White rice (*Oryza sativa* L.) is commonly known as polished rice or milled rice. It is a main food source for over half of the world’s population (Darrington, 2008). Milled rice and its by-products are susceptible to insect attack and oxidation that diminish the quality of the rice and the by-products. When the rice and by-products are exposed to the air for long periods, oxygen in the air oxidizes fats and oils, primarily contained in the bran, converting the min to free-fatty acids (FFA) giving the rice a rancid taste.

The level of oxidation is a function of the level of polishing of the rice. Millers tend to differentiate between ‘ordinary’ and ‘well’ milled rice, the difference being in the amount of bran left on the rice.

Hermetic storage has long been proven to be a good storage technique for cereals. According to Yanai et al. (1979), hermetic storage of milled rice at 30°C for 3 months under vacuum, in nitrogen, or carbon dioxide, had little effect on reducing sugars, fat acidity, texturometer hardness and adhesiveness of cooked rice at 14.7% m.c.

The decrease of oxygen concentration and formation of carbon dioxide is a result of the respiration of insects, molds and fungi, and other biological elements present in the hermetic storage. In hermetic storage, oxygen concentration decreases after some time until it produces an environment lethal to storage insects. In addition, depleted oxygen is beneficial to rice quality because there is reduced oxidation of fats and oils.

**Comparative field trials of hermetic storage and modified atmospheres of milled rice (*Oryza sativa*) in tropical climates**

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**ABSTRACT**

Hermetic storage prevents grain losses and enables preservation of quality and quantity while eliminating the need for contact pesticides or fumigants in storage. Due to respiration of the living organisms in the milled rice (*Oryza sativa* L.) ecosystem, the oxygen levels in hermetic storage typically drop to below 3%. This paper describes works on the effect of hermetic storage on quality control in stored milled rice. Two sets of trials were carried out: in Shuwaikh, Kuwait and East Java, in Indonesia. In Kuwait, one cocoon containing 300 tonnes of basmati rice was stored under hermetic storage (HS), and another cocoon of 300 tonnes of basmati rice was stored under CO₂ based modified atmospheres (MA) for 75 d. In the second set of trials, two cocoons each containing 150 tonnes of milled rice in bags of 15 kg each were stored for one year. In the hermetic storage (HS) trial in Kuwait using previously fumigated rice, the O₂ concentration did not decrease to a lethal level below 6.5% but the rice retained excellent quality. In the MA trial in 75 d, the CO₂ concentration changed from 88%CO₂ to 45%. In HS trial carried out in East Java, O₂ concentration decreased from 19.8% at day 4 to 9.8% on day 30 then continued to decline until the concentration dropped to below 5% after 45 days. After the 5% O₂ was reached, the data were read once every two weeks until the end of the storage period of 360 days. The O₂ concentration remained below 5%. In the MA trial carried out in East Java, the CO₂ concentration dropped from 71% to 19% within 150 days. In all the trials the tested samples of milled rice were without live insects, the m.c. was preserved and the odor was normal.

**Key words:** Carbon dioxide, Cocoon, Hermetic storage, Modified atmosphere, Milled rice storage
Conventional storage has been the predominant system in most countries having a tropical climate. In conventional storage, bagged grains and by-products are stacked and left exposed to ambient air, insects, rodents and birds. Even when applying careful pest control measures, it is difficult to deter the growth of insect pest populations.

Sealed or hermetic storage systems are a very effective means of controlling grain moisture content and insect activity for grain stored in tropical regions. By placing an airtight barrier between the grain and the outside atmosphere, the moisture content of the stored grain remains the same as when the storage was sealed. Hermetic storage provides moisture and insect control without pesticides (Navarro, 2006).

In hermetically sealed storage systems, grains are placed inside an airtight container, which stops oxygen and water movement between the outside atmosphere and the stored grain. There are various types of hermetic storage systems (Villers et al., 2010). Hermetic storage system can be made from specially designed PVC containers such as the: Cocoon™ (formerly called Volcani Cubes); GrainSafe™; SuperGrainbags™ (also known as IRRI Superbags); and TranSafeLiners™ (TSL). The size of hermetic storages can range from 60 litres to 1,000 tonnes capacity. Larger hermetic systems have also been used with milled rice.

For rapid reduction in oxygen levels and reaching unbreathable levels of about 3% oxygen, hermetic storage of dry grain relies heavily on insect respiration. For this reason, chemical fumigation prior to, or during, hermetic storage will significantly affect the ability to reach unbreathable levels of oxygen and slow the process of oxygen reduction. To differentiate between various degrees of gastightness, the term ‘Ultra Hermetic’ is also used to describe a container sufficiently hermetic to reach 3% oxygen level through respiration alone. At higher m.c. the respiration of microflora is more affective and thus consumes the oxygen rapidly (Weinberg et al., 2008).

Hermetic storage technology has emerged as a significant alternative to other methods of storage that provide means of commodity protection from insects and molds, especially in hot and humid climates. This technology, also termed sealed storage, airtight storage or assisted hermetic storage which is a form of bio-generated modified atmosphere. This method takes advantage of the gases produced naturally by the respiratory metabolism of insects and commodities, using them to prevent insect development. Sufficiently sealed structures enable insects and other aerobic organisms in the commodity, or the commodity itself, to generate the MA by reducing the O₂ and increasing the CO₂ concentrations to a level to control development of insect (Navarro, 2006; Villers et al., 2006; deBruin, 2006). Hermetic storage generates a modified atmosphere in an environmentally safe and sustainable manner that eliminates the need for chemical treatments or fumigants.

Only in the last several years hermetic storage has emerged as an important, widely used alternative method of post-harvest storage (Navarro and Donahaye, 2005). This is owing, in part, to increasing concerns about the use of residual pesticides, which endanger the applicator, the environment and the consumer.

In spite of all the advantages of hermetic storage and the experience gained on field trials using the hermetic storage technology, very little experience was gathered on the application using milled rice. Most of the early trials were carried out in laboratory conditions (Donahaye et al., 2001). Some other studies were carried out at small scale (Navarro et al., 1995; Donahaye et al., 1999) or pilot studies of 13.5 tonnes capacity cocoons (De Dios et al., 2001) to demonstrate the value of hermetic storage in maintaining good quality of paddy. Large scale trials on maintaining milled rice stored in a warm climate are lacking. In the present report, the authors have attempted to gather basic data on gas retention using carbon dioxide based modified atmosphere and hermetic storage of milled rice stored in warm climates. Although the information obtained is not complete, the authors are of the opinion that the present report has value in demonstrating the usability of the technology and its beneficial results to encourage the application of the technology under similar weather conditions.

MATERIALS AND METHODS

The trials were carried out under the supervision and with the cooperation of GrainPro personnel. There were two sets of trials; at Shuwaikh in Kuwait, and in Indonesia, in Surabaya, East Java.

Shuwaikh, Kuwait trials

Two cocoons, each containing 300 tonnes of milled basmati rice, were stored under either hermetic storage (HS) or under CO₂ based modified atmospheres (MA) during 2009. The CO₂ was introduced by direct connection of the cylinder to the lower section of the MA cocoon, while at the farthest top side of the cocoon a 4” diameter exhaust port was kept open during the purge phase.

The trials were carried out in the storage facility of KFM (Kuwait Flour Mills and Bakeries Co.). The two cocoons containing 50 kg jute bags were stored for 75 days. The ambient temperatures were approximately
East Java, Indonesia trials

During 2014-15, two cocoons each containing 150 tonnes of milled rice in bags of 15 kg each were stored for one year. These trials were carried out at Bureau of Logistics (BULOG), a government-owned company in Indonesia which deals with food distribution and price control in GBM’s warehouse, located at Banjar Kemanantren, East Java Regional Division, in cooperation with GrainPro Inc. Two PVC cocoons each containing 150 tonnes of milled rice were stored. One Cocoon was purged with CO$_2$ and the second Cocoon was stored under hermetic conditions. The storage was performed inside the warehouses. After loading the Cocoons, a half time pressure decay test was carried out. Monitoring of O$_2$ concentration was performed in the HS Cocoon every day until the concentration decreased to below 5%. After the concentration dropped below 5%, the monitoring was done every two weeks.

The O$_2$ was measured using GrainPro oxygen meter, model GPO2-HH and CO$_2$ was estimated by measuring the O$_2$ concentration using the Grain Pro oxygen meter, model GPO2-AN. The m.c. of the rice was measured using GrainPro conductivity meter type GMK-303CF. The dockage per cent was recorded after separating whole rice from dockage using various sieves. Pest presence was checked from outside of the bags.

RESULTS AND DISCUSSION

Shuwaikh, Kuwait trials

Hermetic storage trials: Changes in O$_2$ concentration within 75 days of storage of hermetic storage (HS) using a Cocoon holding 300 tonnes of milled basmati rice at KFM warehouse in Kuwait are shown in Fig. 1. The O$_2$ concentration under hermetic storage did not decrease to a lethal level below 6.5% (Fig. 1). A decrease of 0.19% O$_2$/day was estimated which is not sufficient to control insects (Navarro, 2012). This lack of O$_2$ depletion was attributed to a fumigation applied before shipment at the export country. Therefore, HS was applied after the insects were controlled and no significant insect respiration was expected. Rice samples, examined by the KFM technical staff at the end of the storage period, were reported to be in good condition. The O$_2$ level at 6.5% after 75 days at the end of the trial would indicate that the rice respiration also remained negligible because of the low m.c. at around 12%.

CO$_2$ based modified atmospheres (MA): Changes in CO$_2$ concentration within 75 days of MA storage of the Cocoon holding 300 tonnes of milled Basmati rice at KFM warehouse in Kuwait are shown in Fig. 2. The Basmati rice Cocoon injected with CO$_2$ reached an internal atmosphere of 88% CO$_2$. The CO$_2$ dropped in 75 days to 45%, showing an average decrease of 1.74% CO$_2$ d$^{-1}$. According to Navarro and Zettler (2001), a reduction of up to 2% CO$_2$ d$^{-1}$ is tolerable in order to control both insects and microflora activity. Also the calculated O$_2$ levels in the MA Cocoon in Kuwait meet the maximum limit recommended by Navarro and Zettler (2001) which was 0.12% O$_2$ d$^{-1}$.

During the purge phase with CO$_2$, the high pressure cylinder was directly connected to the inlet port of the Cocoon. This set-up is suitable to introduce a high concentration of CO$_2$ into the bottom of the Cocoon to force the internal air out of the top. In spite of the fact that the exhaust port was kept open, a ballooning effect (Fig. 3) was observed during the purging phase.
Table 1  Data on quantity (tonne), moisture content (%), O₂ and CO₂ concentrations (%), and qualitative parameters of two Cocoons placed in East Java for one year

<table>
<thead>
<tr>
<th>Location</th>
<th>Pile no.</th>
<th>Treatment</th>
<th>Quantity (tonne)</th>
<th>moisture content (%)</th>
<th>Gas concentration (%) at day 4</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Java</td>
<td>1</td>
<td>HS</td>
<td>150</td>
<td>13.8</td>
<td>19.8 ---</td>
<td>Free Normal</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>MA</td>
<td>150</td>
<td>14.0</td>
<td>5.7 73.0</td>
<td>Free Normal</td>
</tr>
</tbody>
</table>

HS, Hermetic storage; MA, CO₂ based modified atmosphere

This would indicate the introduction of CO₂ was at a higher rate than the volume of air the exhaust port was able to release.

**East Java, Indonesia trials**

**East Java Hermetic storage trials**: Changes in O₂ concentration during one year of HS of milled rice in East Java Regional Division are shown in Fig. 4. The O₂ concentration decreased from 19.8% at day 4 to 9.8% at day 30, then continued to decline until the concentration dropped to below 5% after 45 days.

After 5% O₂ was reached, data were read every two weeks until the end of the storage period of 360 days. The O₂ concentration remained below 5% (Fig. 4).

At the opening of the stack and exposing milled rice samples to air, samples were taken and examined for their quality (Fig. 5). The examined samples were reported with 13.8% m.c., no live insects and their odour was normal (Table 1).

**East Java MA storage trials**: Changes in CO₂ concentration during one year of MA storage of
CONCLUSION

Hermetic and CO₂ based MA storage in Cocoons enabled preservation of quality and quantity of milled rice stored in Kuwait and in East Java. Storage of hermetic or CO₂ based MA carried out in Cocoons each containing 300 tonnes of milled basmati rice in bags for 75 days under Kuwait climate conditions resulted in excellent preservation. In a second set of trials carried out in Indonesia, two Cocoons each containing 150 tonnes of milled rice in bags of 15 kg each were stored for one year. In the hermetic Cocoon in East Java the O₂ concentration decreased to below 5% after 45 days and remained below 5% until the end of the storage period for one year, during which insect development was prevented. During hermetic storage or CO₂ based MA storage, the need for contact pesticides or fumigants in storage was eliminated. Excellent quality of milled rice was retained under hermetic storage, though O₂ concentration did not decrease to a lethal level below 6.5%. Similar results were obtained with CO₂ based MA storage: tested samples of milled were free of live insects, the m.c. was preserved and the odour was normal.

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Fig. 6. Changes in CO₂ and O₂ concentration in G-HF Cocoon containing 150 tonnes of milled rice at East Java warehouse


