Bruin T de, Villers P, Navarro H, Navarro S (2016) Comparative field trials of hermetic storage and modified atmospheres of milled rice (*Oryza sativa*) in tropical climates. Pp. 304–309. In: Navarro S, Jayas DS, Alagusundaram K, (Eds.) Proceedings of the 10th International Conference on Controlled Atmosphere and Fumigation in Stored Products (CAF2016), CAF Permanent Committee Secretariat, Winnipeg, Canada.

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 CO_2 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 O_2 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 CO_2 concentration changed from 88%CO_2 to 45%. In HS trial carried out in East Java, O_2 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% O_2 was reached, the data were read once every two weeks until the end of the storage period of 360 days. The O_2 concentration remained below 5%. In the MA trial carried out in East Java, the CO_2concentration 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

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.

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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 O_2 and increasing the CO_2 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 CO_2 based modified atmospheres (MA) during 2009. The CO_2 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

50ºC inside the warehouse which had a metal ceiling. Temperature of the milled rice was not recorded.

East Java, Indonesia trials

During 2104-15, 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 Kemantren, 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%.

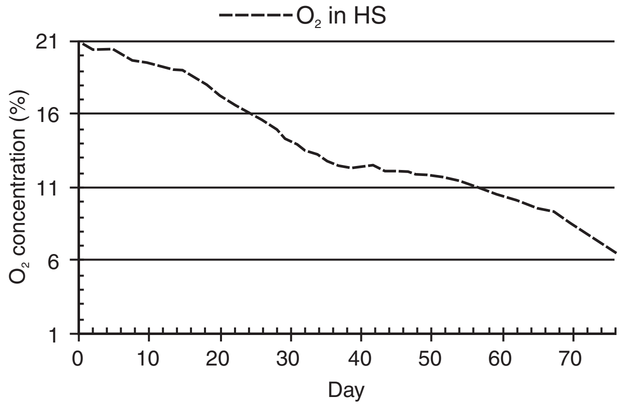

Fig. 1. Changes in O_2 concentration during 75 days of storage of 300 tonnes of Basmati milled rice stored in hermetic Cocoon in KFM warehouse in Kuwait

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.

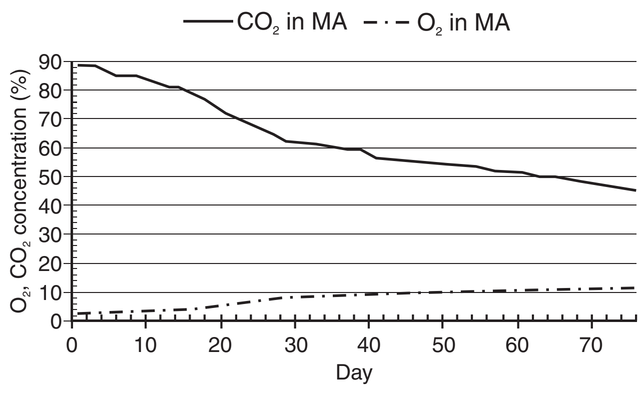

Fig. 2. Changes in CO_2 and O_2 concentrations during 75 days of storage of 300 tonnes of Basmati milled rice stored in G-HF Cocoon in KFM warehouse in Kuwait. CO_2 concentration was calculated from O_2 readings

Table 1 Data on quantity (tonne), moisture content (%), O_2 and CO_2 concentrations (%), and qualitative parameters of two Cocoons placed in East Java for one year

Location	Pile no.	Treatment	Quantity (tonne)	moisture content (%)	Gas concentration (%) at day 4		Qualitative	
					O_2	CO_2	Insects	Odour
East Java	1	HS	150	13.8	19.8	---	Free	Normal
	2	MA	150	14.0	5.7	73.0	Free	Normal

HS, Hermetic storage; MA, CO_2 based modified atmosphere

This would indicate the introduction of CO_2 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 O_2 concentration during one year of HS of milled rice in East Java Regional Division are shown in Fig. 4. The O_2 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.

Fig. 3. Ballooning effect at the end of purging CO_2 on 300 tonnes of basmati milled rice stored in G-HF Cocoon in KFM warehouse in Kuwait

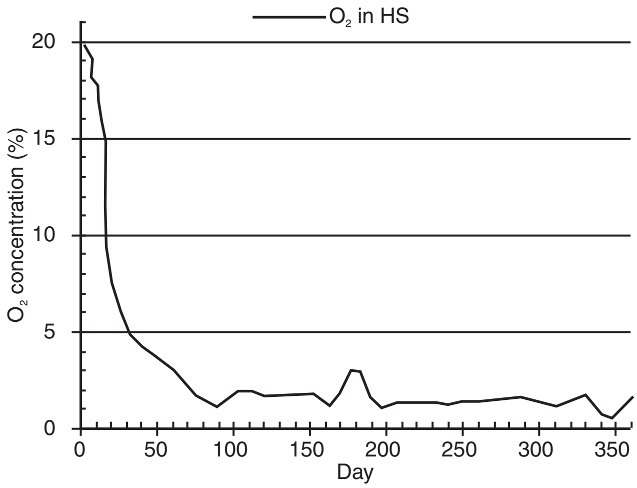

Fig. 4. Changes in O_2 concentration in hermetic Cocoons containing 150 tonnes of milled rice at East Java warehouse

After 5% O_2 was reached, data were read every two weeks until the end of the storage period of 360 days. The O_2 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 CO_2 concentration during one year of MA storage of

Fig. 5. Quality test of milled rice samples at the opening of the stack

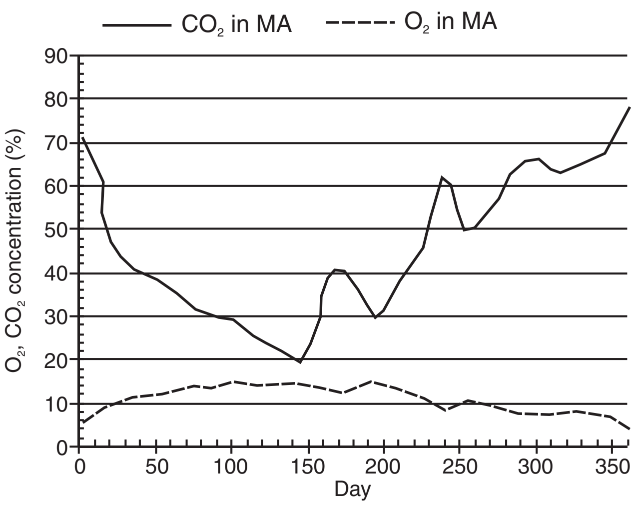

Fig. 6. Changes in CO_2 and O_2 concentration in G-HF Cocoon containing 150 tonnes of milled rice at East Java warehouse

milled rice in East Java Regional Division are shown in Fig. 6. After application of CO_2 the concentration dropped from 71% to 19% within 150 days. That is an average decrease of 0.35% CO_2 d^{-1} indicating that such reduction is below the suggested maximum loss rate for CO_2 as 2% d^{-1} (Navarro and Zettler, 2001).

After 195 days, a second CO_2 purge was applied until a concentration of 62% was attained. Then after 255 days, a third purge attempt was maintained for approximately 1.5 month during which the CO_2 was flowing at a low rate, and a final purge, after 315 days, until the CO_2 concentration reached 79% at the end of the trial. It is unfortunate that the amount of CO_2 used in these trials was not recorded. Although the attempts to maintain the CO_2 concentrations above 60% were apparent, the multiple applications resemble a controlled atmosphere more than MA application. It is very possible that after the initial purge when the concentration dropped to about 19% it would still provide adequate protection for the rice.

Observation of milled rice stored in Cocoon (Table 1) shows that it can maintain the quality of the rice, even in the absence of live pests due to prior fumigation. Qualitatively, the rice stored in the hermetic Cocoon remained in good condition, the colour remained white, granular, still hard and not dusty. Carvalho et al. (2012) also obtained the same results when physical and chemical properties and sensory quality of the CO_2-treated rice was evaluated after cooking. Their results revealed no differences between treated and non-treated polished rice. Levels of CO_2 in the hermetically sealed big bags and silo, containing rice, remained constant, and control efficacy was checked in all tested cases. Complete mortality of *Sitophilus zeamais* (Motschulsky) adults, or eggs of *S. zeamais* was achieved where O_2 levels were 0.7–2.1%.

CONCLUSION

Hermetic and CO_2 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 CO_2 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 O_2 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 CO_2 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 O_2 concentration did not decrease to a lethal level below 6.5%. Similar results were obtained with CO_2 based MA storage: tested samples of milled were free of live insects, the m.c. was preserved and the odour was normal.

ACKNOWLEDGMENT

Authors acknowledge the cooperation of Joel Dator, Technical Services Department GrainPro, technical team of BULOG, Jakarta, and of KFM, Kuwait.

REFERENCES

Carvalho MO, Pires I, Barbosa A, Barros G, Riudavets J, Camara A, Brites CG, Navarro S (2012) The use of modified atmospheres to control *Sitophilus zeamais* and *Sitophilus oryzae* on stored rice in Portugal. Journal of Stored Products Research **50**: 49–56.

Darrington J, Nummer BA (2008) White rice, USU Extension. http://extension.usu.edu/foodstorage/htm/white-rice Accessed 12 August 2016.

de Bruin T (2006) A User's Introduction to Hermetic Storage – How it Works. (unpublished). GrainPro Document Number SL2322TDB0506-4. GrainPro, Inc. Concord, MA USA.

de Dios CV, Cosico MFA, Julian DD, Dator JV, Martinez EM, Tiongson RL (2001) Adoption of hermetic storage on milled rice using the Volcani Cube® in the Philippines. (*In*) Donahaye EJ, Navarro S, Leesch JG (Eds) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, 29 Oct. - 3 Nov. 2000, Fresno, CA. Executive Printing Services, Clovis, CA, USA, pp 251–260.

Donahaye E, Navarro S, Paster N, Andales S, Caliboso FM, Sabio GC (1999) Self regulated atmospheres to prevent fungal damage in moist paddy. Final Report submitted to U.S. Agency for International Development, CDR Project No. C12-057, February 1996 – November 1999, 30 pp.

Donahaye J, Navarro S, Andales S, del Mundo A, Caliboso F, Sabio G, Felix A, Rindner M, Azrieli A, Dias R (2001) Quality preservation of moist paddy under hermetic conditions. (In) Donahaye E, J, Navarro S, Leesch JG (Eds) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products. 29 Oct.-3 Nov. 2000, Fresno, CA, Executive Printing Services, Clovis, CA, USA, pp 209–225.

Navarro S, Donahaye E, Caliboso FM, Sabio GC (1995) Application of modified atmospheres under plastic covers for prevention of losses in stored grain. Final Report, submitted to U.S. Agency for International Development, CDR Project No. C7-053, August 1990 – November 1995, 32 pp.

Navarro S, Donahaye E (2005) Innovative Environmentally Friendly Technologies to Maintain Quality of Durable Agricultural Produce. (In) Ben-Yehoshua S (Ed.), Environmentally Friendly Technologies for Agricultural Produce Quality, CRC Press, Taylor and Francis Group, Boca Raton, FL, pp 205–262.

Navarro S, Zettler JL (2001) Critical limits of sealing for successful application of controlled atmosphere or fumigation. (In) Donahaye EJ, Navarro S, Leesch JG (Eds) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products, 29 Oct. – 3 Nov. 2000, Fresno, CA. Executive Printing Services, Clovis, CA, pp 507–520.

Navarro S (2006) Modified Atmospheres for the Control of Stored-Product Insects and Mites. (In) Heaps JW (Ed) Insect Management for Food Storage and Processing, Second Edition, AACC International, St. Paul, MN, pp 105–146.

Navarro S (2012) Global challenges for the successful application of MA and hermetic storage. (In) Navarro S, Banks HJ, Jayas DS, Bell CH, Noyes RT, Ferizli AG, Emekci M, Isikber AA, Alagusundaram K (Eds) Proc 9th. Int. Conf. on Controlled Atmosphere and Fumigation in Stored Products, Antalya, Turkey. 15 – 19 October 2012, ARBER Professional Congress Services, Turkey, pp 429–439.

Villers P, de Bruin T, Navarro S (2006) Development and applications of the hermetic storage technology. (In) Lorini I et al. (Eds) Proceedings of the 9th International Working Conference on Stored Products Protections Campinas, Sao Paulo, Brazil, ABRAPOS, pp 719–729.

Villers P, Navarro S, de Bruin T (2010) New Applications of Hermetic Storage for Grain Storage and Transport, pp 446–452, Navarro S, Riudavets J (Eds) Fumigation, Modified Atmospheres and Hermetic Storage, Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June to 2 July 2010, Estoril, Portugal Julius-Kühn-Archiv, 425, Bundes for schungsinstitut für Kulturpflanzen, Berlin, 1077 pp.

Weinberg ZG, Yan Y, Chen Y, Finkelman S, Ashbell G, Navarro S (2008) The effect of moisture level on high-moisture maize (*Zea mays* L.) under hermetic storage conditions—*in vitro* studies. Journal of Stored Products Research **44**: 136–144.

Yanai S, Ishitani T, Kojo T (1979) Influence of gaseous environment on the hermetic storage of milled rice. Nippon Shokuhin Kogyo Gakkaishi **26**: 145–150.