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End-use quality characteristics of hermetically stored paddy

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Four paddy varieties (Bg 352, Bg 300, Bg 358 and Bg 360) were stored in hermetic IRRI bags and common woven polyethylene bags (polybags) at room temperature either uninfested or infested with rice weevils (*Sitophilus oryzae* (L.)). After 9 months of storage, samples were tested for insect mortality, gas contents, moisture content (m.c.), thousand grain mass (TGM), porosity, hardness, whiteness, total milled rice yield (TMR), head rice yield (HRY), gelatinization temperature, amylose (AC), crude protein (CP), crude fat, free fatty acid (FFA), thiamine and niacin contents and sensory characteristics. These properties after storage were compared with their initial condition. The oxygen content dropped from 21% to 7% and 13.8% for infested and uninfested IRRI bag samples, respectively. The results showed that m.c., of the IRRI bag samples increased significantly ($P < 0.05$) by 5% when compared to the initial sample but it increased by 15% in polybag stored samples. After 9 months, dry matter loss (DM) was 65% higher in polybag than IRRI bag samples. Highest DM loss was observed in Bg 300 and the lowest DM loss was observed in Bg 358 and Bg 360. Paddy samples stored in IRRI bags showed reduced whiteness compared to polybag stored samples. Storage in IRRI bags significantly increased ($P < 0.05$) TMR, HRY, AC and sensory values compared to polybag samples. However, paddy samples stored in polybags significantly increased ($P < 0.05$) their CP and FFA contents while decreasing sensory values, thiamine and niacin contents. The FFA value of polybag samples was 2.5 times higher than IRRI bag samples. Hermetic storage of dry paddy improved overall paddy quality but different end-use quality parameters were observed in the two paddy grain types of short round (Bg 352 and Bg 300) or intermediate bold (Bg 358 and Bg 360).

1. Introduction

For a stable supply of rice, it is necessary to increase paddy (raw rice) production and minimize postharvest losses during the handling process. Nearly 50% of the paddy harvested in Sri Lanka is kept by farmers (Hafeel et al., 2008), for consumption, seeds and future sale for a period of 6–12 months. It has been estimated that on-farm storage loss of paddy in Sri Lanka is about 8% (Adhikarinayake et al., 2006) due to poor storage, a considerable amount contributed to the total annual production of approximately 4 million metric tons. Current statistics reveal that annual per capita consumption of rice in Sri Lanka is approximately 108 kg.

Storage of paddy in woven polyethylene bags (polybags) is a commonly used, inexpensive and convenient storage method. However, it does not provide the required safety for long-term storage of paddy, especially under humid climatic condition (Weinberg et al., 2008). Even where grains are stored in suitable silos, losses may still occur due to contamination, deterioration, spillage and spoilage. Insect infestation causes significant damage to the quality of paddy during storage (Jood et al., 1993; Trematerra et al., 2004) and tends to speed up undesirable chemical changes among stored grains and their products (Raj and Singaravadivel, 1990; Seitz and Sauer, 1996). Therefore, quality deterioration of paddy or processed rice is unavoidable under common storage systems. Advanced cold storage or controlled atmosphere systems for paddy are not practical at the small farm level as the systems need large spaces and expensive environment control facilities.

Hermetic storage of paddy or processed rice is considered a feasible alternative method to woven polybag storage, and addresses the major problems of mold and insect infestation (Navarro et al., 1997; Donahaye et al., 2001). Hermetic or airtight storage is an excellent method to control insects in stored grain, without the use of chemical pesticides (Navarro, 2006). In this method the storage atmosphere is modified by sealing the container hermetically, so that a low oxygen (O_2) and high carbon dioxide (CO_2) atmosphere is obtained after a few weeks of storage (Navarro and Donahaye,

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2005). The development of both fungi and insects can be prevented when O_2 <3% in the hermetic storage container within 30 days (Moreno-Martinez et al., 2000; Adhikarinayake et al., 2006).

Donahaye et al. (1991) first investigated the possibility of storing bagged paddy outdoors in tropical Sri Lanka using hermetically sealed plastic liners. Adhikarinayake et al. (2006) developed and evaluated an airtight reinforced concrete bin to store paddy in Sri Lanka. In both trials, paddy was stored within the storage structure for 6 months, obtaining excellent hermetic conditions of low O_2 (<5%) and high CO_2 (>9%). They recorded better milling outturn, lower changes in moisture content and reduced mass loss (<0.4%) of paddy during hermetic storage. Although hermetic storage is effective, farmers are reluctant to use the technology due to material cost and practical difficulties such as handling and maintaining the structures. Therefore, farmers prefer to use methods similar to their common polybag storage system. Another disadvantage of airtight storage is that of moisture rising to the product surface in response to temperature differences in a large storage system (Gough, 1985) which may reduce product quality. Because final quality of rice (milled paddy) is important to consumers, low farmer adoption may be due to the uncertainty of the quality of rice under hermetic conditions after extended storage (between cropping seasons). Grain viability, amount of non-reducing sugars, colour, organoleptic qualities and free fatty acid values are some of the quality parameters most susceptible to change during storage of paddy due to ageing (Zhou et al., 2002). Tananuwong and Malila (2011) reported that physicochemical properties of organic rice changed even during storage under vacuum-packed conditions. Most importantly, consumers prefer rice with a white translucent endosperm and good aroma, and will pay a premium price for it. In order to increase farmer adoption of hermetic storage systems and fulfil the market demand of quality rice, a thorough investigation of the effect of hermetic storage on rice quality should be carried out.

The objective of this research was to determine the effects of long-term hermetic storage on *Sitophilus oryzae* (L.) (rice weevil), milling, physicochemical and sensory qualities of different paddy varieties. Ambient storage (25–32 °C and relative humidity 75–85%) is generally used for commercial storage of paddy and other grains in Sri Lanka, and two cropping seasons (9–12 months) is considered a long period for paddy storage under ambient conditions. Feasible and easy handling is important to popularize the hermetic storage method among farmers. Hermetic IRRI super bag is another alternative storage technique, similar to common polybag storage (Hafeel et al., 2008). Therefore, in this study, polybags and IRRI bags are used for packing and storage of four different paddy varieties commonly grown in Sri Lanka. Results of this study will help to determine the applicability and suitability of hermetic bag storage over common polybag storage by considering the end use quality of paddy.

2. Materials and methods

2.1. Sample preparation

Four high yielding paddy varieties (Table 1) of two grain types were cultivated at Rice Research and Development Institute (RRDI), Sri Lanka for the experiment. Paddy was harvested at the physiological maturity defined by the RRDI for each variety. Before storage, paddy samples were sun dried on a smooth drying floor, without exposure to high temperature, to a final moisture content of 12 ± 0.6% wet basis (w.b).

Table 1
Paddy varieties according to their grain type.

Paddy variety	Grain type	Maturity (days)
Bg 352	Intermediate bold	105
Bg 300	Intermediate bold	90
Bg 358	Short round	105
Bg 360	Short round	105

In order to control possible pest and microbial attack, each 5 kg sample was cleaned and disinfested using 5 ml of chloroform ($CHCl_3$) vapour for 12 h in a 5 L gastight chamber prior to storage and initial testing.

2.2. Paddy storage

Paddy samples of 2 kg from each variety were stored under two different types of storage materials, polypropylene bags (polybag) as common storage and IRRI super bags (IRRI bag) for hermetically sealed storage. IRRI bags, obtained from the International Rice Research Institute (IRRI), Philippines, are highly impermeable to air and moisture diffusion, which has an oxygen permeability of 35–55 ml/m^2/day and a water vapour transmission rate of 8 g/m^2/day (Bakker et al., 2003; Anonymous, 2009). Paddy samples were tightly packed into the bags and the mouth of each bag was closed with 5 mm wide PVC cable connectors. Prepared samples were stored in a clean, recently fumigated empty room where the average ambient temperature and relative humidity (r.h.) were 30 ± 2 °C and 80 ± 5%, respectively. All quality characteristics of paddy and their milled rice were measured before storage (initial samples) and after 9 months of storage in the bags.

2.3. Hermetic condition

To evaluate the atmosphere in the IRRI bag, oxygen (O_2) and carbon dioxide (CO_2) concentrations were monitored using a gas analyzer (ICA 15 Dual Analyzer). Two needles (2.5 mm × 5 cm) were inserted through adhesive rubber septa on opposite sides of an IRRI bag. The needles were connected to the inflow and outflow tubes (5 mm diameter) of the analyzer. Temperature and r.h., within the bags were monitored in four additional IRRI bags using T-type thermocouple data loggers (TC08-PicoTech, UK) and relative humidity sensors (Thermo-hygrometer model: HT-800, UK). Thermocouples and r.h., sensors were inserted through the wall of each bag and silicone rubber gel was used to seal the hole around the cables. The initial O_2 concentration of the samples was set to 21%.

2.4. Infestation of insects

Separate sets of experiments were carried out to evaluate the mortality of insects under hermetic conditions. Adult *S. oryzae* (L.) were obtained from a culture maintained for several years at the Department of Agricultural Biology, University of Peradeniya, Sri Lanka. Approximately 3-week old adults reared in paddy were used for the infestation experiment. Storage bags were infested with 100 unsexed adult weevils. Mortality of insects was determined by sifting the paddy samples 30 days after storage began. In another experiment, inert gas concentrations (%) were evaluated in undisturbed infested and uninfested samples every 30 days for up to 9 months.

2.5. Moisture content, dry matter content and thousand grain mass

The moisture content (m.c.) of the initial and stored paddy samples was determined (% w.b) by forced-air oven drying at 105 °C for 24 h (AACC, 2000). Dry matter (DM) was also measured using moisture data. DM losses (%) were calculated related to the initial DM contents of paddy samples.