Modified atmosphere storage of bagged maize outdoors using flexible liners: a preliminary report

D.G. Alvindia, F.M. Caliboso, G.C. Sabio and A.R. Regpala*

Abstract
Field trials were carried out in the Philippines for outdoor storage of maize sealed in flexible liners. Two storage atmospheres were evaluated: carbon dioxide (CO₂)-enriched and hermetic storage. Tests were carried out to determine insect infestation, moisture content, microbial infection, weight loss, grain quality and seed germination. Insect infestation was completely prevented in the CO₂-enriched cubes while few live insects were noted in the hermetic cubes. Insect-damaged kernels and weight loss were minimised. Grain moisture content remained stable after three months although mould growth was noted at the top surface of the stacks. Grain quality was preserved and seed germination was not affected.

Introduction
In the Philippines, few farmers and cooperatives store their grains in well-designed, purpose-built structures. Those without storage facilities usually stack bagged grain in barns, under the eaves of their residences and in the open. Depending on climatic conditions, such stacks are covered with tarpaulins, or plastic sheets. Typically, these storage sites lead to losses caused by insect infestation, moulding, rodents and birds. Another option for the farmers is to sell their produce immediately after harvest. However, the price of grains is depressed during harvest and safe temporary storage is necessary until the market price is more favourable.

Advances in storage technology has led to the development of flexible PVC liners to envelope stacks of bagged grains for outdoor storage (Donahaye and Navarro 1989). The development of ‘storage cubes’ was designed for the hermetic storage of grains in situations where permanent structures are not available (Donahaye et al. 1991). It is also designed for the application of modified atmospheres to prevent reinfestation of the commodity during prolonged storage.

Field evaluation of storage ‘cubes’ under carbon dioxide (CO₂)-enriched and hermetic conditions have been conducted to determine its applicability under Philippine conditions.

Materials and Methods

Site and duration of storage
Storage trials were conducted at Farmers’ Cooperative Incorporated (FCI), Kisolon Sumilao, Bukidnon from 28 October 1991 to 31 January 1992 and 2 April 1992 to 8 July 1992. Details of the trials are given in Table 1.

Grain supplies
Newly-harvested locally-grown yellow maize bagged in 50 kg polypropylene sacks was provided by the Farmers Cooperative Incorporated. Maize was dried down below 14% moisture using a mechanical drier.

Storage structures
The storage cubes were manufactured by Haogenplast Ltd., Israel. These consisted of a lower floor–wall section and an upper roof–wall section. The lower floor–wall section was made of white flexible 0.83-mm-thick polyvinyl chloride (PVC) sheeting while the top cover was made of white nylon reinforced chlorinated polyethylene (CPE) plastic sheet which provided protection from degradation by UV radiation (Donahaye, pers. comm.). The storage cubes are equipped with ports to allow application of modified atmospheres or conventional fumigants by gravity displacement (Donahaye and Navarro 1989). The lower floor–wall and the upper roof–wall are sealed together by a gas-proof zipper. The zippers are covered by a protective over-flap. Dimensions of the 20-t ‘cubes’ are 4450 × 3360 × 2000 mm (length × width × height) with a maximum storage volume of 29.9 m³, and a weight of 76 kg when empty. Provision was made, by means of tension straps and buckles attached to the liner, to keep the walls of the cubes under tension even when they are not filled to capacity. This ensures that there are no folds of material at point of contact around the floor level, thus affording a large measure of protection from rodent penetrations (Navarro and Donahaye 1986).

The control maize was stacked on the wooden pallets and covered with tarpaulin plastic sheets.

Loading
Stacks were set up on a selected area which was cleared of sharp objects. Stacks were built directly on the lower floor–wall section which were spread out straight on the ground. Loading was manually done with 35 bags (5 × 7) per layer and nine layers to a height of 1.9 m. Stacks were constructed in a pyramid shape to allow rain water to run-off immediately on the sides of the cubes.

Grain sampling
Samples were collected during loading and immediately after the trial. Three composite samples of 1 kg were collected from all bags in the stacks using sampling spars. An additional 500 g was collected from the 15 individually marked bags.

Instrumentation
T-type thermocouple cables and 3-mm-diameter plastic tubings were installed at different locations inside the cubes to monitor temperatures and gas composition during storage (Fig. 1).

* Food Protection Department, National Post Harvest Institute for Research and Extension, CLSU Compound 3120, Nueva Ecija, Philippines.
Table 1. Details of storage trials.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Stack code</th>
<th>Treatment</th>
<th>Volume (t)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>C1</td>
<td>CO₂-treated</td>
<td>18.45</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>Hermetic</td>
<td>15.02</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>Control</td>
<td>4.75</td>
<td>93</td>
</tr>
<tr>
<td>II</td>
<td>C4</td>
<td>Hermetic</td>
<td>17.00</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>C5</td>
<td>CO₂-treated</td>
<td>16.62</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>C6</td>
<td>Control</td>
<td>4.58</td>
<td>97</td>
</tr>
</tbody>
</table>

**Insulation**

The top surface of each stack was insulated by adding one layer of dry bagged maize cobs. This was designed to prevent or reduce heat-flow and temperature fluctuations in grains.

**Gassing**

Food grade CO₂ at the rate of 1.5 kg/t was used to establish the modified atmosphere. The gas applicator was made of a flexible metal tube attached to the gas tank valve that was fixed onto the inlet valve of the cube.

**Parameters**

Moisture content determinations were carried out by drying grain samples for one hour in the oven (Anon. 1982). Live insects were sieved from the composite and representative samples. These were sorted according to group and species.

The extent of fungal infection was determined by plating 30 seeds randomly taken from composite samples into each media of Aspergillus Flavus Parasiticus Agar (Pitt et al. 1983); Diglycerol Glucose Agar (Hocking and Pitt 1980), Dichloran Rose Bengal Chloramphenicol Agar (King et al. 1979) and Dichloran Chloramphenicol Agar (Nash and Snyder 1962).

Temperature was recorded daily between 0800—0900 hours; 1200—1300 hours and 1600—1700 hours using the Anritsu type-T model HL600. CO₂ levels were monitored right after gassing and after 1, 3, 5, 9, 11 and 15 days. Thereafter, weekly monitoring was done. The CO₂ level in the hermetic cubes was monitored weekly.

Quality evaluation was carried out to determine the effect of modified and hermetic atmosphere storage on maize. The calculation of quality parameters was determined by hand counting the number of insect damaged, discoloured, mouldy and germinated kernels in each 500 g grain sample. Viability was estimated using the rag-doll method. The actual weight loss was calculated from the difference between the weight of bagged maize at the start and at the end of the storage trial.

Data were statistically analysed using the Multi-Factor Analysis of Variance (AVMF).

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*Fig. 1.* Diagram of experimental stack, showing the different temperature and gas-sampling points. Temperature sensors are located at: (A) above liner; (B) below liner; (C) below insulation; (D) 5 cm inside uppermost bag; (E) 10 cm in; (F) 20 cm in; (G) core of the stack. Gas concentration tubings are located at: (1) below liner; (2) middle core.
**Results**

**Percentage moisture content**

The moisture content of maize in both treatments and controls did not significantly change over the treatment period of 95–97 days (Table 2).

Table 2. Moisture content of maize at start and end of treatments with modified atmospheres in sealed flexible storage cubes.

<table>
<thead>
<tr>
<th>Stack code</th>
<th>Treatment</th>
<th>Initial</th>
<th>Final</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>CO₂-treated</td>
<td>13.16</td>
<td>12.16</td>
<td>ns</td>
</tr>
<tr>
<td>C2</td>
<td>Hermetic</td>
<td>12.56</td>
<td>12.56</td>
<td>ns</td>
</tr>
<tr>
<td>C4</td>
<td>CO₂-treated</td>
<td>11.59</td>
<td>11.93</td>
<td>ns</td>
</tr>
<tr>
<td>C5</td>
<td>Hermetic</td>
<td>11.44</td>
<td>11.72</td>
<td>ns</td>
</tr>
<tr>
<td>C3</td>
<td>Control</td>
<td>13.26</td>
<td>12.23</td>
<td>ns</td>
</tr>
<tr>
<td>C6</td>
<td>Control</td>
<td>11.98</td>
<td>11.82</td>
<td>ns</td>
</tr>
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</table>

ns P > 0.050

**Insect infestation**

Initial and final counts of live insects did not significantly change in CO₂-enriched and hermetic stacks. However, the number of live insects increased significantly over time in the control stacks (Table 3).

The number of live infestations recorded in the hermetic stacks were: *Sitophilus zeamais* (1), *Tribolium castaneum* (1) in the first trial and *Rhizopertha dominica* (1) in the second trial. The live infestations recorded in the control stacks include all the major pests of maize in storage (*Sitophilus zeamais*, *Rhizopertha dominica*, *Tribolium castaneum*, *Carposphorus hemipterus* and *Lathetricus oryzae*).

**Microbial infection**

The various species of fungi isolated from maize and their extent of infection before and after the trial is summarised in Table 4. Stacks of newly-harvested maize were initially infected with *Aspergillus flavus*, other *Aspergillus* species (*fumigatus* and *nidulans*), *Eurotium chevalieri*, *Penicillium citrinum* and *Fusarium moniliforme*.

Results indicate that infection with *Aspergillus flavus* in the CO₂-treated and hermetic stacks of newly harvested maize fell by 100% and 70%, respectively after 3 months of storage. Levels of infection by other *Aspergillus* species in maize increased 14 times in the CO₂-treated stacks and 4 times in the hermetic stacks. Likewise, infection by *Fusarium moniliforme* increased to 7.5 and 30 times in the CO₂-enriched and hermetic stacks, respectively. Level of infection by various fungi in the control stacks generally increased after storage.

**Storage and ambient temperatures**

Temperatures recorded inside the CO₂-treated and hermetic stacks (Figs 2 and 3) were generally lower when compared to the ambient. Point a, which measured the temperature above the liner showed greater fluctuations due to differences in time of day and weather conditions. In spite of the temperature fluctuations outside the storage cubes, temperature inside the cubes remained stable whereas in the control stacks, wide temperature fluctuations were recorded (Fig. 4).

**Carbon dioxide levels**

The CO₂ level of more than 35% was maintained for 11 weeks in the modified atmosphere cube (C1) while highest CO₂ level recorded in the hermetic maize stacks (C2) was 7% (Fig. 5).

**Grain quality**

The quality of maize under CO₂-enriched atmospheres did not significantly change after 3 months of storage. A significant increase in discoloured and insect-damaged kernels were noted on the hermetic stack C4. But other quality parameters where not significantly changed. Discoloured and insect-damaged grains in the control stacks significantly increased over the storage period.

**Maize germination**

Germination of maize did not significantly change during storage irrespective of storage technique employed.

**Weight loss**

The extent of percentage weight loss in maize stored under CO₂-enriched atmosphere (0.252–0.265%) and hermetic condition (0.229–0.379%) was lower than conventionally stored maize (5.073–5.611%) (Table 5).
Table 5. Change in actual weight in maize stored under various conditions

<table>
<thead>
<tr>
<th>Stack code</th>
<th>Treatment</th>
<th>Initial weight</th>
<th>Final weight</th>
<th>Variance (kg)</th>
<th>% weight loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>CO₂-treated</td>
<td>18450</td>
<td>18401</td>
<td>49</td>
<td>0.265</td>
</tr>
<tr>
<td>C2</td>
<td>Hermetic</td>
<td>15020</td>
<td>14963</td>
<td>57</td>
<td>0.379</td>
</tr>
<tr>
<td>C4</td>
<td>Hermetic</td>
<td>17000</td>
<td>16961</td>
<td>39</td>
<td>0.229</td>
</tr>
<tr>
<td>C5</td>
<td>CO₂-treated</td>
<td>16620</td>
<td>16578</td>
<td>42</td>
<td>0.252</td>
</tr>
<tr>
<td>C3</td>
<td>Control</td>
<td>4750</td>
<td>4509</td>
<td>241</td>
<td>5.073</td>
</tr>
<tr>
<td>C6</td>
<td>Control</td>
<td>4580</td>
<td>4323</td>
<td>257</td>
<td>5.611</td>
</tr>
</tbody>
</table>

Fig. 2. Temperature recorded from seven different points in the CO₂-treated maize (Stack 5); a, above the liner; b, above insulation; c, below insulation; d, e, f, 5, 10, 20 cm in from the top surface of the same bag; g, core of the stack.

Fig. 3. Temperature recorded from seven different points in the hermetically stored maize (Stack 4); a, above the liner; b, above insulation; c, below insulation; d, e, f, 5, 10, 20 cm in from the top surface of the same bag; g, core of the stack.

Fig. 4. Temperature recorded from six different points in the control maize (Stack 6); a, above the liner; b, top surface of the centre bag at the uppermost layer of the stack; c, d, e, 5, 10, 20 cm in from the top surface of the same bag; f, core of the stack.

Fig. 5. Carbon dioxide concentrations recorded in CO₂-treated and hermetic maize stacks.

Discussion

The results provided information on the use of PVC flexible liners for modified atmosphere storage of maize in the Philippines. They also demonstrated the insect control capacity of the technology as part of a quality preservation system.

The standard assessment that there should be no live insects after storage was attained in the CO₂-enriched stacks. The complete disinfestation of stacks in the CO₂-enriched cubes demonstrated the enclosures gas tightness, to hold the required standard and gas concentrations of 35% for at least 10 days (Annis et al. 1984). In the hermetic cubes, light infestation was evident (0.33–0.67 live insects/kg) after storage. Despite the presence of live insects, no significant increase of insect damaged kernels was noted.

Mould growth was visible in the CO₂-enriched and hermetic storage cubes. Mould growth in the CO₂-enriched cubes was limited to the insulation while mould growth on the
hermetic cubes was noted on the insulation and on the bags immediately underneath. Moulding was attributed to the inadequate drying of insulation.

There was no significant increase in the moisture content of maize stored under modified and hermetic atmospheres. Weight loss in the modified atmosphere cubes was calculated at 0.25 and 0.30% in the hermetic stacks. These values should be compared with loss evaluation of 5.34% in the conventional storage.

The quality of maize was not significantly affected by modified atmosphere storage. It appears that storage of maize under CO₂-enriched and hermetic atmospheres is better than the conventional practice. However, further work is required under more tightly controlled conditions to quantify the effect of modified atmosphere on maize quality.

The effect of modified atmospheres on maize germination suggest that it can be used for seed storage purposes. The result corroborates the findings of Bason et al. (1987) and Gras and Bason (1989) that carbon dioxide levels of 7.5 to 60% had no significant effect on the mean life-span retention period of maize.

**Conclusion**

Storage of maize for three months in cubes under CO₂-enriched atmospheres prevented insect infestation. Meanwhile, few live insects were recorded in the hermetic cubes. Both storage systems appeared to have advantage in minimise insect-damaged kernels and weight loss.

Modified atmosphere storage of maize under plastic enclosures provides significant advantages of maintaining quality and germinability of maize. The effect of modified atmospheres under plastic enclosures outdoors on the grain microflora would require further research before any conclusion can be drawn.

**Acknowledgments**

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**References**