APPLICATION OF ARTIFICIAL CONTROLLED ATMOSPHERES TO GRAIN STORAGE IN THE TROPICS: CASE STUDY OF NIGERIA

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ABSTRACT

Nigeria produces about 10 million tons of grains annually which need to be stored between one harvest and the other over a period of 8-10 months. Storage methods range from local cribs used by the peasant to warehouse and silo structures used by large-scale grain storage establishments such as the National Grains Board and Agro-allied industries. Insect infestation is controlled only by chemical application. A lot of problems are encountered with silo storage methods and chemical control of insects under Nigerian conditions. This paper examines the application of artificial controlled atmospheres to grain storage in the tropics against the background of existing storage practices and problems in Nigeria.

A research project is being carried out in collaboration between ASSORENI/SNAMPROGETTI and NSPRI, in order to introduce the Nitrogen Storage Technique for Grains into Nigerian practices. The first two of the project's three research phases are described.

In phase I maize was stored for 10 weeks in minisilos filled with nitrogen. The insect infestation, fungal deterioration, seed viability, chemical and nutritional changes in the maize were measured during

the experiment and results showed that the inert gas storage method maintained the quality of the maize much better than storage in air. Another trial storing cowpeas, a grain legume, in the minisilos, is in progress.

Phase II of the project, involving four pilot-scale silos (3 ton-capacity), fully equiped with automatic physical measurement devices and filled with maize, has also commenced. Preliminary results are presented.

INTRODUCTION

Grain forms a substantial part of the staple food in the tropics. Most tropical countries produce far less grain than they require locally and therefore have to spend their hard earned foreign exchange for importing grain. Nigeria produces about 10 million tons of grains annually mainly guinea corn, millet, maize and rice; the Maize and Produce Board in Kenya handles about 5 million bags of maize annually; while the National Agricultural Marketing Board in Zambia handles about 7 million bags of maize annually.

The methods at present used in Nigeria for storage of grains vary according to the level of storage. At the village level or the peasant farmer's level, a very effective structure called "CRIB" has been developed. It serves both as a natural drier and a container. The next level of grain storage is the medium scale level. The conventional warehouse or 'godown' has been recommended for use at this level. Warehouses and silos are used for large scale storage. However some problems are being encountered with the use of silos and therefore warehouses are more favoured.

In all these structures, enormous losses occur during storage. F.A.O. estimated an annual loss of 10% in both farm and store (Anon, 1947) and a loss as high as 24.7% has been reported by Adesuyi and Shode (1977) in farm level storage. The major causes of grain storage losses have been identified as insects, moulds and rodents. Birds can be a major factor in some cases. As a result of these losses, it has been realised that any major effort to increase food production must be supported by effective storage facilities. In realisation of this fact, the seventh special session of the United Nations General Assembly in 1975 passed a resolution that every effort should be made to achieve a 50 percent reduction in post-harvest food losses by the year 1985. This resolution resulted in the Reduction of post-harvest food losses programme of the F.A.O. in 1977.

Chemicals are at present being used extensively to reduce post-harvest grain losses. There are however many problems and risks associated with the use of chemicals, both to consumers and operators. These are mainly:

(i) Danger to storage personnel
(ii) Danger to consumers
(iii) Taint and damage to seed viability
(iv) Problem of insect resistance to chemicals in use.

Therefore the need for a safer alternative is evident.

Hermetic storage, in which oxygen deficient atmosphers are produced by the aerobic respiratory processes of the grain, its microflora and insects to a level that inhibits the further existence or development of aerobic organisms, has long been known. However, the rate at which this process occurs is very critical because the longer it takes, the more damage is done by the organisms causing deterioration. In cases of dry grain storage with low insect infestation, the process of self-sterilisation is so slow that it may not be practicable.

To accelerate the depletion of oxygen to a level suitable for the elimination of all the developmental stages of storage insects, and supression of microorganisms, it is convenient to introduce an inert gas such as nitrogen to replace the oxygen-rich interstitial atmosphere in storage bins (Shejbal, 1979). Successful trials in large--scale facilities using nitrogen gas for the commercial storage of wheat and barley for short and long term periods (Shejbal, 1978) confirmed research carried out in Italy for several years in laboratory and pilot scale silos (Shejbal, 1979). It is known that the use of nitrogen for grain preservation could eliminate some of the major problems of grain storage, if applicable in Nigerian climatic conditions, such as:

- Toxicity of insecticides both to consumers and operators.

- Insect infestation and reinfestation.
- Insect resistance.
- Taint and poor palatability.
- Loss of food reserve through metabolic activities of the stored produce.

Furthermore it could:

- Increase the possibility of storing wet grain until it can be dried.
- Retain viability of stored produce for a long period.
- Improve the palatability of stored produce.

Use of controlled atmosphere would therefore be of value in Nigeria in control of both insect and mould growth especially in the main maize crop which is harvested during the rainy season at moisture contents of 22-25% (Adesuyi, 1968) without assurance of sunshine to dry it.

A collaborative work between ASSORENI (Snamprogetti) and NSPRI was therefore initiated to evaluate this technique and for transferring the technology to Nigeria. The project is divided into three phases, lasting for a total of 30 months. They are as follows:

1st phase: Small-scale trials utilizing two minisilos, each with a capacity of 0.6 m^3.

2nd phase: Experimental pilot-scale trials utilizing four silos, each with a capacity of 4 m^3.

3rd phase: Large-scale field trials utilizing two silos, each with a capacity of 40 to 50 tons.

The following is a report on the first trial in the first phase using the minisilos and on preliminary data of the second phase.

MATERIALS AND METHODS

Two airtight stainless steel mini-silos, useful volume 0.65 m^3, situated in complete shade at the NSPRI, Ibadan are used in the trials of phase 1°.

The minisilos (Fig.1) are equiped with 3 sampling points for gas and grain analyses SA1 - SA3 and SB1 - SB3 for the silos A and B respectively. Thermistors are located in the central axis of the grain column. The silos are connected with the nitrogen distribution system silos was nearly zero. A rapid purge of the silos was carried out in order to substitute the interstitial atmosphere with nitrogen, whereupon a slight constant overpressure was maintained during the whole storage period. For this a pre-set pressure gauge which automatically cuts off the supply of gas into the silos by a solenoid switch when the pressure build-up within the silo attains the set pressure (100 mm w.g.), is incorporated into the gas distribution system and located on the instrument pannel. The initial purge with ultrapure nitrogen was carried out for 14 hours at a rate of 50 litres per hour within one day after loading.

As controls in air, maize of the same quality was maintained in two metal drums, CA and CB (180 l volume each) situated in proximity of the mini-silos.

The concentrations of carbon dioxide and oxygen within the silos were checked once every week, and after every purge following introduction or removal of test insect cages. The temperature of stored grain, pressure within each silo, ambient temperature and humidity were recorded thrice daily.

During loading the maize was sampled in both the silos and controls for insect infestation, insect damage, biochemical and microbiological analysis and sensory evaluation. Samplings were repeated at 4 and 10 weeks and similarly analysed.

Viability tests of stored maize were carried out using fifty seeds per replicate, germinated in sterilized soil in the laboratory (Fig.2).

For trials in phase 2 of the collaborative work, four pilot-scale gastight steel silos, useful volume 4 m^3 each, were built and erected in Ibadan. The alignment of the silos is in a North-South direction in an unshaded area in order to expose the silos to full and direct sunshine.

As can be seen in Fig.3, each silo is protected in a different way against solar radiation: one of the silos is fully insulated with 5 cm rock-wool and galvanized steel sheets, another is insulated similarly only on the roof, while the third is not insulated at all and the last is shaded on the top with a thatch made of palm leaves.

Each silo is equipped with 50 thermistors dislocated in such a way

Fig.2. Viability tests of stored maize in sterilized soil.

that the temperature in the axial and radial sense can be measured at the surface of the bins and at various depths in the stored product mass. The temperature readings are recorded automatically at preset time intervals.

The nitrogen gas flows, pressure maintenance devices and pressure relief valves are similar to those of phase 1, the overpressure maintained in the bins is 50 mm w.g. and gas consumption is measured by gas meters (Fig.4). The four bins were loaded with grade I yellow maize, mean moisture content 12.9%.

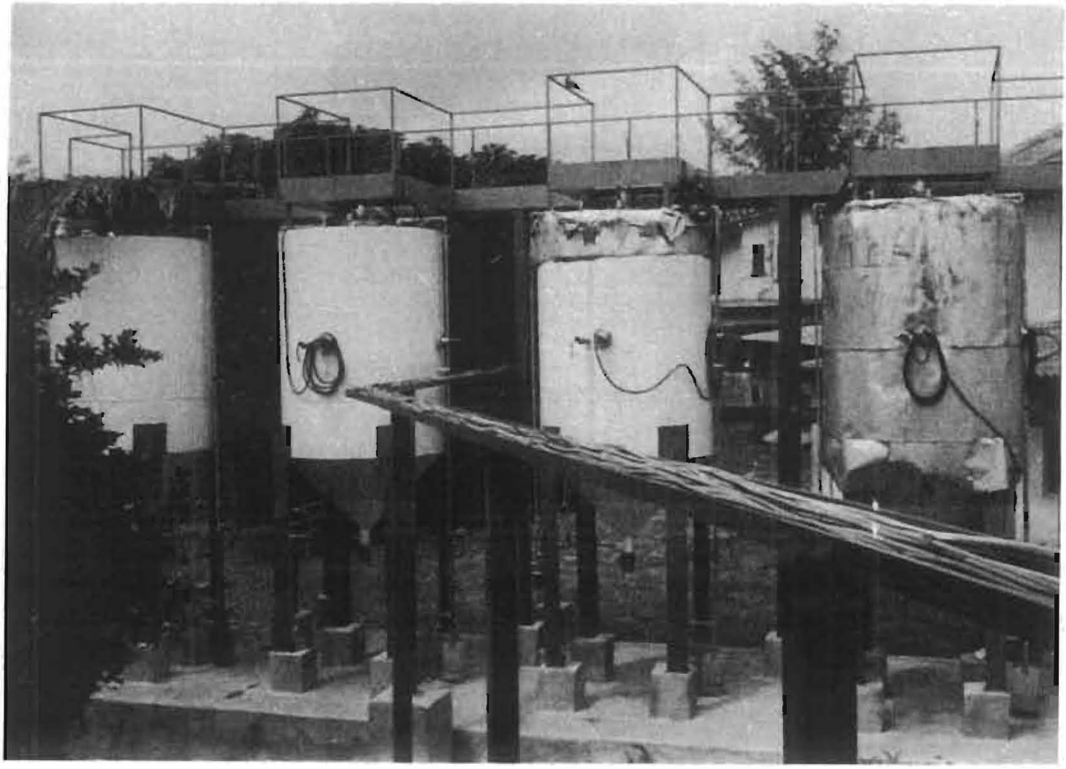

Fig.3. Pilot-scale metal storage bins differently protected against direct solar radiation. Sampling and temperature measurement points are visible on the 4 m^3 -silos. In the foreground, wires conducting to the automatic recorder of temperature at 50 distinct points in each bin.

Fig.4. Pilot-scale metal storage bins with automatic interstitial nitrogen pressure maintenance device, gas meters and pressure releaf valves.

RESULTS

Phase 1.

Temperature measurements in silo A gave an average of 27.2°C with a range of 26.5°C to 27.8°C; silo B an average of 26.6°C with a range of 26.1 to 27.5°C, the ambient relative humidity ranged between 72.0 and 80.9% with an average of 76.3%. The oxygen content of the interstitial atmosphere in the silos was maintained at 0.05% - 0.1% by purges after grain or insect samplings.

The initial moisture content of the experimental maize was 12.7%.

The moisture content level was maintained at about 13% in the minisilos but rose steadily to 16.5% in control A and to 17.2% in control B (see table 1).

The results of the entomology experiments are presented in another paper (Williams et al., 1980). It was found that the egg and the adult stages of Sitophilus zeamais (maize weevil) were more susceptible to nitrogen than the larval and pupal stages. The duration of exposure required to kill the egg, larval, pupal and adult stages of S.zeamais were 4.0, 7.5, 8.0 and 3.0 days respectively while 6.0 days exposure was required to obtain a full kill of larvae of Trogoderma granarium (Khapra beetle).

Tables 2 and 3 show that the initial damage to the maize was between 1.8 and 2.2% and the insect pest population was fairly high with Sitophilus zeamais being the most predominant species. However, it can be seen from the same tables that after 10 weeks storage in nitrogen, the percentage damage remained the same with a sharp contrast in the control where the damage has increased by about 2,100%; secondly, no insect pest was found even after incubation in maize stored in nitrogen, whereas the population in the control had increased by 765%.

Mouldiness of the maize as determined by dilution plating analysis was 9.9×10^5 colonies per gram of maize in the initial samples. While this amount of mouldiness increased substantially to an average of 2.5×10^7 in the controls, maize stored in nitrogen maintained about the same level of mouldiness as the initial samples. At some points, a decrease to an average of 3.9×10^4 colonies per gram was obtained in one of the silos (table 4).

The most predominant species were Aspergillus flavus Link; Fusarium moniliforme Sheld and Aspergillus niger V. Tieghem. Others of rather less importance are Aspergillus tamarii Kita, Paecilomyces varioti Bainier, Rhizopus arrhizus Frischer and Penicillium sp. All these moulds are commonly isolated from grains and other crops during storage in Nigeria. Table 5 shows the average abundance of the different mould species in the maize stored in nitrogen and the controls.

Results of chemical analyses, viability and sensory evaluations are summarized in Table 6. As can be seen, proximate parameters remained

TABLE 1

MOISTURE CONTENT OF MAIZE STORED IN NITROGEN AND IN AIR FOR 4 AND 10 WEEKS. PRE-LOADING MOISTURE CONTENT WAS 12.7%.

Sample	Percent moisture content of maize during storage for weeks	
	4	10
SA 1	12.6	12.7
SA 2	12.7	-
SA 3	12.9	12.7
AVERAGE	12.8	12.7
SB 1	13.1	13.0
SB 2	13.0	-
SB 3	12.9	13.1
AVERAGE	13.00	13.1
CA	15.0	16.5
CB	15.1	17.2
AVERAGE	15.1	16.9

NOTE

SA 1 = Silo A Point 1 (bottom)
SA 2 = Silo A Point 2 (middle)
SA 3 = Silo A Point 3 (top)
idem for silo B
CA = Control drum A (mean sample at 20 cm depth)
idem for drum B.

TABLE 2

INSECT DAMAGE ASSESSMENT ON 500 GRAIN SAMPLES FROM MAIZE STORED IN NITROGEN AND IN AIR.

Treatment	Damage %	
	0 week	10 weeks
Mini Silo A	2.2	2.0
Mini Silo B	1.8	1.6
Controls	1.8	38.0

TABLE 3

INSECT SPECIES AND POPULATION INFESTING MAIZE STORED IN NITROGEN AND IN AIR. COUNTS FROM 1KG SAMPLES.

Period	Location		Sitophilus zeamais	Cryptolestes sp.	Carpophilus sp.	Tribolium castaneum	Moth	Lasioderma serricorne	Total
0 week	Mini silo	Top	10	0	5	9	2	1	27
		Middle	6	0	3	6	0	3	18
		Bottom	8	1	6	8	0	6	29
	Control		9	0	8	4	0	2	23
10 weeks	Mini silo	Top	0	0	0	0	0	0	0
		Middle	0	0	0	0	0	0	0
		Bottom	0	0	0	0	0	0	0
	Control		154	4	1	6	3	8	176

TABLE 4

AVERAGE MOULD COUNTS FROM MAIZE STORED IN NITROGEN AND IN AIR.

Sample	Average number of mould colonies isolated per gram of maize after storage for 4 and 10 weeks. The initial count was 9.9×10^5.	
	4	10
SA 1	2.8×10^5	5.0×10^4
SA 2	3.9×10^5	-
SA 3	8.4×10^5	2.6×10^4
AVERAGE	5.0×10^5	3.9×10^4
SB 1	2.4×10^5	4.4×10^4
SB 2	1.5×10^5	-
SB 3	1.6×10^5	1.8×10^5
AVERAGE	1.9×10^5	1.1×10^5
CA	5.8×10^6	2.2×10^7
CB	4.0×10^6	2.8×10^7
AVERAGE	4.0×10^6	2.5×10^7

Note: For symbol explanation see Table 1.

constant during storage (crude protein, oil content, total ash), while total hexose sugars, total reducing sugars, fructose, glucose, sucrose and starch content remained unaltered in nitrogen but considerable changes of these carbohydrate components were observed for maize stored in the control drums. An increase in the free fatty acid content of oil (very high also at start of experiment) was observed in all samples, particularly marked in the maize stored in air.

The viability tests showed a slight loss for maize stored in nitrogen while there was a substantial reduction in the viability of the controls.

There was no adverse effect on the palatability of maize stored in nitrogen for ten weeks while the control had very poor palatability. The sensory evaluation was carried out on pap (ogi) made from the flour with boiling water. The corn flour was obtained by steeping whole grains in water for 48 hours. Sulphur dioxide was added to the water to prevent fermentation. The corn was wet-milled and sieved.

TABLE 5

AVERAGE ABUNDANCE OF DIFFERENT MOULD SPECIES IN MAIZE STORED IN NITROGEN AND THE CONTROL

Sample	Storage Time (weeks)	Average abundance of the different mould species given as no. of mould colonies per gram in maize						
		A. flavus	A. niger	A. tamarii	F. moniliforme	P. varioti	Penicillium sp	R. arrhizus
0 (initial)	0	5.1×10^{5}	*p	2.1×10^{5}	3.3×10^{5}	p	p	p
SA	4	3.6×10^{5}	0.4×10^{4}	p	0.9×10^{5}	p	1.3×10^{5}	p
SB		6.1×10^{4}	2.6×10^{4}	1.7×10^{4}	4.0×10^{4}	p	6.0×10^{3}	-
C		2.2×10^{6}	1.5×10^{6}	1.7×10^{4}	1.8×10^{6}	-	p	p
SA	10	4.5×10^{4}	p	p	p	p	6.0×10^{3}	-
SB		10.7×10^{4}	4.9×10^{3}	-	-	1.9×10^{4}	-	-
C		2.6×10^{7}	2.9×10^{6}	3.1×10^{4}	1.8×10^{4}	1.1×10^{6}	3.9×10^{6}	1.3×10^{3}

*p (present) means that the colonies are few and irregular.

TABLE 6

CHANGES IN CHEMICAL AND ORGANOLEPTIC FEATURES OF MAIZE STORED IN NITROGEN AND IN AIR FOR 10 WEEKS.

	nitrogen	air
crude protein	unchanged	unchanged
oil content	unchanged	unchanged
ash	unchanged	unchanged
sucrose	unchanged	decreased
glucose	unchanged	increased
fructose	unchanged	increased
starch	unchanged	decreased
free fatty acids	increased	strongly increased
viability	slightly decreased	strongly decreased
palatability	no adverse change	very poor

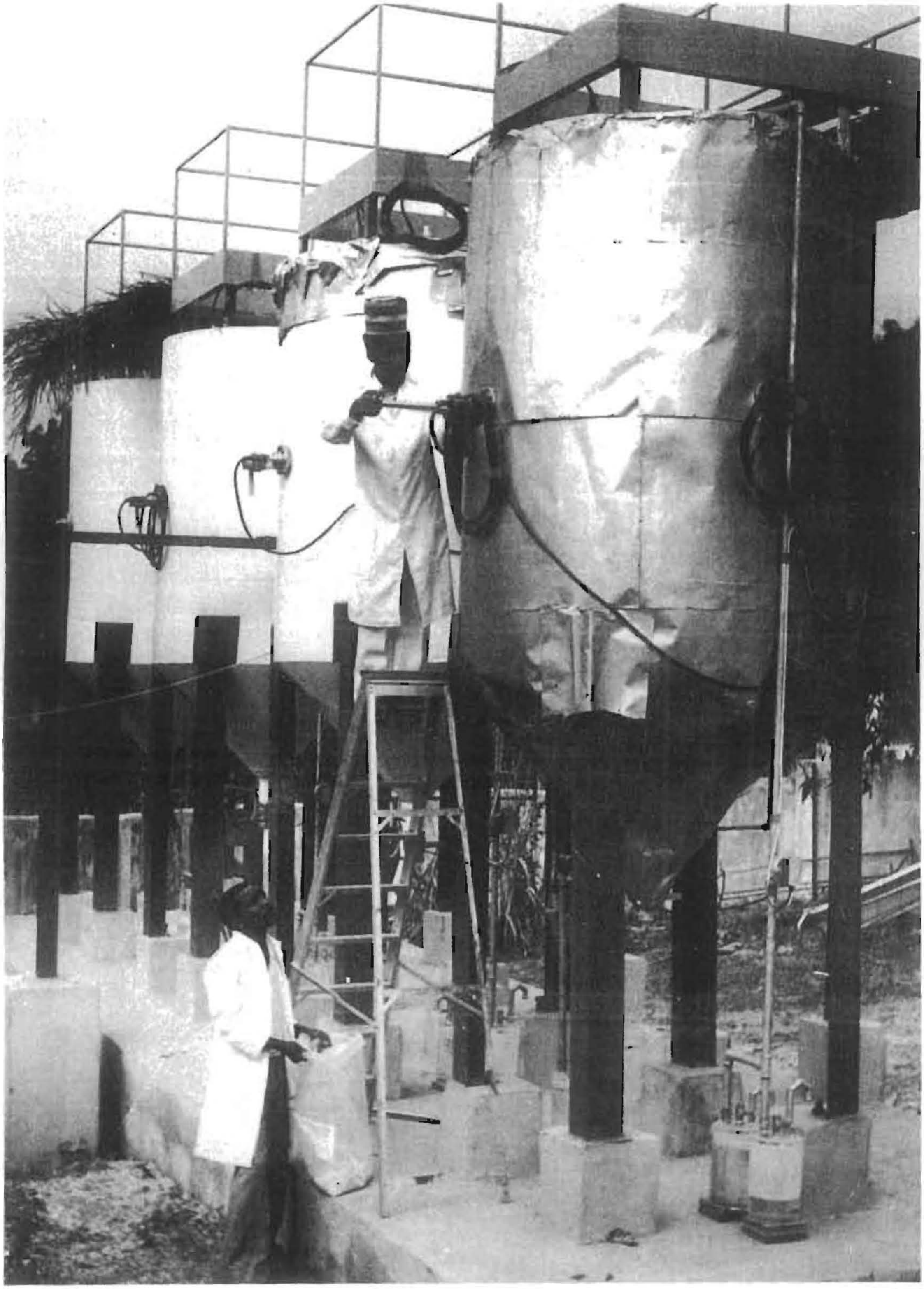

Fig.5. Sampling of pilot-scale nitrogen grain storage bins.

Conclusion regarding the first storage trial in phase 1.

Nitrogen used as inert gas for storage of grains has been found effective in preserving the quality and reducing the substantial losses to which maize is prone under the conditions of the experiment.

As a result of the encouraging trend, the minisilos have now been filled with cowpeas (*Vigna* sp.). Cowpea is a very important vegetable protein in Nigeria. It is highly susceptible to insect damage especially by *Callosobruchus maculatus* which infests it from the field before harvest and continues its destruction in the store. Two varieties of cowpeas, the white and brown, are being tried. The set-up is similar to the trial described above.

Phase 2.

The aims of the first stage of phase 2 of the collaborative research being two-fold:

a) to find the most effective method of adapting metal silos for nitrogen storage of grains to give good storage results in the humid tropics;

b) to find out the effectiveness of using nitrogen gas for controlling deterioration of stored grains under the different treatments to be applied in a),

temperature fluctuations, moisture migration, nitrogen consumption and changes in quality parameters of the stored maize were studied.

As can be seen in Fig.6, diurnal temperature fluctuations of the exposed metal surfaces of the roofs of the unshaded bins are very strong. The largest temperature fluctuation in the headspace gas is observed in the unprotected bin, while in the completely insulated bin and in that with an insulated roof, a certain attenuation of the phenomenon is achieved. The best protection is however obtained by simple shading of the top of the bin (Fig.7); both the roof surface and headspace temperatures show significantly lesser and slower fluctuations. Also the temperature difference between the metal and the gas is small at all periods of the day.

By sampling of the maize on the surface and by direct observation it was found that condensation had not occured in any of the bins du-

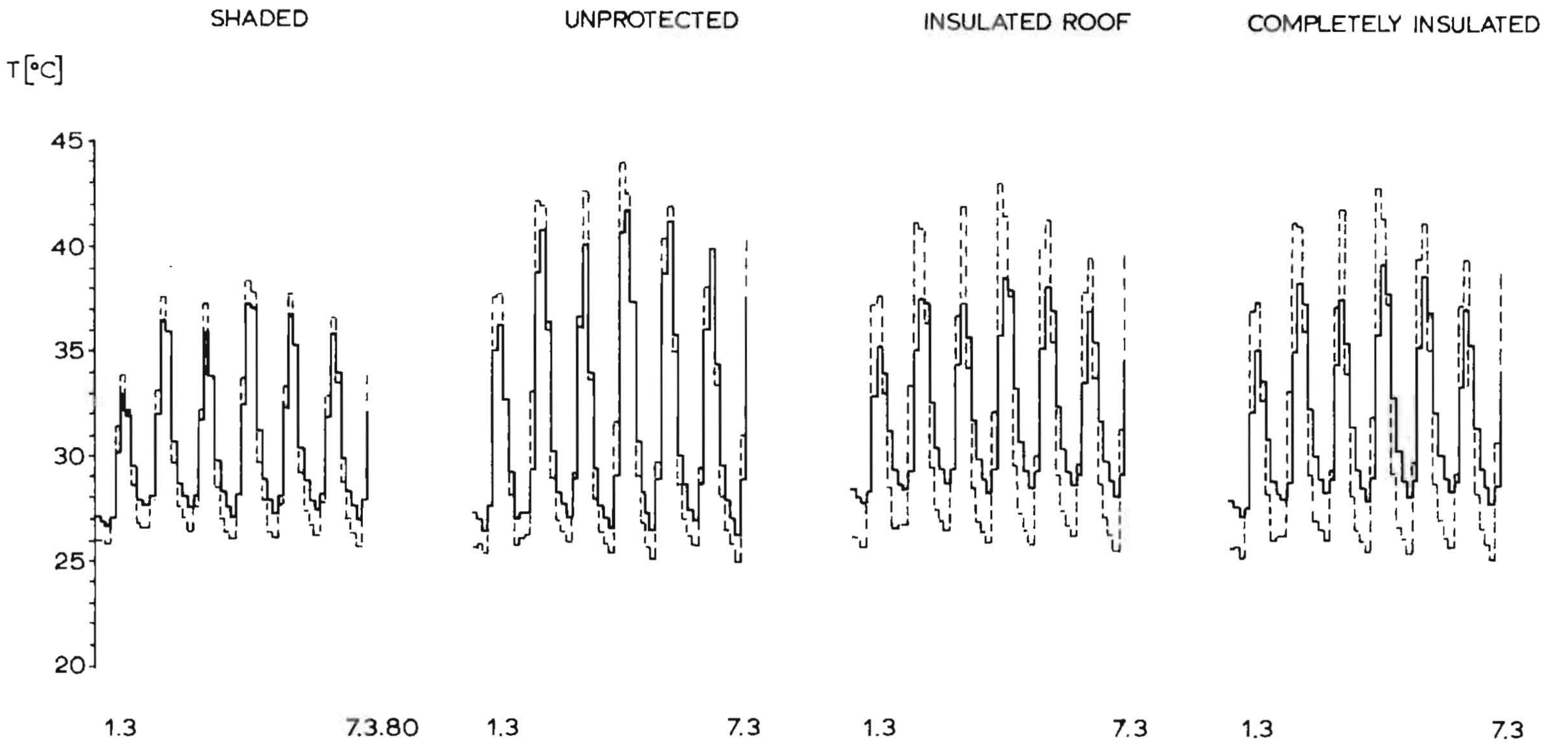

Fig.6. Diurnal temperature fluctuations of metal roof (broken line), in head-space gas (broad full line) and at the depth of 30 cm in stored product (thin full line) in 4 pilot-scale airtight storage bins differently protected against direct sunshine. The graph shows temperature readings recorded every 3 hours for one week (1st to 7th March 1980) during a nitrogen storage trial with dry maize.

All the quality parameters assessed in the experiments of phase 1 are being followed in this phase. Results during the first 4 months indicate that no changes have occurred in any of the silos, where a zero concentration of oxygen is maintained.

Conclusions regarding the first storage trial in phase 2.

Storage of dry maize in airtight metal bins in a nitrogen atmosphere is possible in the humid tropical climate. Exogenous agents, normally causing grain deterioration, are suppressed by complete anoxia. This is easily achieved my maintaining a slight overpressure inside the storage facilities by nitrogen. Heat production in the grain mass being reduced to a minimum, no temperature gradients build up and moisture migration does not occur.

Temperature fluctuations in the stored cereal grain are minimal and where grain is in direct contact with the gastight silo wall, no condensation occurs at ambient temperature excursions typical for the humid tropics.

Large thermal fluctuation in the headspace of metal bins occur due to effects of direct sunshine. At low moisture contents of the stored product in the described experiment (13% m.c. maize) the rate of temperature drop and the minimal ambient temperature reached were found to be such that the dew point was not reached on the roof of an unprotected metal bin. Simple shading of the roof was shown to give better protection against temperature fluctuations in the headspace and on the metal surface than elaborate and costly thermal insulation, thus indicating that higher moisture grain may be stored in a nitrogen atmosphere in the described climatic conditions, without danger of condensation. Experiments are being undertaken to establish the moisture content limits for safe long-term storage of cereal grains in the humid tropics.

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