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Effect of paddy drying depth using open-sun drying on drying time and mill recovery of *Kaiso* variety in eastern Uganda

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Abstract

The smallholder rice farmers in the Uganda dry their paddy using open-sun drying method. In most cases the paddy is badly dried and has very high fissure levels. Such paddy on milling contributes to low levels of mill recovery and whole grain in the milled rice. This study was therefore done to find a recommendable paddy-heap depth for open-sun drying of the pre-dominant local *Kaiso* rice variety in eastern Uganda. In each experiment, the paddy was open-sun dried on cemented floor at ten different depths: control, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm and 110 mm. Drying time showed a linear relationship with paddy drying depth. Mill recovery increased from 57.4 % at control to a maximum average value of 66.3 % and thereafter declined progressively to 63.5 % at 110mm depth. The maximum increment of 14.1 % in whole grain level over control occurred at 70mm depth. Findings from this work indicate that the best drying depths for *Kaiso* rice variety using open sun drying is 70 – 80mm. However at these depths, the paddy takes 7 – 8 days to dry. It is therefore recommended that more research should be done to reduce the drying time to a manageable level for farmers.

Key words: Fissure, paddy drying, whole grain

Introduction

Rice is now one of the important food and cash crops in Uganda. An estimated 80 % of the total national output is produced mostly by small scale farmers with rice gardens of less than 2 hectares. Since the introduction of upland rice in 2002, the number of farmers deriving their livelihood from rice farming has grown from 4,000 to over 96,000 farmers in 2010, accounting for 233,000 tons of milled rice (MAAIF, 2012, UBOS, 2012). The farmers' rapid shift to rice production has been attributed mainly to the higher return on investment among smallholder crop enterprises (NAADS, 2004). The number of rice millers has also shot up from about 100 before 2000 to 591 by 2008 (Candia *et al.*, 2008; MAAIF, 2012).

Ugandan's smallholder rice farmers use rudimentary and inefficient practices and technologies for carrying out post-production rice operations (Odogola, 2006). Most of these farmers also have inadequate knowledge in post-harvest handling and processing of rice (Odogola, 2006). A combination of these two factors has resulted into supply of low quality paddy to rice milling enterprises and factories by farmers. Drying is one of the most critical post-production operations that greatly influence the quality of paddy and hence milled rice. The smallholder rice

farmers in Uganda dry their paddy using direct solar energy either on firmed bare ground, cemented floor, or on tarpaulin. They spread the wet paddy very thinly to a depth of about 20mm, stir frequently and allow it to dry the whole day. Whereas this practice induces rapid drying of the crop, studies have shown that it also causes high fissure levels reaching to 41.7% in the eastern and 60% in the northern regions of Uganda (Candia and Masette, 2012). The high fissure levels in paddy have contributed to the low national mill recovery levels of 55 – 62 % (Candia *et al.*, 2008) and also to the high level of broken-grain in the milled rice (Candia and Masette, 2012).

Due to the abundance of cheap solar energy and lack of appropriate mechanical paddy dryers, Ugandan smallholder farmers will continue to use direct solar energy for drying paddy for some time in the future. The purpose of this study was to determine the optimum paddy drying depth for open-sun drying under Ugandan weather conditions with a view to improving mill recovery and level of whole grain in the milled rice.

Materials and methods

Design of drying experiments

The drying experiments were carried out from 2010 - 2011 during the rice harvesting period of June to August at Doho rice irrigation scheme in Butaleja district, in eastern Uganda. The two experiments of 2010 were performed in June while that for 2011 were done in August. *Kaiso*, which is the most popularly grown swamp rice variety in the country, was used in the experiment. The paddy used in the two experiments was harvested at moisture contents of 25 - 26 % wet basis (w.b) using sickles and threshed by beating method.

In each experiment, the wet threshed paddy was set to dry on cemented floor in the open-sun at ten different profile depths: farmers' practice (about 20 mm), 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm and 110 mm (Fig. 1).



Figure 1. Wet paddy drying depth profiles.

The initial weight of each of the above drying depths was about 150kg. To ensure fairly uniform drying and maintain good taste of milled rice, the paddy was stirred after every one hour and allowed to dry for four hours per day. Thereafter the paddy was transferred to shed over night for tempering. The moisture content of the drying paddy was recorded during every stirring interval. Drying was done daily until each drying depth profile reached the recommended milling moisture content of 12 – 13 %, w.b. (Wimberly, 1983).

Weather data

Relative humidity, vapour pressure, wind speed, temperature and sun hours are the five weather parameters that influence drying. The FAO New-LocCLIM, 2005 was used to obtain these parameters during the rice drying trials at Doho rice irrigation scheme.

Determination of evaluation parameters

Paddy drying time, paddy fissure level, mill recovery level, physical grain loss level, and levels of whole and broken grain were the evaluation parameters used in this study. They were determined using established analytical methods as described below.

Determination of paddy drying time

The paddy drying time was determined by the paddy attaining rice milling moisture content. An electronic hand moisture meter model Riceter m 401 made by Kett-electric Company was used to determine moisture content of the paddy, daily and after every one hour. Once a particular drying depth profile reached the milling moisture content (12 - 13 % w.b.), its drying was stopped and taken for storage. The corresponding drying time in days was then recorded.

Determination of fissure level

A fissure analyser made by Agricultural Engineering and Appropriate Technology Research Centre (AEATREC) was used to determine fissure levels of the dried paddy from all the drying depth profiles. Internationally, a grain count of 100 is used in estimating fissure level (Lan *et al.*, 2002: IRRI, 2009a). To increase data validity the research team opted for a bigger population size and consequently used a grain count of 216 in the analysis of each of the 10 samples from the 10 paddy drying depths. For each main sample 216 well developed grains were randomly handpicked and their husks removed by hand. The fissure analyser used had a capacity of 36 grains. The brown rice grains obtained were then divided into 6 samples and each sample was placed in the fissure analyser. The grains that had fissures were observed, counted and expressed as a percentage of 36 grains. This process was repeated for the remaining 5 samples. The average fissure level in that main sample was then obtained using fissure levels in the 6 small samples. The process was then repeated for the samples from the rest of the drying depths in all the drying experiments.

Determination of mill recovery and physical grain loss

The dried paddy sample of about 40 kg from each drying depth was cleaned and milled using an SB10 *mill-top* rice mill series (rubber roll type). The pressure of polishing unit was set to achieve the whiteness degree of milled rice that is usually required by consumers, a practice being done by rice millers. The weight of

the resultant milled rice obtained was measured and recorded. Mill recovery and physical milled rice loss per unit weight of paddy was computed for each paddy drying depth. The mill recovery was computed using equation (1).

Mill Recovery (%) =

$$\frac{\textit{Weight of milled rice}}{\textit{Weight of paddy}} \times 100$$

Analysis of physical structure of rice seed shows that the white part from which the milled rice is obtained is between 70 - 72 % and the rest is bran and husks (MAFFJ, 1995; IRRI, 2009a). This therefore means that the maximum expected milled rice polished to consumer taste is 72 % of the weight of paddy. The research team used average value of 71 % for computation in this study. Physical grain loss (milled rice) during milling is given by equation (2), while physical milled rice loss per unit weight of paddy is given by equation (3).

$$PL = ME - AR \quad (2)$$

Where:

PL= Quantity of physical grain (milled rice) loss during milling (kg), ME = Quantity of maximum expected milled rice (kg), AR= Quantity of actual (practical) milled rice (kg).

$$P = \frac{PL}{WP} X\,100 \quad (3)$$

Where:

P = Physical milled rice loss per unit weight of paddy during milling (%), PL= Quantity of physical grain (milled rice) loss during drying (kg), WP= Quantity of paddy (kg).

Determination of whole grain and broken grains

The whole grain, large-broken grain and small-broken grain levels in milled rice from each paddy drying depth were determined. Three different samples each weighing 105 g were randomly taken from the milled rice of each paddy drying depth. Each sample was sorted into whole grain, large-broken grain and small-broken grain and their weights measured using a mechanical triple beam balance which has three graduated beams and 2,610 g capacity, made by OHAUS.

The weights obtained were expressed as a percentage of the sample weight. This process was repeated for the other two remaining samples and their average obtained to give the levels of whole grain, large broken grain and small broken grain levels in milled rice.

Data analysis

The research team used descriptive statistics for analysing the data. Regression analysis was used to understand the relationships between evaluation parameters and paddy drying depth. The principle of maxima and minima values obtained from the resultant graphs was used to determine the best and worst paddy drying depths.

Results

Local weather conditions during the experiments

Relative humidity, temperature, sun hours and wind speed are the parameters that greatly influence drying. The values of these parameters during the drying time are shown in Table 1. The air temperatures during the period were oscillating between 25.7 and 28.1 ^{0}C. It was observed that the relative humidity which is a function

of vapour pressure had different values in the two months. The relative humidity in August was varying from 48 - 57 %, a value-range that triggers rapid drying of a substance. The sun hours in the two months were small meaning that the day time was mainly cloudy thus inducing low drying rate. Since the region lies almost on the equator, the wind speeds were really low varying between 2.03 m/s in June to 2.94 m/s in August. These results helped to understand and explain results.

Paddy drying duration

In this experiment, the paddy was considered dry when it attained the recommended milling moisture content of 12 - 13 % w.b for the local varieties (Candia *et al.*, 2008). The paddy drying depths showed different drying times (Fig. 2).

The drying time increased from two and half days, for the control which is farmers' practice of 20 mm paddy depth to, 9 days for the 100 and 110 mm paddy depth. The drying time showed a strong linear relationship with the paddy drying depth ($R^2 = 0.8896$), which correlates well with the logic that the deeper the drying depth, the more time the paddy will take to dry. The deeper paddy depths had more wet paddy per unit area than shallower paddy depths. Consequently they required more energy to remove water from them than their shallower counterparts. Since all paddy depths received the same quantity of solar radiation per unit area and at the same time, automatically the deeper depths needed much more time to reach the recommended milling moisture content. The mean sun hour during the drying period was small (Table 1), which further prolonged the drying time.

Fissure level in the paddy

The paddy used in this study was harvested at the recommended moisture content of 22 - 28 % (w.b.). The samples of rice seed observed immediately after threshing showed no fissures. This

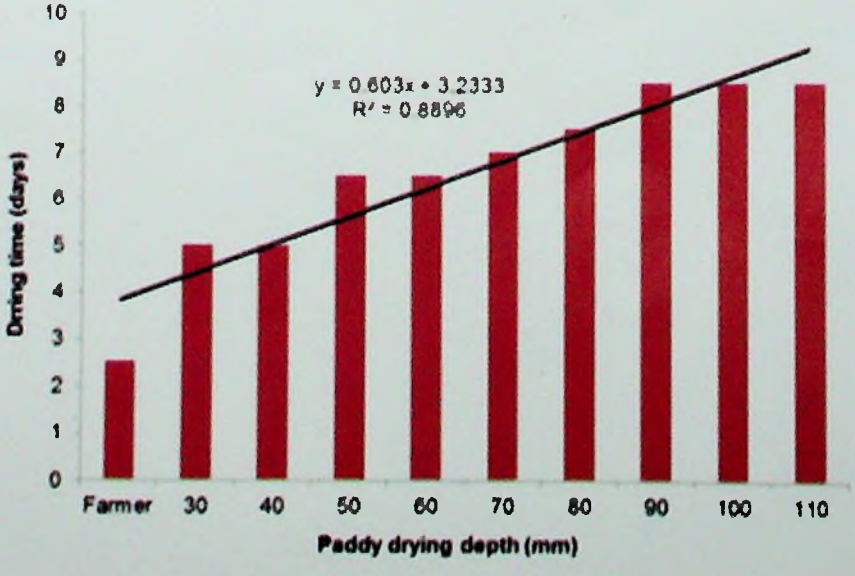


Figure 2. Average Paddy drying time at time different paddy depths.

therefore confirms that the fissures that developed in the paddy occurred during the drying process.

The fissure levels reduced from 18.5 % for the control (farmers' practice) to 7 % at 70mm depth and then increased to 9.7 % at 110mm paddy depth (Fig. 3). The gradual decrease in fissure level as drying depth increased from 20 mm (control) to 70 mm (inflexion point), and then the increase thereafter suggests that there is a strong (R^2 = 0.9474) relationship between drying depth and fissure level which could be described by a second order polynomial equation. This indicates that there are optimal drying depths for paddy using open-sun drying.

Results from this experiment indicate that, for the *Kaiso* variety, this depth lies between 60 mm and 80 mm. The high level of fissure in the shallow paddy depths could be attributed to rapid drying of the paddy caused by low relative humidity and high temperatures during the drying period. At these depths the rice seeds received high solar energy per unit area of drying and also immediately after stirring, the hot seeds underwent cooling process.

The heating and immediate cooling processes resulted into high thermal stress

Table 1. Weather parameters during the drying period

Weather parameter	Months of drying experiments	
	June	August
Temperature (°C)	25.98 - 29.03	25.7 - 29.1
Relative humidity (%)	58.0 - 68.5	48.0 - 57.0
Vapour pressure (mm Hg)	14.40 - 20.70	14.10 - 14.84
Sun hours (hrs)	4.04 - 6.15	3.21 - 5.44
Wind speed (m/s)	2.03 - 2.61	2.19 - 2.94

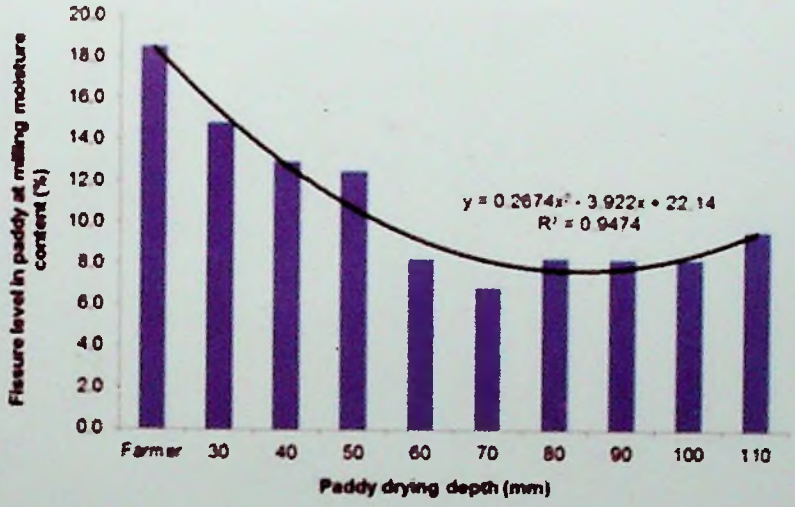


Figure 3. Fissure level in the dried paddy of the different paddy depths.

levels for some seeds to effectively withstand. Such high thermal stresses resulted into severe rupture of the bond between the molecules of some of the seeds.

This phenomenon was minimal at around 70 mm depth. The quantity of solar energy received was adequate to evaporate the water slowly without it remaining within the paddy. However, as paddy depth increased, it was noticed that the fissure level started rising up. This could have been due to increased depth of paddy which was retaining most of the heated vapour from the inner seeds creating large moisture gradient between the top and bottom grain layers. Instead of the hot vapour escaping into the atmosphere; it was adding more energy to the upward neighbouring seeds, thus increasing heat stress on them.

Mill recovery and milled rice physical loss

Level of mill recovery is one of the important factors that determine profitability of rice milling businesses. It is a function of several factors of which the most critical ones include paddy fissure level and moisture content, variety, type of rice mill and mill pressure setting.

In this study, the paddy was dried to the recommended milling moisture content, and milled using some of the good rice mill types and polished to consumer taste. Since the study focused on one variety, and all milling was done using the same mill and at the same pressure, the variations in mill recovery obtained was mainly due to effects of drying on the paddy. The results showed increment in mill recovery from 57.4 % for the control to a maximum average value of 66.3 % and thereafter declined progressively to 63.5 % at 110 mm depth (Fig. 4). The gradual increase in mill recovery to a maximum and thereafter a continuous decline shows that there is a strong (R^2 = 0.8372) correlation between mill recovery and paddy drying depth which is a second order polynomial.

These results further confirm that there is the best drying depth for paddy using open-sun drying. Considering results of mill recovery, *Kaiso* variety, should be dried at paddy depths between 70 mm and 90 mm. The low mill recoveries in shallower and deeper depths than 70 – 90 mm depths are due to the high fissure level in the corresponding paddy.

The computations for the milled rice physical loss levels showed a similar trend to that of mill recovery. This is because the milled rice physical loss at the mill is dependent on the mill recovery. Since a lot of care was taken to eliminate any grain spillage during milling, the variations of physical loss in milled rice could then be attributed to drying depth only.

The level of milled rice physical loss per unit weight of paddy decreased from an average value of 13.9% for the control to 4.7 % at 80 mm depth and thereafter continuously increased to 7.6 % (Fig. 5).

A strong correlation (R^2 = 0.804) of a second order polynomial exists between milled rice physical loss and paddy drying depth. The lowest milled rice loss occurred at 80mm depth, which further indicates that the best paddy drying depth for *Kaiso* variety is around 80 mm depth.

Whole and broken grains

The detailed results of whole grain, large broken and small broken grain are presented in Table 2. The results indicate that there was no clear relationship between the whole, large broken and small broken grains with changes in drying depths (R^2 = 0.1823).

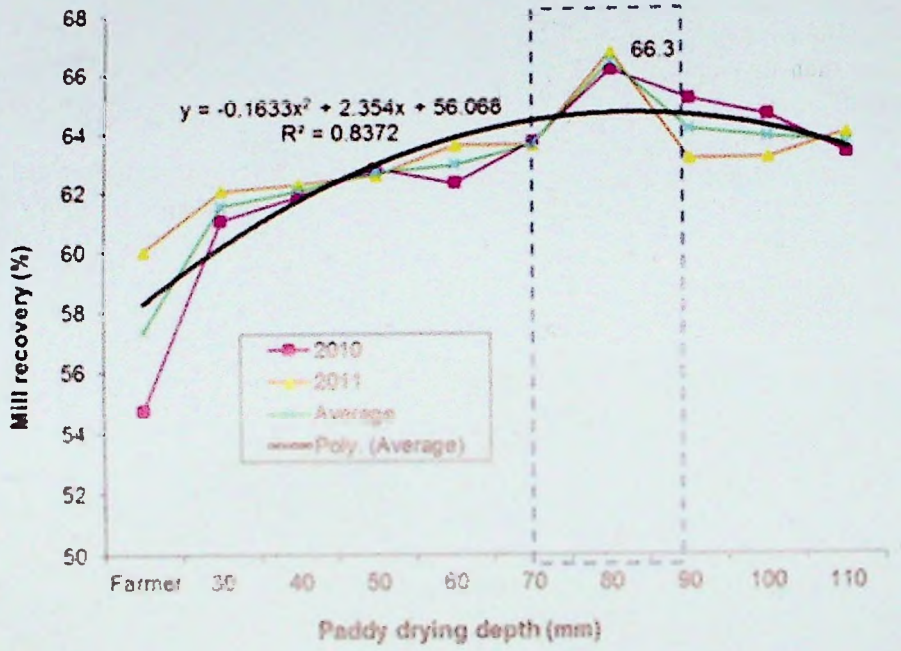


Figure 4. Mill recovery at different paddy depths.

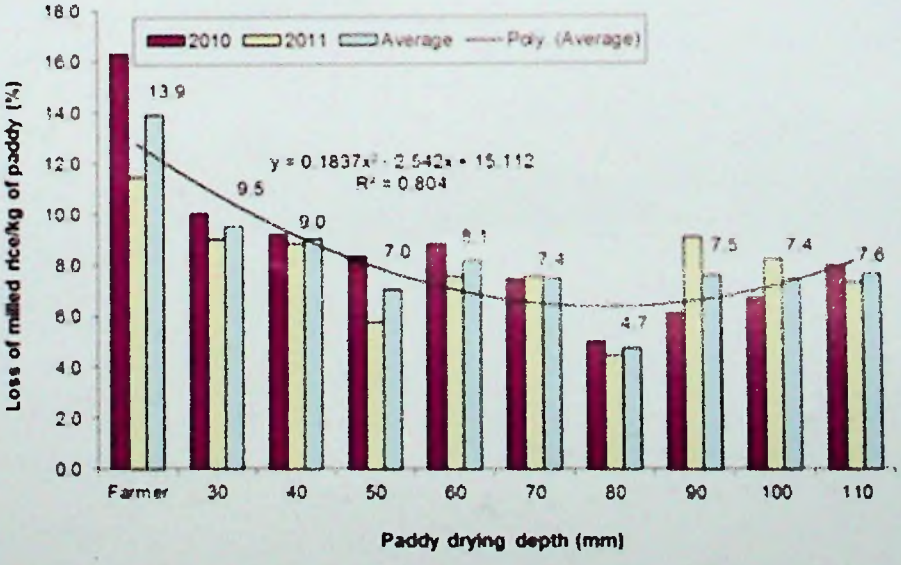


Figure 5. Milled rice physical loss per unit weight of paddy at different drying depths (%).

However the whole grain levels at 70 mm and 80mm drying depths were slightly higher than those for the other drying depths. Farmers' practice registered the lowest whole grain levels consistently. The mean value (46.2 %) of whole grain level in the milled rice due to farmers' practice observed in this study correlates very well with value 47.2 % for eastern Uganda (Candia and Masette, 2012).

There was a maximum increment of 14.1 % in whole grain level over the farmers' practice. The lowest values of total broken grain levels were obtained at drying depths of 70mm and 80mm (Fig. 6).

Table 2. Whole grain and broken grain levels

Paddy drying depth (mm)	Whole grain (%)			Large broken grain (%)			Small broken grain (%)		
	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Farmer	39.1	53.3	46.2	29.9	18.2	24.1	31	22.2	26.6
30	53	56.6	54.8	23.3	20.5	21.9	23.7	22.8	23.3
40	42.9	55.6	49.3	26.9	25.3	26.1	30.2	19.1	24.7
50	41.8	46.1	44.0	27.7	30.2	29.0	30.5	23.7	27.1
60	44.8	54.5	49.7	26.1	24.4	25.3	29.1	21.1	25.1
70	63.9	56.6	60.3	15.9	21.8	18.9	20.2	21.6	20.9
80	55.7	61.1	58.4	21.0	20.2	20.6	23.3	18.7	21.0
90	51.8	42.9	47.4	21.7	33.6	28.7	26.5	21.5	24.0
100	61.8	51.7	56.8	20.0	28.8	24.4	18.2	19.5	18.9
110	52.9	53.9	53.4	24.3	25.4	24.9	22.8	20.6	21.7

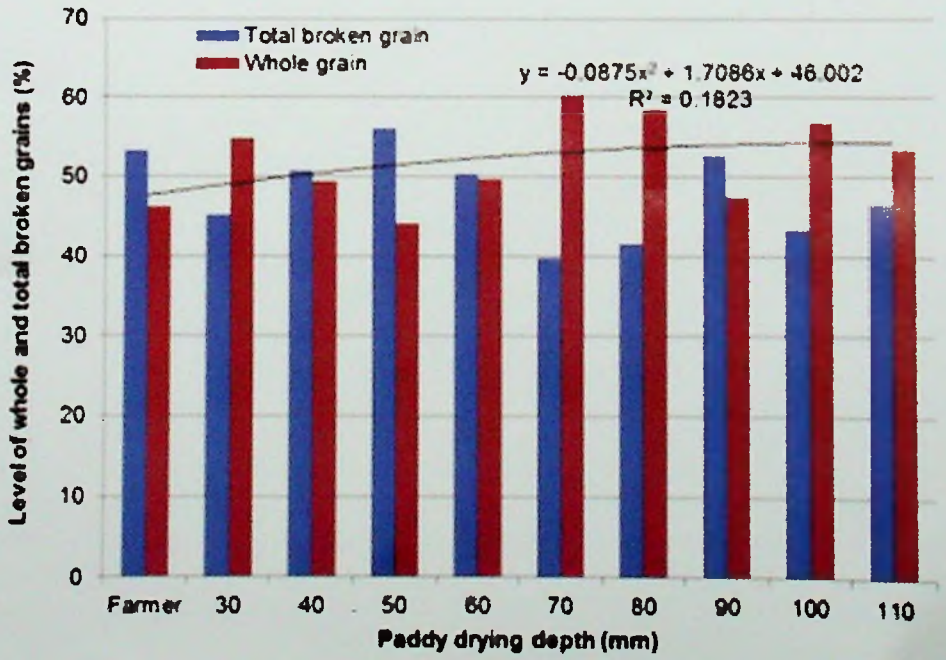


Figure 6. Whole and total broken grain levels at different drying depths (%).

Discussion

Farmers and entrepreneurs will always remain in business if their enterprises are competitive in the market. Levels of mill recovery and whole grain in milled rice are one of the important factors that determine profitability of rice milling businesses.

From this study, it is observed that drying depths of 70 mm and 80 mm presented the best mill recovery and whole grain level for the *Kaiso* variety. This became evident because, paddy dried at these drying depths experienced the lowest fissure level.

Results of similar studies done in South East Asia showed different drying depths. In Philippines, the recommended paddy drying depth using open sun drying method is only 20-40 mm (IRRI, 2009b). In the other South East Asian countries such as Indonesia, the highest whole grain level (56.6 – 57.5 %) was observed at drying depths of 70mm (MAFFJ, 1995) which closely relates to the value (60.3 %) obtained at 70mm drying depth during this study. The differences in the obtained results with that of Philippines could be attributed to mainly weather differences.

The Philippine's weather during harvesting season is generally hot (31 – 33 ^{0}C) and humid with vapour pressure: 22.5 – 23.2 mmHg (FAO, 2005) making drying difficult. To allow drying of paddy, small drying depths need to be used. The mean drying temperatures 25 – 29 ^{0}C, relative humidity of 50 – 68 % (vapour pressure: 14.10 – 20.7 mmHg) experienced in Eastern Uganda (Table 1) during the drying period induces high drying rate, which has devastating effects on mill recovery and whole grain levels.

To reduce the high drying rate, bigger drying depths has to be used in Uganda as opposed to the smaller drying depths in Philippines. The differences in rice varieties used in the two studies could be another source of the variations in the results.

Conclusion

The ultimate objective of this study was to determine the best paddy drying depth using open-sun drying method for the predominant *Kaiso* swamp rice variety. Considering the results observed in this study for fissure levels in paddy, mill recovery, milled rice physical loss and whole grain levels, the best drying depths for Kaiso variety using open sun drying is between 70 - 80mm. At these depths farmers and other entrepreneurs are able to reduce physical grain loss during milling by 9.2 % and improve level of whole grain in milled rice by 14.1 %.

Most consumers especially those in Uganda require rice with very high level of whole grain. However, the cottage rice milling factories which are majority in Uganda do not grade rice. The 14.1 % increment in whole grain level is a good achievement because farmers and entrepreneurs will make more money.

Even if there was grading, an entrepreneur who dried his/her paddy at 70 mm drying depth will attract more customers and get more money. Unfortunately at these drying depths, the paddy takes 7 - 8 days to dry.

Farmers usually do not have such time, it is labour intensive to dry paddy and movement of paddy in and out of the store increases physical grain loss during drying. This long drying duration might make it difficult for farmers to adopt the method. Further research is still necessary to reduce the drying time to a manageable level for farmers.

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