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# Use of biogenerated atmospheres of stored commodities for quality preservation and insect control, with particular reference to cocoa beans

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**Abstract:** Preliminary data for insect control and for quality preservation of stored cocoa beans is presented, as a methyl bromide alternative, by employing a novel approach through the use of biogenerated modified atmospheres. The respiration rates of fermented cocoa beans from Makassar, Sulawesi, Indonesia, were determined under laboratory conditions. Initial insect populations found in these cocoa beans samples consisted of *Carpophilus* spp., *Ahasverus advena*, *Cryptolestes* spp., and Psocids. Respiration rates of cocoa beans at equilibrium relative humidities (r.h.) of 59, 68, and 73% were determined at 26°C in hermetically sealed 1 L capacity jars containing 500 g commodity. At the equilibrium r.h. of 73%, the respiration of the cocoa beans depleted the oxygen concentration to <1% and increased the carbon dioxide concentration to 23% within six days. To obtain a similar oxygen depletion for cocoa beans at 68% equilibrium r.h, a duration of 23 days was required, while for the sealed cocoa beans in equilibrium with 59% r.h. the oxygen concentration after 23 days had only decreased to 10.8%.

Under field conditions in a cocoa bean storage facility in Makassar, Indonesia, a hermetically sealed flexible structure containing 6.7 tonnes of cocoa beans at an initial moisture content of 7.3% (70% equilibrium r.h.) was monitored for oxygen concentration and quality parameters of the beans. The measurements showed a decrease in oxygen concentration to 0.3% after 5.5 days. No insects survived the oxygen depleted biogenerated atmosphere. These encouraging results reveal the possibility of utilizing biogenerated atmospheres in integrated pest management (IPM) for the quality preservation (by preventing the development of FFA, molds, and mycotoxins), and insect control of cocoa pests.

**Key words:** cocoa beans, respiration rate, modified atmospheres, methyl bromide alternatives, IPM, storage pest control

## Introduction

Cocoa beans are usually harvested twice yearly in a “main”, and a “secondary” harvest. Timing and duration of the harvests are dependent upon climatic conditions. The beans are treated through a process of fermentation after they have been removed from the fruit. This process is necessary to moderate the initially bitter flavour of the cocoa beans and to develop their typical flavour. By fermentation, the highly bitter tannins present in the beans are oxidized, resulting in the formation of aromatic substances and the development of the typical brown to deep red-brown colour of the cocoa beans. As a result of the heat generated by fermentation, the cocoa beans lose their ability to germinate. Depending on the region, fermentation of cocoa beans is termed either “dry” or “wet”. In the dry fermentation process cocoa beans are sun dried for several weeks until the pulp decays, whereas in the wet process, the pulp is washed away and subsequently the cocoa beans are sun dried till the moisture content reaches 7% (wet basis). Wet fermentation demands a better post harvest infrastructure than dry fermentation and produces better quality beans. Most of the beans in Africa (Ivory Coast, Ghana) are handled by wet fermentation, whereas most of the Indonesian beans are dry fermented. The beans are collected by traders and sold to exporters who decide either to sell right away or keep the commodity in storage for several months, to speculate for better market prices. In West Africa, some companies are trying to introduce bulk handling in containers, but most of the trade is still in jute bags of about 70 kg. Climatic conditions in the tropics: high humidity levels of 70 to 90% r.h. and temperatures around 30$^{o}$C are ideal for storage insects and molds to develop on agricultural products. The most common storage pest in cocoa beans from Indonesia and South America is the cocoa moth or the tropical warehouse moth *(Ephestia cautella)*, whereas the dominant species in cocoa beans from West Africa is the rice moth *(Corcyra cephalonica*). In addition, several other storage species are known to infest cocoa beans; among them are storage beetles such as the flour beetle (*Tribolium casteneum*) which is very common. Infestation is a major problem and therefore the beans are frequently fumigated using phosphine or methyl bromide (MB).

Fumigants are widely used for pest control both in cocoa beans and also in other stored products to prevent economic and quality losses caused by these insect pests. However, increased public concern over the adverse effects of pesticide residues in food and the environment has led to their partial substitution by alternative control methods. Consequently, non-chemical and environmentally user-friendly methods of pest control in the post harvest sector are becoming increasingly important. MB has been phased out in developed countries since 2005 and will be phased out in developing countries by 2015, because of its contribution to stratospheric ozone depletion (UNEP, 2002). In contrast; phosphine remains popular, particularly in developing countries, because it is easier to apply than MB. However, many insects have developed resistance to phosphine over the last decade (Cao et al. 2003; Savvidou et al. 2003).

Biogenerated atmospheres can be achieved in hermetically sealed storage systems, and are based on the generation of oxygen-depleted and carbon dioxide-enriched interstitial atmospheres as a result of the respiration of living organisms. Intermediate moisture contents (at equilibrium air relative humidities of 65 to 75%) of stored commodities are inevitable in tropical climates due to the difficulties in maintaining safe moisture contents for long-term storage. Under hermetic conditions, stored commodities with intermediate moisture contents generate modified atmospheres due to the respiration of the microflora and the commodity itself. The objective of this work was to provide preliminary data on this novel approach of using biogenerated modified atmospheres as a methyl bromide alternative for insect control, and for the quality preservation of stored cocoa beans.

## Materials and methods

### *Laboratory trials*

The laboratory trials were carried out in the Department of Food Science, Israel. Dry fermented cocoa bean samples weighing about 1.2 kg each originating from Makassar, Indonesia were tested for their equilibrium r.h. and infestation level. Infestation levels were determined by sieving the samples through a 10 mesh size US standard sieve and examining the beans for free insects.

The equilibrium r.h. was determined using a humidity tester (Defensor® Novasina model ms1, Switzerland) with box sensor enMBRK-3. The equilibrium r.h. values expressed in this paper as percentages are equivalent to the decimal values in terms of water activity ($a_w$) which is the ratio of the water vapour pressure in the agricultural commodity to the water vapour pressure of pure water at the same temperature.

The equilibrium r.h. value of the cocoa beans was determined as 82% at a temperature of 25°C. The initial samples were then dried in a drying oven at 45°C to obtain equilibrium r.h. levels of 73, 68 and 59%.

Respiration rates of the cocoa beans were determined after the insects were removed from the beans. Concentrations of oxygen and carbon dioxide were determined using a gas chromatograph (SRI 8610C, SRI Instruments USA) equipped with a thermal conductivity detector, with Porapak Q and Molecular Sieve 5A columns for detecting the oxygen, and the carbon dioxide concentrations. Weighed amounts of 500 g of cocoa beans were placed in 1 Liter capacity glass jars sealed with gastight metal covers equipped with silicon septa for gas sampling. The gas composition within each jar was periodically sampled using a 1 mL "pressure-lock" syringe through the septum. Gas samples were taken according to the respiration intensity of the cocoa beans inside the jars. The jars were stored throughout the respiration tests at 26°C.

***Field trial in Makassar, Indonesia***

A field trial was carried out in a warehouses located in Makassar (Ujung Pandang), Indonesia, starting on June 6 and ending November 17, 2005. The trial consisted of storing locally available bagged cocoa beans in a gas-tight sealed GrainPro* Cocoon of 15 $m^3$ capacity. The Cocoon accommodated 108 jute bags each of 62.5 kg capacity comprising a total of 6.75 tonnes of cocoa beans. The initial moisture content (m.c.) was determined on ten samples taken from the bottom, middle and top layers of the stack. The average m.c. of each sample was taken at the start of the trial in June and at the end of the trial.

## Results and discussion

***Laboratory trials***

Examination of the two samples of cocoa beans received in the laboratory (weighing together 2.45 kg) revealed that there was a significant insect population in the samples. The insects consisted of: adults of *Cryptolestes* sp. (30 dead and 6 live), adults of *Carpophilus* sp. (5 live), Acarina (> 20 live), adults of *Ahasverus advena* (10 dead); *Psocidae* (> 20 live), adults of field flies (12 dead), Phycitid moths (1 dead larva, 1 dead adult), and adults of *Araecerus fasciculatus* (2 dead). Such an insect population would require periodic control measures during the storage time of the cocoa beans.

The equilibrium r.h. values were determined on the samples of cocoa beans received from the warehouse in Makassar. This is a convenient and accurate measure as an alternative to the determination of moisture content in vacuum ovens or other methods. According to the ICCO (Anonymous, 1999) the moisture content of cocoa beans should meet the export standard of the country exporting the beans; in general this is around 7.5% but ranges from 5.5% to 8% depending on the country concerned. According to the Transport Information Service (TIS) (Anonymous, 2006), when transporting cocoa beans in containers, care should be taken to ensure that the moisture content of the cocoa beans on packing is approx. 6 – 8%, which corresponds to an equilibrium relative humidity of 55 – 75% (at 26°C). These are

* Mention of trade names or commercial products in this article is solely for providing specific information and does not imply recommendation or endorsement by the Israel Agricultural Research Organization.

values that arouse considerable problems from the outset, because the higher moisture content cited of 8% corresponds to the mold growth threshold of 75%. Moreover, cocoa beans have an elevated fat content which, in conjunction with moisture, results in hydrolytic/enzymatic fat cleavage and self-heating of the cocoa beans. An examination of the low temperature/dew point difference will also show how rapidly the dew point of the cocoa bean cargo is reached on cooling. It is thus recommended to insist on a water content of 6% or less when transporting cocoa beans in containers.

To clarify the relationship between the moisture content and equilibrium r.h. of cocoa beans, Fig. 1 was compiled using the data of Gough (1975) at 27° – 29°C. Data in Fig. 1 are close to the values given by the ICCO but are quite different from data provided by Hall (1960) and TIS (Anonymous, 2006). Therefore, data in Fig. 1 should be viewed as guiding information until additional data becomes available in the literature. Our approach using the equilibrium r.h. values strengthens the view of using the equilibrium r.h. to determine the micro-floral activity in cocoa beans since this activity is dependent on the water activity, which is a more meaningful criterion, and is the decimal of the equilibrium r.h. values.

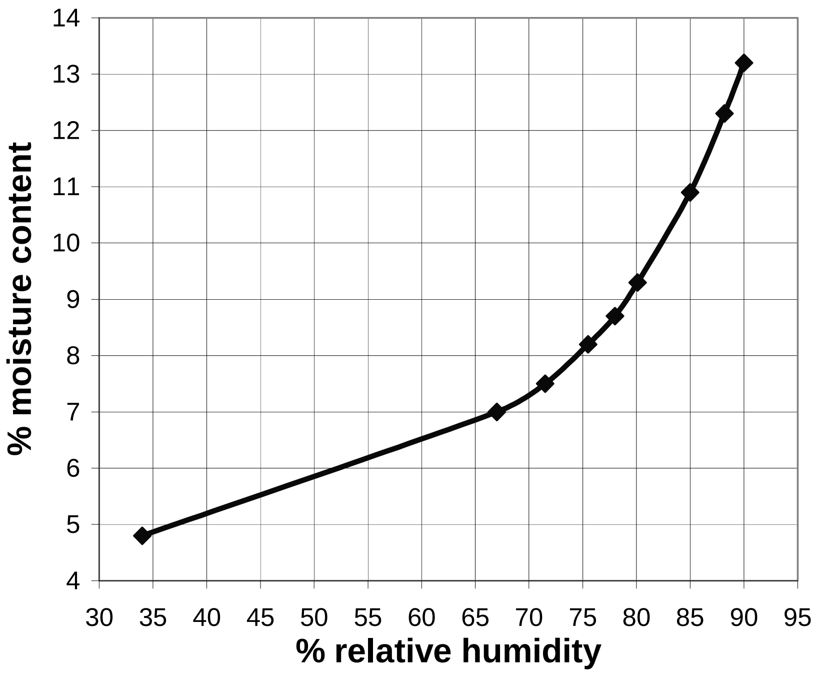


Fig. 1. Equilibrium moisture content of cocoa beans at 27° – 29°C (Gough, 1975).

Respiration rates determined on cocoa beans free from insects at equilibrium r.h. values of 59, 68, and 73% are shown in Figures 2, 3, and 4, respectively. From these figures it is obvious that the increase in the equilibrium r.h. values caused a significant increase in respiration rates. The respiration rate values for the 82% equilibrium r.h. was not graphically presented in this paper, since the extremely high gas exchange intensity necessitated gas analysis almost every two hours, that would necessitate measurements over a work day period that was not available to the laboratory. However the respiration rate could be calculated and resulted in complete depletion of oxygen within 36 h. In contrast, Fig. 2 shows that at 59% equilibrium r.h., even after 21 days the oxygen level remained at 11%. The respiration rates shown in Figures 3 and 4 reveal that an equilibrium r.h. value between 68% and 73% would be sufficient for the generation of an oxygen depleted atmosphere within a one to two week period. Such an atmosphere would be suitable for the control of all storage insects. This deduction would imply that for the cocoa beans industry, the repeated fumigations using phosphine or methyl bromide might be superfluous. All that is necessary would be to seal the commodity and let the organisms including the insects themselves to deplete the oxygen to a level where survival would no longer be possible. In the case of phosphine a ten days exposure, now has to be, and is implemented for a successful fumigation due to insect resistance problems. In the case of cocoa beans, the ICCO (Anonymous, 1999) recommended moisture content of 7.5% for storage, would be sufficient to rely on biogenerated atmospheres, since this moisture content is in equilibrium r.h. with about 70% (Fig. 1).

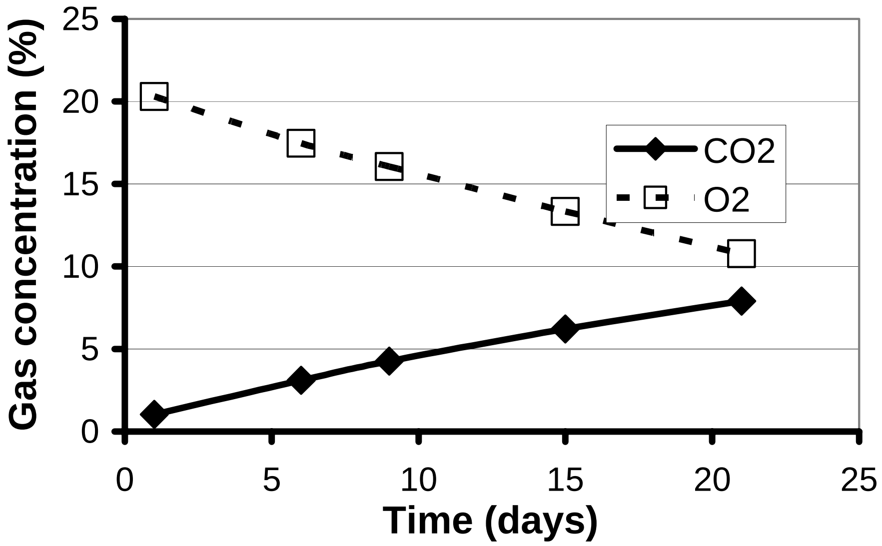


Fig. 2. Respiration rate of cocoa beans at 59% equilibrium r.h. and 26$^{o}$C.

***Field trial in Makassar, Indonesia***

Fig. 5 shows the set up of the GrainPro* Cocoon before and after sealing. The Cocoon was kept for about six months inside the warehouse during which period the ambient temperature ranged closely around 30$^{o}$C. The cocoa bean samples that were taken before and after the storage period showed a slight but significant increase in moisture content from 7.3 to 7.7%. This range of moisture content is equivalent to a range of about 70 to 73% equilibrium r.h. (Fig. 1). According to the laboratory data for the equilibrium r.h. of 73% (Fig. 4), it would be reasonable to expect an oxygen drop within 6 days. Not surprisingly, Fig. 6 shows an oxygen depleted atmosphere within 5.5 days, this being very close to the laboratory data. Such an atmosphere would be sufficient to control the existing insect population. Indeed at the opening of the Cocoon in November, no live insects were recorded on the ten cocoa bean samples.

On the opening of the Cocoon in November, several mouldy sacks were observed on the top of the stack. Although such appearance caused concern, according to the TIS (Anonymous, 2006), if the moisture content is < 6%, cocoa beans become brittle, while at a moisture content of > 8%, there is a risk of vapor and mold damage which cause depreciation which may go as far as total loss due to rot. A fundamental distinction is drawn between two types of moisture damage: sweat damage and vapor damage:

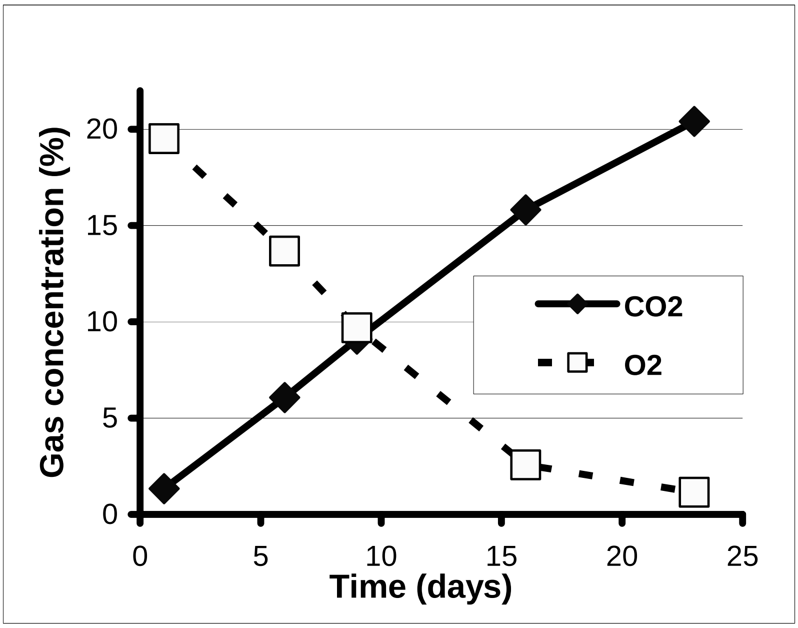


Fig. 3. Respiration rate of cocoa beans at 68% equilibrium r.h. and 26°C.

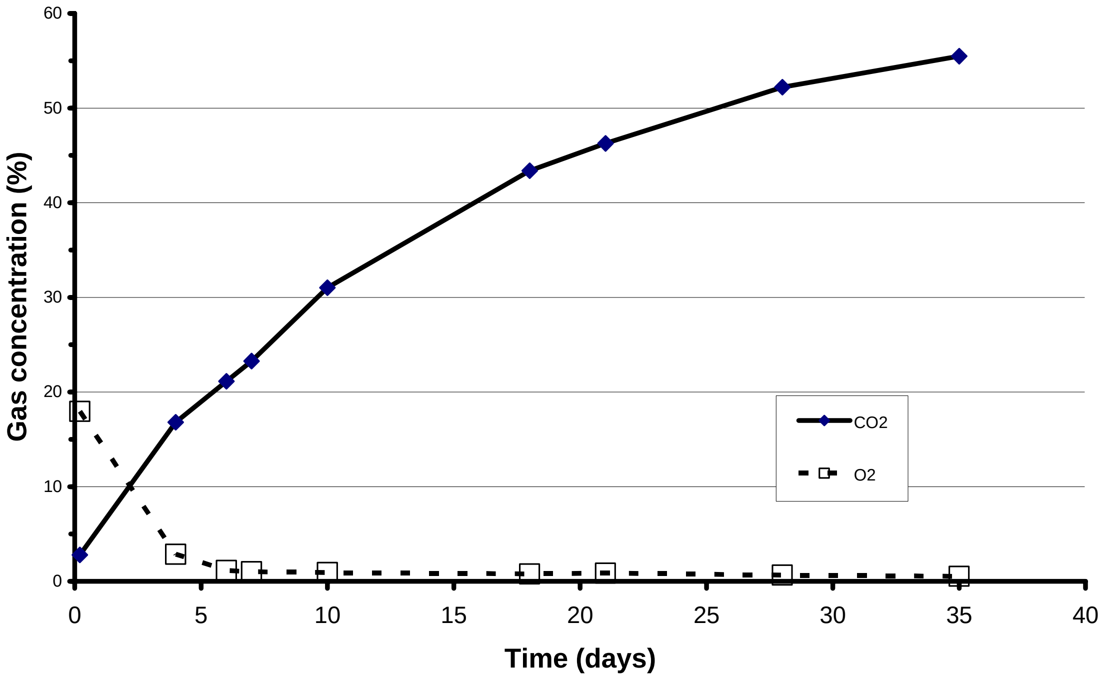


Fig. 4. Respiration rate of cocoa beans at 73% equilibrium r.h. and 26°C.

**Sweat damage (mould damage)**: Recognizable by spots on the bag fabric caused by drops of drip water. Under these spots, there are clusters of cocoa beans covered with white mold and stuck together. In serious cases, the mold penetrates into the kernel of individual beans. As a result, these then smell and taste musty. Such losses are usually limited to only a few bags in a consignment and are caused by the formation of ship sweat below deck, especially at night when the surrounding atmosphere and thus the outer walls of the hold cool down. If the upper layer of bags in the hold is inadequately covered, the dripping cargo sweat cannot be absorbed, penetrates into the bags containing the cocoa beans and causes the damage described above.

Fig. 5. The GrainPro cocoon, before sealing (left) and after sealing (right) (courtesy of Tom deBruin).

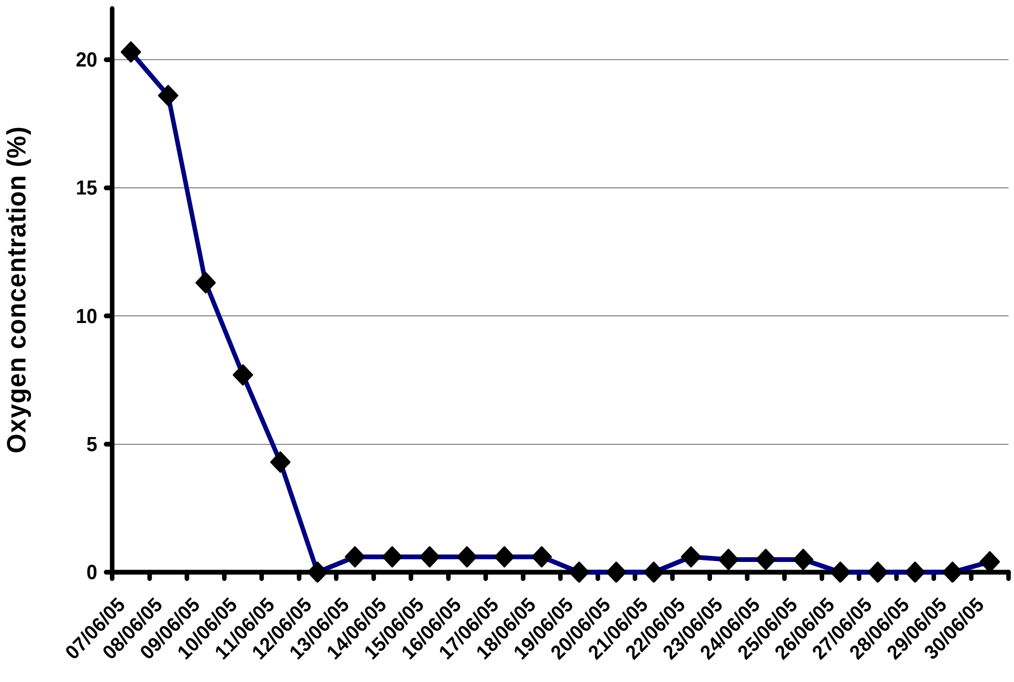


Fig. 6. Changes in oxygen concentration recorded throughout the storage period in Makassar, Indonesia.

**Vapour damage**: this is caused by excessive relative humidity in the hold or container. While the cocoa beans have only a thin covering of mold, from time to time the damage affects the entire contents of the bags stowed in a hold. Vapor damage is thus generally much more extensive than sweat damage. Marked mold growth is not normally observable, but aroma and flavour are still considerably degraded. For this reason, care must be taken not only to prevent formation of sweat, but also to ensure favorable relative humidity values in the hold/container.

From the observations made at the opening of the cocoon in November, most probably the observed white mouldy spots on the bags were caused due to condensation that could be attributed to sweat damage, since except for the several bags on the top of the stack the rest of the bags remained without such visible mould spots. These encouraging results have led to additional trials with slightly lower equilibrium r.h. of cocoa beans.

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