Evaluation of performance of grainsafe hermetic storage system for drying and storage paddy

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Abstract: A study was carried out to assess the performance of a hermetic grain storage system, branded “GrainSafe”, for drying and storage compared to sun drying. The study aimed to conduct experiments on the system to assess its technical performance as a dryer at first. Two GrainSafe dryers were installed for drying and storage experiments. Parallel sun-drying experiments were carried out. The parameters assessed were quantitative (weight loss) and the quality of rice yielded from milling, germination, milling recovery, aflatoxin contamination, insect infestation, and economic viability of their use. However, the higher (9.6%) weight loss attained compared with GrainSafe Dryers (1,7%) was probably due to relatively low ambient relative humidity under sun drying and the protection attained in GrainSafe Dryers against birds, flies dust, and rain by virtue of being a closed system. Paddy dried in GrainSafe Dryers had a better mill recovery (62-64%) than sun drying (51%). The sun-dried paddy yield was significantly lower in head rice compared with paddy dried in GrainSafe Dryers. However, the paddy dried in GrainSafe Dryers was higher in terms of germination rate (82-85%) compared with the sun-dried paddy (80%). The hermetic system's use for drying and storage was superior to sun drying. Both systems were found to be economically viable. However, more research in different areas is required before disseminating the hermetic system for drying and storage.

Key words: Post-harvest loss, paddy drying, milling recovery, head rice

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1. Introduction

Rice (Oryza spp) belongs to the family *Graminae*. It is a cereal grain grown in areas with hot climates providing seeds that are used as food. Rice refers to two grass species (*Oryza sativa* and *Oryza glaberrima*) and is native to tropical and subtropical southeastern Asia and to Africa. Postharvest food loss is defined as measurable qualitative and quantitative food loss along the supply chain, starting at the time of harvest till its consumption or other end uses [10]. Every year, an estimated 1.3 billion tons - roughly one-third - of the food produced for human consumption worldwide is lost or wasted. In industrialized countries, significant waste occurs at the consumption stage, while in low-income countries, food losses take place primarily during the early and middle stages of the supply chain [6].

International Rice Research Institute in the Philippines has estimated that between 5 and 16 percent of paddy is lost in the primary postharvest period, which includes harvesting, handling, threshing, and cleaning. During the drying, storage, milling, and processing stages, another 5 to 21 percent disappears. Total estimated losses, not accounting for later losses at retailers and consumers levels, run from 10 to 37 percent of all the rice grown [10]. Other recent scientific surveys place paddy losses in China at between 5 and 23 percent (not accounting for processing) [13]. This is not a profitable or sustainable way to farm. Some stages in the paddy post-harvest systems are more critical than others, particularly in tropical and subtropical areas where paddy is more vulnerable to damage and more likely to suffer qualitative and quantitative losses. Delay in threshing after harvesting of crop results in significant quantity and quality loss, as the crop is exposed to the atmosphere and is susceptible to rodents, birds, and insect attack [4]. As in the case of harvesting, lack of mechanization is the major reason for this delay that causes significant losses.

High moisture accumulations in the crop lying in the field may even lead to the start of mold growth and mycotoxin production in the field. Unfortunately, due to small farm sizes, local rice farmers continue to rely on traditional open-sun drying methods for drying their paddy. As it dries the paddy is raked every one-two hours and depending on two days to dry. In most cases the paddy is over-dried, resulting in high grain fissuring. The purpose of this study was to evaluate the performance of the GrainSafe hermetic storage system for drying and storage in Burundi compared with sun drying.

2. Materials and Methods

2.1. Description of the study area

This research was conducted at the International Rice Research Institute (IRRI) in Burundi which is located in Bujumbura city, at the University of Burundi (UB), Mutanga campus in the Faculty of Agronomy and Bio-engineering (FABE).

2.2.Experimental materials

A hermetic storage system, branded "GrainSafe", was adapted to the drying and storage of paddy, and termed GrainSafe hermetic dryer (Fig.1). Two units were each set using a bin for holding grains, a perforated air distribution system for distributing air to the grains and a blower for creating the pressure that drives the ambient air through the grain bulk. A renewable energy power unit (2 solar panels rated 300 watts and 12 V DC power) was used to run the blower. A box made of wood was used to make the blower housing. Two deep-cycle batteries (75 Ah) were used to conserve the energy from the solar panel. The perforated air duct measuring approximately 10 cm long and 4 cm wide was installed facing down in the GrainSafe dryer. The perforations were made on the one-half side of the PVC pipe, with the middle portion not perforated to hold the ducting in place and avoid collapse. The PVC pipe size was 8.89 cm in diameter. The perforations were covered with a wire screen mesh to prevent clogging of the grains. The resistors were connected to the blower before connecting to the power supply from the battery and the controller was used to control the power from solar panels. The GrainSafe units were exposed to the sunshine for two hours before installation to remove length differences and folds of PVC zippers. A platform was prepared with dimensions 130 cm x 130 cm and one meter high to provide access to holding/unloading and monitoring. Four posts and beams were used to keep the platform stable and secure. Ordinary materials (wood, angle iron, and galvanized pipe) were used to construct the platform. The Rodent guards were installed to protect against rodent attacks (one set can be installed on the platform legs).

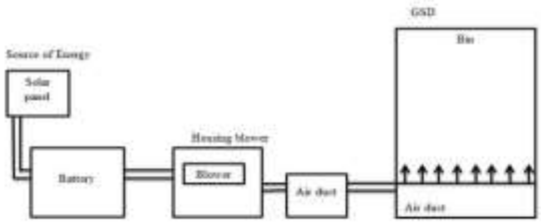

Fig.1: Schematic diagram of GrainSafe Dryer

2.3.Assessment of drying performance

Two GrainSafe hermetic units adapted as dryers were used for paddy drying in the same environment as sun drying. A GrainSafe hermetic unit had a capacity of 1.3 tons. Paddy was loaded in a GrainSafe unit at a bulk depth of 1.2 m. In these units, the blower was run by an independent energy system, which was operated during day time when the ambient relative humidity was less than 75% to avoid moisture re-absorption by the grain mass.

The 1st unit (GSD1) was used as a split drying storage in comparison with sun drying of paddy spread at 50 mm depth on a tarpaulin sheet. Split drying was done to check for possible changes in grain quality during the drying phase in the GrainSafe due to the effects of weather. Sun drying was done during day times from 8:00 am to 4:00 pm for

several days. In the 1st GSD unit and for sun drying, moisture content was considered to have reached equilibrium at around 14% wet basis, which also marked the end of drying. The 2nd unit (GSD2), which was used as a combination of drying and storage, was kept undisturbed until the end of the set storage period. In this unit, it was perceived that during storage drying was also taking place.
At the end of the perceived drying, the parameters measured were the quantitative losses encountered measured as the difference between initial and final weights and grain quality including, moisture content, milling recovery, head yield, seed viability, and aflatoxin levels. The results were compared with the same under-sun drying.

2.4.Assessment of storage performance

This assessment was done to find variability in quantitative and qualitative losses caused by adapting the GrainSafe for drying and storage. After the perceived drying samples of about 100 kg each were drawn from the sun-dried grain bulk and the 1st GSD unit and each was stored in polypropylene bags for a period of four months (From July 2021 to October 2021) undisturbed under ambient household conditions. The remainder of the grain in GSD1 and the grain in the 2nd unit (GSD2) were also kept for a period of four months undisturbed. This amounted to four sampling units at the end of storage. During storage in the GSD1 and GSD2 units, the blowers were switched off. Storage temperatures and relative humidity were monitored at 9:00, 13:00, and 17:00 daily from the beginning to the end of the experiment. The temperature was measured using dry and wet bulb thermometers (Zeal, UK) inside the storage room while relative humidity inside and outside the storage room was measured using a Hygro-Thermometer. The response variables measured were quantitative losses, grain quality for drying, grain viability, insect infestation, and the presence of aflatoxin.

2.5.Determination of drying and storage response variables

2.5.1. Moisture content and weight loss

The drying rate can be determined from the combination of moisture content and appropriate weight loss data. In this study, seed moisture content was determined at the purchase point, during drying, and during storage, periods using the Check PLUSTM SW 08120 moisture meter. During drying moisture content was measured at two-hour intervals. Samples for moisture content determination were drawn from the bottom, middle and top of GSD and under sun drying by using the seedburo sampling unit.

2.5.2. Seed quality test

A germination test was conducted for samples drawn from both GSD1 and sundried paddy at the end of the set drying period. The same parameter was tested for the stored paddy under conventional storage conditions for the sun-dried paddy and a portion of the GSD1 dried paddy, a portion of paddy stored in GSD1, and paddy in GSD2. In this study, rules of the International Seed Testing Association (ISTA) were followed to determine the germination rate. One hundred and twenty-five seeds were taken randomly from each sample and tested in three replicates. Plastic containers were used to contain sterile sand for the test.
The sterile sand was moistened and placed at the bottom of each container to about 6 cm thickness. The selected seeds were placed uniformly on the moist sand in the containers, with a little amount of dry sand spread over them. The containers were kept in a rack covered with an iron net at room temperature for fourteen days, during which water was sprayed over the containers for better germination. Seeds with roots or shoots longer than 2 mm were considered as germinated seeds [11]. First, counting was done 5 days after the seeds setting and final counting was done at 14 days after the seeds set. The normal seedlings, abnormal seedlings, dead seeds, and un-germinated seeds were counted.

Fig. 2: Seedlings in the germination test

2.5.3. Determination of mill recovery

About 25 kg of dried paddy from each drying structure was milled using SB 10 mill-top rice mill series (rubber roll type). The same process was done to the stored samples. The milling was conducted in five replications of five kilograms each, making a total of 25 kg for each sample. The pressure of the polishing unit mill was set to achieve the whiteness degree of milled rice that is usually required by the consumers. The weight of the resultant milled rice obtained was recorded.

2.5.4. Determination of head rice yield

The head rice and total broken grain amounts were determined from the milled rice. Five different samples, each weighing 105 g were randomly taken from the milled rice from each paddy drying unit (GSD1, GSD2 , and sun drying).

2.5.5. Aflatoxin contamination

Determination of aflatoxin was done using the AOAC International (1996) 990.33 (49.217) official method.

2.5.6. Insect infestation

Insect infestation on the stored paddy was determined according to the rules of the International Seed Testing Association (ISTA) method. One hundred gram of rice seeds from each sample was used for dry inspection. Seeds were placed on a clean table board and worked with the help of forceps to separate them into different groups. These were also observed visually with the help of a hand magnifying glass. Seeds were separated into different groups such as apparently healthy seeds, spotted seeds, and deformed seeds. Apparently, healthy seeds have normal color without any spots, spotted seeds may be diseased and deformed seeds are irregular in shape. The number of seeds in the above groups was counted and the result was expressed as a percentage.

2.6. Data collection

2.6.1. Assessment of drying and storage performance of GrainSafe Dryer

2.6.1.1.Moisture content and weight loss

The initial and final weight of paddy dried and stored was collected by using a weigh scale and recorded. Initial and final moisture content was collected using a moisture meter. The moisture content during drying was collected after two-hour intervals (Top, middle, and bottom) from 8:00 am to 5:00 pm by using seedburo. The amount of moisture removed from the paddy samples was determined using Equation 1 by [1].

$$M_w = \frac{Mp(\mathrm{Mi} - \mathrm{Mf})}{100 - \mathrm{Mf}} \quad \ldots\ldots (1)$$

Where: Mw is the mass of water removed from wet paddy (kg); $M_p$is initial mass of paddy to be dried (kg); M_i is initial moisture content of paddy (wb); $M_f$is final moisture content of paddy (wb).

The weight of paddy samples was determined using a weighing scale (Digital weight scale W2C and Model-252).

The drying rate of paddy samples during the drying period was calculated using Equation 2 as described by Aktar, 2016.

$$DR = \frac{\text{Percentage moisture removed}}{\text{Time hour}} \quad \ldots\ldots (2)$$

2.6.1.2.Seed viability

A sample of one hundred twenty-five (125) grains was randomly taken from GrainSafe

Dryers and sun-dried paddy after drying and after storage to assess the seed viability. After the germination test, the seed vigor index was determined by using equation 2 for the seed quality test by[9].

$$\% \, viabilityindex = \frac{NG}{TG} * 100 \ldots\ldots\ldots(4)$$

Where, **NG** is the number of seeds that germinated and **TG** is the total number of seeds tested for germination.

2.6.1.3. Milling recovery

A sample of twenty-five (25) kilograms was randomly taken from each experimental unit to assess the mill recovery. Mill recovery for each treatment was computed using Equation (5).

$$\text{Mill Recovery (\%)} = \frac{\text{Weight of miled rice}}{\text{Weight of paddy}} \text{x100..(5)}$$

2.6.1.4.Head yield

A sample of one hundred and five (105) grams of milled rice was randomly taken from each GrainSafe Dryers and sun-dried. Each sample was sorted into head rice and total broken grain; and weighed using OHAUS mechanical triple beam balance, which had three graduated beams and 2,610 g capacity. The weights obtained were expressed as a percentage of the sample weight. The following formula (Equation 6) was used to calculate head rice.

$$\text{HRR (\%)} = \frac{Weight\ of\ whole\ grains}{Weight\ of\ paddy\ sample} X100 \ldots (6)$$

Where: HRR is head rice recovery.

2.6.1.5.Aflatoxin contamination

A sample of one (1) kilogram of paddy and milled rice were randomly taken from each experimental unit to assess aflatoxin levels.

2.6.1.6.Insect infestation

A sample of two hundred and fifty (250) grains was randomly taken from each storage structure to evaluate insect infestation. The percentage of infestation was determined as shown below (Equation 7):

$$\text{Insectinfestation(\%)} = \frac{\boldsymbol{Number\ of\ damaged\ grains}}{\boldsymbol{Total\ number\ of\ grains}} \boldsymbol{x100} \ldots\ldots (7)$$

2.7.Data analysis

Analysis of variance (ANOVA) was performed on experimental data collected using GEN STAT Discovery Edition 15 and separation of treatment means was done using Duncan's multiple range tests.

Vigour index= Germination, % × Total seedling length, cm …… (3)

The viability index was calculated according to[15] using the following equation (Equation 4):

3. Results and discussions

3.1.Drying of paddy in Grain Safe

3.1.1. Drying performance

3.1.1.1.Variation in moisture content

Moisture content decreased gradually in both GrainSafe units from the initial value. The initial average moisture content was 26.7% w.b., which decreased to an average moisture content of 11.7% w.b. for GS1 and GS2 at the end of drying. The process was achieved in 168 hours (21days) (Fig.3) and 144 hours (18 days) (Fig.4) for GSD1 and GSD2, respectively. In GSD1, the drying operation was stopped when the moisture content at the top of the drying bin reached 14% w.b.in 20 days. Sun drying took only five days (40 hours) to reach an equilibrium moisture content of 13.9% w.b. However, for GSD1, the moisture content was decreased up to day 8 and raised on day 9 due to running off the blower on day 8 where the relative humidity was above 75%. It was the same for GSD2. It was observed that the drying time was longer for GSD1 than GSD2, that trend was due to the quantity of paddy penetrating the air duct and the air circulating slowly.

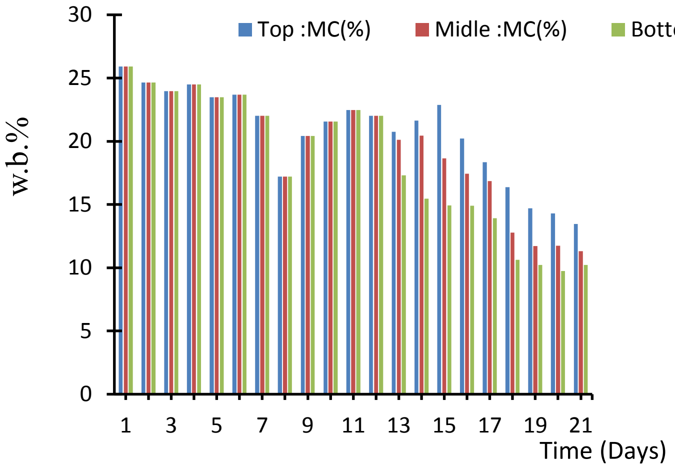

Fig.3.Average moisture content in GSD1

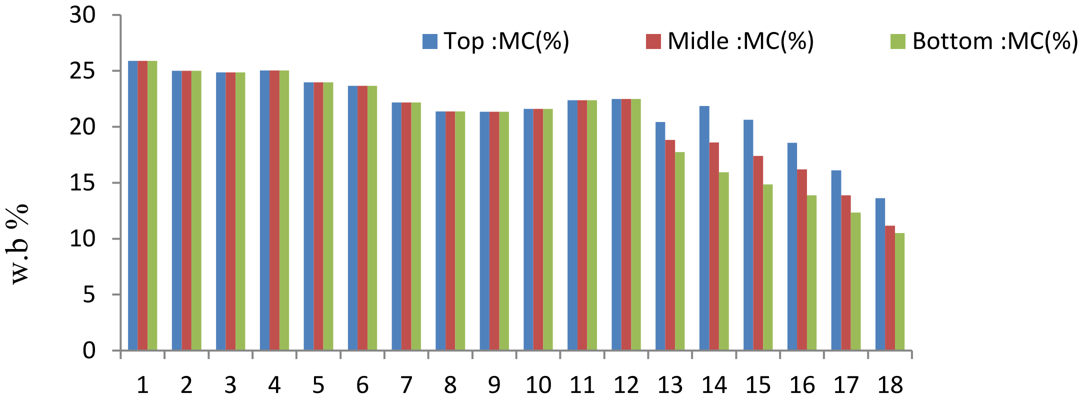

Fig.4. Average moisture content during drying in GSD2

Based on the results, the time taken for the gradual decrease of moisture content from 26.7% w.b. to reach a mean equilibrium moisture content of about 11.7 % w.b., which was 168 hours (21 days) for GSD1 and 144 hours (18 days) for GSD2 was quite long. Although in GSD1 the process was stopped when moisture content at the top of the GSD reached 14% in 21 days such as long drying periods which may lead to unnoticed mold deterioration and low attractiveness as farmers may be busy farming or attending to other equally important tasks. Although sun drying took only five days (40 hours), a period shorter than in the case of GSDs, attaining equilibrium moisture content of 13.9% wet basis, the woes (rain during drying, over dried and dust contamination) faced by it may not make it better than the GrainSafe unless there are very serious changes in quality. Besides, the use of GrainSafe as a dryer is a new field that can be improved for better drying performance.

3.1.1.2.Weight loss

In this study weight loss was used as an alternative method of determining drying performance. The performance of drying paddy in GrainSafe in comparison with sun drying was studied and the results are presented in Table 1. The highest drying rate was observed in sun drying. However, sun drying has been shown to register relatively higher weight loss (9.6%) compared with GSDs (1.7%) although they were generally low.

Table 1.Technical performance of GSD

	Wti	MCi	Wtf	MCf	Wtf14%	Wtl14%	DL (%)	DT(Hr)	DR (%)
Sun drying	320	25.3	289	13.9	289.34	30.7	9.6	21	0.54
GSD1	930	26.7	890	11.7	913.8	16.2	1.7	168	0.09
GSD2	930	26.7	891	11.77	914.1	15.9	1.7	144	0.1

Key words:Wti = initial weight (kg), MCi = Initial moisture content, Wtf = Finial weight, MCf = Final moisture content, Wtf 14%= Final weight at 14%, Wtl Weight loss at 14%, DL = Drying loss, DT= Drying time, DR = Dying rate .

Based on the weight loss results, the relatively higher (9.6%) weight loss attained compared with GSD1 (1.7%) was probably due to relatively low ambient relative humidity under sun drying and the protection attained in the GSD1 against birds, flies, dust and rain by virtue of being a closed system. [2] reported drying losses of 2.41% to 3.95% in the traditional open sun drying method, which is still higher than that registered for the GSD1 under the current study. This implies that, although it is a slow dryer, the GSD has the capability of attaining low weight loss. This is because there was no chance of adding/mixing impurities as well as wetting with rain water during drying using a GSD dryer as opposed to the case of the open sun drying method. In another study, [10]found a drying loss of 3-5% in traditional open sun drying and 1-2% in mechanical drying. The loss of 1.7% in GSD1 is within the same range as what was encountered in mechanical drying, which is rendered the best and most convenient drying system. [6]reported that the most postharvest losses were 26-37% due to pests and diseases.

3.1.1.3.Grain quality

3.1.1.3.1. Mill recovery

Sun-dried paddy resulted in significantly lower ($p<0.001$) mill recovery compared with paddy dried in the GSDs (Table 2).

Table 2 Mill recovery after drying

Structure	Mean	LSD	P-value
Tarpaulin	51.07 b	3.739	<.001
GSD1	62.80 a		
GSD2	63.87 a		

The results have demonstrated that paddy dried in GSDs has a better mill recovery (62-64%) than sun drying (51%). The difference in mill recovery between sun drying and the use of GSD was significant ($p<0.05$). Reasons for low mill recovery for sun-dried paddy could not be established. However, thermal stresses and non-uniform mixing during sun drying are possible causes.

3.1.1.3.2. Head rice and broken rice

Grain quality was determined for the sundried paddy, GS-dried paddy and the GS in-storage dried paddy. The results have shown sun drying of paddy yielded a significantly lower ($p<0.001$) head of rice compared with paddy dried in GSDs. The same is mirrored in the proportion of broken rice, which was highest in sun-dried paddy (Table 3).

Table 3.Head rice recovery in GSD and sun drying

Head rice				Broken rice			
Structure	**Mean**	**LSD**	**P-value**	**Structure**	**Mean**	**LSD**	**P-value**
Tarpaulin	52.60a	3.45	<.001	Tarpaulin	52.40b	3.45	<.001
GSD1	65.65b			GSD1	39.35a		
GSD2	66.00b			GSD2	39.00a		

The results have shown sun drying of paddy yielded a significantly lower ($p<0.001$) head of rice compared with paddy dried in GSDs. The same is mirrored in the proportion of broken rice, which was highest in sun-dried paddy. [14] reported that the paddy drying conditions affected paddy breakage during milling so that paddy breakage rapidly increased with the decreasing moisture content of paddy drying air.

3.1.1.3.3. Germination test

A germination test was done in terms of germination rate and vigor index for sun-dried and GSD-dried paddy (Table 3.4). It was observed that paddy dried in GSDs resulted in a relatively higher mean germination rate (82-85%) compared with sun-dried paddy (80%) (Table 4). This was also reflected in the relatively lower vigor index (1816) for sun-dried paddy compared with GSDs-dried paddy (1820-1844) (Table 4).

Table 4.Seeds quality test of paddy dried under sun and in GSD

	Trial	Number of seed germinated	Dead seeds	Germination rate, %	Average rate, %	Seedling length, cm	Vigour index	Average of vigour index
GSD 1	Top	106	19	84.6	85.2	23	1946	1820
	Middle	105	20	84		21	1764	
	Bottom	109	16	87.2		20	1750	
GSD 2	Top	96	29	80	82.6	22	1760	1844
	Middle	98	17	81.6		24	1958	
	Bottom	108	17	86.4		21	1814	
Sun drying	1	108	17	86.4	80.8	22	1901	1816
	2	94	31	75.2		23	1730	

The results have demonstrated relatively higher germination (82-85%) and vigor (1750-1958) for GSD-dried paddy compared with sun-dried (1730-1901) paddy. This was probably attributed to non-uniform drying and high-temperature pockets in paddy depth of spread during sun drying. Drying seeds at a high temperature may induce damage, including stress cracks, which lowers germination and destroys specific enzymes[12];[8].

3.1.1.3.4. Aflatoxin contamination

Results on aflatoxin contamination are presented in Table 5.

Table 5. Average aflatoxin contamination in milled rice

Drying structure	Aflatoxin levels(ppb)
Tarpaulin	11
GSD1	4.8
GSD2	2.3

Sun-dried paddy was contaminated with aflatoxin at the level of 11 ppb compared with 5 ppb for paddy dried in GSDs. The relatively higher levels of aflatoxin in sun-dried paddy were an indication of probable contamination with soil debris [5]. However, the values of the aflatoxin observed in the GSD1 and GSD2 were below the recommended value of 20 ppb set by FAO for human food[7]. Therefore, using GrainSafe units for drying resulted in safe food for human consumption.

3.2. Combined drying and storage

3.2.1. Temperature and relative humidity of storage room

In this study, it was important to monitor temperature and relative humidity during storage as factors that affect storage performance including the quality of grain. The temperature and relative humidity of the storage room were measured and recorded from the beginning to the end of the experiment (Fig.5).

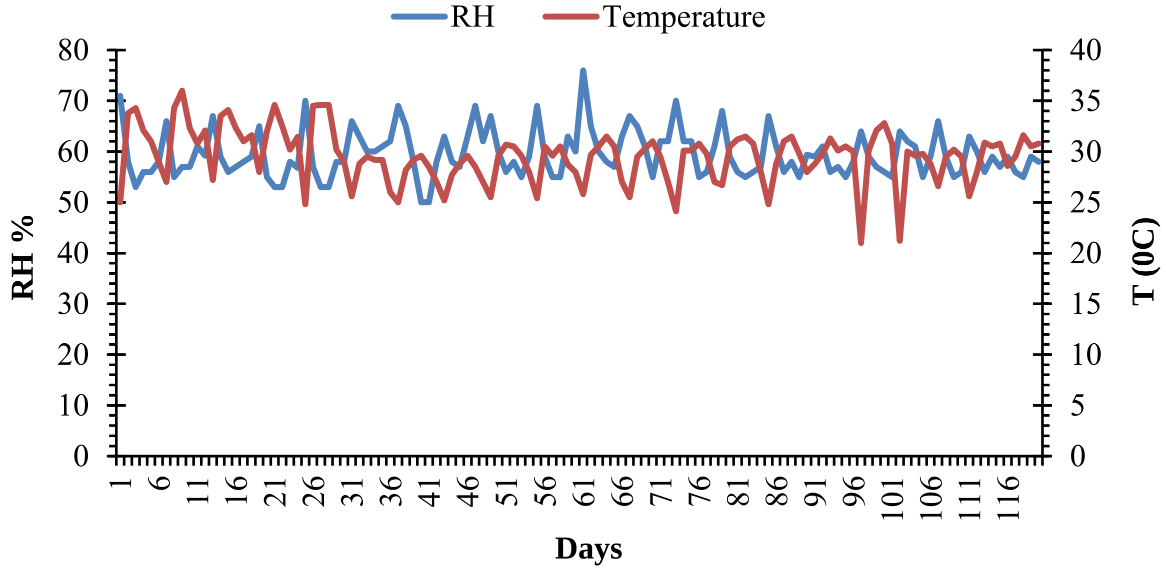

Fig.5.Temperature and relative humidity of storage room

The average daily temperature and relative humidity during storage were 24.8°C to 34.5 °C and 55% to 97%, respectively. High grain temperatures along with excessively broken kernels interact, providing the necessary conditions for stored-grain insect reproduction and survival. The most favourable grain temperature for insects is about 27°C [3]. At temperatures above 35°C or below 15°C, the

reproduction of insects is almost nil, developmental time is extended, and survival time is reduced [3]. Normally, relative humidity affects the rate of population increase of insects less dramatically.
However, up to 70 per cent relative humidity, there may be a progressive increase in insect multiplication and beyond 70 per cent relative humidity, mould formation sets in. Such moulds may be associated with the production of aflatoxin and affect the stored product quality. On the other hand, low moisture content coupled with low humidity will provide protection against insect infestation [3]. In this study, the recorded average temperature and relative humidity of the storage room gave favourable conditions for completing the life cycle of different stored grain insects in sacks. As GSD is a hermetic storage technology, the stored paddy was not influenced by the ambient air temperature and relative humidity.

3.2.2. Moisture content of stored paddy

The changes in moisture content of paddy stored for four months in polypropylene sacks and GSDs are presented in Fig. 6. It was observed that there was no effect on the moisture content of sun-dried paddy due to use of sacks but for paddy dried in the split drying-storage unit (GSD1) and stored in the same type of sacks percentage moisture content increased by 2.2, slightly higher than the same paddy (1.6) that remained stored in the same unit. The increment in moisture content in the in-storage unit GSD was about 1.5. During the storage period, relative humidity fluctuated between 56 and 80% while room temperature ranged from 21 to 34 degrees centigrade.

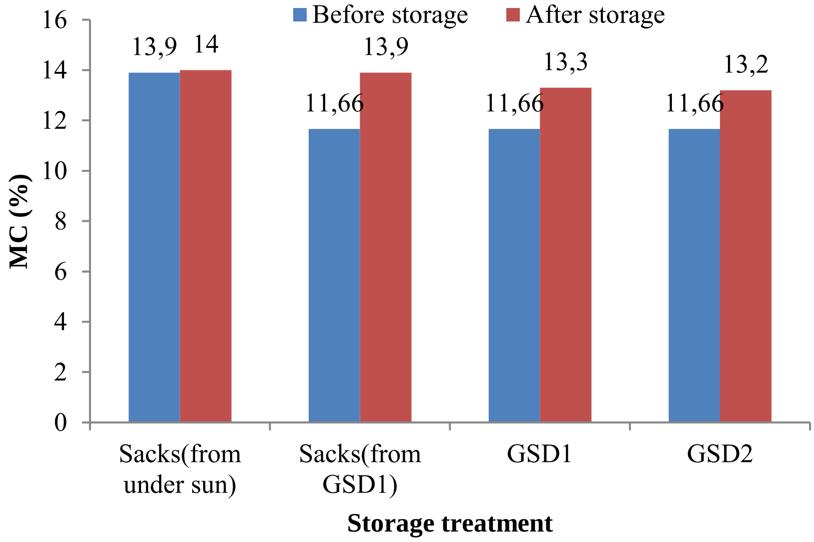

Fig.6. Changes of moisture content over storage period

Moreover, for all storage treatments, final moisture content ranged between 13.2 and 14%, having increased from 11.7% for GrainSafe dried paddy and almost no change for the sun-dried paddy. The reason for this behavior could be that the grain stored in GSDs was still thriving to achieve equilibrium moisture content, which appears to be about 14% w.b., which was attained by sun drying under ambient conditions. The most favorable grain moisture range for stored-grain insects is 12% to 18% [16]. This implies that GSD-stored paddy could also be attacked by insects if a sufficient amount of oxygen were available but nevertheless storage gas composition experiments were not conducted. Moreover, such insects may proliferate more on mold-damaged grain but this was not observed in the current study.

3.2.3. Losses of paddy after storage

Paddy stored four months after sun drying displayed the highest storage loss, followed by GSD1 dried and stored in sacks, in-situ drying and storage in GSD2, and the minimum was for GSD1 and split-drying and storage (Table 6).

Table 6. Losses after storage in GSDs and sacks

Structure	Wti (kg)	MCi (%)	Wtf (kg)	MCf (%)	Wtf14% (kg)	Wtl14% (kg)	Storage loss (%)
Stored in sacks from sun drying	289	13.9	276	14	276.3	12.6	4.5
Stored in GSD1	812	11.66	810	13.2	811.8	0.2	0.24
Stored in sacks from GSD1	465	11.66	415	13.9	419.8	45.2	1.1
Stored GSD2	465	11.66	460	13.3	461.1	3.9	1.07

Key words:Wti = initial weight (kg), MCi = Initial moisture content, Wtf = Finial weight, MCf = Final moisture content, Wtf 14%= Final weight at 14%, Wtl Weight loss at 14%.

In another study, [10] reported a 5-10% loss in traditional open storage and a 1-2% loss in mechanized storage. However, such losses may be regarded as moisture loss in the mechanism of attaining equilibrium unless physical losses were vividly observed. Since the entire storage treatments paddy reached equilibrium moisture content it may imply that the use of GSDs for drying followed by storage in the same unit was better than the use of any other drying means followed by conventional storage in sacks. However, the use of GSDs for drying gave relatively better storage results even when traditional sacks were used.

3.2.4. Grain quality after storage

3.2.4.1.Mill recovery after storage

The results for milling recovery reflecting the effects of both drying and storage are presented in Table 7. It is shown that paddy stored in GSD2 registered higher mill recovery (71.2%) followed by GSD1 (70%). The lowest recovery (63.6%) was for the sun-dried and sack-stored paddy.

Table 7.Evaluation of mill recovery after drying

Material	Mean
Sacks (Under sun)	63.60a
Sacks (GSD1)	69.60ab
Stored in GSD1	70.00b
Stored GSD2	71.20b

Milling recovery for sun-dried and sack-stored paddy was a significant difference ($p<0.05$) than GSD stored paddy. However, drying in GSD followed by sack storage also gave slightly lower milling recovery. This could be due to the easiness of moisture reabsorption in sacks. In another study, it was found that storage in sacks can lead to insect infestation which may aggravate moisture reabsorption which causes the rice kernel to fissure [19].

3.2.4.2.Head rice yield

Whole rice grains are referred to as head rice and are considered good quality rice, while small broken grains are considered as bad quality rice. Milling after storage was done to evaluate the grain quality and the results are presented in Table 8. It is shown that paddy stored in GSDs (approximately 70-74%) had good head rice than paddy stored in sacks (65-68%) irrespective of drying means.

Table 8. Head rice yield

	Head rice				Broken rice		
Material	**Mean**	**LSD**	**P-Value**	**Material**	**Mean**	**LSD**	**P-value**
Sacks(Under sun)	65.40a	12.2	0.535	Sacks(Under sun)	39.60a	12.17	0.525
Sacks(GSD1)	67.80a			Sacks(GSD1)	37.20a		
Stored in GSD1	69.78a			Stored in GSD1	31.16a		
Stored GSD2	73.74a			Stored GSD2	35.22a		

It is shown that paddy stored in GSDs (approximately 70-74%) had good head rice than paddy stored in sacks (65-68%) irrespective of drying means. However, there was no significant difference ($p<0.525$) between paddy stored in GSDs and in sacks due to the same conditions of storage relative humidity and temperature. This was probably attributed to moisture re-absorption in the course of storage for four months. Moreover, other factors such as milling set-up may have contributed to affecting all the storage treatments equally.

3.2.4.3.Germination test after storage

The results on germination rate and vigor of stored paddy seeds reflecting the drying history are presented in Table 9. It is shown that the germination rate of sun-dried paddy was slightly lower (92-93%) than that for paddy dried in GSD units (94-95%). The same trend was displayed in the vigor index values.

Table 9. Germination test after storage

	Trial	Number of seeds germinated	Dead seeds	Germination rate, %	Average rate, %	Seedling length, cm	Vigour index	Average of index
GSD1	1	117	8	93.6	94	24	2246	2162
	2	118	7	94.4		22	2077	
GSD1(Stored in sacks)	1	116	9	92.8	94	23	2134	2210
	2	119	6	95.2		24	2285	
GSD2	Top	118	7	94.4	94.9	23	2183	2158
	Middle	119	6	95.2		24	2285	
	Bottom	119	6	95.2		21	2005	
Sun drying(stored in sacks)	1	115	10	92	92.8	20	1840	1987
	2	117	8	93		19	2134	

Note: GSD is GrainSafe Dryer

It is also shown that storage of the GSD-dried paddy in sacks did not affect the germination rate and vigor index of the paddy that remained stored in the GSD.

As the germination test was done to find out which means of storage is better than others in conserving seed viability, the use of GSDs resulted in a good performance. The slightly reduced germination due to storage in sacks could be attributed to moisture re-absorption by paddy seeds in combination with high temperature. Seed viability is mostly affected by the combination of high moisture content and temperature [3]. [17] reported that the duration of storage has a profound effect on paddy storage in terms of decreased bulk density and germination percentage. This loss is more pronounced in bag storage as compared to silo storage[17].

3.2.4.4.Aflatoxin contamination

The results for dying and storage combinations on aflatoxin contamination of the milled rice are presented in Table 10.

Table 10.Aflatoxin contamination after storage

Storage Structure	Aflatoxin levels(ppb)
Sacks (Under sun)	12
SD1(in sacks)	5.8
GSD1	2.3
GSD2	2.3

Note: GSD is GrainSafe Dryer

As storage in sacks gave the highest aflatoxin levels compared with storage in GSDs, it would appear that an increase in aflatoxin is possible if storage in sacks is done for extended periods, especially in humid climates. In another study, [17] reported that fungal incidences were found to be high in jute bags and polylines jute bags. These findings raise concerns about the use of sacks for storage even where drying was adequately done.

3.2.4.5.Insect infestation

The results on the insect's infestation are presented in Table 11.

Table 11. Insect infestation

Storage structure	Numbers of insect per 250 gr
Sacks	10
Sacks(GSD1)	9
GSD1	0
GSD2	0

Note: GSD is GrainSafe Dryer

In this study, insect infestation was influenced by the different storage technologies. More insects were found in paddy stored in *sacks* while no insects were found in hermetic storage (GSD). This was attributed to the reduction of O_2 and increasing CO_2 concentrations due to the metabolism of the stored paddy, live insects, and other aerobic organisms inside the sealed container which also led to their own death. In another study, [18] reported that the low permeability of the hermetic structures also maintains safe constant moisture levels in the stored product regardless of ambient exterior humidity.

4. Conclusion

The GrainSafe hermetic storage technology was successfully tested for use as both a dryer and a storage unit. The quality attributes of paddy dried in the GrainSafe Dryer were better than in sundried paddy. It is recommended that this method should undergo further testing in other geographical areas before wider dissemination is done.

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