



Effects of introduction of combine harvester and flatbed dryer on milling quality of three glutinous rice varieties in Lao PDR

Khamtay Vongxayya, Darunee Jothityangkoon, Danuphol Ketthaisong, Jaquie Mitchell, Phetmanyseng Xangsayyasane & Shu Fukai

To cite this article: Khamtay Vongxayya, Darunee Jothityangkoon, Danuphol Ketthaisong, Jaquie Mitchell, Phetmanyseng Xangsayyasane & Shu Fukai (2019) Effects of introduction of combine harvester and flatbed dryer on milling quality of three glutinous rice varieties in Lao PDR, Plant Production Science, 22:1, 77-87, DOI: [10.1080/1343943X.2018.1532303](https://doi.org/10.1080/1343943X.2018.1532303)

To link to this article: <https://doi.org/10.1080/1343943X.2018.1532303>



© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 16 Oct 2018.



Submit your article to this journal [↗](#)



Article views: 1617



View related articles [↗](#)



Citing articles: 5 View citing articles [↗](#)

Effects of introduction of combine harvester and flatbed dryer on milling quality of three glutinous rice varieties in Lao PDR

Khamtay Vongxayya^{a,b}, Darunee Jothityangkoon^a, Danuphol Ketthaisong^a, Jaquie Mitchell^{id}^c, Phetmansyeng Xangsayyasane^b and Shu Fukai^c

^aDepartment of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand; ^bNational Agriculture and Forestry Research Institute, Rice Research Center (RRC), Vientiane, Lao PDR; ^cSchool of Agriculture and Food Sciences, The University of Queensland, QLD, Australia

ABSTRACT

Mechanization is required to increase labour productivity and improve grain quality for rainfed lowland rice in Lao PDR and neighbouring countries. An experiment was conducted in dry season in 2016 with three rice varieties and also in wet season in 2017 with two varieties to investigate the effect of introduction of combine harvester and flatbed dryer on milling quality of glutinous rice. The treatments were different harvest methods (hand and combine harvester), drying methods (sun and forced air drying with flatbed dryer) and storage period up to 6 months. Head rice yield (HRY) improved greatly with forced air drying with mean HRY of 46.1% compared to 28.8% in sun drying. Milling quality of grain harvested by combine was similar to that of hand-harvested crop. The results also revealed large difference in HRY between varieties; mean HRY across two seasons was 40.1% and 27.1% for Thadokkham (TDK8) and TDK11, respectively. These treatment effects and also their interactions on HRY were strongly related to the proportion of broken rice. HRY declined from 39.4% to 35.4% with 4-month storage, but there was no further reduction with 6-month storage. This study showed that the milling quality of glutinous rice improved greatly with the introduction of flatbed dryer but only little with combine harvester. Milling quality also varied greatly among varieties and slightly with storage period. Further study is required to investigate physiological and morphological characteristics of varieties and post-harvest methods that determine the milling quality of rainfed lowland rice.

Abbreviations: HRY: head rice yield; BR: brown rice; MR: milled rice; MC: grain moisture content; TDK: Thadokkham; WS: wet season; DAP: days after planting; RRC: Rice Research Center; H: harvest; D: drying; S: storage

ARTICLE HISTORY

Received 4 April 2018
Revised 13 September 2018
Accepted 23 September 2018

KEYWORDS

Rice variety; forced air drying; milling quality; storage periods and head rice yield

1. Introduction

Glutinous rice also called sticky or waxy rice is characterized by the opaque appearance or milky colour and very low amylose content, with the endosperm starch consisting mainly of amylopectin (Bean, Esser, & Nishita, 1984). It is commonly grown in northeast Thailand and Lao PDR, and the latter has the highest per capita production of glutinous rice (Schiller, Hatsadong, & Doungsila, 2006). The total rice production in Lao PDR is about 3.5 million tons, of which more than 90% is glutinous. The percentage of wet season (WS) rice production is 80%, dry season (DS) rice 15% and upland rice 5% (DAO, 2012). Most rice is grown in the WS under rainfed conditions but some glutinous rice is also grown in irrigated environments in the DS (Vongphachanh, 2016).

The rice quality is mainly determined by physical and chemical indices including amylose content (Juliano,

1985). Milling quality particularly head rice yield (HRY) has become important with the increased commercialization and marketing of rice in Lao PDR and neighbouring countries such as Thailand, Vietnam and Cambodia while it was not a major concern to rice farmers in subsistence agriculture (Bunna et al., 2018). Milling quality of rice grown during the DS is particularly difficult to maintain as the crop is harvested in late April or early May and often encounters early rain and proper drying is required (Juliano & Duff, 1991). Rice quality is dependent on the rice variety and is also affected by the crop production environment, harvesting and post-harvest practices including processing, milling systems, storage conditions and storage periods (JICA, 2015).

Combine harvester was introduced only recently in Lao PDR to save labour cost and counters the reduced labour availability in rural areas. Combine harvesting service is spreading in Central Laos as it provides higher

return to farmers compared to traditional hand harvesting (Xangsayasane et al., 2019). Combine grain loss in the field is comparable to hand-harvested crops when grain loss during threshing is added to that harvested by hand (Xangsayasane et al., 2019; Bunna et al., 2018). The combine harvester has higher speed to harvest grain resulting in more damage grains and slightly lower HRY (Andrews, Siebenmorgen, Vories, Loewer, & Mauromoustakos, 1993). Bunna et al. (2018) also found slightly higher HRY in hand-harvested crops than in combine harvested crops in WS in Cambodia. However, their work was conducted on non-glutinous rice, and also their sun drying conditions were different for combine and hand-harvested crops.

Hand-harvested rice crops are commonly sun-dried in the field before threshing. Combine harvester not only harvests crops but also thresh, and rough rice can be dried in the sun on a concrete floor. Grain may crack during the process as dried grain adsorbs water, with subsequent breakage during threshing and milling (Calderwood, Bollich, & Scott, 1980; Jindal & Siebenmorgen, 1994). However, HRY of sun-dried rough rice may increase greatly if grain is stirred frequently and kept under shade during the time of intensive solar radiation (Meas, Cleland, Bronlund, Mawson, & Hardacre, 2013; Meas et al., 2011). Artificial drying in protected conditions with constant supply of heat and constant humidity conditions can reduce cracking and subsequent breakage of grains, particularly if high moisture grains are dried under low humidity conditions (Banaszek & Siebenmorgen, 1990). Combine harvested paddy can be dried in the sun using a mat or dried artificially using mechanical dryer (Xangsayasane et al., 2019) and proper drying techniques to reduce moisture content in rough rice are a key factor in improving milling quality and head rice recovery and hence its commercial value.

Grain is subject to deterioration if it is not properly stored. During storage, the rice may have changed physical quality such as yellowness, and head rice and also chemical quality depending on variety, chemical components and surrounding conditions (Alisa, Benjavan, Sansanee, & Chanakan, 2013). Storage of low moisture content grains can reabsorb moisture leading to the development of hydro stresses in the rice kernel, resulting in fissure formation causing eventual reduction in HRY (Hashemi, Haque, Shimizu, & Kimura, 2008). During milling, kernels with fissures tend to break, leading to lower HRY recovery.

HRY may also vary among different varieties. As milling duration increases, head rice decreases, but the relationship is variety dependent (Yadav & Jindal, 2008). They mentioned HRY of leading Thai variety KDML105 decreased much faster than any other Thai

varieties they examined. Grain shape including length and the ratio of grain length to width also affects HRY (Zhou et al., 2015). Among indica genotypes, those with high amylose content tended to have high HRY (Zhou et al., 2015). Most Lao varieties are similar in shape and have low amylose content. Thadokkham varieties (TDK) are most common and cultivated in the central and southern Laos, and TDK8 is considered as the leading variety while TDK11 is recommended for unfavourable growing conditions (Inthapanya et al., 2012). More recently, VTE450-2 variety was released after extensive participatory variety selection process (Mitchell, Sipaseuth, & Fukai, 2014) and is almost exclusively grown in the Vientiane region.

The objective of this study therefore was to determine the magnitude of effect of harvest and drying methods and storage period on the HRY of three varieties, TDK11, TDK8 and VTE450-2, and hence to identify factors most affecting grain quality. The work will direct future research efforts to improve grain quality for rice marketing purposes.

2. Materials and methods

Two experiments were conducted in the experimental farm of Rice Research Centre (RRC), Vientiane Capital, Lao PDR in DS 2016 and WS 2017 to investigate the effects of harvesting method, drying method and storage period on milling quality of three glutinous rice varieties.

2.1. Experimental design

Treatments common in both seasons were two harvesting methods (hand and combine) and two drying methods (sun and forced air). Two varieties (TDK8 and TDK11) were also used in both seasons, while VTE450-2 was also included in the DS. There were also four storage periods of dried paddy up to 6 months in DS while in the WS, dried paddy was milled immediately after drying. Split-split-plot design was used in both seasons. Harvest method was treated as the main plot, drying method as sub-plot and storage period as sub-subplot. The control treatment was considered as hand harvested, sun-dried with no storage period, and the effect of combine harvesting, forced air drying and storage was evaluated against HRY obtained in the control.

2.2. Cultural practice and weather conditions

Three paddy fields were used to accommodate three varieties in DS and two paddy fields for two varieties in WS. Each paddy field was about 2400 m² with a

plot size of $5.5 \times 50 \text{ m}^2$ (eight plots per variety to accommodate two harvesting methods with four replications in DS and six plots per variety with three replications in WS). The sowing date was 24 December 2015 and transplanting 22–23 January 2016 for DS, and 22 June and 22–23 July 2017 for WS.

Experimental area was first ploughed and 2 weeks later ploughed again and was harrowed and levelled for hand transplanting. Three to four seedlings were transplanted per hill to a depth of 3–4 cm, and hill spacing was $25 \times 25 \text{ cm}$. Fertilizer was applied at a rate of 90–30–30 kg/ha (N, P_2O_5 , K_2O). The basal fertilizer was applied at a rate of 30–30–30 kg/ha (N, P_2O_5 , K_2O) and top dressed with urea at 25 and 45 days after transplanting at a rate of 30 kg N/ha.

Experimental area was irrigated after transplanting, and standing water of 5–10 cm depth was maintained until the irrigation supply was cut-off by Central Irrigation Centre on 2/5/2015 and 13/10/2017; this coincided with approximately 2 weeks before harvesting. Pests and diseases were monitored and controlled when necessary. The experimental plots were kept free of weeds by hand weeding during the whole experimental period.

Daily weather conditions during the crop growing seasons (2016 DS and 2017 WS) and during storage of the 2016 DS crop were collected from the Central Weather Bureau at the Rice Research Center. The daily weather conditions in 2016 DS during crop growth, at harvest and during storage in the WS are depicted in [Figure 1\(a\)](#). At planting and the first 2 months of the 2016 (DS) crop growing season, average daily temperatures were $24.6 \pm 0.48^\circ\text{C}$ with a maximum of $29.6 \pm 0.56^\circ\text{C}$ and a minimum of $16.7 \pm 0.40^\circ\text{C}$ and a relative humidity of $65.3\% \pm 1.14\%$. As the season progressed, temperatures rose and by harvest in May, the daily maximum and minimum temperatures and relative humidity were on average $37.3 \pm 0.45^\circ\text{C}$, $24.4 \pm 0.49^\circ\text{C}$ and $61.7\% \pm 1.54\%$. The early WS rain began in mid-May just after the harvest of TDK11 (9 May). Thus, TDK8 and VTE-450-2 were exposed to some light showers, this was only 1.7 mm rainfall 1 day prior to harvest of TDK8 (16 May), but a total of 37 mm rainfall occurred over 4 days in the week before the harvest of VTE450-2 on 22 May.

During the first 2 months of storage in the WS of 2016, the daily maximum and minimum temperatures and relative humidity were on average $32.2 \pm 0.28^\circ\text{C}$, $23.2 \pm 0.20^\circ\text{C}$ and $77.1\% \pm 0.90\%$, respectively, and between 2 and 4 months of storage, the ambient conditions were similar ($32.9 \pm 0.20^\circ\text{C}$, $23.7 \pm 0.13^\circ\text{C}$ and $72.5\% \pm 0.80\%$), while they were somewhat reduced between 4 and 6 months ($31.4 \pm 0.21^\circ\text{C}$, $19.7 \pm 0.26^\circ\text{C}$,

$67.5\% \pm 0.70\%$), particularly minimum temperature and relative humidity.

For the 2017 WS crop, [Figure 1\(b\)](#) during harvest time between the end of October and early November, the average temperature was $28.2 \pm 0.21^\circ\text{C}$, while maximum and minimum temperature were $31.6 \pm 0.30^\circ\text{C}$ and $21.2 \pm 0.30^\circ\text{C}$ with a relative humidity of $66.7\% \pm 0.62\%$ with the last rainfall event occurring on 17th October, 11 days prior to the first harvest.

2.3. Harvesting treatments

Harvesting was conducted when 80% of panicles on a plot basis were of golden brown appearance (based on biweekly field checking). Each variety was harvested by hand or by combine harvester (Kubota Model DC70). The combine harvester was tested on-farm for six seasons. It has a capacity of harvesting 5 ha/day or 0.6 ha/h under favourable conditions and 3 ha/day or 0.4 ha/h under unfavourable conditions such as lodged crops. Harvesting in the DS all took place in May. TDK 11 was harvested on 9 May in hand harvest (137 DAP) and on 10 May for combine harvest (138 DAP), TDK 8 was harvested on 16 May (144 DAP) for hand harvest and combine harvest, respectively, and VTE450-2 was harvested on 22 May (150 DAP). However, the combine did not function properly on the last day and hence only hand harvesting results are available for VTE450-2. In DS, hand harvest was done using sickles to cut the plants and threshed by treading and using a wooden board, and the paddy was transported for drying. In WS for hand harvesting, plants were cut and dried in the field for 2 days, then threshed by mechanical thresher (Kasetphattana Model KPE-4). Harvesting in WS took place in late October to early November, with TDK11 harvested on 28 October (128 DAP) and TDK8 on 6 November (137 DAP), respectively.

2.4. Drying method treatments

Threshed paddy was dried immediately either in the sun or using forced air until 14% moisture content (wet basis) was obtained. For WS hand-harvested crops, the plants were dried in the field for 2 days before threshing, but the moisture content of paddy was still above 14%, and hence further drying was required. For combine harvested crops in both seasons, and also hand-harvested crops in DS, initial moisture content at the beginning of drying treatment period was much higher and hence drying took longer compared to the WS hand-harvested crops.

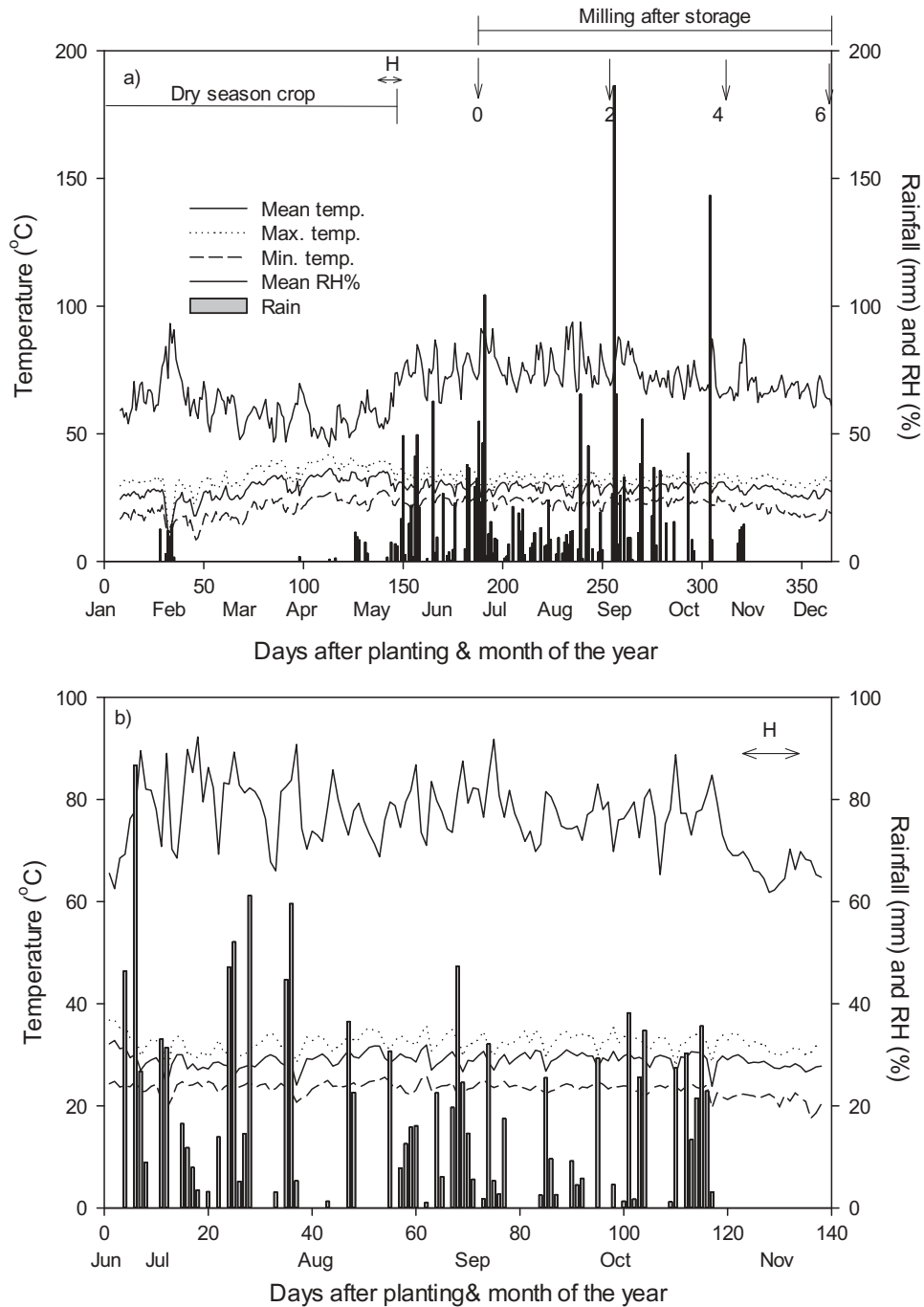


Figure 1. Daily mean, maximum and minimum air temperature, rainfall and relative humidity during the dry season crop (December–May), harvesting (H), storage and time of milling (indicated by arrows) from June to December, 2016 (a) and during the crop growing season in wet season 2017 (b).

2.4.1. Sun drying

For both seasons, in each harvesting treatment, 40 kg of paddy/replication for sun drying was taken and spread on a plastic mat at 1–3 cm thickness and dried in the sun from 9am to 4pm. The daily minimum and maximum air temperature at the time of drying were 26.5–38.6°C for DS and 20–33°C for WS.

2.4.2. Forced air drying

The mechanical dryer in RRC with a drying capacity of 2 t was used for this treatment. In this study, forced air drying was used without heating. For each harvest treatment, 125 kg of paddy per replication was put into a net with four replications (500 kg) and placed in a drying bin to 20–30 cm thickness and the blower forced dry air to be

distributed through the bin to dry grain. Drying rate was typically around 0.5–1% moisture removal per hour.

2.5. Storage

After drying and cleaning, the paddy was divided into four bags (replications) per treatment, each bag contained 15 kg. They were stored in the seed separator house at RRC under ambient temperature for up to 6 months from June to December 2016. Weather conditions during storage are reported in the results section. The paddy samples were milled every 2 months to determine the milling quality. The storage treatments were utilized only in the DS experiment. In WS 2017, paddy was milled immediately after drying, and milling quality was determined.

2.6. Measurements

At each time of milling, paddy samples were taken from the top, centre and bottom of the bags for analysis of milling quality and grain moisture content. The moisture content was measured using a handheld Kett-Riceter M401 moisture meter. Paddy weighing 125 g was dehulled using a bench-top husker (model THU-35, Satake, Hiroshima, Japan). The brown rice was cleaned to remove the hulls not totally removed by dehulling. The brown rice was then polished using a Satake rice polisher for 30 s (model TM05, Hiroshima, Japan) and the milled sample was separated to whole grain and broken grain; HRY was defined as milled rice having kernel length of at least 80% of its original

length. Milling quality of brown rice (%), milled rice (%), head rice (%) and broken rice (%) was then determined on a weight basis and presented as a percentage of rough rice.

2.7. Data analysis

The analysis of variance (ANOVA) was performed for the split–split plot design and split plot design using STAT 10. Mean comparison was made using the least significant difference (LSD) at $p < 0.05$. The data for combine harvested VTE450-2 in DS were not available. Therefore, for DS, two ANOVAs were conducted; one for all the three varieties for hand-harvesting only, and the other for each variety for hand and combine harvesting together.

3. Results

3.1. Milling quality of hand and combine harvested crops in DS

The effects of harvest method, drying method and storage period on milling quality of hand and combine harvested crops are shown in Table 1. TDK11 had poorer milling quality compared with TDK8; brown rice was only slightly lower, but difference increased in milled rice and particularly in HRY. The large decrease in HRY was associated with much higher broken rice in TDK11. Artificial drying using forced air drying produced much higher HRY than the sun drying. Forced air drying resulted in only small increase in brown rice and milled rice

Table 1. Milling quality of two rice varieties (TDK11 and TDK8) produced in dry season 2015–2016, in response to different harvest methods, drying methods and storage duration (split–split plot design).

Factors	TDK11					TDK8				
	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)
Harvest methods (a)										
Hand harvest	76.17a	59.97a	25.61b	34.37a	13.74a	78.31a	65.54a	43.95a	21.59b	13.91a
Combine harvest	76.96a	61.45a	28.75a	32.70a	13.19b	78.05a	66.16a	37.29b	28.87a	13.72a
Drying methods (b)										
Sun drying	75.98b	58.98b	16.80b	42.18a	13.35a	78.04a	65.28b	34.29b	30.99a	13.90a
Forced air drying	77.14a	62.45a	37.55a	24.89b	13.58a	78.32a	66.42a	46.94a	19.47b	13.72a
Storage periods (c)										
0 month	77.88a	63.78a	29.71a	34.07a	12.67c	79.1 a	66.84ab	42.95a	23.89c	13.47c
2 months	77.15ab	61.43b	27.11b	34.32a	13.79b	78.69b	67.04a	42.77a	24.27bc	13.88b
4 months	74.71c	56.97c	25.16c	31.81b	14.58a	76.47c	63.40c	38.18b	25.22b	14.58a
6 months	76.52b	60.68b	26.74b	33.94a	12.81c	78.41b	66.10b	38.56b	27.54a	13.33a
F-test										
Harvest (H)	ns	ns	**	ns	*	ns	ns	**	**	ns
Drying (D)	**	**	**	**	ns	ns	**	**	**	ns
Storage (S)	**	**	**	*	**	**	**	**	**	**
H × D	ns	ns	ns	ns	ns	ns	*	**	*	**
H × S	*	ns	**	ns	ns	ns	ns	ns	ns	ns
D × S	ns	ns	*	*	ns	ns	ns	**	**	ns
H × D × S	ns	ns	ns	ns	ns	ns	ns	*	ns	**
CV (a) %	1.51	3.46	4.02	7.10	3.48	0.77	1.78	1.40	3.14	1.78
CV (b) %	1.30	3.90	7.10	10.06	2.81	0.73	1.01	5.04	8.45	2.43
CV (c) %	1.49	3.97	5.62	6.79	2.22	0.77	1.76	4.24	4.24	2.08

BR: Brown rice; MR: milled rice; HRY: head rice yield, broken rice; MC (grain moisture content).

ns: Not significant. *,**Significantly different at $p \leq 0.05$ and 0.01, respectively.

Means followed by different letter(s) are significantly different by LSD at $p \leq 0.05$

proportion, and the larger HRY was mainly related to the reduced proportion of broken rice.

HRV of TDK11 decreased from 29.7% to 25.2% with storage period up to 4 months but it did not decrease further with the storage to 6 months. There was no significant decline in brown rice or broken rice with 2 months storage, but there was by 4-month storage. Grain moisture content was highest after 4 months storage, which coincided with the high humidity of the WS, while it was lowest after 6-month storage, which coincided with low humidity in the beginning of the DS. HRY of TDK8 decreased from 42.9% to 38.2% with storage period up to 4 months but it was similar at 6 months. The reduction in HRY was accompanied by an increase in broken rice, and a reduction in brown and milled rice proportions also; milled rice proportion decreased from 66.84% to 63.4% with 4-month storage.

There were significant two-way interactions of harvest by storage period and drying by storage period for TDK11. HRY was higher when rice was harvested by

combine than hand. When hand-harvested rice paddy was stored at ambient temperature, HRY declined in the first 2 months of storage after which no further decline was observed. However, for combine harvested rice paddy, there was a gradual decline in HRY until 4 months. For both hand and combine harvested crops, HRY increased from the 4- to the 6-month storage (Figure 2a). The HRY of TDK11 in forced air drying was higher than sun drying (37.6% vs. 16.8%) and with forced air drying during storage of combine harvested paddy, HRY decreased from 0 to 4 months, whereas HRY under sun drying reduced at 2 months with no further reduction with storage time (Figure 2b). There was a significant interaction of harvest method by drying method by storage period for TDK8 (Figure 2c). HRY of hand and combine harvested paddy was higher when rice was dried using forced air compared with sun drying. In both drying methods, HRY was maintained for the first 2 months but declined at 4 months with no further decline observed.

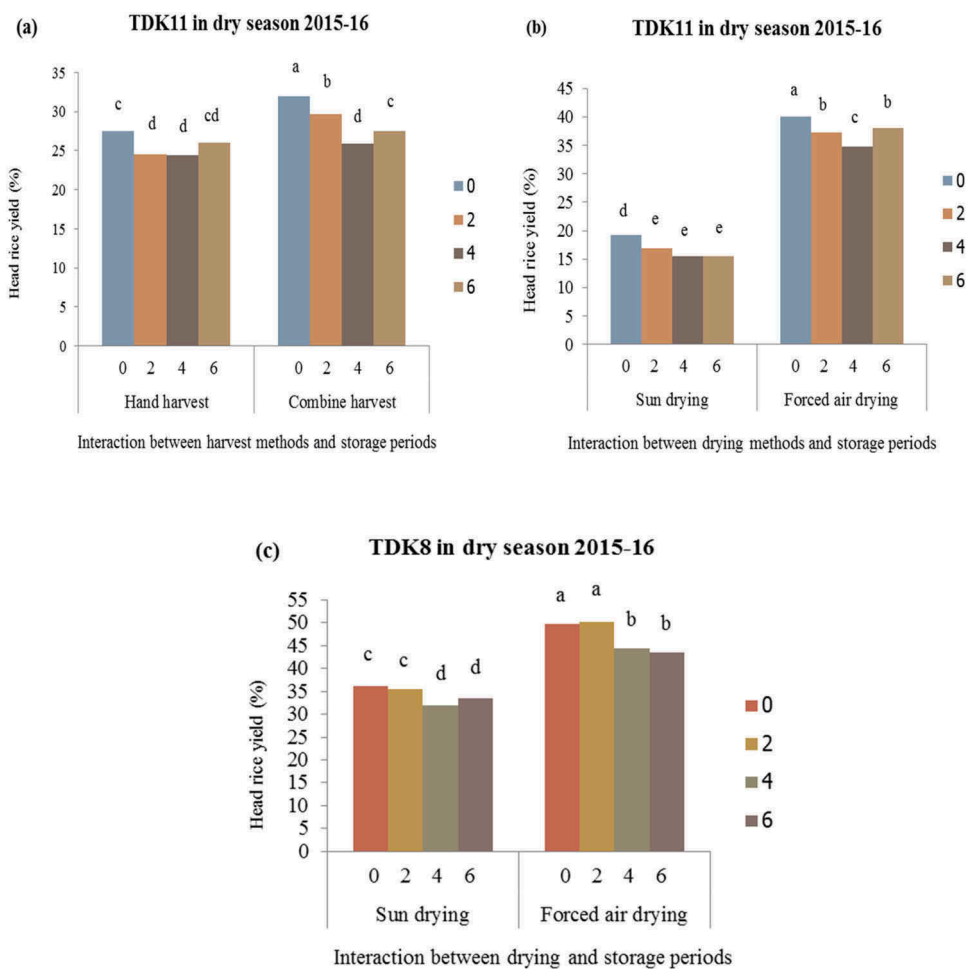


Figure 2. Head rice yield interactions between harvest methods and storage period of TDK11 (a) and drying methods and storage period of TDK11 (b) and between drying methods and storage period of TDK8 (c) produced in dry season 2015–2016.

3.1.1. Effects of drying method and storage period on milling quality of hand-harvested VTE450-2

When the effect of both drying method and storage period was considered for the DS VTE405-2 hand-harvested crop, large reduction in HRY with sun-dried compared to forced air drying was observed (Table 2), which was a similar result as described above for TDK11 and TDK8. HRY for forced air drying was 50.6% compared to sun drying which was 34.4%. This was largely due high broken rice in sun-dried paddy, although milled rice was also slightly lower. HRY was slightly decreased from 44.3% to 40.3% with storage period up to 4 months with no further decline observed.

While the effect of drying methods was large, there was a significant two-way interaction effect for HRY between drying method and storage period. HRY of forced air was higher than sun drying, the paddy was stored at an ambient temperature for sun drying was not significantly different during the whole 6-month storage period, but with forced air drying, HRY declined only after 4 months (Figure 3).

3.2. Comparison of milling quality of two varieties under different harvesting and drying conditions between 2016 DS and 2017 without storage

Individual variety analysis of TDK11 and TDK8 in WS showed that HRY of combine harvest was higher than in the hand-harvested paddy, and artificial drying using forced air was higher HRY than sun drying. In addition, HRY of TDK8 was higher than in

Table 2. Milling quality of VTE450-2 rice produced in dry season 2015–2016 harvested by hand and its response to drying methods and storage duration.

Factors	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)
Drying methods (a)					
Sun drying	77.75a	63.38b	34.36b	29.02a	14.36a
Forced air drying	78.22a	65.65a	50.61a	15.04b	13.94a
Storage periods (b)					
0 month	79.19a	65.60ab	44.34a	21.26b	13.89b
2 months	78.46ab	65.90a	44.28a	21.62b	14.14b
4 months	76.20c	62.29c	40.26b	22.02ab	14.79a
6 months	78.10b	64.26b	41.06b	23.20a	13.79b
F-test					
Drying (D)	ns	*	**	**	ns
Storage (S)	**	**	**	*	**
D × S	ns	ns	**	**	ns
CV (a) %	1.34	2.14	5.49	8.86	4.51
CV (b) %	1.02	2.21	4.05	6.67	3.08

BR: Brown rice; MR: milled rice; HRY: head rice yield; broken rice; MC (grain moisture content).

ns: Not significant. *,**significantly different at $p \leq 0.05$ and 0.01 , respectively.

Means followed by different letter(s) are significantly different by LSD at $p \leq 0.0$ (split plot design).

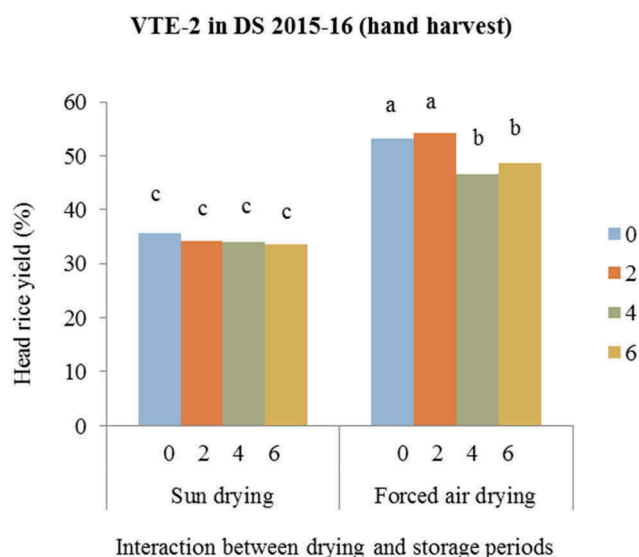


Figure 3. Interaction between drying methods and storage period on head rice yield of VTE450-2 produced in dry season 2015–2016 and stored during 2016 wet season.

TDK11 for WS 2017 and without interaction between harvest method and drying method in TDK11 (Table 3a). On the other hand, there were significant two-way interactions between harvest method by drying method in WS for TDK8, in which the combine harvest using forced air had higher HRY than in the hand harvest using forced air, but there was no difference in harvest method when sun-dried (Figure 4a).

In DS 2015–2016, the HRY of TDK11 was higher in the hand harvest compared to combine harvest. On the other hand, HRY of TDK8 had a higher HRY in the hand-harvested paddy, but forced air drying had higher HRY compared to sun drying and had lower broken rice in both varieties (Table 3b). In addition, there were significant two-way interactions between harvests by drying method in DS for TDK8, while both harvest methods had low HRY for sun-dried paddy, using forced air was higher HRY in the hand harvest (Figure 4b). There was a significant two-way interaction between harvest and drying method in DS for TDK11, the HRY of both hand and combine harvest using forced air drying was not significantly different, but HRY of hand harvest and sun-dried was lower than combine harvest sun-dried (Figure 4c).

In WS hand-harvested crop, plants were dried in the field first before threshing and then the paddy was dried either in the sun or in the forced air drying. In this case, the advantage of forced air drying was smaller. In this case of the harvest method and drying

Table 3. Milling quality of two rice varieties under hand (H) and combine (C) harvested and sun (S) and forced air (F) dried, after harvest in 2016 in dry season and wet season 2017 without storage.

Factors	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)	BR (%)	MR (%)	HRY (%)	Broken rice (%)	MC (%)
Wet season 2017 (a)										
					TDK11			TDK8		
Harvest methods (a)										
Hand harvest	76.86a	61.13b	31.17b	29.96a	13.45a	78.06a	65.42a	43.50b	21.92a	14.03a
Combine harvest	76.29a	63.17a	37.22a	25.94b	13.36a	77.79a	65.93a	46.78a	19.14a	13.68a
Drying methods (b)										
Sun drying	75.63b	61.52a	31.04b	30.48a	12.96b	77.37a	64.72a	38.42b	26.38a	13.81a
Forced air drying	77.52a	62.78a	37.35a	25.43b	13.85a	78.48a	66.62a	51.94a	14.67b	13.90a
<i>F</i> -test										
Harvest (H)	ns	*	**	*	ns	ns	ns	*	ns ^x	ns
Drying (D)	*	ns	**	**	**	ns	ns	**	**	ns
H × D	ns	ns	ns	ns	ns	ns	ns	**	ns ^y	ns
CV (a) %	0.83	0.77	2.37	4.56	0.94	0.53	1.33	1.44	5.88	1.57
CV (b) %	0.98	1.43	2.74	3.85	1.8	1.3	1.94	1.53	7.84	1.74
Dry season 2015–2016 (b)										
					TDK11			TDK8		
Harvest methods (a)										
Hand harvest	77.41b	62.67b	27.50b	35.16a	12.92a	79.25a	66.54a	46.47a	20.07b	13.56a
Combine harvest	78.34a	64.89a	31.90a	32.98b	12.41b	79.05a	67.13a	39.42b	27.71a	13.37b
Drying methods (b)										
Sun drying	77.68a	63.17a	19.29b	43.89a	12.46b	79.08a	66.52a	36.16b	30.35a	13.50a
Forced air drying	78.07a	64.38a	40.13a	24.25b	12.87a	79.22a	67.15a	49.73a	17.42b	13.43a
<i>F</i> -test										
Harvest (H)	*	*	*	*	*	ns	ns	**	**	*
Drying (D)	ns	ns	**	**	**	ns	ns	**	**	ns
H × D	ns	ns	*	ns	ns	ns	*	**	*	ns
CV (a) %	0.48	2.05	5.7	3.56	1.69	0.66	1.16	3.23	6.66	0.7
CV (b) %	0.64	2.52	6.52	5.83	1.62	0.66	0.97	3.76	6.8	1.23

BR: Brown rice; MR: milled rice; HRY: head rice yield; broken rice; MC (grain moisture content).

ns: Not significant. *,**Significantly different at $p \leq 0.05$ and 0.01 , respectively.

Means followed by different letter(s) are significantly different by LSD at $p \leq 0.05$ (split plot design).

^x $p = 0.0576$; ^y $p = 0.0564$.

method interaction, HRY of crops dried in forced air was always higher than those in the sun. The interaction of harvest and drying method was different in direction between WS and DS. On the other hand, HRY of TDK8 was greater in crops harvested by combine than by hand in WS while the opposite was the case in DS (Figure 4(a,b)).

4. Discussion

The results in two seasons show consistently large effects of drying methods and varieties on HRY while the effects of harvesting methods were small and not consistent between the seasons. The effect of storage duration which was determined only in DS was also small. The results show that HRY of paddy dried in the sun was significantly lower than that in the forced air drying as a result of increased broken rice during milling. Advantage of forced air in maintaining higher HRY is likely to be due to its ability to provide uniform and controlled temperature and humidity for the grains under protected conditions during drying while the disadvantage of sun drying would be the larger fluctuates in temperature and moisture conditions, which resulted in increased cracking in the kernels. Akowuah, Addo and Bart-Plange (2012) found that moisture and temperature gradients were created

during paddy drying and this induced internal cracking of the endosperm and led to the development of fissures. Schluterman and Siebenmorgen (2007) reported that fissures drastically reduced the mechanical strength of rice kernels causing their breakage during milling, thereby reducing HRY. Wongpornchai, Dumri, Jongkaewwattana and Siri (2004) found that HRY was most clearly affected in the sample dried by hot air at 70°C, which resulted in HRY slightly less than half that obtained at 30 and 40°C and by sun drying. However, they observed no significant variation in the percentages of whiteness among the rice samples obtained from the different drying methods and storage times up to 10 months.

Forced air drying using dryers is thus a promising method compared to sun drying (Akteruzzaman and Parvin, 2004). However, natural sun drying of paddy will continue to be a widely adopted method of drying rice by small farmers in developing countries (Imodu & Olufayo, 2000). HRY can be increased in the sun drying with some modifications of the technique. For example, HRY was higher when grains were stirred frequently, drying grain on a mat rather than on concrete (Imodu & Olufayo, 2000) or drying only in the morning rather than for the whole day (Xangsayasane et al., 2019).

In the present experiments, the advantage of forced air drying was greater in the DS than in WS. This may be

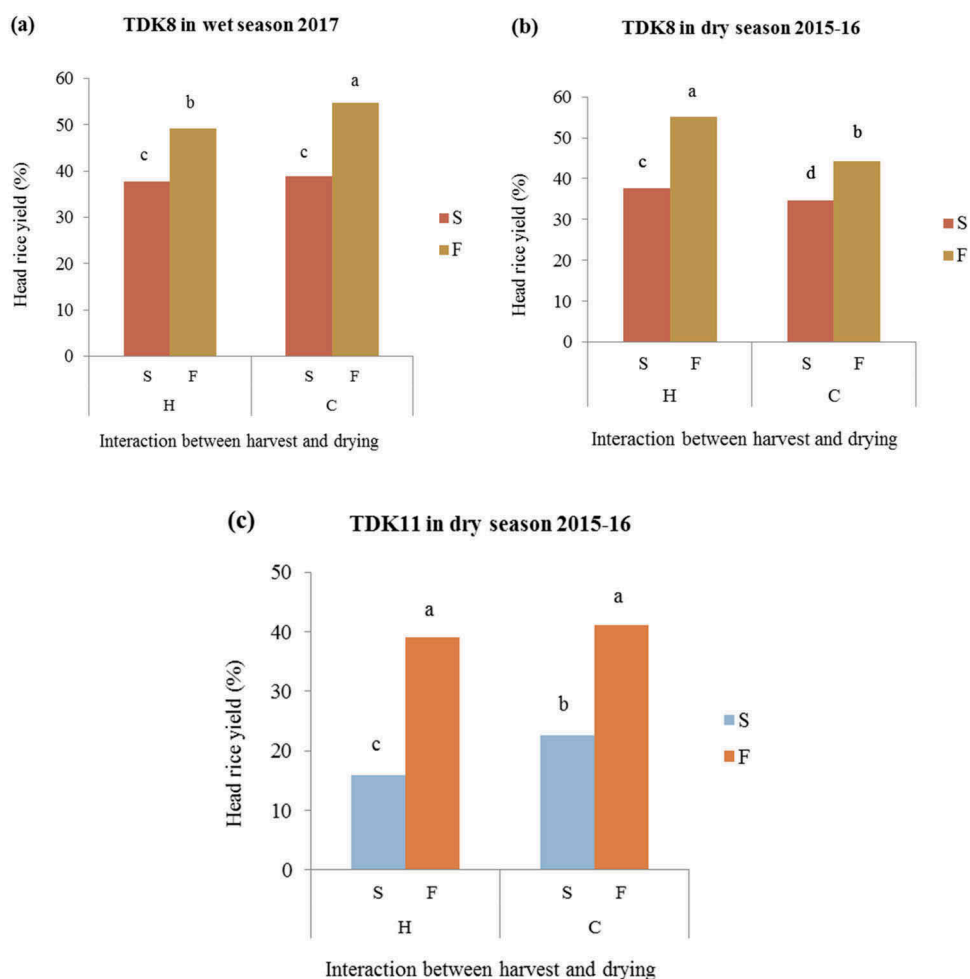


Figure 4. Interactions between harvest methods, drying methods on head rice yield of TDK8 produced in wet season 2017 (a) and dry season 2016 (b) and DS 2016 of TDK11 (c).

because the hot and wet condition at the end of DS caused more grain cracking in the sun drying. However, the drying time where sun drying and forced air drying were used for comparison was shorter in WS than in DS for hand-harvested crops, as hand-harvested plants had been dried in the field first in WS, and this may reduce the drying treatment effects in WS. On the other hand, for combine harvested crops, drying methods were similar resulting in similar effect of drying method on HRY between the two seasons. Currently, only one flatbed dryer is available for drying contracting service in Central Laos, and its charge is about \$20/3 t of rough rice. It is thus likely that there is economic benefit of artificially drying if HRY increases from 30% to 45% as was found in the present work in the DS.

Although HRY was significantly higher in combine harvested crops in WS and in hand-harvested crop in DS, the difference was rather small in both seasons. Bunna et al. (2018) found slightly higher HRY in hand-harvested crops than in combine harvested crops in WS

in Cambodia. Combine harvesting results in similar grain yield with only slightly higher grain loss in the field than hand harvesting, but when grain loss during threshing is added, the total grain loss is similar between the two harvesting methods (Bunna et al., 2018). Farmer's net return is greater with combine than with hand harvesting as long as the combine contractor fees are less than 20% of the total rice harvested (Xangsayasane et al., 2019). These findings indicate that adopting combine harvesting service is likely to be beneficial to the farmers, and in fact the number of combines has started to increase sharply in the last few years in Central Laos. Grain quality is likely to be maintained with the introduction of combine harvesting, provided combine harvested high moisture rough rice is dried adequately.

In the present work, the variation in HRY obtained by different harvesting methods, drying methods and different varieties was strongly related to the variation in broken rice. A negative correlation between HRY and broken

rice was observed by Bunna et al. (2018) when the rice crop was harvested by combine or hand at different times during ripening. It is well known that delayed harvesting during ripening results in lower HRY with increased grain cracking. This is related to reduced grain moisture content with delay in harvesting (Thompson & Mutters, 2006, Xangsayasane et al., 2019). The fissuring of rice grain occurs in late harvested, low moisture grain as a result of adsorption of moisture by the grain under high humidity or rainfall conditions (Jindal & Siebenmorgen, 1994). The results in two seasons indicate that HRY in TDK8 was greater than that in TDK11 under any drying and harvesting conditions, and also the DS results show the lower HRY in TDK11 compared to TDK8 and VTE450-2 under any storage durations.

HRY is known to be affected by the genetic make-up of a crop; for example, high HRY tends to be obtained in genotypes with low amylose content (Zhou et al., 2015) and thicker grain under delayed harvesting conditions (Jindal & Siebenmorgen, 1994). However, apparent amylose content is similar between TDK8 and TDK11 (3.72–3.77%) according to Nawaz et al. (2016). The grain shapes of these two varieties are also similar and unlikely to have affected HRY greatly. While the high HRY was also associated with slightly higher brown rice and milled rice in TDK8 than in TDK11, the difference in HRY was mostly caused by the large difference in broken rice proportion found after milling. The results also show that the degree of milling was higher in TDK11 than in TDK8 in both seasons (18.9–20.6% in TDK11 and 15.6–15.7% in TDK8, for no storage conditions). Thus, the difference in HRY between the varieties may be smaller if the milling condition was adjusted to obtain maximum HRY for each variety. There were significant interactions between variety and drying method for HRY in both seasons, and HRY on TDK11 was particularly low in DS. These varieties were harvested on different days, and sun drying conditions would be different which may have caused the interaction effect on HRY.

HRY declined gradually with storage time in three varieties in hand harvesting and two varieties in combine harvesting. The lowest HRY was obtained after 4 months' storage when rainfall and humidity were high during the peak WS. It is well documented that the hygroscopic nature of seeds results in fluctuations in grain moisture content when storage is under ambient conditions (Dhaliwal, Sekhon, & Nagi, 1991; Gujral & Kumar, 2003). Moisture equilibration between seeds and environmental conditions results in an increase or decrease in moisture content (Copeland & McDonald, 1999; Strelec et al., 2010; Volenik, Rozman, Kalinović, Liška, & Šimić, 2006), which can be significant when storage spans across WSs and

DSs, particularly in tropical environments. Increased atmospheric moisture level may have caused cracking in low moisture content grains during storage resulting in fissure formation which led to the eventual reduction in HRY (Hashemi et al., 2008). At the time of milling of the 6 months storage period in the present experiment, minimum temperature and relative humidity had declined significantly compared to the previous 4 months and this may have affected HRY.

The present work has shown that the introduction of combine harvester may result in only a small effect on milling quality of glutinous rice. However, combine harvested crops are high in moisture, which needs to be dried adequately for production of high milling quality. While flatbed dryer can be used with forced air drying for the production of high quality rice, as demonstrated in the present work, most flatbed dryers are rather small, e.g. 4 t capacity, which is unlikely to meet the needs of rice harvested by a combine; for example, a combine harvester can harvest an area of 3 ha in a day, resulting in about 10 t of grain to be dried each day. In DS, the chance of rainfall during the drying period is high, and hence sun drying can be risky. A few options are available; one is the use of large flatbed dryer as is utilized commonly in Vietnam. Another is the use of tarpaulin for sun drying so that grain can be protected in the event of rain (Xangsayasane et al., 2019). It is also possible to use large capacity vertical dryers that have been recently installed in several large mills in Laos. These options need to be examined further in relation to grain quality and the benefit to the rice farmers and the agribusiness concerned.

Acknowledgements

We wish to thank the Australian Centre for International Agricultural Research (ACIAR) project CSE-2012-077 for financial support, and Agronomy Division, Faculty of Agriculture, Khon Kaen University (KKU) Thailand for support of equipment/instruments and laboratory. The senior author wishes to thank for KKU Scholarship for ASEAN and Greater Mekong Sub-region (GMS) countries.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Australian Centre for International Agricultural Research [CSE-2012-077].

ORCID

Jaquie Mitchell  <http://orcid.org/0000-0001-7641-7935>

References

- Akowuah, J. O., Addo, A., & Bart-Plange, A. (2012). Influence of drying temperature and storage duration on fissuring and milling quality of jasmine 85 rice variety. *Journal of Science and Technology*, 32, 26–33.
- Akteruzzaman, M., & Parvin, J. (2004). Drying of paddy in wet season by mechanical dryer for improving farmer income. *Bangladesh Journal of Political Economy*, 20, 153–171.
- Alisa, C., Benjavan, R., Sansanee, J., & Chanakan, P. (2013). Effects of storage temperature on viscosity among different rice varieties. *KKU Research Journal*, 4, 411–418.
- Andrews, S. B., Siebenmorgen, T. J., Vories, E. D., Loewer, D. H., & Mauromoustakos, A. (1993). Effects of combine operating parameters on harvest loss and quality in rice. *Transactions of the ASAE*, 36(6), 1599–1607.
- Banaszek, M. M., & Siebenmorgen, T. J. (1990). Head rice yield reduction rates caused by moisture adsorption. *Transaction of ASAE*, 33, 1263–1269.
- Bean, M. M., Esser, C. A., & Nishita, K. D. (1984). Some physicochemical and food application characteristics of California waxy rice varieties. *Cereal Chemistry*, 61, 475–480.
- Bunna, S., Sereyvuth, H., Somaly, Y., Ngoy, N., Mengsry, L., Sareth, C., ... Fukai, S. (2018). Head rice yield of crops harvested by combine and hand at different ripening times in Cambodia. *Experimental Agriculture*. doi:10.1017/S0014479717000606
- Calderwood, D. L., Bollich, C. N., & Scott, J. E. (1980). Field drying of rough rice: Effect on grain yield, milling quality, and energy saved. *Agronomy Journal*, 72, 649–653.
- Copeland, L. O., & McDonald, M. B. (1999). *Principles of seed science and technology*. Dordrecht: Kluwer Academic Publishers Group.
- Dhaliwal, Y. S., Sekhon, K. S., & Nagi, H. P. S. (1991). Enzymatic activities and rheological properties of stored rice. *Cereal Chemistry*, 68, 18–21.
- DOA. (2012). *Agricultural statistics year book (2012)*. Vientiane Capital, Lao PDR: Department of Agriculture Ministry of Agriculture and Forestry.
- Gujral, S. H., & Kumar, V. (2003). Effect of accelerated aging on the physicochemical and textural properties of brown and milled rice. *Journal of Food Engineering*, 59, 117–121.
- Hashemi, J., Haque, A., Shimizu, N., & Kimura, T. (2008). Influence of post drying duration on the head rice yield of aromatic rice. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript FP 07 034. Vol. X. May.
- Imodu, P. B., & Olufayo, A. A. (2000). The effect of sun-drying on milling yield and quality of rice. *Bioresource Technology*, 74(3), 267–269.
- Inthapanya, P., Boualaphanh, C., Xangsayaxane, P., Bounphanousay, C., Voradeth, S., & Kanyavong, K. (2012). New high yielding glutinous rice varieties: Thadokkham 8. *The Lao Journal of Agriculture and Forestry*, 25, 40–61.
- JICA. (2015). *Handbook on rice post-harvest Techniques*. Department of Agriculture & Livestock (NDAL) Konedobu and Japan International Cooperation Agency (JICA) Project on Promotion of Smallholder Rice Production (Phase 2).
- Jindal, V. K., & Siebenmorgen, T. J. (1994). Effect of rice kernel thickness on head rice yield reduction due to moisture adsorption. *Transactions of ASAE*, 37, 487–490.
- Juliano, B. O. (1985). Criteria and tests for rice grain qualities. In B.O. Juliano, L.R. Pollard & G. Argosino (Eds.), *Rice: Chemistry and technology* (pp. 443–524). St Paul, MN: American Association of Cereal Chemists.
- Juliano, B. O., & Duff, B. (1991). Rice grain marketing and quality issues. In *Rice grain quality as an emerging priority in national breeding programs* (pp. 54–64). Los Banos: International Rice Research Institute.
- Meas, P. P., Cleland, A. H. J., Bronlund, D. J., Mawson, J. E., Hardacre, A., & Rickman, J.F. (2013). Relating rice grain quality to conditions during sun drying. *International Journal of Food Engineering*, 9(4), 385–391.
- Meas, P., Paterson, A. H. J., Cleland, D. J., Bronlund, J. E., Mawson, A. J., Hardacre, A., & Rickman, J. F. (2011). Effects of different solar drying methods on drying time and rice grain quality. *International Journal of Food Engineering*, 7(5), Article 11.
- Mitchell, J. H., Sipaseuth, & Fukai, S. (2014). Farmer participatory variety selection conducted in high- and low-toposequence multi-location trials for improving rainfed lowland rice in Lao PDR. *Crop and Pasture Science*, 65(7), 655–666.
- Nawaz, M., Fukai, S., & Bhandari, B. (2016). Effect of different cooking conditions on the pasting properties of flours of glutinous rice varieties from Lao People's Democratic Republic. *International Journal of Food Properties*, 19(9), 2026–2040.
- Schiller, J. M., Hatsadong, & Doungsila, K. (2006). A history of rice in Laos. In J. M. Shiller, M. B. Chanphengxay, B. Linquist, & S. Apparao (Eds.), *Rice in Laos* (pp. 9–28). Los Banos: International Rice Research Institute.
- Schluterman, D. A., & Siebenmorgen, T. J. (2007). Relating rough rice moisture content reduction and tempering duration to head rice yield reduction. *Transactions of the ASABE*, 50, 137–142.
- Strelec, I., Ruža, P., Ilonka, I., Vlatka, J., Zorica, J., Ugarčić-Hardi, Ž., & Sabo, M. (2010). Influence of temperature and relative humidity on grain moisture, germination and vigor of three wheat cultivars during one year storage. *Poljoprivreda*, 16(2), 20–24.
- Thompson, J. F., & Mutters, R. G. (2006). Effect of weather and rice moisture at harvest on milling quality of California medium-grain rice. *Transactions of ASABE (American Society of Agricultural and Biological Engineers)*, 49, 435–440.
- Volenik, M., Rozman, V., Kalinović, I., Liška, A., & Šimić, B. (2006). Influence of relative humidity and temperature on changes in grain moisture in stored wheat and sunflower. *Proceedings of the 9th International Working Conference on Stored Product Protection*, Campinas, Brazil, 24–29.
- Vongphachanh, P. (2016). *Disease survey of rice in Lao PDR and control of sheath diseases*. Master of Science Thesis, Faculty of Agriculture, Khon Kaen University, Thailand.
- Wongpornchai, S., Dumri, K., Jongkaewwattana, S., & Siri, B. (2004). *Effects of drying methods and storage time on the aroma and milling quality of rice (Oryza sativa L.) cv. Khao Dawk Mali 105*. Thailand: Department of Chemistry, Faculty of Science, Chiang Mai University.
- Xangsayasane, P., Vongxayya, K., Phongchanmisai, S., Mitchell, J., & Fukai, S. (2019). Rice milling quality as affected by drying method and harvesting time during ripening in wet and dry seasons. *Plant Production Science*, 22(1), 98–106.
- Yadav, B. K., & Jindal, V. K. (2008). Changes in head rice yield and whiteness during milling of rough rice (*Oryza sativa* L.). *Journal of Food Engineering*, 86(1), 113–121.
- Zhou, L., Liang, S., Ponce, K., Marundon, S., Ye, G., & Zhao, X. (2015). Factors affecting head rice yield and chalkiness in indica rice. *Field Crops Research*, 172, 1–10.