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Rice milling quality as affected by drying method and harvesting time during ripening in wet and dry seasons

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ABSTRACT

Head rice recovery is known to decrease with the delay in harvesting during ripening, but this effect may differ between wet season (WS) and dry season (DS) and among different paddy drying methods. In five experiments, rice was harvested by hand between 25 and 45 days after flowering in DS and WS when temperature around harvest was slightly above and below 30°C, respectively. The highest head rice recovery was generally obtained when rice was harvested at 25 days after 75% flowering. Delaying harvest to 30 days resulted in significant reduction in head rice recovery in 3 out of 7 cases and further delay to 35 days resulted in significant reduction in 8 out of 10 cases. For the crops harvested 25 days after flowering and dried with a flatbed dryer head rice recovery improved compared to sun drying in two experiments. When harvesting was delayed, sun drying tended to reduce head rice recovery compared to artificial drying. Sun drying only in the morning also improved head rice recovery compared to drying for the whole day. For a given drying method, head rice recovery decreased with increase in heat sum from flowering to harvest. It is concluded that rice crops should be harvested in both DS and WS around 25 days after 75% flowering when heat sum with base temperature of 10°C was around 450–500 degree-days. If an artificial dryer is not available, rough rice should be sun dried only in the morning with frequent stirring and mixing to promote more even drying.

Abbreviations: WS: wet season; DS: dry season

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Artificial drying; sun dry; delay harvesting; milling quality; head rice recovery

1. Introduction

Important physical quality measures of rice grain include total milled rice and head rice recovery, both of which are important characteristics particularly for marketing purposes. Head rice recovery is the portion of milled rice that are whole kernel with more than 75% length, as a percentage of rough rice weight. As Laos and other countries in the Mekong region, move from subsistence-oriented rice cultivation to more market-oriented production, high head rice recovery is required. To achieve the highest percentage of head rice recovery after milling, several harvesting and post-harvest techniques are required such as optimum time of harvesting, proper drying and good storing facility before milling. Siebenmorgen et al. (2013) reviewed preharvesting factors affecting head rice recovery including harvesting time and moisture content at the time of harvest.

Harvesting time greatly affects head rice recovery. Delay in harvesting time generally increases broken rice and reduces head rice recovery. This is related to reduced grain moisture content at the time of

harvesting (Thompson & Mutters, 2006). The fissuring of rice grain can occur in late harvested, low moisture content grain as a result of adsorption of moisture by the grain in high humidity or rainfall conditions (Jindal & Siebenmorgen, 1994). However, if grain is harvested too early, grain is immature and grain yield has not achieved its maximum. Counce et al. (1990) showed head rice recovery started to decline after 4 weeks after heading, but the actual times of decline depended on soil type and timing of drainage. Recent work conducted in wet season (WS) crops in Cambodia under similar rice growing conditions to Laos showed a sharp decline in head rice recovery when harvest was conducted at 35 compared to 25 and then further decline when harvest was delayed to 45 days after 50% flowering in both hand and combine harvested crops (Bunna, Sereyvuth, et al., 2018). At 35 days after flowering, grain moisture content was still high (24–25%), yet grain fissuring was observed at harvest, and this appeared to have caused kernel to break during milling which resulted in reduced head rice recovery. In Laos,

glutinous rice is grown most commonly in the WS (Schiller et al., 2001). In areas where irrigation water is available, dry season (DS) crops may be grown but their thermal environment differs greatly (Sipaseuth et al., 2009). Thus, in the WS, crops are planted after the temperature decreases with the commencement of the WS around June and temperatures remain similar to maturity. In contrast, in the DS, planting takes place in the coldest time of the year and temperatures gradually increase during the season of April/May when the crop is harvested under very high daily mean temperatures exceeding 30°C (Schiller et al., 2001; Sipaseuth et al., 2009). Thus, milling quality particularly head rice recovery may be affected by high temperature during grain filling (Abayawickrama et al., 2017; Counce et al., 1990). While yield may be similar between WS and DS in Laos (Sipaseuth et al., 2009), DS crops are also subjected to early season rainfall events at the time of harvesting, and this could also affect rice grain quality. Thus, the harvesting time may be more critical in the DS with high temperature and possible rainfall events prior to harvesting compared with WS. In temperate areas and in the WS in the tropics, rice matures under conditions of decreasing temperature, and most studies on the effect of harvesting time on milling quality were conducted under these conditions, e.g. in California, Thompson and Mutters (2006), Bunna, Sereyvuth, et al. (2018) in Cambodia. One objective of the present work was to pinpoint optimum harvest time by harvesting crops at 5-day intervals from 25 days after flowering in both WS and DS. DS crops require irrigation and hence, they are grown in much smaller areas in the Mekong region including Laos and Cambodia but they tend to be traded more often than the WS crops (Fukai & Ouk, 2012) and hence high head rice recovery is required.

Proper drying technique to reduce moisture content in rough rice is a key factor in improving milling quality. Sun drying usually increases broken rice percentage, if drying is conducted for a whole day. If temperature of the grain gets too high, head rice recovery is reduced (Truong et al., 2012). Thus, shading around midday and stirring the bed where the rough rice is piled would reduce the damage to the grain (Meas et al., 2011; Paterson et al., 2013). Faster drying through increased air circulation may reduce the time of drying but often increases the damage to the grain (Meas et al., 2011). A similar point was also made by Imodu and Olufayo (2000) who found that sun drying on a concrete floor took a longer time than on a matt surface; however, it produced higher head rice recovery. In the present study, different sun drying methods were compared with the artificial drying using a flatbed dryer for grains harvested at different times during ripening.

2. Materials and methods

Samples were collected from both research station experiments and drying method work from villages.

2.1. Time of harvest and drying method experiments

There were five experiments conducted to examine the effect of harvesting time during ripening and drying method prior to milling. All experiments were conducted at the Rice Research Centre, Vientiane, Lao PDR, using TDK8, a common commercial rice variety. All experiments were planted using a transplanter (Experiment 1, 25 June 2014, Experiment 2, 10 January 2015, Experiment 3, 15 January 2016, Experiment 4, 28 June 2016, Experiment 5, 5 January 2017). Experimental size was 12 × 40 m. Fertilizer was applied at the recommended rate of 90:30:30 kg/ha of N, P₂O₅ and K₂O. The experimental plot was flooded by irrigation water from transplanting until 20 days after 75% flowering, i.e. 75% of panicles flowered. Key aspects of these experiments are shown in Table 1.

In Experiments 1–3, harvesting time spanned 25–45 days after 75% flowering. As 45 days after flowering was found to be too late for head rice recovery, Experiments 4 and 5 were harvested at 25, 30 and 35 days after flowering. At each time of harvest, three areas (replicates) of 2 m² each were harvested by hand within the experimental field, except in Experiment 5 where there was no replication. The samples were harvested, then threshed by hand and dried using either the flatbed dryer or sun drying (Plate 1). The flatbed dryer has a capacity of 1 t and was used for about 12 h to reduce grain moisture content to 14%. The temperature of grain varied from 38 to 41°C depending on the depth of flatbed dryer. In all experiments, a tarpaulin sheet was used for sun drying (sun drying method 1), while in Experiments 4 and 5, a nylon net was also used (sun drying method 2). In the sun drying, grains were piled to 2–5 cm thick and turned around and mixed every 2–3 h in Experiments 1–3, while shorter intervals of 2 h were adopted in Experiment 4 and 5. Maximum temperature during sun drying was 32°C and minimum temperature was 21.3°C with mean temperature of 28.3°C. When samples were dried to 14% moisture content in Experiment 1–4, they were milled to evaluate milling quality. From each sample, 125 g of paddy rice was used for the determination of milling quality. The procedure of milling quality determination commenced with dehulling the cleaned rough rice to remove the hulls using a bench-top husker (Satake, model no. THU-35, Hiroshima, Japan). Brown rice was then cleaned to remove the hulls not totally removed by dehulling. Polishing the brown rice then followed using a Satake rice polisher



Plate 1. Flatbed drying versus sun drying using tarpaulin at Pakpung village in Central Laos.

Table 1. Seasons, harvesting time treatments and drying method treatments of Experiments 1–5.

Experiment	Season	Time of harvesting (days after flowering)	Drying methods			
1	2014WS	25, 30, 45	Flatbed dryer	Sun drying 1a	–	
2	2014/15DS	25, 35, 45	Flatbed dryer	Sun drying 1a	–	
3	2015/16DS	25, 35, 45	Flatbed dryer	Sun drying 1a	–	
4	2016WS	25, 30, 35	Flatbed dryer	Sun drying 1a	Sun drying 2a	
5	2016/17DS	25, 30, 35	Flatbed dryer	Sun drying 1a,b	Sun drying 2a, b	

Sun drying 1: using tarpaulin sheet; sun drying 2: using nylon net; a and b: rough rice dried for whole day (10 h) and dried in the morning only (5 h) for 2 days, respectively.

(Satake, model no. TM05, Hiroshima, Japan) for 60 s, and the sample was separated to determine the head rice recovery (yield). Measures of milling quality determined included milled rice (%), hull (%), bran (%), head rice recover (%) and broken rice (%) on a weight basis.

In Experiment 4, milling took place 1, 10 and 20 days after drying to examine the effect of storage time on head rice recovery while in Experiments 1–3, milling took place immediately after rough rice drying. In Experiment 5, the sun drying duration was for 5 h from 8 am to 1 pm and repeated on the following day, or continuously for 9 h from 8 am to 5 pm. Milling was conducted 2 days and also 10 days after drying, and as there was almost no difference between these 2 times of milling for each treatment, they were thus considered replications.

2.2. Drying methods in villages

The work to compare drying methods of combine harvested rough rice was conducted on-farm with participation of farmers in five villages in Bolikhamxay and Khammouane provinces in Central Laos. In 2014/15DS, eight samples were collected after sun drying and eight samples from flatbed dryer. In 2015WS, 8 samples were taken from flatbed dryer and 10 samples from sun drying. In 2015/16DS, 6 samples were from flatbed dryer and 8 from sun drying. In each village, combine harvested rough rice was dried in a 4-t flatbed dryer or sun dried with tarpaulin sheets. Paddy was dried for about 10–12 h in a flatbed dryer to reduce moisture to 14–15%, while it took about 17–18 h under sun drying (dried from 8 am to

1 pm, and paddy thickness was 2–5 cm). Under sun drying, rough rice was mixed every 2–4 h and when rough rice was dried to 14% moisture content, the samples were collected for milling quality evaluation at RRC in Vientiane as described above.

Statistical analysis was conducted using a two-way analysis of variance with harvest time and drying method with three replications for all quality measures in each DS, while a one-way analysis was conducted in the WS. Village quality samples were analysed across 3 seasons utilizing 8–10 samples in an unbalanced analysis of variance using GenStat v17.

3. Results

3.1. Time of harvesting experiments

Figure 1 shows monthly mean temperature and rainfall in the experimental years of 2014–2017. Mean temperature increased from January to April during the DS experiments and exceeded 30°C in April during grain filling stage. Temperature from June to October during the WS experiments was about the same around 29°C. Rainfall increased sharply from April to May with the onset of the WS, and monthly rainfall exceeding 300 mm was maintained until September while it decreased sharply in October when the WS experiments were harvested. Table 2 shows the heat sum with base temperature of 10°C from flowering to each harvest and also mean daily temperature prior to each harvest for all experiments. Temperature was generally higher in the DS than in the WS, but DS temperature varied among the 3 years of testing. Experiment 3 in 2016DS experienced the highest mean temperature of around 33°

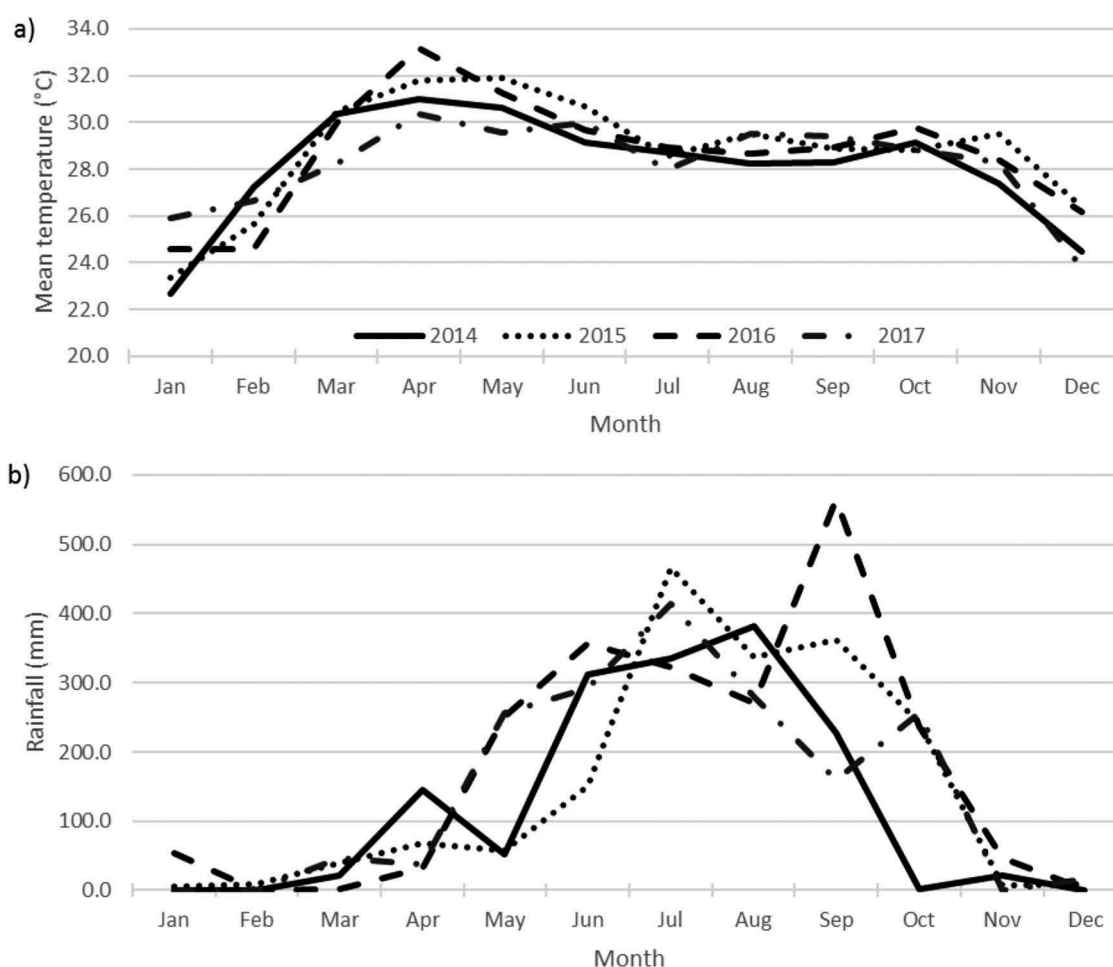


Figure 1. (a) Mean monthly temperature (°C); and (b) total monthly rainfall (mm) for 2014–2017.

Table 2. Heat sum (degree-days) from flowering to each harvest (a) and mean daily temperature (°C) for 15 days prior to each harvest, of 5 experiments.

Season	Experiment	Days after flowering			
		25	30	35	45
2014WS	1	470	567		849
2015DS	2	534	–	753	981
2016DS	3	569	–	796	1038
2016WS	4	480	582	676	
2017DS	5	487	590	700	
(b)		Days after flowering			
2014WS	1	28.5	29.2		28.8
2015DS	2	31.4	–	32.0	32.3
2016DS	3	33.5	–	32.4	33.3
2016WS	4	29.4	29.8	29.5	
2017DS	5	30.3	31.1	31.3	

C for the 2 weeks prior to harvest. On the other hand, Experiment 5 in 2017DS experienced rather cool temperature soon after flowering, and heat sum from flowering to maturity was only slightly higher and temperature prior to harvest only 1–2°C higher compared with WS.

When rough rice was sun dried on tarpaulins, head rice recovery decreased from between 27–37% down to 7–8% as harvest was delayed from 25 to 45 days after

Table 3. Head rice recovery in Experiments 1, 2 and 3 when rice was harvested 3 times during ripening and dried using sun drying and artificial dryer (sun dried only in Experiment 1).

Harvesting time (days after flowering)	Head rice recovery (%)				
	Seasons				
	14WS	14–15DS	15–16DS		
	Drying method				
	Sun	Dryer	Sun	Dryer	Sun
25	31.1	52.2	27.4	46.9	37.2
30	25.3	na	na	na	na
35	na	36.1	26.1	34.4	31.5
45	7.1	8.2	8.4	17.0	8.0
Mean	21.2	32.2	20.7	32.8	25.6
LSD5% (time)	5.9**		2.1**		2.5**
LSD5% (method)			1.71**		2.04**
LSD 5% (T × M)			2.96**		3.53*

na: Not available; *significant at $p < 0.05$; **significant at $p < 0.01$.

flowering (Table 3). When an artificial dryer was used in Experiments 2 and 3, head rice recovery was much higher between 47% and 52% at 25 days after flowering and this decreased to 34–36% and 8–17% at 35 and 45 days after flowering, respectively. Responses of other milling quality indicators to harvest time and drying methods were similar among the three experiments,

Table 4. Brown rice, milled rice and broken rice when rice was harvested 3 times during ripening and dried using flatbed dryer or sun-drying in 2014/15DS.

Time	Brown rice (%)			Milled rice (%)			Broken rice (%)		
	Dryer	Sun	Mean	Dryer	Sun	Mean	Dryer	Sun	Mean
25	77.7	76.3	77.0	64.4	60.7	62.6	12.2	33.2	22.7
35	76.0	77.6	76.8	62.6	61.2	61.9	26.5	35.1	30.8
45	74.7	75.2	75.0	55.1	57.0	56.1	46.9	48.6	47.7
Mean	76.1	76.4	76.3	60.7	59.6	60.2	28.5	39.0	33.7
LSD5% (time)	ns			0.96**			3.5**		
LSD5% (method)	ns			ns			2.85**		
LSD 5% (T × M)	ns			ns			ns		
CV%	0.4			4.4			10.2		

ns: Not significant; **significant at $p < 0.01$.

Table 5. The effect of drying method (sun drying with tarpaulin sheet or nylon net or use of dryer) and duration (5 or 10 h in the sun drying and 12 h in dryer) on head rice recovery of rice crops harvested at 25, 30 and 35 days after flowering.

Time of harvesting	Tarpaulin		Nylon		Dryer	Mean
	5	10	5	10	12	
25	48.9	43.6	45.7	44.1	44.7	45.4
30	35.0	28.4	49.5	44.8	44.4	40.4
35	24.7	17.0	37.3	22.8	43.1	29.0
Mean	36.2	29.7	44.2	37.2	44.1	38.3
LSD5% (time)						1.5**
LSD5% (method)						1.8**
LSD 5% (T × M)						3.4**

**significant at $p < 0.01$.

Experiment 5 conducted in 2016/17DS.

and the results of 2014/15DS only are shown in Table 4. There was no significant effect of treatments on brown rice, but milled rice decreased when harvest was delayed to 45 days after flowering. On the other hand, broken rice was significantly affected by both harvest time and drying method; there was a sharp increase in broken rice

with the delay in harvest time after 25 days after flowering and also broken rice increased greatly with sun drying compared with the flatbed dryer.

This effect of treatments on broken rice caused the variation in head rice recovery. This negative relationship between broken rice and head rice recovery is seen in all experiments, and the correlation between broken rice and head rice recovery was high, for example $R^2 = 0.96$ in 2016WS (Experiment 4).

In Experiment 4, there was significant interaction effect of harvest time and drying method for each milling time in head rice recovery (Figure 2). In general, harvesting at 25 days after flowering produced the highest head rice recovery, followed by harvesting at 30 days, and the least head rice recovery was achieved when rice was harvested at 35 days after flowering. However, there was significant interaction effect at each milling date. Thus, when milling was conducted immediately 1 day after rough rice was dried, head rice recovery was highest for crops harvested at 25 and 30 days after flowering and dried with artificial dryer and also harvested at 25 days and sun dried using nylon net. As milling was delayed to 10 days after drying, head rice recovery generally increased slightly when the crop was harvested at 25 and 30 days after flowering, but it decreased when harvested at 35 days after flowering, and hence the effect of harvesting date became greater. When milled at 20 days after drying, the head rice recovery range increased further in some treatments, and rice harvested 25 days after flowering and dried using artificial dryer produced the highest head rice recovery at almost 55%.

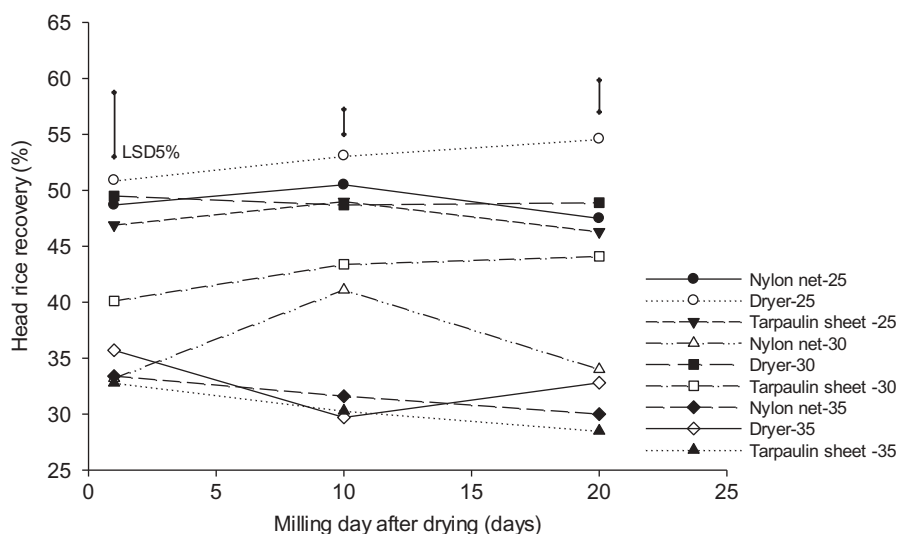


Figure 2. Change in head rice recovery as milling was delayed after drying time for 9 harvest time (25, 30 and 35 days after flowering) and drying method (nylon net, flatbed dryer and tarpaulin) treatments. LSD (5%) bars are also shown. Experiment 4 conducted in 2016WS.

In the 2016/17DS experiment (Experiment 5), milling after 2 or 10 days after drying had almost no effect on milling quality, and hence, they were used as two replications and mean values calculated. There was highly significant interaction effect of harvest time and drying method in this experiment (Table 5). Head rice recovery was similar among all treatments when rice was harvested 25 days after flowering, but as harvest was delayed, sun drying with tarpaulin resulted in lower head rice recovery than the other drying methods. Use of nylon net was effective in producing high head rice recovery at 30 days after flowering, but when the harvest was delayed to 35 days, it resulted in lower head rice recovery compared with the use of artificial dryer. Drying only in the morning (5 h) resulted in significantly higher head rice recovery than drying the whole day particularly when harvest was delayed. Nylon net produced higher head rice recovery than tarpaulin except when the crop was harvested at 25 days after flowering when the head rice recovery was similar.

With the increase in heat sum at later harvests, head rice recovery decreased linearly for both flatbed dryer and sun drying for the whole day using tarpaulin (Figure 3(a,b)). The correlation coefficient was higher in the flatbed dryer than the sun drying, indicating larger variation in head rice recovery in sun drying for a given thermal condition during grain filling. The large variation in head rice recovery under sun drying can be also seen when other sun drying methods are added in Figure 3(c).

3.2. Drying methods and grain quality of combine harvested crops in villages

The collection of samples from three seasons has shown consistent and significantly ($p < 0.01$) higher head rice recovery when dried with flatbed dryer than with sun drying with the overall mean of 45.3% compared with 35.7%. There was also highly significant interaction of season and drying method, and flatbed dryer was particularly advantageous in 2015WS compared with the two DS. The advantage of flatbed dryer in each season was almost solely accounted for by the smaller broken rice percentage, and mean broken rice was almost half of that in sun dried rice in 2015WS (Table 6). On the other hand, the advantage of flatbed dryer was smaller in milled rice and drying method did not have significant effect on brown rice.

4. Discussion

The current work which examined head rice recovery of hand harvested rice in Central Laos across five crop seasons identified that the optimum harvesting time for high head rice recovery was before 30 days after

75% flowering. This is suggesting an even earlier harvest than Bunna, Sereyvuth, et al. (2018), who indicated from their work in southern Cambodia, that rainfed lowland rice should be harvested by either hand or combine before 35 days after 75% flowering in the WS to achieve high head rice recovery.

In the current work, the delay in harvest from 25 to 30 days after flowering resulted in significant reduction in head rice recovery in 3 out of the 7 cases tested for crops with continuous whole day drying and milled immediately after drying. In these seven cases, mean head rice recovery was 44.3% and 37.9% for 25 and 30 days after flowering, respectively. Delaying harvest to 35 days after flowering resulted in significant reduction in head rice recovery in 8 out of 10 cases tested for crops with continuous whole day drying and milled immediately after drying. The mean head rice recovery of these 10 cases was 44.3% and 31.3% for 25 and 35 days after flowering, respectively. Thus, the work has demonstrated a rapid decline in mean head rice recovery after 25 days after flowering for rainfed lowland rice in the Mekong region. This indicates that the time of harvesting is critical particularly in the Mekong region where temperature is still high around harvesting time. Mean minimum temperature at the time of common harvesting in WS is 24°C in Cambodia (Bunna, Sereyvuth, et al., 2018) and 20°C in Laos (Sipaseuth et al., 2009) and 21°C during harvesting in the present experiments. These are higher than the corresponding temperature in the temperate regions, for example 15°C at Yanco, NSW, Australia (Farrell et al., 2006). In the WS, crops are commonly harvested 28–30 days after flowering in the Mekong region, but close observation and quick decision may be required after 25 days after flowering to achieve the highest head rice recovery possible.

Vongxayya et al. (2019) found in Vientiane, Laos, that head rice recovery was similar between WS and DS under artificial drying, but head rice recovery obtained under sun drying was lower in DS, and suggested that high air temperature in DS from preharvesting to milling may have caused more grain cracking in sun drying, resulting in more broken rice and lower head rice recovery in DS. The present work showed that head rice recovery decreased linearly with heat sum, and the relationship was unique across WS and DS. As temperature prior to the harvest was higher in DS than in WS by about 3°C in the experimental years, the optimum harvest time would be sooner after flowering by a few days in DS. The earliest harvest taken in the present experiments was 25 days after flowering in both seasons, and the heat sum was about 475 degree-days in WS. With mean temperature around harvesting time of 32°C in the DS, the same heat

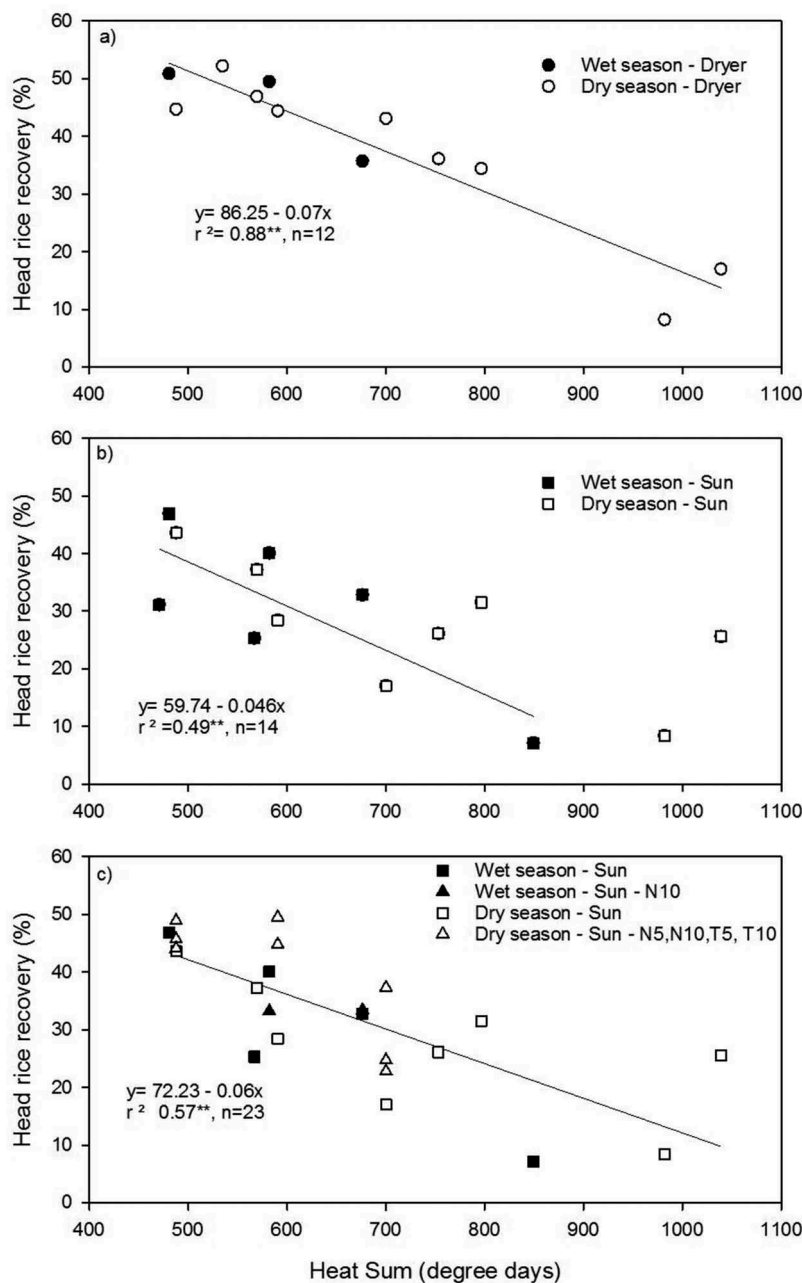


Figure 3. Relationship between head rice recovery (%) and heat sum (degree-days) for material dried via (a) mechanical dryer; (b) sun drying using a Tarpaulin; and (c) sun dried with various combinations of netting (N) and tarpaulin (T) and drying time in hours (5 or 10).

sum would be achieved in 22 days after flowering. In WS in Phnom Penh, Cambodia, the mean temperature for 15 days prior to harvest was 27.0–29.0°C (Bunna, Sinath, et al., 2019), which was slightly lower than 28.5–29.8°C recorded for WS and much lower than 30.3–33.5°C recorded for DS in the present experiments. The lower temperature in Cambodia was associated with later harvesting in November–early December compared with harvesting in October in the present WS experiments in Laos. The heat sum calculated with 10°C base temperature for the Cambodian case is about 420 and 500 degree-days for harvesting at 25 and 30 days after

flowering (Bunna, Sinath, et al., 2019). The head rice recovery at these two harvests were similar in their experiments, suggesting the maximum heat sum beyond which head rice recovery may decline would be around 500 degree-days. In temperate rice crops in southern NSW, Australia, the mean temperature during late grain filling period in March is about 20°C (Farrell et al., 2006), the maximum heat sum for maintaining the highest head rice recovery of about 70% is about 450 degree-days (Peter Snell, pers. comm.). Thus, the estimation of the present work of 475 degree-days would be close to those estimated in Cambodia and southern Australia.

Table 6. Comparison of rice milling quality of combine harvested rice dried using flatbed dryer or sun drying in villages across three seasons.

Season	Brown rice (%)			Mill rice (%)			Broken rice (%)			Head rice recovery (%)		
	Flatbed	Sun	Mean	Flatbed	Sun	Mean	Flatbed	Sun	Mean	Flatbed	Sun	Mean
2014–2015DS	77.3	76.9	77.1	64.2	62.4	63.3	19.7	24.4	22.1	44.5	37.9	41.2
2015WS	75.6	75.2	75.4	62.6	60.0	61.3	12.9	24.4	18.7	49.2	35.6	42.4
2015–2016DS	75.1	74.8	75.0	61.7	59.7	60.7	20.8	25.2	23.0	41.0	34.6	37.8
Mean	76.1	75.4	75.8	62.9	60.7	61.8	17.5	24.8	21.2	45.3	35.7	40.5
LSD5% (S)			1.37**			2.23*			1.61**			2.17**
LSD5% (D)			ns			1.82*			1.31**			1.77**
LSD5% (S × D)			ns			ns			2.28**			3.07**
CV%			2.46			4.93			10.22			7.34

S: Season; D: drying method; **significant at $p < 0.01$; *significant at $p < 0.05$.

Comparison of sun drying and artificial drying using the flatbed dryer has shown the general advantage of artificial drying; means of four experiments where comparison of artificial dryer and sun drying with tarpaulin for the whole day were 38.6% and 29.0%, respectively, across three harvesting times, and 48.7% and 38.8% for crops harvested at 25 days after flowering. This general advantage of the artificial dryer would be due to the use of constant heat without the excessive heat generated in the early afternoon with sun drying. Thus, in Experiment 5, head rice recovery increased from 29.7% to 36.2% for tarpaulin and from 37.2% to 44.2% as each sun drying duration was reduced from 10 to 5 h. The effect of reduced sun drying duration was particularly large when harvesting was delayed beyond 25 days, indicating high fissured grain at the time of harvesting would require more gentle method of drying. High temperature is known to affect head rice recovery (Truong et al., 2012, Wongpornchai et al., 2004). In a similar experiment in Cambodia where different methods of sun drying were examined, higher head rice recovery was found when the rice grain was shaded during the peak sun between 11 am and 2 pm (Meas et al., 2011). When grain was harvested at 25 days after flowering, there was no significant difference between nylon net and tarpaulin during sun drying, and this confirms the result of Meas et al. (2011). However, the present result shows that nylon net was better than tarpaulin in maintaining higher head rice recovery when harvesting was delayed and head rice recovery generally decreased. The fine mesh nylon net is commonly available in villages and sometimes used for drying rice. However, if rain comes grain can be exposed and may be spoilt, for example in some years rain comes early between late March and April. The tarpaulin on the other hand could be folded to prevent the grain being exposed to rainfall. Poor air ventilation with tarpaulin sheet compared with the nylon net may be related to the susceptibility of fissured grain to be broken at the time of milling. It thus appears that the harsher drying condition of tarpaulin over nylon net and sun drying over the artificial dryer cause fissured grain to be broken at milling, and hence

more constant steady heat is required in these cases. The results of Experiment 4 and 5 indicated that milling can be done after rough rice is stored for up to 10 days.

The flatbed dryer was used as a reference point for the head rice recovery obtained under constant artificial drying in comparison to sun drying. Flatbed dryers are commonly used in Vietnam for grain drying for high head rice recovery (Truong et al., 2011), but it is not used commercially in Laos. In our attempt to use it for demonstration purpose, the user was charged about 40USD/4 t. The purchasing cost was around 5500USD. While much more expensive, some large mills have started to install high capacity vertical dryers where about 25 t of rough rice could be dried overnight. The number of these dryers in Central Lao province of Khammouane increased from 1 to 4 between 2015 and 2017 (Fukai et al., 2019).

Participating farmers made comments that sun drying required much more work, while flatbed dryer did not require constant attention. It should be pointed out that the sun drying was conducted throughout the day, and the higher head rice recovery may be obtained if sun drying had been done in the morning only (8 am–1 pm), but under these circumstances, it would take 3 days for drying to reduce moisture content to 14%. Improvement in techniques in both drying methods could reduce broken rice percentage.

5. Conclusion

Time of harvest was the main factor affecting head rice recovery, and when the harvest was delayed to 35 and 45 days after 75% flowering, broken rice increased greatly, while head rice decreased sharply. The optimum time for harvesting was about 25 days after 75% flowering to achieve the highest head rice recovery. In addition, the flatbed dryer generally increased head rice recovery after milling compared with sun drying. However, sun drying only in the morning and avoiding afternoon heat would help to achieve higher head rice recovery. Therefore, optimum time of harvesting with appropriate drying

technique could increase head rice recovery and could meet the white rice standards for market, both locally and internationally. In areas where an artificial dryer is available, this would optimize head rice recovery, but with improvements in sun drying method, it was possible to increase head rice recovery.

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