DRYING OF PADDYUNDER HERMETIC STORAGE CONDITIONS IN BURUNDI

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN POST HARVEST TECHNOLOGY AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2022

EXTENDED ABSTRACT

This study assessed the extent to which rice producers from Kidwebeziirrigation scheme could know their productivity loss during post-harvest activities and assessed the performance of drying and storing paddy in Grain Safe Dryer. To achieve these objectives, first simple random sampling was used to select 147 rice farmers in the study area. The collected data were subjected to analysis where output responsiveness with respect to each of the inputs, technical, allocation and economic efficiencies was estimated. Statistical Package for Social Sciences (SPSS) analysis was used to estimate the perception of paddy loss during post-harvest activities. The study further assessed factors affecting loss levels among rice producers. Grain Safe Dryers were installed to assess the performance during drying and storage of paddy. The study applied GENSTAT to analyse the data from using Grain Safe Dryer to dry and store paddy. Findings of this study reveal that the paddy lost during post-harvest activities were between 0 and 9%.Furthermore, the results show that the major factor affecting post-harvest losses in the study area was the material used in post-harvest activities. The study showed that the Grain Safe Dryer had high drying performance comparing to the sun dried paddy. Moisture contents of dried paddy were varied in sun drying and in the two Grain Safe Dryer units with the changes in atmospheric conditions. The initial moisture content was 25.3%, which decreased until it all reached 11.7% (in 19 days) in Grain Safe Dryers and 13.9% (in 3days) under sun drying. In case of germination percentage it was found to be higher (85.2%) in Grain Safe Dryer compared to sun drying (80.8%). Quality of rice after milling was found to be better (80%) in Grain Safe Dryer than sun drying (30%).On the other hand, seeds handled in Grain Safe Dryers gave higher germination rate and quality due to moisture content removed slowly during drying compared to sun drying. However, in terms of moisture removed, good quality, and germination percentage in Grain Safe Dryers were better compared to the sun dried paddy. However, it is recommended to carry more studies on Grain Safe Dryer to be assessed in different ecological zones before wider dissemination of the hermetic storage system for use as a dryer.

DECLARATION

I, Dionise Ahishakiye, do hereby declare to Senate of Sokoine University of Agriculture, that this dissertation is my original work done within the registration period and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

________________________ ______________

Dionise Ahishakiye Date

(MSc. Post-Harvest Technology and Management Candidate)

The above declaration is confirmed by;

________________________ ______________

Prof. V. C. K. Silayo Date

(Supervisor)

________________________ ______________

Dr. Gummert Martin Date

(Supervisor)

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ACKNOWLEDGEMENTS

All praises to Almighty God and Jesus Christ My Lord and Savior to have protected me. This study would not have been accomplished without the technical and moral assistance from many persons. I wish therefore to express my sincere gratitude to a number of persons who contributed to the success of this work.

To mention only few of them, I express profound gratitude to my supervisor, Prof. V.C.K. Silayo of School of Engineering and Technology, Department of Food Science and Agro-processing, Sokoine University of Agriculture for his professional comments, wise guidance and constructive advices throughout my research.

Special thanks go to Ministry of Environment, Agriculture and Livestock and International Rice Research Institute (IRRI) Burundi for the full scholarship grant, without which I could not be able to pursue the MSc. Program at Sokoine University of Agriculture. I extend my thanks to Dr. Martin Gummert, Co-supervisor based in IRRI Philippine, for his guidance through numerous issues on technical aspect.

Lastly my deep appreciation goes to the smallholder rice producers in Kidwebezi irrigation schemes and their association leaders for their cooperation during the entire period of data collection. I remain solely responsible for any error in content or in design inherent in this dissertation.

DEDICATION

This dissertation is dedicated to my beloved wife Evelyne Shimirimana, my daughter Anny Briella Ikezwe and my son Jean Hervé Ahishakiye for their sincere love and patience while I was away from home.

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Paper II

Ahishakiye, D., Silayo V.C.K., and Gummert, M. (2022).Evaluation of the performance of Grain Safe hermetic storage system for drying and storage. *International Journal of Agriculture.*

ABBREVIATIONS AND ACRONYMS

%	Percentage
Ah	Ampere hour
ANOVA	Analysis of Variance
BIF	Burundian Franc
DC	Direct Current
EAC	East Africa Community
FAO	Food and Agriculture Organization
FAOSTAT	Statistics- Food and Agriculture Organization
Genstat	General Statistic
GSD	Grain Safe Dryer
IRRI	International Research Institute
ISTA	International Seed Test Association
^{o}C	Celsius degree
PHL	Post-Harvest Losses
PVC	Polyvinyl chloride
SPSS	Statistical Package for Social Sciences
SSA	Sub-Sahara Africa
V	Volt

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Rice (*Oryzasativa* L.) is a staple food consumed by over half of the world's population. In 2018, the total world production of paddy was about782 million metric tonnes(FAOSTAT, 2018). Milled rice production in the East African Countries increased from just under one million tonnes in 2005 to 1.8 million tonnes in 2014 (Ghins *et al.*, 2017). During this period Tanzania accounted for around 83 percent of production, Uganda 9 percent and Kenya, Burundi and Rwanda less than 5 percent each (Ghins *et al.*, 2017).

In Burundi, paddy is among the important crops for income generation for both the households and the rural merchants (Baramburiye, 2010). However, paddy production is reduced by losses that occur due to inadequate post-harvest operations. Among these, inadequate drying and storage operations contribute greatly to postharvest losses. The paddy post-harvest system requires improvement where the use of resources for research and development, particularly with regard to the level of post-harvest losses is unavoidable**.** Post-harvest losses (PHL) are high for different crops, but are of particular concern for grains, especially cereals and pulses, which form the base for food and income of the majority. Estimates of the postharvest losses of food grains in the developing world from mishandling, spoilage and pest infestation are estimated at 25% (Sadiya and Hassan, 2018); this means that one-quarter of what is produced never reaches the consumer for whom it was grown, and the efforts and money spent in production are lost-forever. However, estimates of quantitative losses eventually give a broad picture of where the losses are occurring, their relative scale and how a specific crop has been handled during the post-harvest operations. The drying and storage losses of paddy range from 10 to 20 percent(Sadiya and Hassan, 2018).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 (Hodges *et al.*, 2011). PHL refers to measurable quantitative and qualitative food loss in the postharvest system (de Lucia and Assennato, 1994). This system comprises interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food. Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries (Kader, 2002). Quantity losses refer to those that result in the loss of the amount of a product. Loss of quantity is more common in developing countries (Kitinoja and Gorny, 2010). A recent FAO report indicates that at global level, volumes of lost and wasted food in high income regions are higher in downstream phases of the food chain, but just the opposite in low-income regions where more food is lost and wasted in upstream phases (FAO, 2013). Postharvest losses in food crops occurring during harvesting, threshing, drying, processing, storage, transportation, etc. have been estimated to claim between 30 and 40% of the expected output (Sadiya and Hassan, 2018).Most farmers in Africa, both small and large, rely almost exclusively on natural drying of crops by combining sunshine and movement of atmospheric air through the product; consequently, damp weather at harvest time can be a serious cause of postharvest losses (De Lima, 1982). Grains should be dried in such a manner that damage to the grain is minimized and moisture levels are lower than those required to support mold growth during storage (usually below 13-15%). This is necessary to prevent further growth of fungal species that may be present on fresh grains. The harvested crop may be dried in the yard or in a crib. Post-harvest losses at storage are associated with both poor storage conditions and lack of storage capacity. It is important that stores be constructed in such a way as to provide: dry, well-vented conditions allowing further drying in case of limited opportunities for complete drying prior to storage; protection from rain and drainage of ground water; and protection from entry of rodents and birds and minimum temperature fluctuations.

1.2 Problem Statement

Post-harvest losses of paddy grain occur at both on farm and off farm levels (Appiah *et al*., 2011). These losses take place at every step from harvesting to consumption and ultimately lead to reduced quality and availability. Farmers have been using the traditional sun drying method to dry paddy. Despite some advantages of this method, its application is limited due to unpredictable changes of weather. Moreover, in areas with low solar radiation intensity sun drying may need to be prolonged in order for the crop to attain the required moisture content of 12-16% wet basis. The prolonged exposure of grain to atmospheric factors during sun drying may lead to high probability of contamination due to dust and other extraneous matter, pest (rodents, birds, insects, mould, etc) attack, quantitative loss due to inappropriate handling and reduced grain quality due to temperature variations in the grain bulk. Furthermore, high humidity and occurrence of rain may heighten qualitative loss. Use of in-bin hot-air drying technology is a solution to bulky drying but the technology is relatively expensive in terms of energy and capital investment required. In addition, supply of electricity as an important energy for heating the drying air may be erratic or not available. The technology that is also used to dry bulk grain is the near ambient drying, which is a form of in-storage drying, but is also capital intensive in terms of structural work and high level of instrumentation required. Innovative use of hermetic structures for drying can replace sun drying in the open environment and the conventional hot-air drying systems. De Groote *et al*. (2013) investigated the use of the hermetic systems in controlling maize storage pests in Kenya. However, there is limited information about drying with hermetic storage system to achieve adequate drying and minimize postharvest losses. Therefore, adoption of hermetic storage systems in combination with drying is an important area targeted by this study.

1.3 Justification

In Burundi, paddy is a commercial crop, which can be cultivated in marshlands during rainy seasons (Rufyikiri, 2012). Combined drying and storage in the same structure wasallowed for day and night-time continuous drying while at the same time protect the grain against bad weather. This may lead to reduced post-harvest losses which would have occurred during sun drying. Among the promising technologies was the Grain Safe, which is a commercial hermetic storage technology for controlling conditions which support the growth *A. flavus* and *A. parasiticus* for safer and healthier food (Villers *et al*., 2010). It's used as both a dryer and a storage system combination structure should reduce labour cost and minimize the postharvest losses of paddy that usually occur while transferring dry paddy from a dryer to a storage system. Moreover, technical information on the performance of the Grain Safe when used as a dryer in comparison with sun drying was obtained. Therefore, in this study the potentials of adapting the Grain Safe for drying paddy in Burundi would be revealed. The information gain from the study will be useful to farmers, researchers, policy makers and other stakeholders in similar areas for adoption.

1.4 Objectives of the Study

1.4.1 Overall objective

The overall objective of this study was to assess the effects of drying in hermetic storage systems on post-harvest losses of paddy in Burundi.

1.4.2 Specific objectives

i. To assess farmers' perception of paddy post-harvest losses.
ii. To evaluate performance of the Grain Safe hermetic storage system for drying and storage of paddy.
iii. To assess the cost-benefit of using the Grain Safe for drying and storage.

1.5 Materials and Methods

1.5.1 Study site

A Survey on farmers' perception and knowledge of post-harvest losses of rice was carried out at Kidwebezi irrigation scheme in Mpanda District located west of Burundi. A semi structured questionnaire was used to collect data. The experimental study 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).

1.5.2 Data collection

Data was collected through administering a structured questionnaire which comprised of open and close-ended questions; key informant interviews were also done. The following key information was collected from the respondents. During drying moisture content was measured at two-hour intervals. Samples were randomly taken from milled from each paddy drying units (Grain Safe Dryers) to assess the performance of drying units and storage structures. Each sample was sorted into head rice and total grain, and weighed for paddy dried and stored. Germination test was conducted for samples drawn from Grain Safe Dryers and sun dried at the end of the set drying and storage period.

1.5.3 Data analysis

Collected data for objective one was coded and subjected to statistical Package for Social Sciences (SPSS) software version 16 using Descriptive Statistics. The collected data on objective two were subjected to one way Analysis of Variance (ANOVA) using Genstat® 15th edition computer software. Duncan's multiple range tests was used to establish the multiple comparisons of mean values at 5% significant level. For objective three the computed cost-benefit ratio (CBR) value was interpreted based on: 'CBR' < 1, as a project that is not economically viable and 'CBR' ≥ 1 as a project that is viable in terms of economic efficiency.

1.6 Organisation of the Dissertation

This dissertation is developed in publishable manuscripts format consisting of four chapters. Chapter one is a general introduction and justification, chapter two and three consisted of manuscripts in the form of publishable papers. Chapter four is the general conclusions and recommendations. Parts of chapter two and three will be published as follows:

Paper I

Ahishakiye, D., Silayo, V.C.K., and Gummert, M. (2022).Assessment of farmers' perception on paddy postharvest losses in Kidwebezi irrigation scheme in Burundi. *International Journal of Biosciences*.

Paper II

Ahishakiye, D., Silayo V.C.K., and Gummert, M. (2022).Evaluation of the performance of Grain Safe hermetic storage system for drying and storage. *International Journal of Agriculture*.

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CHAPTER TWO

2.0 ASSESSMENT OF FARMERS' PERCEPTION ON PADDY POSTHARVEST LOSSES IN KIDWEBEZI IRRIGATION SCHEME IN BURUNDI

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2.1 Abstract

Postharvest losses of paddy occur at both on-farm and off-farm levels. This study was carried out to help gather information on rice postharvest losses at Mpanda District in Bubanza Province due to inadequate postharvest practices. A survey questionnaire was administered to 147 farmers in the Kidebwezi rice producers' association. Typically, they were characterized by 0-3 acres of land holding, an age range of 20-60 years by the majority (71.7%), more than 20 years of farming experience for a good number (53.7%) of them, and mainly (71%) producing in one season. They were dominated by male (84.4%) farmers. The study revealed that the majority (71%) of the farmers experienced postharvest losses ranging between 0 and 9% where farmers (58.5%) considered it to be high. It was also reported that the low quality of the milled rice was attributed to low head rice, broken rice, purity, and discoloration often leading to variation in pricing. The majority (62.6%) reported post-harvest losses (PHL) to mostly occur during drying. The PHL is significant in the scheme, which is for interventions to improve drying. However, paddy production is reduced by losses that occur due to inadequate post-harvest operations. Among these, inadequate drying and storage operations contribute greatly to postharvest losses. The findings of this study may assist in carrying out suitable post-harvest interventions by the government and scheme members. Further, studies are recommended in other rice production areas for more informed policy-making.

Keywords: Paddy drying, quantitative losses, milling quality, interventions.

2.2 Introduction

Paddy rice production in Sub-Sahara Africa (SSA) in 2018 was estimated at 26.5 million tons from a total of 11.95 million hectare of harvested area (IRRI, 2020). This quantity did not reach the table of consumers due to PHL that can be subdivided into quantitative (weight) and qualitative (value) loss. Quantitative PHL in grains is estimated at 17%, but significant differences exist between directly measured losses and estimates obtained by interviews (Prusky, 2011, Minten *et al.*, 2020), demonstrating the poor knowledge of actual losses by value chain actors. Some estimates for average losses in East and Southern Africa, for instance, put Postharvest losses for grains at 10-20 per cent (in terms of weight loss), with some regions reaching as high as 25-35 per cent (Prusky, 2011, Minten *et al.*, 2020). In South and Southeast Asia, rice physical losses are 10–25% and quality losses can discount prices by up to 30 per cent (Gummert, 2013; Manners-Bell and Miroux, 2013; FAO, 2011). More previous extensive studies suggested that about 15 per cent of grain may be lost in the postharvest system (Liang *et al.,* 1993; Parfitt *et al.,* 2010). Liang *et al.* (2015) estimated rice losses in China at 5%–23% (excluding processing) while in Vietnam at 10%–25% under typical conditions and 40%–80% under extreme conditions of inadequacy in storage facilities, high temperature and humidity (Stuart, 2011). Most of the PHL estimation research has focused on quantitative loss with complete neglect of qualitative loss which makes the reported estimates incomplete (Prusky, 2011). In addition, PHL estimation on rice has mostly been done in Asia although rice is also an important staple crop widely cultivated in Africa. PHL refers to measurable quantitative and qualitative food loss in the postharvest system (de Lucia and Assennato, 1994). This system comprises interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food.

Quality losses include those that affect the nutrient/caloric composition, the acceptability, and the edibility of a given product. These losses are generally more common in developed countries (Kader, 2002). Quantity losses refer to those that result in the loss of the amount of a product. It has been reported that about 9 percent of paddy is lost due to use of old and outdate methods of drying and milling, improper and unscientific methods of storage, transport and handling. It has been estimated that total postharvest losses of paddy at producers' level was about 2.71 percent of total production (Patil, 2011). To minimise postharvest losses, precautions should be taken to follow proper postharvest practises. They include timely harvest at optimum moisture percentage (20 percent to 22 percent) (Patil, 2011), use of proper method of harvesting; avoid excessive drying, fast drying and rewetting of grains. Ensure drying of wet grain after harvest, preferably within 24 hours to avoid heat accumulation, uniform drying to avoid hot and wet spots and mechanical damage due to handling. The losses in threshing and winnowing can be avoided using better mechanical methods. Proper sanitation during drying, milling and after milling to avoid contamination of grains and protect from insects, rodents and birds and use of proper technique of processing i.e. cleaning, parboiling and milling helps in reduction in postharvest losses. To avoid storage losses maintaining optimum moisture content i.e. 12 percent for longer period and 14percent for shorter storage period is essential (Patil, 2011).

Efforts to identify and resolve postharvest issues along the rice value chains in many SSA countries are impeded by the lack of a simple, adoptable and well-defined practical methodology for estimating PHL. Rice yield gap in Africa is estimated at 5.8 t/hm^2(Africa Development Bank, 2016) and the causes of this difference between the actual farm yield and yield under best practice have been well documented (Tanaka *et al.,* 2015). There is, however, a need to reduce current knowledge deficits and improve our understanding of postharvest practices and losses in SSA. This will require an understanding of the point of losses, their magnitude and factors affecting those losses. These losses take place at every step from harvesting to consumption and ultimately lead to reduced quality and availability. These problems can be minimized by carrying out appropriate postharvest interventions. However, such interventions will require sufficient information on precise postharvest losses, the nature of the losses, and where most of losses occur along the production chain.

2.3 Materials and Methods

2.3.1 Study area

This study was conducted on the farmers of the Kidwebezi irrigation scheme located in Mpanda District, northwest of Burundi. It has a command area of 83 ha shared by 238 farmers within the Kidwebezi producer association. It is located at latitude 3011'60" South and longitude 29023'59" East (Figure 2.1). Kidwebezi irrigation scheme was selected as the area of interest for the study for two reasons. First, it is located in the plains of Imbo where the bulk of rice is produced in Burundi, involving 238 farmers. Therefore studying the efficiency of the rice sector using the highest production schemes as an empirical basis shades light and provide insights useful for research, policy, and practice. Second, the scheme offers the advantage of being well organized in such a way that farmers keep a record of rice farming activities. Therefore, data on rice production in the Kidwebezi irrigation scheme is realistic and will be updated with results from this study.

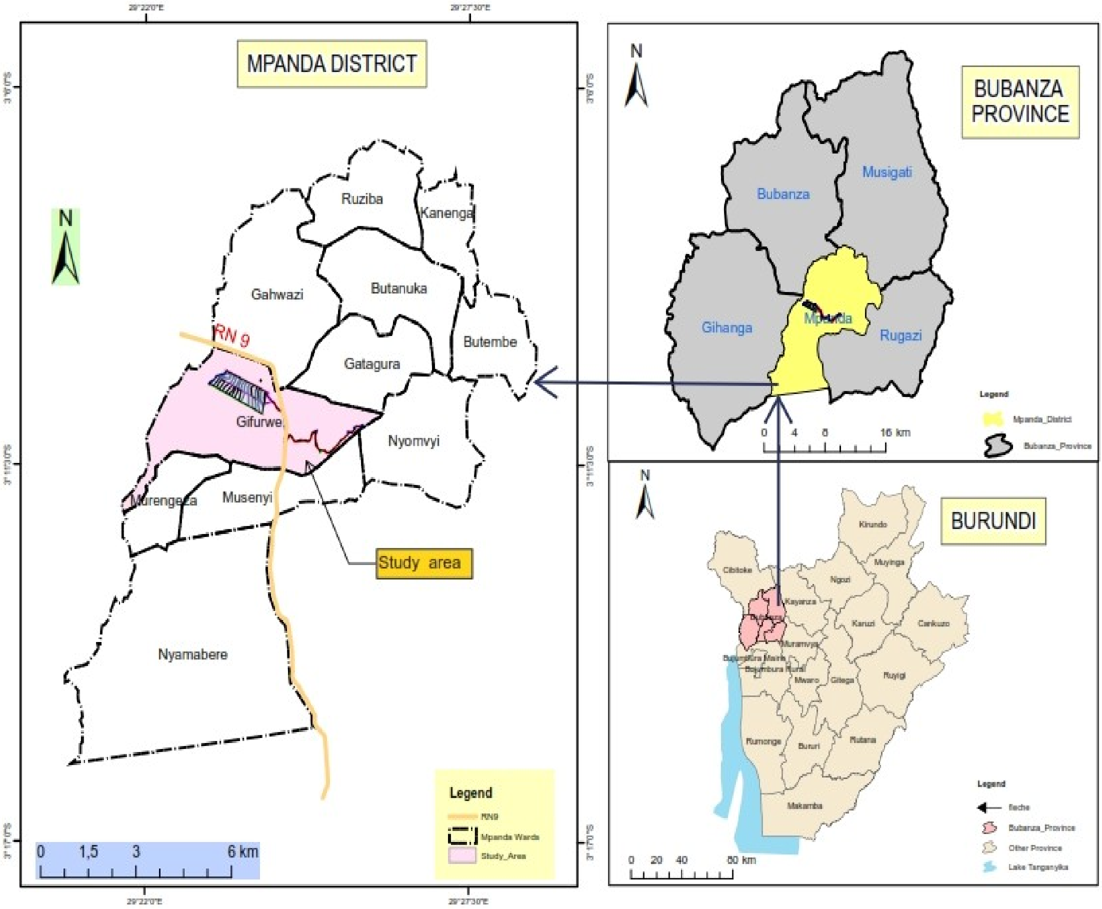

Figure 2.1: Location map of Mpanda District showings the study area

2.3.2 Assessment of farmers’ perception on paddy postharvest losses

A Survey on farmers’ perception and knowledge about post-harvest losses of rice was carried out at Mpanda District using a semi-structured questionnaire. The semi-structured questionnaire was administered to one hundred forty-seven rice farmers in the Kidwebezi irrigation scheme which constitute the rice farming community in Bubanza Province. The aim of the survey was to gather information on postharvest losses from the rice farmers and at which stages they experienced most of the post-harvest losses. Information on farmers’ perceptions of methods of reducing postharvest losses was also collected.

2.3.2.1 Sampling design

Given that the total number of rice farmers in the scheme is known (N = 238), the targeted population is finite and hence the sample size was determined by applying the standard method as proposed by Krejcie and Morgan (1970) as follows:

$$n ¿ \frac{x^2 * N * p * q}{d^2 * (N-1) + x^2 * p * q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

(1)

Where n = sample size, χ2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (at 95% confidence level, χ2 = 3.8416≈ 3.84), N = total number of farmers, p = population proportion considered to be 0.5 to provide maximum sample size, q = (1-p) = 0.5 and, d = degree of accuracy expressed as a proportion (d = 0.05). By applying the formula above, the sample size for the study was 147 rice farmers.

The list of all farmers in the scheme was obtained from the Mpanda Rice Farmers' Association. The sample frame was therefore obtained by arranging alphabetically names of all rice producers. Having arranged all 238 rice producers in alphabetical order, simple random sampling was applied to constitute the sample. As such, the sampling interval was given as the ratio of the total number of farmers to the sample size (238/147), which is 2. Hence each 2nd farmer was selected to be interviewed.

2.3.2.2 Data collection

Data were collected by administering a structured questionnaire comprised of open and close-ended questions; key informant interviews were also done (Appendix1). The following key information was collected from the respondents: Experience in growing rice, size of land, seasons per year and experience with postharvest losses, perception of paddy postharvest losses, variation in price, stage of occurrence of paddy postharvest losses, and reduction of postharvest losses.

2.3.2.3 Data analysis

Collected data were coded and subjected to statistical Package for Social Sciences (SPSS) software version 16 using Descriptive Statistics.

2.4 Results and Discussion

2.4.1 Assessment of farmers' perception on paddy postharvest losses

The survey was carried out on rice farmers at the Kidwebezi irrigation scheme in Mpanda District with the aim of gathering information on postharvest losses from the rice farmers and the stages at which they experienced substantial amounts of the losses. One hundred forty-seven (147) rice farmers in the "Kidwebezi irrigation scheme" were interviewed.

2.4.1.1 Age and gender

The age of the surveyed rice producers in the Kidwebezi irrigation scheme ranged from 20 to 71 years. Out of this, 30.1% of the farmers were aged between 20 and 39 years, 25.4% were aged between 50 and 60 years, and 22.2% were in the age range of 40 to 49 years category as shown in Figure 2.2. The surveyed farmers were dominated by males (84.4 %) compared with female farmers (15.6%) (Figure 2.3).

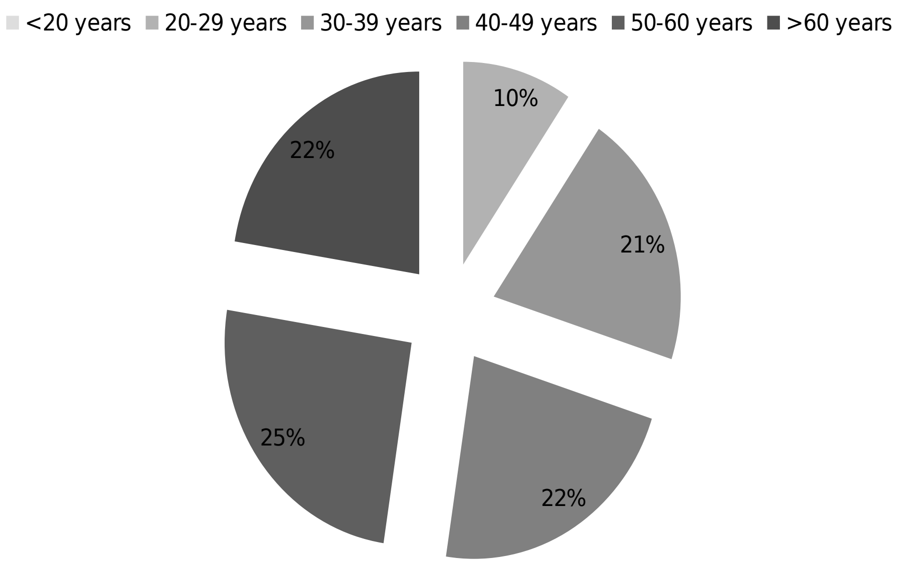

Figure 2.2: Age distribution of farmers

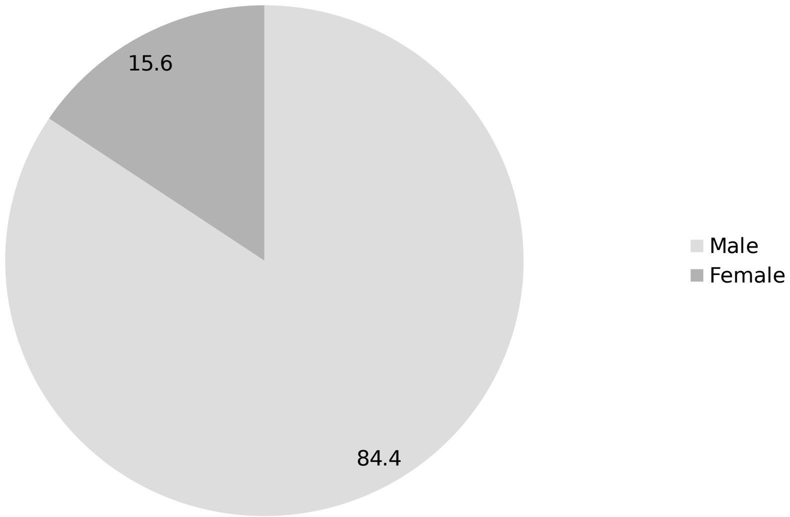

Figure 2.3: Gender distributions of farmers

Based on the results of this study, the majority of the farmers (77.9%) were the active age of 20-60 years, implying that they had different experiences with post-harvest losses. However, considering the age above 40 years to reflect long-term experience it implies that the majority of the surveyed farmers (69.9%) were experienced in rice farming and could shed light on rice postharvest losses. Since the results have shown male farmers dominate the group it is probably an indication that males are dominant in rice production and also land ownership.

2.4.1.2 Experience on growing rice in the study area

The mean farming experience of the rice farmers (Figure 2.4) in the study area was 20 years. The majority of farmers (53.74 %) had more than 20 years of experience in rice farming.

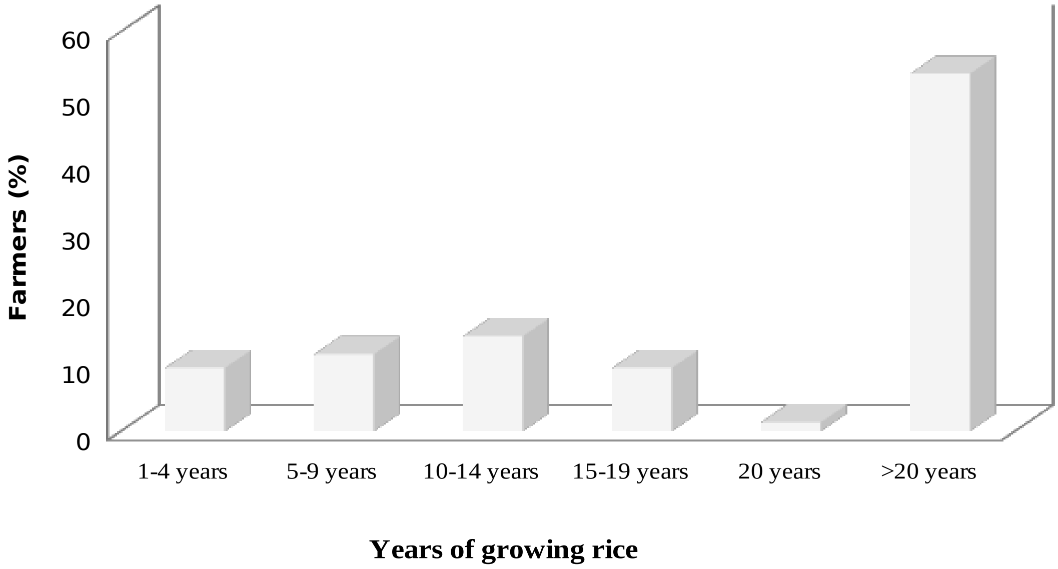

Figure 2.4: Experience on growing rice in the study area

Based on the survey results, the majority of the farmers (53.74%) have grown paddy for more than 20 years. This is a long-term experience for a farmer to be knowledgeable in the value chain including postharvest issues. Therefore, the majority of farmers in the study area have a background in postharvest losses in the value chain.

2.4.1.3 Farm size of land in the study area

Results on the size of land in the Kidwebezi irrigation scheme are presented in Figure 2.5. In the Kidwebezi irrigation scheme, the overwhelming majority of the farmers (93.8%) had 0-3 acres of land and only a few had more than 4 acres.

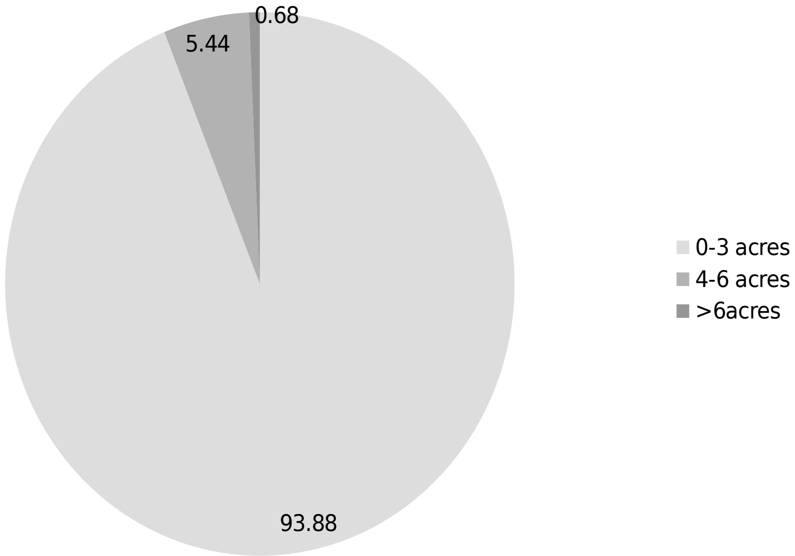

Figure 2.5: Farm land in the study area

Based on the study results, the overwhelming majority (93.8%) of the farmers own 0-3 acres of land under paddy cultivation. This means that most of the reported information on paddy postharvest losses and the efforts to curb them has been concentrated on this category of farmers. However, there is no study has been done to substantiate this.

2.4.1.4 Seasons per year and experience on post-harvest losses in the study area

The seasonal postharvest losses experienced by rice farmers in the study location are presented in Figure 2.6. It is shown that the majority of farmers (71%) produce rice in one season while a few (29 %) produce it in two seasons due to accessibility of water. Irrespective of the season all the farmers experience losses during post-harvest practices (Figure 2.6).

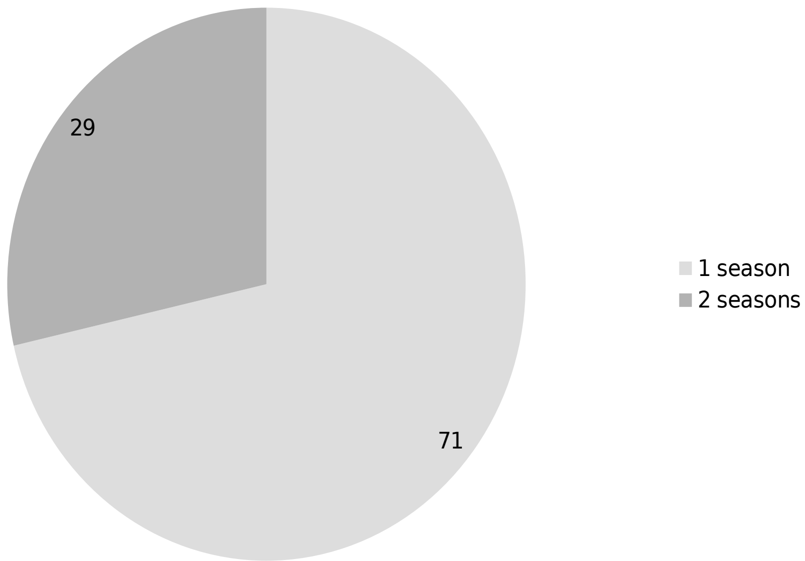

Figure 2.6: Growing rice per year in the study area

These results have shown that the majority (71.43 %) of farmers produce in one season and the remaining in two seasons. However, no apparent reasons were provided for this trend although the low production season could be a result of farming during the dry season with strict sharing of water resources. Irrespective of the seasonal occurrence of postharvest losses was reported, implying that there might be unnoticeable differences in losses due to seasons.

2.4.1.5 Perception of paddy post-harvest losses in the study area

It was observed that the majority of farmers (90.48 %) experience relatively low (0-9%) paddy post-harvest losses while a few experience losses ranging from 10 to 29% (Figure 2.7).

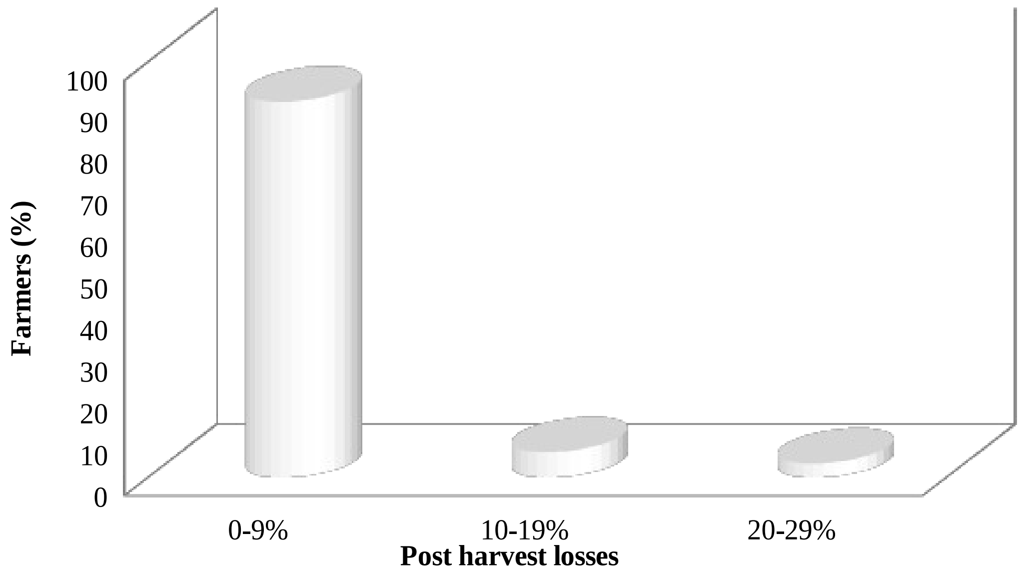

Figure 2.7: Farmer's perception of paddy post-harvest losses in the study area

However, a good number (58.5%) of farmers reiterated the incurred postharvest losses to be generally high (Figure 2.8).

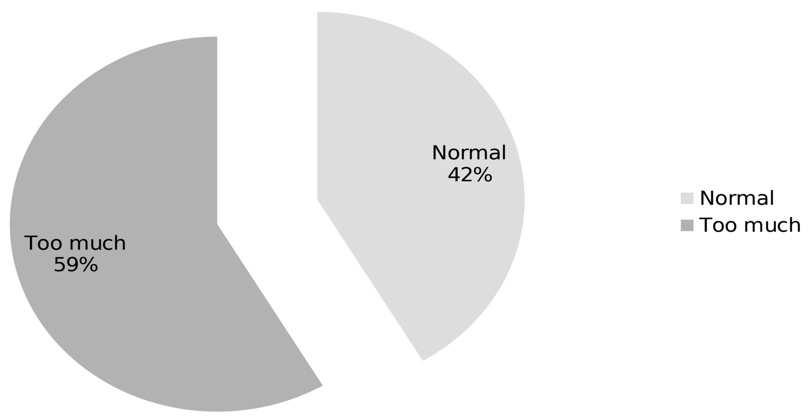

Figure 2.8: Perception of post-harvest losses of rice in general in the study area

The survey results have indicated majority (90.48%) of the farmers lost between 0 and 9% of their paddy harvested. Comparing with loss data reported from other studies the reported loss is relatively small implying that either the farmers are very keen on postharvest technology and management or they are not able to account for postharvest losses.

According to IRRI (2011), between 5 and 16 % of paddy is lost in the postharvest phase, which includes harvesting, handling, threshing, and cleaning. Some studies on average losses in East and Southern Africa (FAO, 2011), for instance, estimate postharvest losses for grains at 10-20 % (in terms of weight loss), with some regions reaching as high as 25-35 %. In South and Southeast Asia, rice physical losses are 10–25% and quality losses can discount prices by up to 30 % (Gummert, 2013; Manners-Bell and Miroux, 2013; FAO, 2011). However, some (58.73 %) indicated post-harvest losses of rice, in general, to be quite high without any quantification, which also reveals a lack of knowledge in postharvest loss assessment among them.

2.4.1.6 Variation in price of rice in the study area

The surveyed farmers indicated the quality traits that lead to a variation in rice price to be head rice, broken rice, purity, and discoloration. Besides, their reactions were a bit mixed as some (47.6 %) indicated price variation between 50 and 100 BIF, others (39.68%) reported variation between 150 and 200 BIF and the remaining few (12.92%) reported variation between 200 and 400 BIF (Figure 2.9).

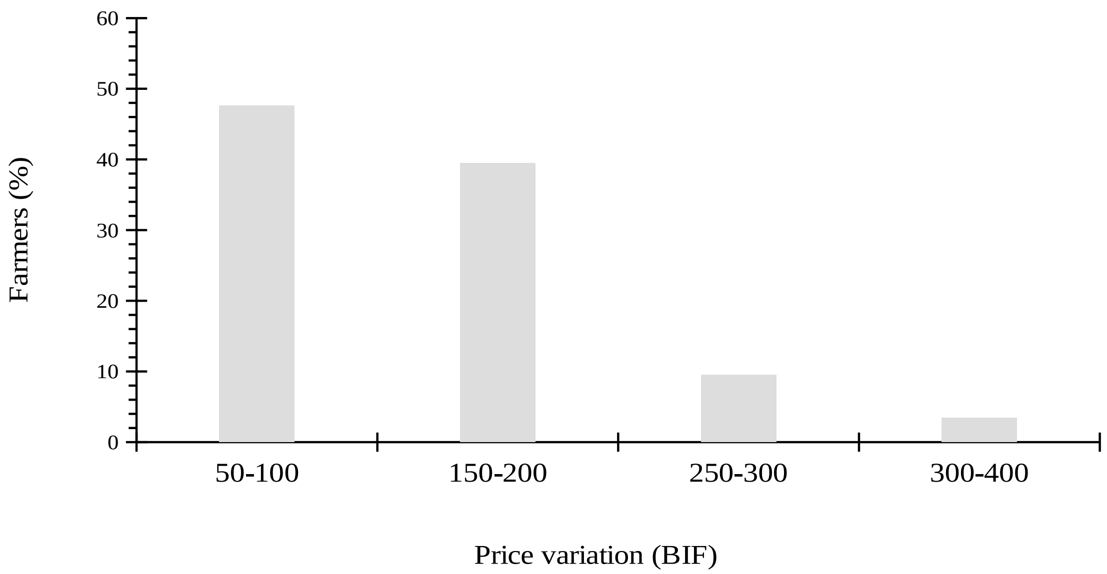

Figure 2.9: Price variation of rice in the study area

The results have reported that price variation is caused by quality traits including head rice, broken rice, impurities, and colour. Price variation in the range of 50-400 BIF was reported, the majority (47.6%) lies between 50 and 100 BIF. Although quality traits may result from agronomic and postharvest issues including milling technology, inadequate drying technology which may also be affected by the production seasons might have contributed. However, during the survey, it was difficult to distinguish quality losses between seasons.

2.4.1.7 Stages of occurrence of paddy postharvest losses in the study area

The stages of paddy postharvest losses in the study area are presented in Figure 2.10. It is shown that the majority of farmers (62.59%) incurred more postharvest losses of paddy during drying. However, a relatively small proportion of farmers indicated post-harvest losses also occur at the storage and milling stages.

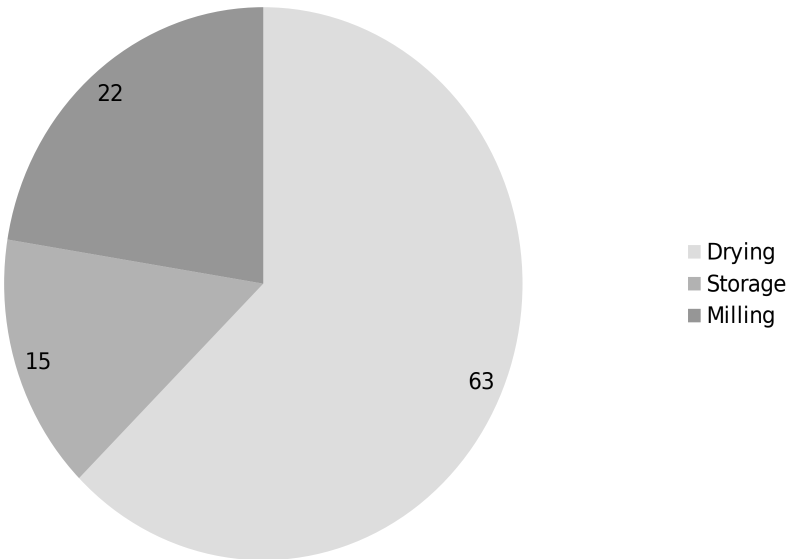

Figure 2. 10: Stage of paddy postharvest losses in the study area

Based on the results, most (62.59%) of the farmers recorded postharvest losses during sun drying. There could be several reasons for this but moving the paddy in and out responding to sunshine hours or when it rains might have contributed to losses. However, there was no distinction made between weight losses due to moisture reduction of physical losses. It was also interesting for the farmers to mention postharvest losses accruing from storage and milling, which may be difficult to give a plausible explanation for.

2.4.1.8 Reduction of postharvest losses in the study area

In the study area, farmers have shown to have different opinions with regard to the reduction of postharvest losses (Figure 2.11). The majority of the farmers (66.67%) preferred to perform drying on strong tarpaulin while some (7.48%) preferred using a concrete surface. Besides a few more (23.13%) indicated storage in strong bags as better means of curbing paddy postharvest losses. The use of conventional dryers and high-quality milling machines were the ideas contributed by an unnoticeable fraction of the farmers.

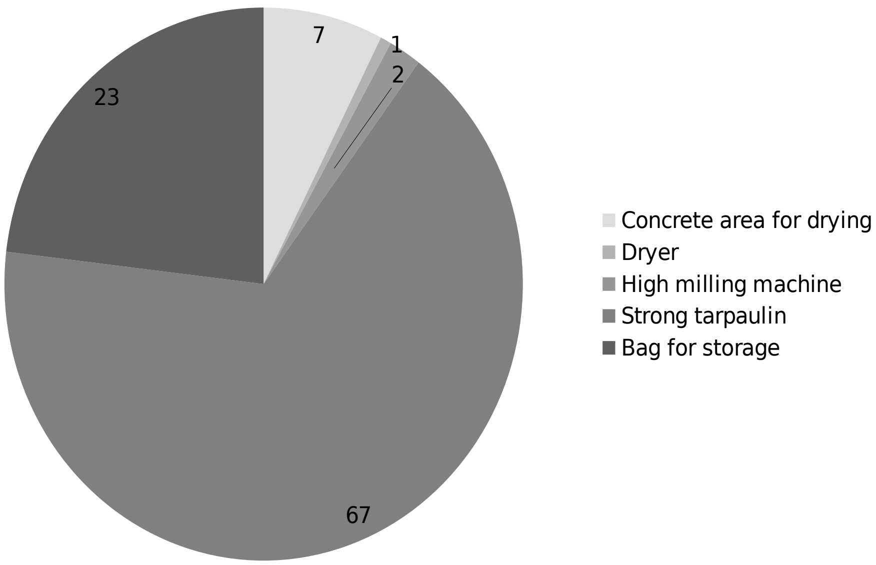

Figure 2.11: Reduction of postharvest losses in the study area

Majority (67%) of farmers reported that use of strong tarpaulin sheet can help them to reduce postharvest losses. Other strategies reported are the uses of concrete area for drying, conventional hot air dryers, high milling machines and bags for storage. The message that can be drawn from the farmers is that use of better drying technologies such as harvester, dryer can solve the issue of postharvest losses.

2.5 Conclusion and Recommendation

The survey to determine farmers' perception of rice postharvest losses was successfully done. It has been revealed that about 90% of the rice farmers interviewed experienced postharvest losses of rice and that the losses were very high. Lack of post harvest machinery (Harvester,dryer..) was the major problem resulting in the high post harvest losses of rice.It is recommended that improving drying technology as means of helping them reduce the losses in rice.This study should be repeated at different ecological zones to generate more information on postharvest losses to enable intervention by policy makers.

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CHAPITER THREE

3.0 EVALUATION OF PERFORMANCE OF GRAINSAFE HERMETIC STORAGE SYSTEM FOR DRYING AND STORAGE OF PADDY

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3.1Abstract

A study was carried out to assess the performance of hermetic grain storage system, branded “Grain Safe”, for drying and storage compared to sun drying. The study aimed at conducting experiments on the system to assess its technical performance as dryer at first. Two Grain Safe dryers were installed for drying and storage experiments. Parallel sun drying experiments were carried out. The parameters assessed were quantitative (weight loss) and quality of rice yielded from milling, germination, milling recovery, afflation contamination, insect infestation and economic viability of their use. Higher (9.6%) weight loss was attained in sun drying compared with Grain Safe Dryers (1.7%) was probably due to relatively low ambient relative humidity under sun drying and the protection attained in Grain Safe Dryers against birds, and rain by virtue of being a closed system. Paddy dried in Grain Safe Dryers had a better mill recovery (62-64%) compared with sun drying (51%).The sun dried paddy yield was significant lower in head rice compared with paddy dried in Grain Safe Dryers. However, the paddy dried in hermetic system was higher in terms of germination rate (82-85%) after four months compared with the sun dried paddy (80%).Use of the hermetic system for both 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 both drying and storage.

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

3.2 Introduction

Rice (Oryza spp) belongs to the family *Graminae*. It is a cereal grain grown in areas with hot climate providing seeds that are used as food. Rice refers to two grass species (*Oryzasativa* and *Oryzaglaberrima*) and is native to tropical and subtropical south eastern Asia and 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 (Hodges *et al.*, 2011). 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 (FAO, 2011).

International Rice Research Institute (IRRI, 2020) 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 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 (Hodges *et al.*, 2011). Other recent scientific surveys place paddy losses in China at between 5 and 23 percent (not accounting for processing) (Liu, 2014). 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 (Asemu *et al*., 2020). 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 mould growth and mycotoxin production in the field and during postharvest. 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 after every one or two hours and depending 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 GrainSafe hermetic storage system for dryin and storage in Burundi compared with sun drying.

3.3 Materials and Methods

3.3.1 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).

3.3.2 Experimental materials

A hermetic storage system, branded “Grain Safe”, was adapted to drying and storage of paddy, and termed Grain Safe hermetic dryer. In hermetic storage the grains are enclosed in a hermetically (airtight) container made from material with very low oxygen permeability. The biological processes inside the container like the respiration of insects and the grains very quickly consume the oxygen and produce CO2.The oxygen levels can drop to 3% or less; at which point insects at all development stages die. Two units were 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 (Appendix 5 and Appendix 8). 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 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 Grain Safe dryer. The perforations were made on 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 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 Grain Safe units were exposed under the sun shine for two hours before installation to remove length difference and folds of PVC zippers. A platform was prepared with dimensions 130 cm x130 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 secured. Ordinary materials (wood, angle iron, and galvanized pipe) were used to construct the platform. The Rodent guards were installed to protect against rodents attacks (one set can be installed on the platform legs).

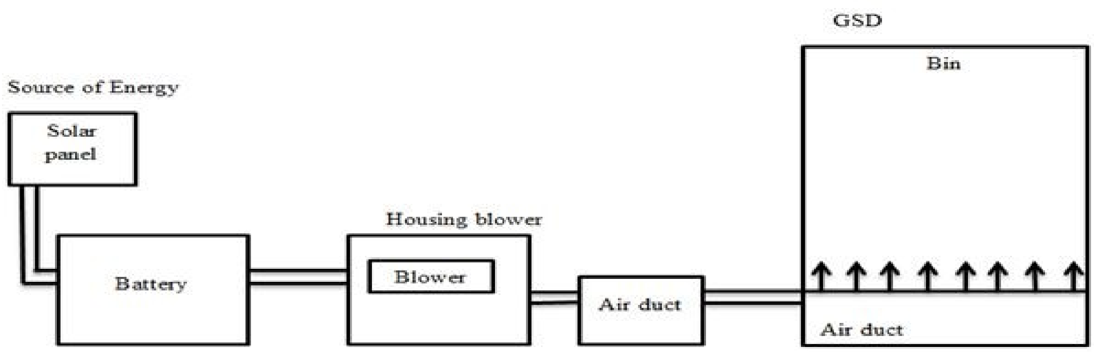

Figure 3.1: Schematic diagram of GSD

3.3.3 Assessment of drying performance

Two Grain Safe hermetic units adapted as dryers were used for paddy drying in the same environment with sun drying. A Grain Safe hermetic unit had a capacity of 1.3 tons. Paddy was loaded in Grain Safe unit in a bulk depth of 1.2m. 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 change in grain quality during the drying phase in the Grain Safe due to 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 afflation levels. The results were compared with the same under sun drying.

3.3.4 Assessment of storage performance

This assessment was done to find variability in quantitative and qualitative losses caused by adapting the Grain Safe 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 stored in polypropylene bags for a period of four months (From July 2021 to October 2021) undisturbed under ambient household conditions. The reminder of 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 ttemperatures and relative humidity were monitored at 9:00, 13:00, and 17:00 daily from the beginning to the end of the experiment. Temperature was measured using dry and wet bulb thermometer (Zeal, UK) inside the storage room while relative humidity inside and outside the storage room were measured using a Hygro-Thermometer. The response variables measured were quantitative losses, grain quality as for drying, grain viability, insect infestation and presence of aflatoxin.

3.3.4.1 Determination of drying and storage response variables

3.3.4.1.1 Moisture content and weight loss

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 dryingmoisture 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 seed burro sampling unit.

3.3.4.1.2 Seed quality test

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 International Seed Testing Association (ISTA, 1999) were followed to determinate 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 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 (Hossain *et al.,* 2012). First counting was done 5 days after seeds setting and final counting was done at 14 days after seeds setting. The normal seedlings, abnormal seedlings, dead seeds and un-germinated seeds were counted.

Figure 3.2: Seedlings in the germination test

3.3.4.1.3 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.

3.3.4.1.4 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).

3.3.4.1.5 Aflatoxin contamination

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

3.3.4.1.6 Insect infestation

Insect infestation on the stored paddy was determined according to rules of International Seed Testing Association (ISTA, 1999) 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 hand magnifying glass. Seeds were separated into different groups such as apparently healthy seed, spotted seed and deformed seed. Apparently healthy seeds have normal colour without any spot, 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 percentage.

3.3.4.2 Appraisal of Cost-Benefit Ratio of using the Grain Safe in drying and storage

Economic evaluation of using the Grain Safe for drying and storage was based on investment costs, operational costs and maintenance costs compared with sun drying and the consequent conventional storage. The investment costs considered were the cost of each piece of the Grain Safe unit and accessories, including the electrical equipment, structure, instrumentation equipment and electrical installation and material used for sun drying and conventional storage. For the determination of the investment costs, these costs were divided into three categories: supply/handing material costs, engineering cost, labour cost and maintenance costs. The engineering costs combined design, manufacturing processes, modelling of the pieces, architectural plans and installations. The supply/handing costs involved the material supply.

3.3.5 Data collection

3.3.5.1 Assessment of drying and storage performance of Grain Safe Dryer

3.3.5.1.1 Moisture content and weight loss

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 seed buro (Appendix7). The amount of moisture removed from the paddy samples was determined using Equation 1 by Aktar, 2016.

$$M_w ¿ \frac{Mp(Mi-Mf)}{100-Mf} \text{...} \quad (1)$$

Where: *Mw* is 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).

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

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

DR¿ $\frac{Percentage\ moisture\ removed}{Time\ hour}$ ……………………………………………….…………

(2)

3.3.5.1.2 Seed viability

A sample of one hundred twenty five (125) grains was randomly taken from Grain Safe Dryers and sun dried paddy after drying and after storage to assess the seed viability. After germination test, seed vigour index was determined by using equation 2 for seed quality test by Govindaraj *et al*. (2017).

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

Viability index was calculated according to Ogendo *et al.* (2004), using the following equation (Equation 4):

$\%\ viability index = \frac{NG}{TG} * 100$……………………………………….…………….. (4)

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

3.3.5.1.3 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).

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

3.3.5.1.4 Head yield

A sample of one hundred and five (105) grams of milled rice was randomly taken from each Grain Safe 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.

$$\text{HRR } (\%) = \frac{\text{Weight of whole grains}}{\text{Weight of paddy sample}} X\, 100 \ldots\ldots (6)$$

Where: HRR is head rice recovery.

3.3.5.1.5 Aflatoxin contamination

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

3.3.5.1.6 Insect infestation

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

$$\text{Insect infestation } (\%) = \frac{\text{Number of damaged grains}}{\text{Total number of grains}} x\, 100 \ldots\ldots (7)$$

3.3.5.2 Evaluation of cost-benefit of using Grain Safe hermetic system for drying and storage

Economic Analysis was evaluated based on cost-benefit ratio (CBR), which determines the return per unit of investment by using (Equation 14) by Chen *et al.*(1994) and Wambua and Jóhannesson (2018). Recommendations were made based on the outcome of the calculated CBR values.

$$CBR = \frac{b_{tot}}{C_{tot}} \ldots\ldots (8)$$

Where:

b_{tot}, *is the benefit at specified period*

C_{tot}, *is the cost at specified period*

Data collected included material cost, installation cost, labour cost, maintenance cost and the value of dried and stored paddy. The benefit-cost ratio (r) of Grain Safe was determined according to the formula stated by Chen *et al.* (1994) (Equation 9):

$$\mathbf{r} = \frac{b_{tot}}{C_{tot}} \quad \ldots\ldots (9)$$

Where, r is benefit-cost ratio, b_{tot} is total benefit and C_{tot} is total cost.

From the obtained BCR (r) value, interpretation will be done as follows; for $r < 1$ means non-viable project, for $r \geq 1$ means a viable project.

3.3.6 Data analysis

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

3.4 Results and Discussions

3.4.1 Drying of paddy in Grain Safe

3.4.1.1 Drying performance

3.4.1.1.1 Variation in moisture content

Moisture content decreased gradually in both Grain Safe units from initial value. The initial average moisture content was 26.7%w.b., which decreased to 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) and 144 hours (18 days) for GSD1 and GSD2, respectively. In GSD1, 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 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 run off the blower at 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 quantity of paddy penetrated in air duct through the wire mesh covered the perforations damaged and the air circulated slowly. Note that for GSD2 there was not barrier for air circulation inair duct.

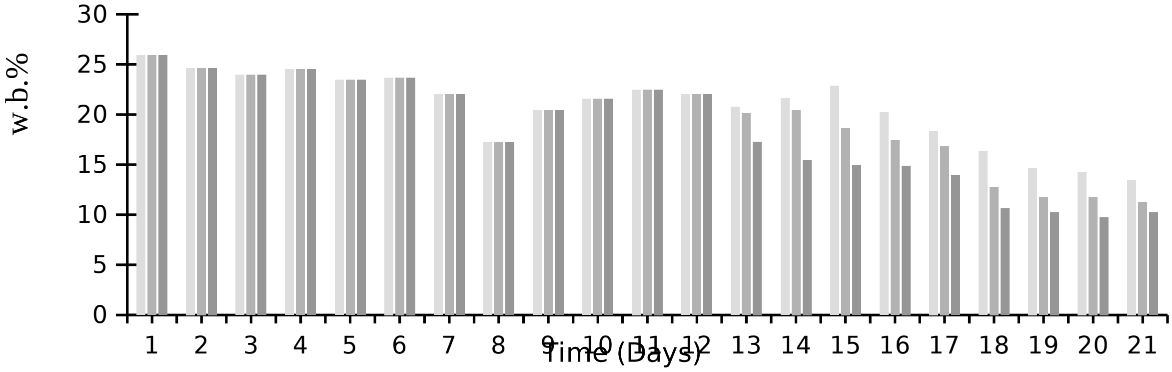

Figure 3.3: Average moisture content in GSD1

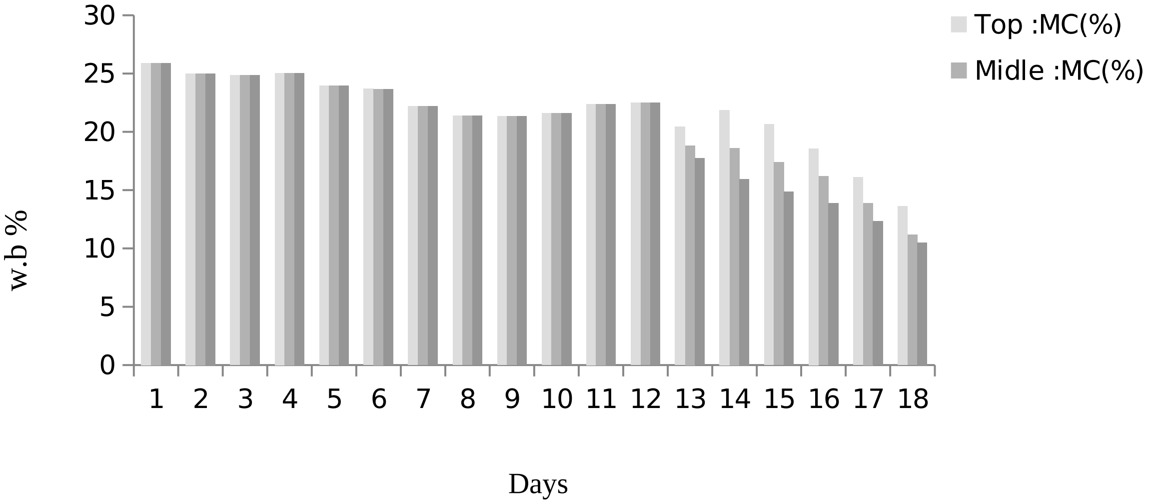

Figure 3.4: Average moisture content during drying in GSD2

Based on the results, the time taken for the gradual decrease of moisture content from 26.7% w.b. to reach 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 long drying periods which may lead to unnoticed mould 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 Grain Safe unless there are very serious changes in quality. Besides, use of Grain Safe as a dryer is a new field that can be improved for better drying performance.

3.4.1.1.2 Weight loss

In this study weight loss was used as an alternative method of determining drying performance. The performance of drying paddy in Grain Safe in comparison with sun drying was studied and the results are presented in Table 3.1. The highest drying rate was observed in sun drying. Sun drying has shown to register relatively higher weight loss (9.6%) compared with GSDs (1.7%), although they were generally low.

Table 3.1: 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 rainby virtue of being a closed system. Alam *et al.* (2016) reported drying losses of 2.41% to 3.95% in 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 drying technology, the GSD has the capability of attaining low weight loss. FAO, 2011 reported that the most postharvest losses were 26-37% due to pest and diseases. This is because there was no chance of adding/mixing impurities as well as wetting with rain water during drying using GSD dryer as opposed to the case of the open sun drying method. In another study, Hodges *et al*. (2011) found 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.

3.4.1.2 Grain quality

3.4.1.2.1 Mill recovery

Sun dried paddy resulted in significantly lower (p<0.001) mill recovery compared with paddy dried in the GSDs (Table3.2).

Table 3.2: 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%) compared with sun drying (51%). The difference in mill recovery between sun drying and 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.

3.4.1.2.2 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 rice compared with paddy dried in GSDs. The same is mirrored on the proportion of broken rice, which was highest in sun dried paddy (Table 3.3).

Table 3.3: 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 rice compared with paddy dried in GSDs. The same is mirrored on the proportion of broken rice, which was highest in sun dried paddy. Nalley *et al.* (2016) 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.

3.4.1.2.3 Germination test

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

Table 3.4: 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**
GSD1	Top	106	19	84.6	85.2	23	1946	1820
	Middle	105	20	84		21	1764	
	Bottom	109	16	87.2		20	1750	
GSD2	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 vigour (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 seed at a high temperature may induce damage, including stress cracks, which lowers germination and destroys specific enzymes (Igathinathane *et al.*, 2008; Gawrysiak-Witulska *et al.*, 2019).

3.4.1.2.4 Aflatoxin contamination

Results on aflatoxin contamination are presented in Table 3.5.

Table 3.5: 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 (B1) 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 (Bullerman and Bianchini, 2007, Hoeltz *et al.*, 2009). However the values of the aflatoxin observed in the GSD1 and GSD2 were below the recommended value 20 ppb set by FAO for human food (FAO, 2015). Therefore, using Grain Safe units for drying resulted in safe food for human consumption.

3.4.2 Combined drying and storage

3.4.2.1 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 quality of grain. Temperature and relative humidity of the storage room measured and recorded from the beginning to the end of the experiment (Figure 3.5).

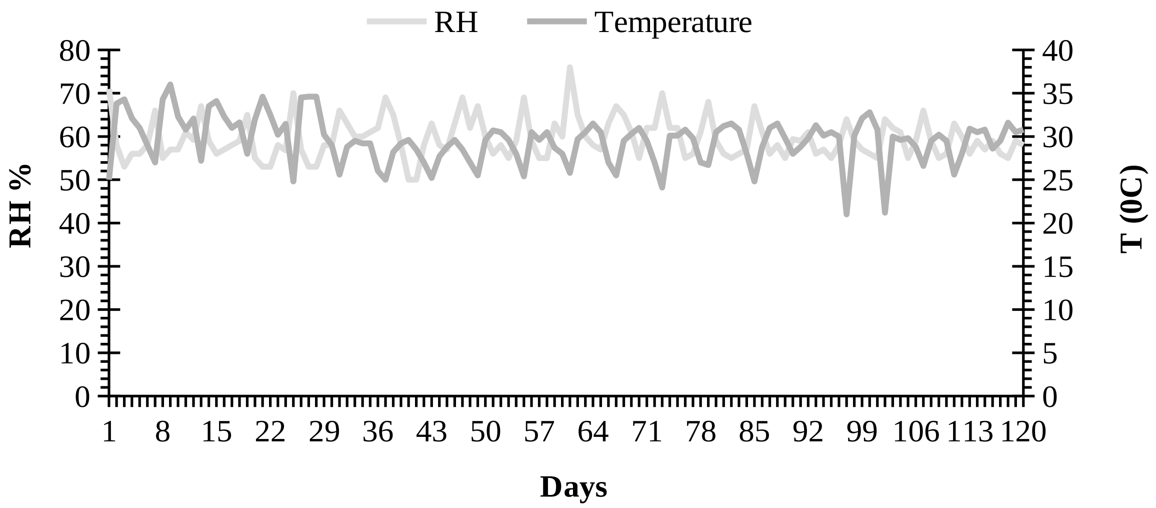

Figure 3.5: Temperature and relative humidity of storage room

The average daily temperature and relative humidity of during storage were 24.8°C to 34.5 °C and 55% to 97%, respectively. High grain temperatures along with excessive 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 (Anuja, 2010). At temperatures above 35°C or below 15°C, reproduction of insects is almost nil, developmental time is extended, and survival time is reduced (Anuja, 2010). Normally, relative humidity affects the rate of population increase of insects less dramatically.

However, up to 70 percent relative humidity, there may be progressive increase in insect multiplication and beyond 70 percent 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 (Anuja, 2010). In this study, the recorded average temperature and relative humidity of storage room gave favourable condition 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 due to the materials made the hermetic.

3.4.2.2 Moisture content of stored paddy

The changes in moisture content of paddy stored for four months in polypropylene sacks and GSDs are presented in Figure 3.6. It was observed that there was no effect on 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. 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.

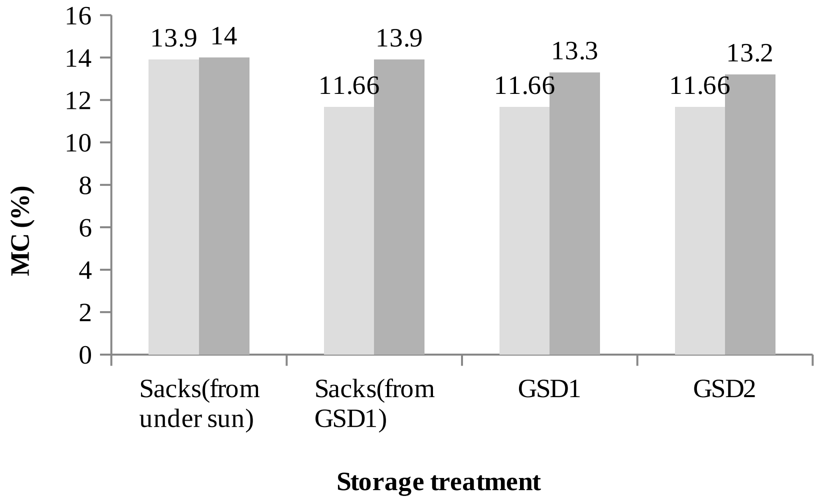

Figure 3.6: Changes of moisture content over storage period

Moreover, for all storage treatments, final moisture content ranged between 13.2 and 14%, having increased from 11.7% for Grain Safe dried paddy and almost no change for the sun dried paddy. The reason for this behaviour 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 favourable grain moisture range for stored-grain insects is 12% to 18% (Phil Harein, 2002). This implies that GSD stored paddy could also be attacked by insects if sufficient amount of oxygen were available but nevertheless storage gas composition experiments were not conducted. Moreover, such insects may proliferate more on mould damaged grain but this was not observed in the current study.

3.4.2.3 Losses of paddy after storage

Paddy stored four months after sun drying displayed highest storage loss, followed by GSD1 dried and stored in sacks, in-situ drying and storage in GSD2, and the minimum was for GSD1and split-drying and storage (Table 3.6).

Table 3.6: 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, Hodges *et al.* (2011) reported 5-10% loss in traditional open storage and 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 uses of GSDs for drying followed by storage in the same unit was better than use of any other drying means followed by conventional storage in sacks. However, use of GSDs for drying gave relatively better storage results even when traditional sacks were used.

3.4.2.4 Grain quality after storage

3.4.2.4.1 Mill recovery after storage

The results for milling recovery reflecting the effects of both drying and storage are presented in Table 3.7. 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 3.7: Evaluation of mill recovery after drying

Material	Mean	LSD	P-value
Sacks(Under sun)	63.60a	6.03	0.069
Sacks(GSD1)	69.60ab		
Stored in GSD1	70.00b		
Stored GSD2	71.20b		

Milling recovery for sun dried and sack stored paddy was 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 (Zhou *et al*., 2015).

3.2.2.4.2 Head rice yield

Whole rice grains are referred to as head rice and are considered as 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 the Table 3.8. 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 3.8: Head rice yield

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

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 affecting all the storage treatments equally.

3.4.2.4.3 Germination test after storage

The results on germination rate and vigour of stored paddy seeds reflecting the drying history are presented in Table 3.9. It is shown that 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 vigour index values.

Table 3.9: 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 germination rate and vigour index from 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, use of GSDs resulted in 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 (Anuja, 2010). Sandeep *et al.* (2015) reported that duration of storage has 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 (Sandeep *et al.*, 2015).

3.4.2.4.4 Aflatoxin contamination

The results for dying and storage combinations on aflatoxin contamination of the milled rice are presented in Table 3.10.

Table 3.10: 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 Grain Safe Dryer

As storage in sacks gave highest aflatoxin levels compared with storage in GSDs, it would appear that increase in aflatoxin is possible if storage in sacks is done for extended periods especially in humid climates. In another study, Sandeep *et al.* (2015) reported that fungal incidences were found to be high in jute bags and polylined jute bags. These findings raise concern on uses of sacks for storage even where drying was adequately done.

3.4.2.4.5 Insect infestation

The results on the insect's infestation are presented in Table 3.11.

Table 3.11: 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 reduction of O_2 and increasing CO_2 concentrations due to 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, Villers *et al*., 2010 reported that the low permeability of the hermetic structures also maintain safe constant moisture levels in the stored product regardless of ambient exterior humidity.

3.4.3 Appraisal of Cost-Benefit Ratio of using the Grain Safe in drying and storage

The results were based on consideration of materials cost, GSD cost, assembly and operating cost of GSD as well as use of tarpaulin sheet for sun drying (Tables 3.12 and 3.13). It is shown that the total cost (C_{tot}) and total benefit (b_{tot}) of using the GSD were BIF 3 248 000and 2 717 980respectively with cost-benefit ratio (CBR) of about 1.2 (Table 3.12) and for sun drying were BIF 484 200 and 4 060 000 respectively with CBR of about 8.4. Since CBR>1, it means the GSD and tarpaulinare both viable.However, use of tarpaulin sheet is more economically viable but the negative quality factors on the dried and stored paddy discredit it. Since the CBR is greater than one, the GSDs is ecomically viable for use as an intervention in paddy postharvest losses at the farmers and research institutions.

Table 3.12: Cost benefit analysis of using Grain Safe structure in drying paddy

No	Materials	Unit	Quantity	Amount (BIF)	Cost(Ctot)	Benefit (btot)
1	GrainSafe Dry	piece	1	597 000	597 000	
2	Blower	piece	1	298 500	298 500	
3	Blower housing	piece	1	150 000	150 000	
4	Air duct distribution	piece	1	139 300	139 300	
5	Photovoltaic power plant	piece	1	995 000	995 000	
6	Platform	piece	1	100 000	100 000	
7	Operation cost	person	2	50 000	100 000	
8	Maintenance	time	2	100 000	200 000	
9	Value of dried paddy	kg	812	1 000		812 000
	Four times to dry per year	kg	3248	1 000		3 248 000
	Total Cost				**2 579 800**	**3 248 000**
	contingency	percentage	0.1	2 381 800	2 38 180	
	Grand Total Cost				**2 817 980**	**3 248 000**
					BCR	**1.15259867**

Table 3.13: Cost-benefit ratio of using tarpaulin sheet (sun drying)

No	Materials	Unit	Quantity	Amount (BIF)	Cost(Ctot)	Benefit (btot)
1	Tarpaulin sheet	piece	8	35 000	280 000	
2	Labour	person	40	5 000	200 000	
3	Value of dried paddy	kg	812	1 000		812 000
	Four times to dry per year	kg	3248	1 000		3 248 000
	TotalCost				**480 000**	**3 248 000**
	consider 10% loss	Percentage	0.1	8 120 000		812 000
	Contingency	Percentage	0.1	42 000	4 200	
	Grand total Cost				**484 200**	**4 060 000**
					BCR	**8.4**

The results of this study showed that the economic analysis done to the GSD gave cost-benefit ratio (CBR) of 1.2 (Table 3.12) compared to sun drying the benefit cost ratio is greater (8.4) than GSD.

3.5 Conclusion and Recommendation

The Grain Safe hermetic storage technology was successfully tested for use as both a dryer (GSD) and a drying unit. Quality attributes of paddy dried in the GSD were better than in sundried paddy. The moisture content was changed due to low permeability of hermetic structures and was maintained in stored products. Insect infestations were observed in paddy stored in sacks and no one in hermetic storage. Although sun drying appears to be cheaper, use of the GSD is economically viable. It is recommended that this method should undergo further testing in other geographical areas before a wider dissemination is done.

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CHAPTER FOUR

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The survey has revealed that about 90% of the rice farmers interviewed indicated that they experienced postharvest losses of rice and that the losses were very high. Respondents also reported that the problem of lack of postharvest technology was the major problem resulting in the high postharvest losses of rice. According to the rice farmers, mechanization of the postharvest activities and providing technical knowhow to acquire appropriate machinery could help reduce the losses in rice. Considering the results observed in this study Grain Safe Dryer should initially be used to dry paddy in different farmers and researcher institution. It is recommended that this method could then be promoted and should further be tested with other area before a wider dissemination is done. Paddy samples dried and stored in Grain Safe hermetic storage system were assessed the quantity (weight loss) and quality. However, the weight loss was higher (9.6%) of sun dried paddy compared with paddy dried in Grain Safe Dryers (1.7%). It was observed that mill recovery is better for paddy dried in Grain Safe Dryers compared with sun dried paddy. Moisture content, insect infestation and germination rate of stored paddy were checked after four months of storage. Number of insect infestation per 250 g of stored paddy was found highest in Sacks (10) while no insect was found in Grain Safe Dryers. Paddy in Grain Safe Dryer showed highest (94.9%) after storage germination percentage over Sacks (92% after storage). Moisture content of paddy changed from the day of storage due to porous behaviour of sack. The suitable moisture content for growth and development of stored grain insect ranges from above 12% to 18%. As moisture content of paddy in sack becomes high, it induces frequent insect attack. Temperature and relative humidity are also important factor for insect growth. The suitable temperature ranges from

15°C to 35°C for growth of stored grain insect. Results obtained from the economic calculations show that the Grain Safe dryers are capable to generate sound profits even in the existing operating conditions. Profit from a Grain Safe dryer is highly dependent on its annual utilization. Sun drying, whenever possible, is the cheapest option for the farmers if they want to sell their dry paddy.

4.2 Recommendations

i. Grain Safe Dryer can be adopted through training, demonstration among the farmers level before introduction at farmers level.

ii. Government should concern about the availability of the improved Grain Safe hermetic storage System for drying and storing paddy.

iii. Rice should be dried where the moisture content is controlled.

iv. This study should be repeated at different ecological zones to generate more information on postharvest losses.

APPENDICES

Appendix 1: A Questionnaire to determine rice farmers' knowledge and perception of post-harvest losses of rice from harvesting to storage.

Place: …………………… Date ……………..………… Age ……………………….

Name of respondent: ……………………………… Sex: A. Male B. Female

1. How long have you been growing rice? A. 1-4 years B. 5-9 years C. 10-14 years D 15-19 years E.20 or more years.

2. What is the area of your rice field in acres? ....

3. What rice variety or varieties do you grow? ……………….…………………….…

How many seasons per year?

4. Do you experience post-harvest losses? A. Yes B. NO

5. What causes pre harvest losses of rice according to your perception? ....

6. What causes post-harvest losses of rice according to your perception? …………..….

7. Do you own any post-harvest equipment or machine? A. Yes B. No

8. Do you use any post-harvest equipment or machine? A. Yes B. No

9. If yes, which one/s………………………………………….………………..….

10. What quantity of rice do you lost during the post-harvest activities? A. 0-9% B.10-19% C. 20-29% D.30-39% E.40% and above.

11. What is your perception of post-harvest losses of rice in general? A. Normal B. Too much.

Do you get a better price of better quality rice? What is the price difference (%)?……..…..

What quality traits lead to variation in price? Purity?Head Rice / broken grains? Discoloration?Off type varieties? ....

12. What harvesting method do you use? ....

13. What threshing method do you use? ……………………………………..…….

14. How do you dry your rice? ....

15. At what stage do you experience the highest post-harvest losses? A. Harvesting B. Threshing C. Drying D. Transportation E. Winnowing F. Milling

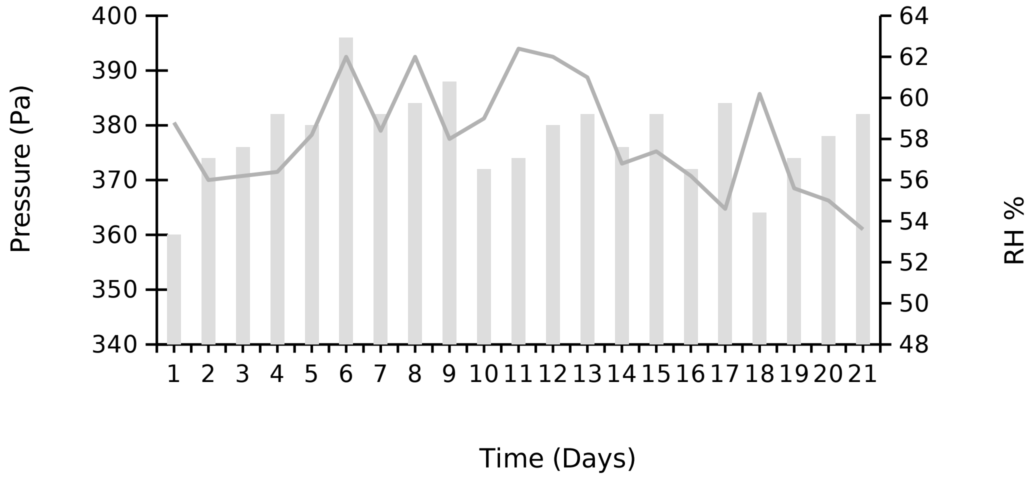
16. Do you store your rice before milling? A. Yes B. No

17. Where do you mill your rice? ....

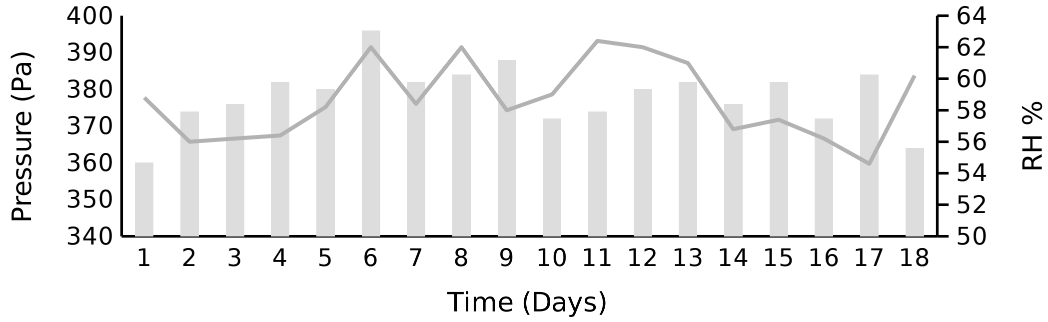
18. Which type of milling machine do you use to mill your rice? ....

19. What do you think can be done to reduce post-harvest losses of rice from harvesting to milling? ....

Appendix 2: Average of pressure and relative humidity daily during drying (GSD1)



Appendix 3: Average of pressure and relative humidity daily during drying (GSD2)



Appendix 4 : ANOVA tables

Summary table for analysis of variance (ANOVA) for mean head rice after drying

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Structure	2	1749.50	874.75	40.30	<.001
Position	2	133.58	66.79	3.08	0.058
Structure	4	105.38	26.35	1.21	0.322
Residual	36	781.45	21.71		
Total 44 2769.92					

Summary table for analysis of variance (ANOVA) for mean mill recovery after drying

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Structure	2	59.91	29.96	1.16	0.322
Residual	42	1081.07	25.74		
Total	44	1140.98			

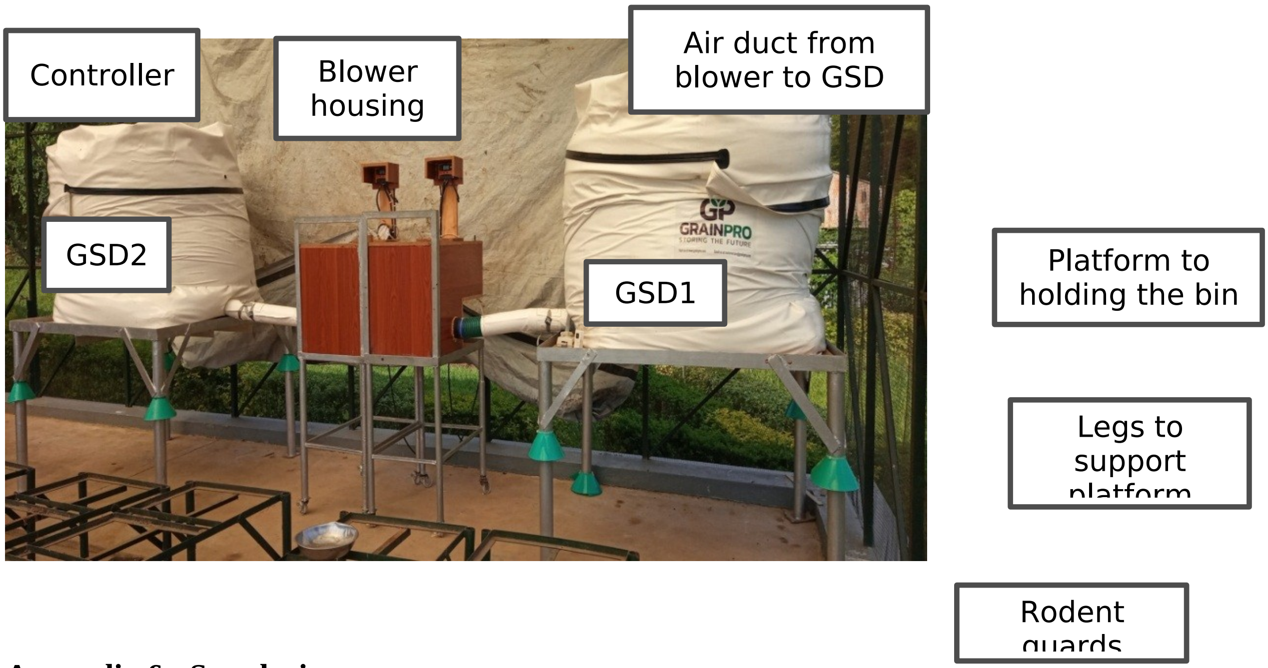
Summary table for analysis of variance (ANOVA) for mean head rice after storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Structure	3	186.73	62.24	0.76	0.535
Residual	16	1318.66	82.42		
Total	19	1505.39			

Summary table for analysis of variance (ANOVA) for mean mill recovery after storage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Structure	3	173.60	57.87	2.86	0.069
Residual	16	323.20	20.20		
Total	19	496.80			

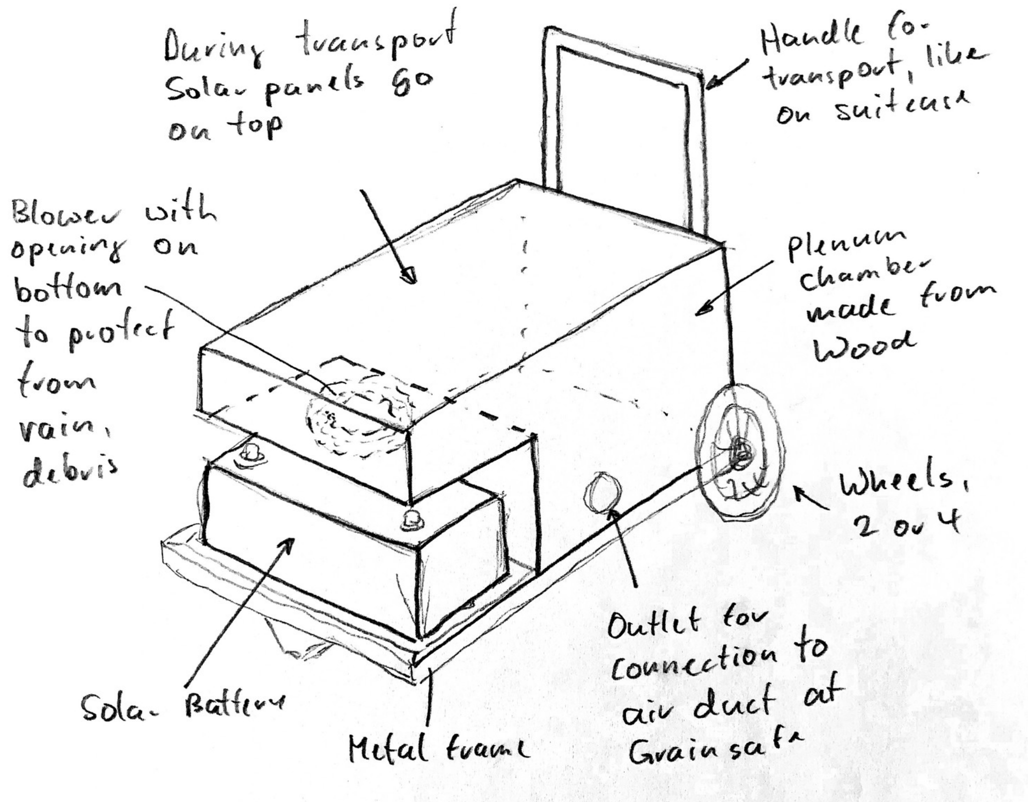
Appendix 5 : Experimental set-up of GSDs



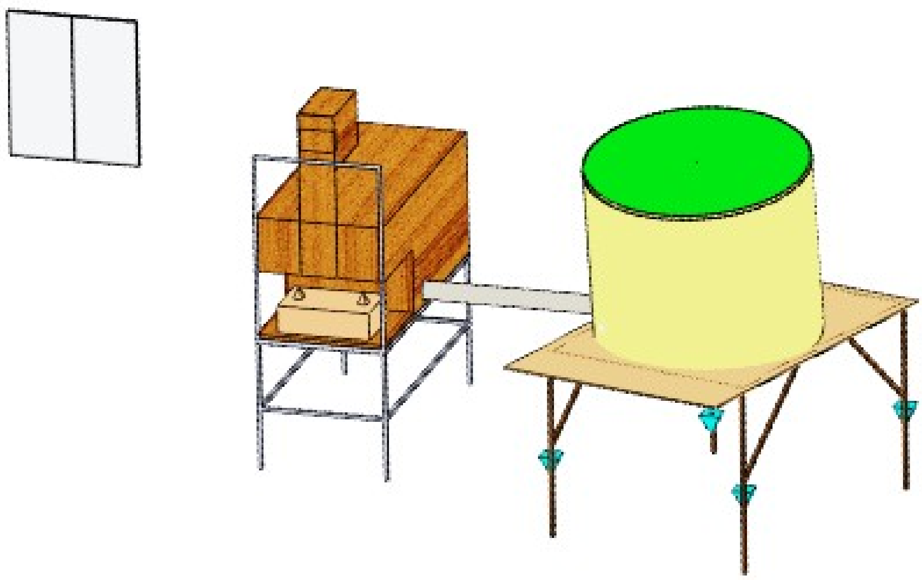
Appendix 6 : Sun drying

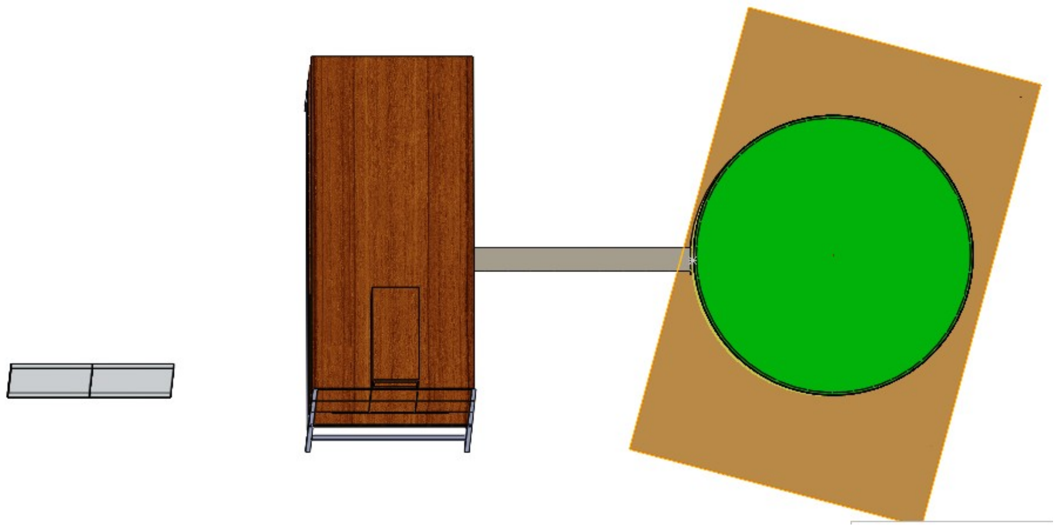
Appendix 7 : Grain samplers used to take sample in GS (Seedburo)

Appendix 8 : Blower housing

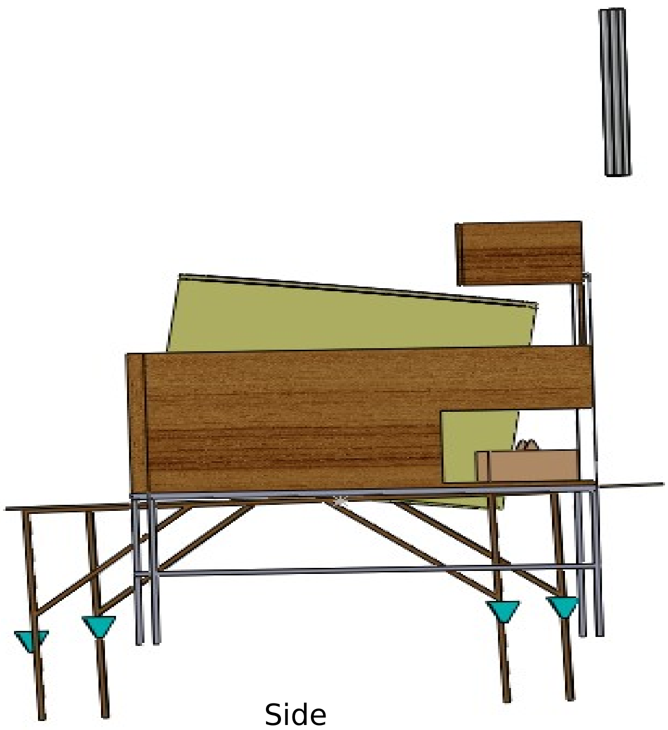


Appendix 9 : Elevation of experimental setup

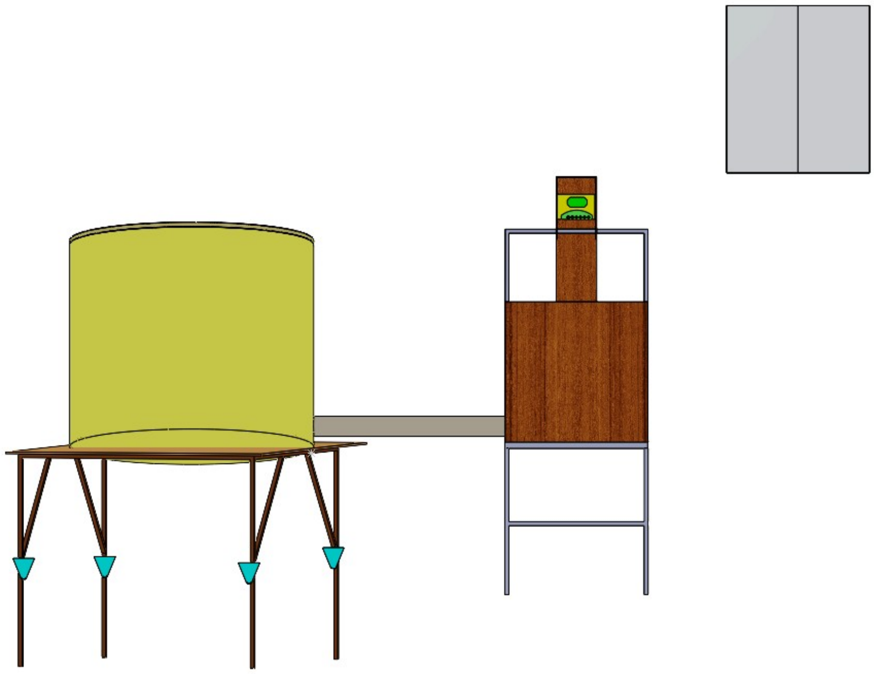




Plan



Side



Side elevation