for returns on their investments. Further, very few, if any, store their grains longer than one season. For such short-term storage, the conventional storage method involving the use of pesticides would still appear more economical. But if long-term storage (fifteen months and above) is contemplated, such farmers would actually be better off economically using CA technology for storage.

The only bodies that can and often do hold large stocks of grain for long periods as food security items are the various governments (national and state) in Nigeria. Although the federal government of Nigeria has a laudable policy and has built infrastructures for strategic grain reserves throughout the country, CA technology has not yet been adopted for storage of grains by the Government.

(v) *Nature of grain marketing in Nigeria*

The industrialists who utilize grains in the manufacturing industries and who can afford to pay high initial capital costs, do not hold large stocks of grain for long periods. Storage usually lasts only a few weeks or a few months at most, with the grain being withdrawn at regular intervals for processing. Under this type of storage system, CA storage technology would be uneconomical.

THE FUTURE OF CONTROLLED ATMOSPHERE TECHNOLOGY IN NIGERIA

International concern over the use of toxic chemicals in food and the environment is growing daily. For many decades, several chemicals have been available for use as fumigants for pest control in stored-products. The number of such chemicals now allowed by many advanced countries has decreased, with restrictions now placed on such substances as ethylene dibromide, ethylene dichloride, carbon tetrachloride, etc. Today, only methyl bromide and phosphine are still accepted internationally, somewhat reluctantly. Methyl bromide usage in Nigeria for stored products pest control has declined to an insignificant level over the past two decades. Phosphine is used considerably. Recent reports of resistance of several insect pests to this fumigant especially in tropical countries (Taylor and Halliday, 1986) are disturbing, if not alarming. Clearly, an alternative has to be found to phosphine for stored-product insect control.

Increasing emphasis is now being placed on preventive or direct control measures that do not involve the use of toxic chemicals in controlling pests in crop storage. The consumer, at least in the advanced countries of the world, now demands food that is free from pesticides. A technology for crop storage that produces such food is the CA storage technology. This technology is compatible with modern philosophies of pest control and safe food now spreading throughout the world. Nigeria cannot be an exception.

It is hoped that as the standard of living rises, and as people become increasingly aware of the dangers of having toxic chemicals in their food, they will demand, as others are now doing, for toxic-free foods. CA technology will, therefore, come into prominence more and more. The problems facing CA adoption in Nigeria are not insurmountable. New advances in CA technology, such as the use of nitrogen generators, the use of an O_2 absorbing system to produce O_2-deficient atmospheres, development of selectively permeable membranes to separate O_2 from N_2, and sealing techniques that guarantee airtightness in silos and reduce gas consumption will reduce operating costs and make CA technology economical in Nigeria. Besides, the ever-rising cost of pesticides in Nigeria can only discourage their use and make the CA technology more competitive in the future.

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