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FULL PAPER

RESEARCH NOTE

IMPROVING RICE QUALITY AND MINIMIZING LOSSES THROUGH EFFECTIVE POSTHARVEST MANAGEMENT

Tyrone C. Juganas, Manuel Jose C. Regalado*, and Joel A. Ramos

Rice Engineering and Mechanization Division, Philippine Rice Research Institute
Maligaya, Science City of Muñoz, Nueva Ecija
*Corresponding Author: leunam.odalager@gmail.com

Abstract

Recent progress in the Philippine rice R&D featured PalayCheck®, an integrated crop management system for irrigated lowland rice. Despite this, farmers still lag behind when it comes to rice harvesting and postharvest. This study was conducted to verify a recent improved postharvest management protocol from harvesting to commercial milling to reduce postharvest losses and enhance paddy (*palay*) and milled rice quality. Trials were conducted in the farmer's field in Villa Cuizon, Science City of Muñoz, Nueva Ecija where effects of harvest timing (optimum at 90-95% maturity for combine and 85-90% for manual, five days early, and five days late) and methods (combine and manual harvesting) were examined. Effects of drying (mechanical and sun drying) and storage (hermetic and ambient) methods on the milling and head rice recoveries of the rice harvest were also evaluated and compared. Grain losses were determined using standard assessment methods. Results showed that timely combine harvesting reduced harvest losses by two percentage points from 3.1 - 1.1%. Moreover, drying the paddy immediately after harvest and keeping it in hermetic storage increased milling recovery by 1.2 percentage points from 64.4 - 65.6%. By implementing the postharvest management procedure at the farmer's field level, in spite of the difficulty in controlling operating conditions, total postharvest losses could be reduced and paddy and milled rice quality and quantity can be improved.

Keywords: *Harvesting, Paddy/milled rice quality, Postharvest losses, Rice postharvest management*

Introduction

Our country is dedicated to achieve major improvements in terms of harvest and postharvest facilities. To encourage such advancements, the Republic Act 10601 (Agriculture and Fisheries Mechanization Law of 2013) was established. This law requires the creation, endorsement, and incorporation of modern, affordable, and eco-friendly agricultural and fishing tools and machinery to maximize production and proficiency, obtain food safety and security, as well as raise farmers' and fisherfolks' incomes.

Substantial progress has been made in the Philippine rice production sector; however, there are still problems with post-production such as high harvest and postharvest losses. The Philippine Center for Postharvest Development and Mechanization (PHilMech) found that post-production operations from harvesting to milling incurred an average loss of 16.47% (Salvador et al., 2012). Although timely paddy harvesting using a combine harvester has been shown to reduce grain-shattering losses in the field to 2% or less (Regalado and Ramos, 2018; Gummert et al., 2020), combine harvesting losses can also rise up to 10% (Gummert, 2022). Findings from a market study conducted by the IRRI CORIGAP project in 2015 revealed that this issue primarily stemmed from the high-speed operation of combines by service provider operators. These operators were often unaware of how machine settings could impact the harvesting performance of the combine, particularly in terms of grain losses (Gummert, 2022). Combine harvesting if improperly done has been shown to have reduced milling outputs. Results of the IRRI Kellog's project on postharvest loss assessment in Chainat, Thailand in 2016 showed that total milling recovery of combine-harvested paddy (62%) was two percentage points lower than that of manually harvested paddy (64%) and head rice yield was even lower by 12 points at 45%, in contrast to manual at 57% (Gummert, 2022). To effectively address these challenges, a comprehensive integrated crop management system should be implemented such as the updated PalayCheck® System (PhilRice, 2022), which encompasses not only production but also harvesting, threshing, cleaning, drying, storage, and milling operations. In response to this need, the Rice Engineering and Mechanization Division (REMD) of Philippine Rice Research Institute (PhilRice) has developed a rice postharvest management protocol to be followed and carried out to attain operational key checks, which will help reduce postproduction losses and improve milling recovery (Regalado and Ramos, 2018; Regalado et al., 2022). The enhanced PalayCheck® system with the postharvest management protocol will help educate farmers on preserving the quality of paddy so they can produce a better-quality product that commands a higher price.

Thus, it is essential to field test the integrated rice postharvest management protocol to help train the farmers and processors to meet competitive market standards.

This study validated a protocol for managing rice postharvest operations previously developed and validated in controlled field experiments at PhilRice Central Experiment Station (CES) (Regalado and Ramos, 2018) by testing it at farmers' fields and commercial rice mills. The objective was to prove our hypothesis that by following the procedure at farmers' fields even if operating conditions are difficult to manage or control, harvest and postharvest efficiencies can still be increased, post-harvest losses can substantially be reduced, and quality of paddy and milled rice can be further improved.

Materials and Methods

Identification, validation, and selection of farmer-partners

During the field testing of the developed rice postharvest management protocol, the cooperating farmer and rice miller, who met the following criteria were selected:

1. A portion of the rice crop harvest area would be provided for the harvesting experiment;
2. The farmer-partner would provide a crop harvest area of at least 0.50 ha; and
3. The farmer-partner would be willing to sell the harvested crop from the experiment area for the succeeding storage and milling experiments.

Field testing of postharvest management protocol

The farmer-partner's crop was harvested at three different times: the determined optimum harvest date based on the variety maturity date and visual assessment (118 days after seeding [DAS] for Syngenta NK 5017 planted during 2018 dry season and 114 DAS for NSIC Rc 222 planted during 2018-2019 wet season) five days before and five days after the optimum harvest date. This was based on the crop's physiological maturity as outlined by PalayCheck® System (PhilRice, 2022). Crops were harvested when most of the grains in the panicles are golden yellow (80%) and only 20% of those at the base or neck of the panicles were in hard dough stage.

Two methods were used: (1) manual reaping, collection and piling, and mechanical threshing on the first day; and (2) combine harvesting on the first day. During the harvest, the area provided was divided into three strips corresponding to the three harvest methods. Grain losses incurred during each harvest operation were assessed based on Komuro's (1995) methods.

Collection of harvest losses samples

The harvest losses samples were collected using a 1 m x 1 m quadrant (Figure 3), replicated in three and randomly placed in each treatment or plot. All the grains that were inside the quadrant at the moment it landed in a random position within the plots were collected and placed in a container for further assessment. Foreign materials and soil clods were separated from the samples and were weighed to determine the harvest losses.

Drying and storage tests

In this study, two drying methods were used: (1) sun-drying on concrete pavement, in which drying was done in the morning until 2 p.m. to avoid high ambient temperatures of more than 50°C and (2) mechanical drying using a one-ton capacity flatbed dryer with heated air temperatures of 43 - 45°C. The moisture content (%MC) was measured every 30 min until the samples reaches recommended MC of 13 - 14%. Storage methods included placing 50-kg woven polypropylene sacks of dried paddy (14% MC, wet basis) on a plastic pallet (ambient condition) and in a PhilRice SACLOB (hermetic enclosure) (Regalado et al., 2022).

Figure 1. Manual harvesting, reaping, and mechanical threshing in Villa Cuizon, Bantug during the 2019 dry season (DS).

Figure 2. Mechanical harvesting of rice crop using combine harvester (2019 DS).

Figure 3. Gathering of harvest losses using 1 m x1 m quadrant.

Combine-harvested crops were stored in the PhilRice SACLOB, which is made of plastic-lined sheets and equipped with a simple closing mechanism capable of maintaining a hermetic condition (Orge et al., 2007). Meanwhile, manually-reaped and mechanically-threshed crops were stored on a plastic pallet. Paddy harvested five days before and after the optimum harvest date, which was manually harvested, collected, piled, and mechanically threshed, was stored on a plastic pallet. Storage losses after three months were evaluated using the procedure outlined by Komuro (1995).

Figure 4. Sun-drying of manually harvested samples at PhilRice CES.

Figure 5. Mechanical drying of combine harvested rice crops using 1-tonner flatbed dryer (2019 DS).

Furthermore, storage losses were measured and evaluated by recording the initial weight (weight after drying and first day of storage) and final weight (weight after 3 months of storage and before milling) of the samples per treatment.

Milling and laboratory tests

Due to the challenges in locating a private rice miller equipped with the necessary commercial multi-pass rice mill, mechanical dryer, solar drying pavement, and sufficient storage area, and who was willing to participate in drying, milling, and storage experiments at their facility, these tests were conducted at PhilRice instead. The total milling and head rice recovery were determined by milling all stored paddy using PhilRice's commercial rice mill, which is a one-ton capacity multi-pass mill (Bui Van Ngo, Viet Nam) at the Business Development Division (BDD). Milled rice were tested 3 months after storage.

Farmer's practice

While the majority of paddy harvesting in the country is traditionally done by hand using a sickle, a survey across 13 provinces has shown that threshing operations are largely mechanized (Franco, 2002). However, recent trends suggest that full mechanization of harvesting operations has risen to 8 - 9% in Regions I, II, and IV. In contrast, the Cordillera Administrative Region and Region III have mechanization rates of 2% and 0.5%, respectively (Bingabing et al., 2015). These shifts can be traced back to the government's initial introduction and the subsequent active promotion of combine harvesters by the private sector.

Survey conducted by Bureau of Post Harvest Research and Extension (BPRE, now PHilMech) in 2001, 2004, and 2006 showed that sun-drying remains the predominant method for drying grains, accounting for 95% of the drying practices (BPRE,

Figure 6. Storage of combine harvested and mechanically dried samples using SACLOB.

Figure 7. Commercial milling of paddy using 1-ton multi-pass rice mill after three months of storage.

2008). Approximately 50% of the harvested rice paddy is dried on roads or highways, 45% on multi-purpose drying pavements, and a mere 5% using mechanical dryers (Cachuela et al., 2009). Sun-drying typically takes 1 - 2 days to achieve a moisture content of 14% in the grains. It is the most cost-effective method, with a price range of PhP5 - PhP10 per 50-kg bag of paddy per day, making it the preferred choice for most farmers. However, sun-drying is only feasible under sunny or fair weather conditions. Most of the Filipino farmers still rely on traditional and manual practices due to lack of access to mechanized technologies and equipment.

Results and Discussion

Influence of harvest date and method on harvest losses

Table 1 shows differences in harvest losses between harvest date and method. The lowest harvest losses in 2018 DS were 1.06% (manual), 0.98% (combine), and 0.91% (combine) for samples harvested five days earlier, on-time, and five days later, respectively. The 2018 wet season (WS) data showed the lowest harvest losses of 1.32%, 1.37%, and 1.46% for five days early harvest, on-time, and five days late harvest for combine harvested crops. In 2018, the combine harvesting method had the lowest harvest losses for both seasons, with the exception of a manually harvested five days early on the 2018 DS, which had a 7% lower harvest loss than the combine harvested crops. Early manual harvest had the lowest average loss (1.20%), while harvesting five days late had the highest loss (3.06%). Combine harvesting had significantly lower harvest losses throughout the year because of its ability to simultaneously perform multiple tasks such as reaping, gathering, piling, and threshing. This minimizes crop handling operations and reduces grain losses compared with manual harvesting, which involves multiple handling steps and often leads to greater grain losses (Regalado and Ramos, 2018).

Table 2 shows that during DS, there is no significant difference between harvesting five days early and on-time harvesting. This suggests that it is optimal to harvest either five days early or on time during DS to minimize losses due to grain shattering or falling. This occurrence is typically observed in DS as the grains tend to over-mature more quickly with low moisture content, making the rice crops heavier and more prone to lodging (Zhang et al., 2021). Conversely, during the WS, the lowest harvest losses of 2.37% were observed when harvesting was done five days late for manual harvesting. For combine harvesting, the magnitude of grain losses did not significantly differ across different harvest times.

Harvesting on schedule with a combine harvester resulted in the lowest average percentage of losses for both the 2018 DS and WS. As indicated in Table 2, harvesting earlier than the optimal harvest time reduced losses by 1.10 - 1.40% compared with harvesting later than the optimal date (1.74%). However, early harvesting often results in a high percentage of immature or unfilled grains, leading to drying losses and a negative impact on yield. Baktiar et al. (2013) noted that about 15 - 20% of the grains in a panicle are immature/unfilled when harvested before physiological maturity. Likewise, delayed harvesting can increase losses due to grain shattering. Zhang et al. (2021) explained that grains easily detach from the panicle due to low moisture content. The results demonstrated that harvest timing significantly affects harvest losses as paddy maturity varies. Therefore, it is crucial to harvest the paddy at its optimal condition to minimize losses when using a combine harvester. Hasan et al. (2019) suggested that mechanical harvesting methods such as using a combine harvester can reduce losses by up to 4.47% compared with manual harvesting. This method not only decreases losses but also conserves time, labor, and costs.

Table 1. Influence of harvest date and method on total harvest losses, 2018.

	Total Harvest Losses, %							
	2018				2019			
	Combine Harvested		Manually Harvested		Combine Harvested		Manually Harvested	
	DS	WS	DS	WS	DS	WS	DS	WS
5 days early	1.14	1.32	1.06	2.91	0.98	1.36	2.20	2.60
On time	0.98	1.37	1.81	2.72	0.97	1.24	2.39	3.07
5 days late	0.91	1.46	2.56	2.37	2.05	0.94	3.30	4.02

Table 2. Influence of harvest date and method on harvest loss - ANOVA (2018-2019).

Harvest Date	Total Harvest Losses, %			
	2018 DS	2018 WS	2019 DS	2019 WS
5 days early	1.10^{c}	2.12^{b}	1.49^{b}	1.98^{b}
On time	1.40^{b}	2.05^{b}	1.68^{b}	2.16^{b}
5 days late	1.74^{a}	1.92^{a}	2.67^{a}	2.48^{a}
Harvest method				
Combine harvester	1.15^{b}	1.39^{b}	1.33^{b}	1.18^{b}
Manual reaping and mechanical threshing	1.81^{a}	2.67^{a}	2.56^{a}	3.23^{a}
ANOVA				
Harvest date (HD)	*	*	*	*
Harvest method (HM)	*	*	*	*
HDxHM	*	*	ns	*

In a column, within season, means followed by different letters are significantly different at 5% level of significance
* - significant ns - not significant

During WS, harvest losses are typically higher than during DS due to damp crop conditions and muddy or waterlogged fields (Francisco, 2009, as cited in Regalado and Ramos 2018; dela Cruz and Calica, 2016). Inclement weather such as rain and strong winds can cause the rice crop to lodge, leading to increased losses. Tables 1 and 2 show that harvesting five days late during WS results in lower losses than harvesting on-time or five days early. This is because the lower solar irradiance during the wet season, due to more cloudy days, delays grain maturity. However, it is unusual to have lower grain losses during WS, as previous research indicates that WS generally incurs higher losses than DS (dela Cruz and Calica, 2016). The improved harvest losses observed in the 2019 WS compared with the 2019 DS when using combine harvesting could be attributed to the effective operation of the combine harvester. While an increase in harvest losses is typically expected during this season due to adverse and unpredictable weather conditions, planting submergence-tolerant varieties like NSIC Rc222 and ensuring efficient machine operation during harvesting can help minimize losses even during WS.

Influence of harvest date on milling recovery of combine-harvested and manually reaped rice crops (commercial milling)

The harvest time significantly affected the breakage of grains (Table 3 - 4). Combine-harvested samples that were dried using a flatbed dryer and stored in PhilRice SACLOB had higher milling recovery than manually harvested samples that were sun-dried and stored in ambient conditions.

Table 3. Influence of harvest date on milling recovery of combine harvested rice crops (commercial milling), 2018-2019.

Harvest Time	Milling Recovery, %			
	Combine harvested, mechanically dried, and stored in SACLOB			
	2018		2019	
	DS	WS	DS	WS
5 days early	64.61	61.58	60.56	67.89
On time	66.79	64.48	63.56	67.68
5 days late	63.93	62.37	63.91	69.99

In terms of commercial milling, on-time harvest had the highest average percent milling recovery of 66.79%, followed by five days early harvest (64.61%) and five-day late harvest (63.93%) during 2018 DS. This is attributed to the shattering and over drying of grains during late harvest. The milling recovery was affected because low moisture content of grains has a direct effect on the final weight of the milled grains. During the 2019 WS, samples harvested five days later showed the highest milling recovery of 69.99%. Higher recoveries were obtained in 2019 WS because the postharvest processing machines such as the flatbed dryer and rice mill, functioned properly and efficiently as a result of the preventive maintenance implemented before the postharvest activities. This contrasted with the operational issues encountered with the machine during the 2019 DS. For manually harvested samples, five-day early harvested crops had the highest milling recovery of 69.93%. Table 3 shows that lower milling recovery was obtained when paddy was harvested earlier than the optimum harvest date for combine and manual harvesting, particularly during WS. This is because harvesting too early often results in a high proportion of immature paddy, which leads to unfilled grains, giving low yield and milling recovery (IRRI, 2023). About 15 - 20% of the grains in a panicle is immature/unfilled grains when harvested earlier than physiological maturity (Baktiar et al., 2013). In some cases, the best harvest time for rice may not be the optimal date. Table 4 indicates that during the 2018 DS, manual harvesting of rice crops five days earlier than the recommended time led to a higher milling recovery. The accelerated maturity rate of crops during the DS likely caused the rice to mature earlier than anticipated, which could have contributed to the enhanced recovery.

Table 4. Influence of harvest date on the milling recovery of manually reaped rice crops (commercial milling).

Harvest Time	Milling Recovery, %			
	Manually reaped and mechanically threshed, sun-dried and stored in ambient condition			
	2018		2019	
	DS	WS	DS	WS
5 days early	69.93	61.61	59.66	66.37
On time	65.08	66.81	60.71	66.11
5 days late	68.57	64.15	60.72	67.66

In Table 5, the ANOVA results demonstrate significant variations in the differences between the two treatments and their interaction when examining parameters independently. Both the combine and manual methods were significantly influenced by the three harvest dates from 2018 WS to 2019 DS. In the 2019 DS, both the harvest date and method significantly impacted the milling recovery, as controlling the moisture content of rice paddy was easier during this season. However, due to unpredictable weather patterns, typhoons were difficult to forecast, which affected the harvest schedules. Conversely, the differences among the three harvest dates significantly influenced the harvest methods used during both 2018 DS and 2019 DS to WS.

Influence of harvest date and method, drying and storage methods on head rice yield (commercial milling)

The results showed that samples harvested using a combine harvester, mechanically dried in a flatbed dryer, and stored in a PhilRice SACLOB had a higher head rice yield than samples manually harvested and sun dried, which were stored under ambient conditions. Data showed that samples harvested on-time had the highest average head rice recovery during the 2018 DS and WS at 73.39% and 77.29% respectively (Table 6). Additionally, the study found that manually harvested samples five days earlier than the optimal date had the highest percent head rice recovery during the 2018 WS. Furthermore, samples harvested using a combine harvester, mechanically dried, and stored in SACLOB had higher head rice recovery during 2019 DS and WS than the samples that were manually harvested,

Table 5. Influence of harvest date and harvesting method, drying, and storage methods on milling recovery (commercial milling).

Harvest Date	Milling Recovery (%)			
	DS 2018	WS 2018	DS 2019	WS 2019
5 days early	67.27^{a}	61.62 ^{b}	60.14^{b}	67.13^{a}
On time	65.94^{a}	65.65^{a}	62.15^{a}	66.89^{a}
5 days late	66.26^{a}	63.25^{a}	62.31^{a}	68.83^{a}
Harvest method				
Combine harvester	65.12^{b}	62.82^{a}	62.71^{a}	68.52^{a}
Manual reaping and mechanical threshing	67.86^{a}	64.19^{a}	60.36^{b}	66.71^{b}
ANOVA				
Harvest date (HD)	ns	*	*	ns
Harvest method (HM)	*	ns	*	*
HDxHM	*	ns	ns	ns

In a column, within season, means followed by different letters are significantly different at 5% level of significance
* - significant   ns – not significant

mechanically threshed, sun-dried, and stored under ambient conditions (Table 6 - 7). However, it was observed that the head rice recovery was significantly lower for this year, owing to technical problems in the rice milling machine's blower and polisher, which negatively impacted the quality of the milled rice. It is therefore crucial to ensure that the machine is at its optimal level to achieve favorable results.

Table 6. Influence of harvest date on head rice percentage of combine harvested rice crops (commercial milling).

Harvest Time	Head Rice Recovery, %			
	Combine harvested, mechanically dried, and stored in SACLOB			
	2018		2019	
	DS	WS	DS	WS
5 days early	72.27	76.60	47.68	54.56
On time	73.39	77.29	43.83	52.54
5 days late	69.41	69.48	38.08	52.35

Table 7. Influence of harvest date on head rice percentage of manually reaped rice crops (commercial milling).

Harvest Time	Head Rice Recovery, %			
	Manual reaped and mechanically threshed, sun-dried, and stored in ambient condition			
	2018		2019	
	DS	WS	DS	WS
5 days early	65.61	74.19	31.10	53.21
On time	69.93	70.72	40.09	55.91
5 days late	68.28	68.93	33.91	54.64

Table 8 shows that the harvest date, harvest method, and the interaction between these two factors significantly affect the head rice percentage of the samples. However, technical issues in the pillow blocks, blower, and polisher of the rice milling machine during the 2019 DS resulted in a lower head rice percentage.

Effect of harvesting, drying, and storage on milling recovery and head rice yield (commercial milling laboratory test)

Table 9 and 10 indicate that the percent milling recovery can be influenced by harvest date and harvesting method, drying, and storage methods. During the 2019 DS, the highest milling recovery was observed for rice crops harvested either on time or late, regardless of whether they were harvested by combine or manually. Similarly, during the WS, late harvests yielded the highest recovery for both combine and manually harvested crops. It is crucial for the grains to maintain an optimal moisture content of 13 - 14% to ensure high milling and head rice recovery. On-time harvesting is strongly recommended for commercial milling as the grains are mature and losses are more manageable compared with the samples that were harvested late.

During the 2019 DS, the timing and method of harvest significantly influenced the milling recovery and head rice recovery. This is likely due to the ease of controlling the moisture content of the rice paddy during this season. However, during the WS, paddy grains were more prone to moisture reabsorption, leading to increased breakage and a lower head rice percentage (Table 7).

The study also found that using combine harvester, mechanical dryer, and hermetically sealed storage had a positive impact on grain quality during the WS (Table 8). This agrees with the results obtained by Kanta (2016), which showed that paddy quality for production and consumption can deteriorate because of high moisture content and insect infestation. The use of hermetic storage units such as SACLOB can help preserve grain quality by preventing insect infestations and reducing moisture levels.

Table 8. Influence of harvest date and harvesting method, drying, and storage methods on head rice percentage (commercial milling).

Harvest Date	Head Rice (%)			
	DS 2018	WS 2018	DS 2019	WS 2019
5 days early	68.94^{b}	75.39^{a}	55.39^{a}	53.89^{a}
On time	71.66^{a}	74.01^{a}	53.35^{a}	54.23^{a}
5 days late	68.85^{b}	69.21^{b}	50.82^{b}	53.50^{a}
Harvest method				
Combine harvester	71.69^{a}	74.46^{a}	43.20^{a}	53.15^{a}
Manual reaping and mechanical threshing	67.94^{b}	71.28^{b}	35.03^{b}	54.59^{a}
ANOVA				
Harvest date (HD)	*	*	*	ns
Harvest method (HM)	*	*	*	ns
HDxHM	*	*	*	ns

In a column, within season, means followed by different letters are significantly different at 5% level of significance
* - significant ns – not significant

Influence of harvest date, harvesting method, drying, and storage methods on grain moisture content, fissuring, and physical losses after storage

Table 11 presents the impact of harvest date, harvesting method, drying, and storage method on grain moisture content, fissured grains, and physical losses after storage. The results indicate that using PhilRice SACLOB as a storage environment leads to lower storage losses (3.1% lower) than ambient conditions. This is because SACLOB maintains moisture content (MC) after three months of storage and minimizes moisture reabsorption and grain cracking or fissuring. Numerous studies have demonstrated that hermetic storage technology maintains constant moisture levels inside the container during storage, suggesting that interactions with the external environment are effectively limited (Likhayo et al., 2018). Samples harvested on time result in fewer fissured grains and storage losses, but manual harvesting leads to higher fissured grains and storage losses. This could be due to improper drying techniques during sun-drying and aeration procedures during storage, which have been identified as primary contributing factors to fissure formation (Craufurd, 1963; Siebenmorgen, 1992; Chen et al., 1997).

Overall, samples harvested by combine harvester and stored in SACLOB units showed a 1.2% decrease in MC after three months and a 7% decrease in fissure grain percentage compared with the manually harvested samples stored in ambient conditions.

Total harvest and postharvest losses influenced by harvest and postharvest methods

Validation of the 2018 - 2019 dry and wet season harvests for commercial milling using combine and manual methods was conducted. The combine harvesting method resulted in losses ranging from 1 - 1.5% while manual harvesting led to 2 - 4% losses for different harvest dates. Figure 9 presents the average losses from both methods for both seasons. The lowest losses (10.97%) were observed in the 2018 DS with combine harvesting while the highest losses (19.22%) occurred in the 2019 WS with manual harvesting.

Table 9. Influence of harvest date, harvesting, drying, and storage methods on milling recovery and head rice percentage (commercial milling laboratory test).

Harvest Date	Milling Recovery (%)		Head Rice (%)	
	DS 2018	WS 2018	DS 2018	WS 2018
5 days early	67.27[a]	61.62 [b]	68.94[b]	75.39[a]
On time	65.94[a]	65.65[a]	71.66[a]	74.01[a]
5 days late	66.26[a]	63.25[a]	68.85[b]	69.21[b]
Harvest Method				
Combine Harvester	65.12[b]	62.82[a]	71.69[a]	74.46[a]
Manual Reaping & Mechanical Threshing	67.86[a]	64.19[a]	67.94[b]	71.28[b]
ANOVA				
Harvest Date (HD)	ns	*	*	*
Harvest Method (HM)	*	ns	*	*
HDxHM	*	ns	*	*

In a column, within season, means followed by different letters are significantly different at 5% level of significance
* - significant, ns - not significant

Table 10. Influence of harvest date, harvesting, drying, and storage methods on milling recovery and head rice percentage (commercial milling test).

Harvest Date	Milling Recovery (%)		Head Rice (%)	
	DS 2019	WS 2019	DS 2019	WS 2019
5 days early	60.14[b]	67.13[a]	55.39[a]	53.89[a]
On time	62.15[a]	66.89[a]	53.35[a]	54.23[a]
5 days late	62.31[a]	68.83[a]	50.82[b]	53.50[a]
Harvest method				
Combine harvester	62.71[a]	68.52[a]	43.20[a]	53.15[a]
Manual reaping and mechanical threshing	60.36[b]	66.71[b]	35.03[b]	54.59[a]
ANOVA				
Harvest date (HD)	*	ns	*	ns
Harvest method (HM)	*	*	*	ns
HDxHM	ns	ns	*	ns

In a column, within season, means followed by different letters are significantly different at 5% level of significance
* - significant, ns - not significant

Table 11. Influence of harvest date, harvesting method, drying, and storage methods on grain moisture content, fissuring, and physical losses after storage.

	Combine Harvesting				Manual Harvesting			
	% MC after drying & before storage	% MC after storage	% Fissured Grain	% Storage Losses	% MC after drying & before storage	% MC after storage	% Fissured Grain	% Storage Losses
5 days early	12.78	13.08	21.65	2.36	13.24	13.29	29.42	8.23
On time	12.38	12.71	13.67	1.55	12.69	13.31	23.72	4.66
5 days late	12.48	12.98	28.02	2.33	12.86	13.13	31.27	2.56
Average	12.54	12.92	21.11	2.08	12.93	13.25	28.13	5.15

The results indicated that manual harvesting led to higher losses due to multiple handling steps such as cutting, piling, hauling, and threshing. In contrast, mechanized harvesting using a combine harvester reduced grain loss by combining these steps into one operation (Hasan et al., 2020). Manual harvesting is time-consuming, requiring 100 - 150 hours of labor per hectare, which makes it costly for farmers. Therefore, using a combine harvester is an effective solution to reduce both costs and losses (Alizadeh and Allameh, 2013).

Figure 8 shows the seasonal trend of total harvest and postharvest losses incurred during harvesting, collection, hauling, drying, storage, and milling. Typically, WS has higher losses than DS because of weather-related lodging. However, in 2019 DS, combine harvested samples had 13.09% total losses, which is higher than expected. Most of these losses came from delayed drying owing to flatbed dryer issues, leading to quality deterioration and increased losses during drying and milling (BPRE, 2008; Shahar et al., 2017).

Despite the higher than expected losses during the 2019 DS for combine harvested samples (13.09%), this method still performed better than manually harvested crops with higher losses of 17.32%. Overall, data from 2018 - 2019 showed lower total losses in DS and even lower using combine harvester, flatbed dryer, and SACLOB. Total harvest and postharvest losses could be reduced to 10.97% in 2018 DS and 11.39% in 2019 WS.

Conclusion and Recommendations

A recently developed protocol for rice postharvest management was tested at a farm in Villa Cuizon, Science City of Muñoz, Nueva Ecija. The trials were designed to examine different harvest timings and methods including combine harvesting and manual reaping. The samples harvested using the combine were dried using a flatbed dryer (with a heated air temperature of 43 - 45°C), bagged in sacks, and stored in a hermetic enclosure. The samples that were manually reaped and mechanically threshed were sun-dried, bagged in sacks, and stored under ambient conditions. The samples were dried to a moisture content of 14%, and grain losses were calculated using Komuro's assessment methods.

Optimum harvest time using combine harvester had the lowest average loss at 1.14%, compared with harvesting five days early (1.20%) or five days late

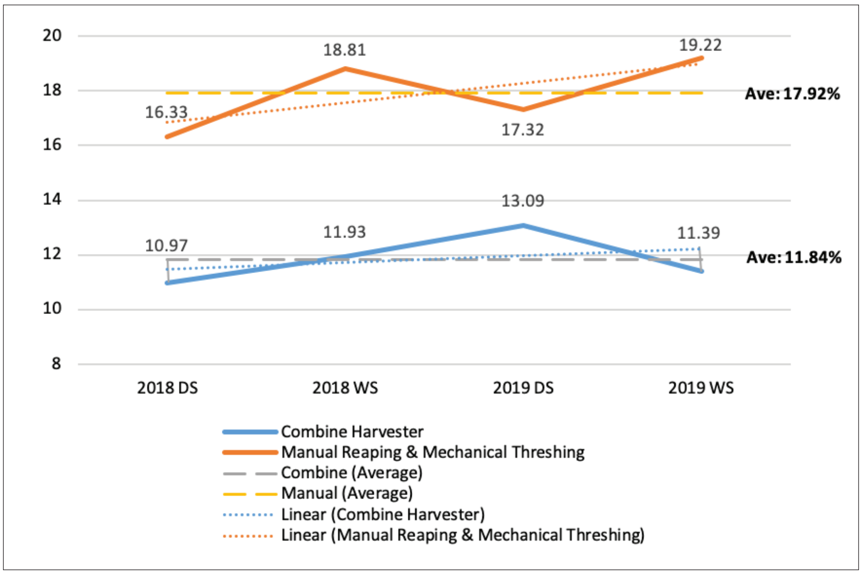

Figure 8. Total harvest and postharvest losses (%) as influenced by harvest methods.

(1.34%). Manual harvesting had higher losses over using combine harvester because it requires multiple handling and operations. Early manual harvest had the lowest average loss (1.20%) while harvesting five days late had the highest loss (3.06%). Rice crops harvested at the optimum time with a combine harvester, dried mechanically in a flatbed dryer, and stored in SACLOB had the highest milling recovery at 65.63% than manually reaped and mechanically threshed samples (65.28% harvested five days late). For head rice percentage, five days early combine-harvested, flatbed dried, and SACLOB-stored samples had the highest figure of 62.78%. Rice harvested at the optimum time had the lowest fissured grain and storage losses with both methods. The results showed that timely combine harvesting, immediate mechanical drying of fresh harvest, and SACLOB storage effectively reduced losses and improved paddy and milled rice quality.

Mechanical drying increases the percentage of milled rice and head rice yields by reducing the risk and occurrence of over-drying. Storing dried paddy inside a hermetic enclosure such as the SACLOB increases total milled and head rice recoveries. Thus, by implementing the postharvest management protocol, harvest and postharvest efficiencies can be increased, post-harvest losses can substantially be reduced, and quality and quantity of paddy and milled rice can be improved.

In light of the study's findings and results, we emphasize the importance of proper maintenance and operation of harvest and postharvest equipment. By doing so, losses can be further reduced and grain quality can be improved. Secondly, rice crop harvesting using a combine harvester should adhere to the postharvest management protocol. This will not only reduce harvest and postharvest losses but also aid in producing high-quality milled rice or rice products. Furthermore, a study exploring the effect of the blower setting of the combine harvester's cleaning section could be beneficial. The correct air speed and volume setting can lead to lower grain losses and more efficient use of the machine. Lastly, manual harvesting of rice crops should also follow the improved postharvest management protocol as it could assist farmers who lack access to such machines, technologies, and facilities in minimizing grain losses.

Acknowledgment

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IDENTIFICATION OF PLANT GROWTH-PROMOTING BACTERIA AS POTENTIAL ENHANCER FOR DROUGHT TOLERANCE IN UPLAND RICE

Sam Raven D. Andres[1], Jerwin R. Undan[1], Editha V. Evangelista[2], and Jayvee A. Cruz-Kitma[3]*

[1]Department of Biological Sciences, Central Luzon State University, Science City of Muñoz, Nueva Ecija
[2]Department of Agriculture-Crop Biotechnology Center,Maligaya, Science City of Muñoz, Nueva Ecija
[3]Agronomy, Soils and Plant Physiology Division, Philippine Rice Research Institute
*Corresponding Author: Jayvee A. Cruz-Kitma: jayveeacruz@gmail.com

Abstract

Drought poses a significant challenge to agricultural crop production, leading to a low average yield of upland rice. We screened 75 potential isolates for their growth-promoting activities. The aim was to evaluate the effectiveness of rhizospheric bacteria on enhancing the growth and drought tolerance of upland rice. The top five performing isolates in indole-3-acetic acid production and ACC deaminase activity (isolates 53, 54, 59, 87, and 124) were screened for drought tolerance using various levels of polyethylene glycol (PEG). These bacterial isolates produced both indole-3-acetic acid (IAA) and 1-Aminocyclopropane-1-carboxylate (ACC) deaminase and were able to enhance the shoot length, root length, and dry matter percentage of upland rice under growth room conditions. In this study, inoculation with bacterial isolates 53, 54, 59, 87, and 124 significantly increased the shoot length of seedlings treated with bacterial isolates at 15% and 35% PEG at 7 days after sowing (DAS), in shoot length at 15% PEG at 14 DAS, fresh weight of rice seedlings in 25% PEG, and dry matter percentage at 35% PEG. However, in fresh weight at 15% and 35% PEG no significant difference was recorded but a percentage increase of up to 16.38% and 39.58% was observed respectively. An improvement of up to 25% in drought tolerance was also noted. These findings suggest that plant growth-promoting bacteria can be a promising approach to mitigate drought stress. However, it is recommended to re-evaluate the selected isolates for drought tolerance at the seedling stage to validate previous results and conduct field assessments to determine the effect of biotic and abiotic stresses. Hence, it is recommended to identify the bacterial isolates using 16S rDNA analysis.

Keywords: *Indole-3-acetic acid, 1-aminocyclopropane Carboxylic acid, Phosphate solubilization, Starch hydrolysis, Polyethylene glycol*

Introduction

Drought is one of the major constraints to agriculture. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) has issued a warning that El Niño phenomenon in the Pacific Ocean, which is frequently associated with drought in the Philippines, has intensified. This could potentially affect food security, especially on rice, which is a staple food for Filipinos. The nation's rice self-sufficiency program is facing a significant challenge due to the increasing population and high per capita rice consumption. In 2012, the Philippines was the fourth-largest importer of rice globally, having imported 1,500 million tons. The National Food Authority (NFA) has stated that due to the strong El Niño, rice imports could increase to 2 million tons for 2016 (Macas, 2015).

Upland rice production in the Philippines is currently low at approximately 2 t/ha due to factors such as weeds, decreased or excessive nutrient supply, and drought stress. Water application is the dominant factor affecting rice growth and yield. The Department of Agriculture (DA) recognizes upland rice farming as an important initiative in achieving the goal of rice sufficiency in the region and the country. The upland rice environment offers a chance to address household-based food availability, income, and nutrition in the community.

Breeders targeting rainfed environments aim to improve drought resistance in rice, including upland rice, for which drought is the major abiotic constraint on production. Inoculating rice with Plant Growth Promoting Bacteria (PGPB) in the greenhouse has been shown to increase chlorophyll, leaf area, tiller number, plant height, root shoot biomass, and subsequently grain yield. PGPB contributes a significant amount of nitrogen to increase rice plant biomass and improve the nitrogen status of the soil. Certain rhizobacteria, including actinomycetes, may act as plant growth enhancers.

Bacteria can survive under stress conditions due to the production of exopolysaccharide (EPS), which protects microorganisms from water stress by enhancing water retention and regulating the diffusion of organic carbon sources. Inoculating plants with drought-tolerant ACC deaminase containing native beneficial microorganisms may increase the drought tolerance of plants growing in arid or semi-arid areas. In a study by Cruz et al. (2014), inoculation with NB3 and AVermi7 at a full rate of fertilization significantly increased grain yield by 62% and 48%, respectively, relative to the uninoculated treatment. This demonstrates the potential of these actinomycetes as plant growth-promoting inoculants for upland rice. Field assessment is recommended to determine the effect of biotic and abiotic stresses on the performance of promising actinomycetes.

Identifying and evaluating actinomycetes isolated from upland areas as potential fertilizer to increase the yield of rice in upland areas is valuable, as several studies have shown its pronounced effect on yield components of crops such as rice and corn. The study aimed to isolate bacteria for enhancing the growth of upland rice, including screening bacterial isolates for ACC deaminase activity, IAA production, phosphate solubilization, and starch hydrolysis in vitro. Five selected plant growth-promoting bacteria were screened under drought stress induced by polyethylene glycol (PEG) as potential drought resistance enhancers, and were identified using the Biolog Microbial Identification System (BiOLOG).

Materials and Methods

Isolation of bacteria from the rice environment

Rhizospheric bacteria samples were obtained from rice plants in Occidental Mindoro and isolates from the Philippine Rice Research Institute (PhilRice), collected from drought areas in various regions of the Philippines. To isolate bacteria from the rhizosphere, the entire root system was carefully collected, and soil adhering to the roots was removed by tapping. The roots were then placed in diluent, shaken, and diluted to create four 10-fold dilutions, each of which was spread onto AGS media plates. To obtain rhizospheric bacteria isolates, plant roots were washed with tap water, ethyl alcohol, chlorox, and sterile distilled water to remove soil particles. The roots were then macerated, incubated at room temperature (28 - 30°C) for 7 days, and spread plated to isolate colonies from the soil in the rhizosphere. Samples with 10^{-3} and 10^{-4} dilution factors were used, and colonies were examined after incubation.

Screening of bacterial isolates for growth-promoting activities (GPA) in vitro

All rhizosphere isolates and existing isolates were screened and tested for ACC-deaminase activity, IAA production, N_2 fixation, P-solubilization, and siderophore production.

ACC-deaminase activity

To test the ACC-deaminase activity, the isolates were grown using the Dworkin and Foster's salts minimal agar medium without nitrogen, supplemented with either 2 g (NH4)2SO or 3 mM ACC (Sigma) per liter as the sole nitrogen source. The heat-labile ACC was filter sterilized through sterile millipore membranes and the filtrate was added to the salts' medium after autoclaving. Five-day-old isolates grown on rich OMYEA were streaked in triplicate on DF agar medium plates amended with either $(NH_4)_2S0_4$ or ACC. The plates were then incubated at 28 ± 2 ºC in the dark for 7 days. The growth and sporulation of the isolates on DF-ACC agar were used to indicate the efficiency of selected isolates in utilizing ACC and producing ACC deaminase.

IAA production

To quantify IAA production, the organisms were grown in Minimal Salts (MS) medium (KH_2PO_4, 1.36 g; Na_2HPO, 2.13 g, $MgS0.7H_20$, C.2 g; trace element solution, 1 mL/L, which consists of $CaCl_2.2H_20$, 700 mgM: $FeSO_4$ H20; MnSO .H20, 20 mgM; $CaSO_4$. H_20, 40 mg/ml, ZnSO $.7H_20$, 20 mg/ml H_3BO_3, 3 mg/ml; $CoCl.6H_20$, 7 mg/ml; Na_2MO_4 $2H_20$, 4 mg/ml) (Frankenberger and Poth, 1988) or in B broth or KMB broth supplemented with tryptophan. After 72 h incubation, the cultures were centrifuged and the IAA in the supernatant was detected by colorimetric method (Gordon and Weber, 1951). The Fe-H_2SO reagent consists of the following: 1.0 ml of 0.5 M FeCl 50 mL distilled water; 30 mL of H_2So. One ml of bacterial supernatant was added with 1 ml of the reagent. Pink to red color indicates a positive reaction.

Phosphorus solubilization

To assess the phosphate solubilizing activity, the isolates were grown on solid media that contained precipitated tricalcium phosphate using the modified Pikovskaya medium (Subba Rao, 1999). This medium contained 10 g glucose, 5 g tricalcium phosphate, 0.5 g $(NH_4)_2S0_4$, 2 g KCl, 0.1g $MgSO_4$ 7H2O, traces of $MnSO_4$ and $FeSO_4$, 0.5 g yeast extract, 15 g agar, and 1000 mL distilled water. The bacterial isolates were spot-inoculated onto the surface of the agar, and after 7 days of incubation, the presence of a clearing zone around the isolate was noted.

Starch hydrolysis

To test the starch hydrolysis, the isolates were grown in the starch agar. The test organisms were inoculated onto a starch plate and incubated at 30°C until growth is seen (i.e., up to 48 h). The Petri plate is then flooded with an iodine solution.

Screening of Selected Isolates for its Survival Under 15%, 25%, 35% Drought Stress Condition Induced by Polyethylene Glycol (PEG)

A SNAP-PEG solution was created with varying water potentials by adding appropriate concentrations of polyethylene glycol (PEG 8000) to the SNAP solution. PEG was dissolved in SNAP solution making a final concentration of 15% (water potential of -2.5 bars), 25% (water potential of -7.5 bars), and 35% (water potential of -12.5 bars) PEG in SNAP solution (S-P solution) (Michel, 1983). Bacterial isolates were grown in AGS media and used to prepare bacterial suspensions with a 10 - 6 dilution factor. NSIC Rc 192 seeds were sterilized using tap water, ethanol, and bleach. The seeds were then soaked in bacterial suspension for two hours, with control seeds soaked in sterilized water. The seeds were transferred to sterilized Petri plates with moist laboratory wipes to promote germination and then incubated for 2 - 3 days before being transferred to test tubes with 0.5 mL of SNAP-PEG solution. The setup was done in four replicates. Root length and shoot length were measured at 7 and 14 days after sowing while fresh weight was recorded at 14 days after seeding (DAS). Oven dry weight was also recorded. The design of the experiment was completely randomized design (CRD).

BiOLOG System

The selected bacterial isolates were subjected to further characterization using the BiOLOG system as per the manufacturer's instructions. The BiOLOG system compares an unknown biopattern to a database of reactions for a numerical probability calculation to assign qualitative levels of identification based on the similarity between the unknown organism and the database taxa. If a unique identification pattern is not recognized, a list of possible organisms is given, or the strain is determined to be outside the scope of the database. The test data from the unknown organism is compared to the respective database to determine a quantitative value for proximity to each of the database taxa. The results of the analysis were conducted at the University of the Philippines - Diliman.

Statistical Analysis

Gathered data from drought stress conditions using polyethylene glycol (PEG) comprising plant height, root length, fresh weight, and oven dry weight were analyzed using ANOVA in SAS software for Statistical Analysis. In assessing significant differences among treatments, Fisher's least significant difference (LSD) was used.

Results and Discussion

Isolation of Bacteria from the Rice Environment

Twenty-five potential plant growth-promoting rhizobacteria were isolated from the rhizosphere of rice taken from Occidental Mindoro in addition to the existing fifty bacterial isolates from PhilRice. Seventy-five bacterial isolates are screened for plant growth-promoting activities (Supplemental Figure 1).

Screening of Bacterial Isolates for Growth Promoting Activities (GPA) in Vitro Five strains of bacteria were chosen for their ability to promote plant growth, specifically in their production of IAA and ACC deaminase (Figure 1). These five strains produced the highest levels of IAA (ranging from 44.4 to 115.6 ppm) and positive ACC production, and were identified as isolates 59, 54, 53, 87, and 124. Four of these strains were from existing PhilRice isolates, while one was from the 25 isolated rhizospheric bacteria from Occidental Mindoro. However, two of the selected strains were negative for phosphorus solubilization and only one was positive for starch hydrolysis. Of the 75 total isolates, only 15% tested positive for starch hydrolysis, 33.33% for phosphorus solubilization, and 20% were negative for ACC deaminase activity. While ACC deaminase-producing bacteria are known to promote plant growth, bacteria lacking ACC deaminase have also been shown to increase plant growth, and IAA-producing bacteria can modify plant morphology to enhance nutrient and water absorption. This makes IAA production and ACC deaminase activity the criteria for selecting bacterial isolates (Glick, 2005; Husen et al., 2011).

Screening of Selected Isolates for their Survival under 15%, 25%, and 35% Drought Stress Condition Induced by Polyethylene Glycol (PEG)

The results depicted in Figures 2 and 3 illustrate the impact of bacterial isolates on the growth of rice seedlings under varying levels of PEG-induced drought stress. In Figure 1, bacterial isolate 87 showed a significant increase in shoot length at 7 DAS under 15% PEG and 35% PEG, while at 25% PEG, no significant difference was observed. However, the percentage increase still indicates that the bacterial isolate affected the growth of rice seedlings, which can be attributed to the production of IAA and ACC deaminase (Francis et al., 2010; Glick, 2005). Similarly, in Table 1, bacterial isolate 59 exhibited a significant increase in shoot length at 15% PEG, while no significant difference was observed in most other levels of PEG. Nonetheless, the percentage increase in shoot and root length suggests that the bacterial isolate still affected the growth of rice seedlings. Table 3 also demonstrated a significant difference in fresh weight for seedlings treated with bacterial isolate 124 at 25% PEG, while percentage increases were observed at 15% and 35% PEG. This can be attributed to the production of indole-3-acetic acid, which enhances plant morphology and root function (Bashan and Holguin, 1997). While there was no significant difference in dry weight between the control and bacterial isolate 124, a percentage increase was still observed. This underscores the positive impact of bacterial isolates on plant growth (Vessey, 2003).

Dry matter refers to the solid constituents of feed that remain after all the water content has evaporated. It is an important indicator of plant growth as it indicates the availability of nutrients (Whipps, 2001). Seedlings treated with bacterial isolates 53, 54, 59,

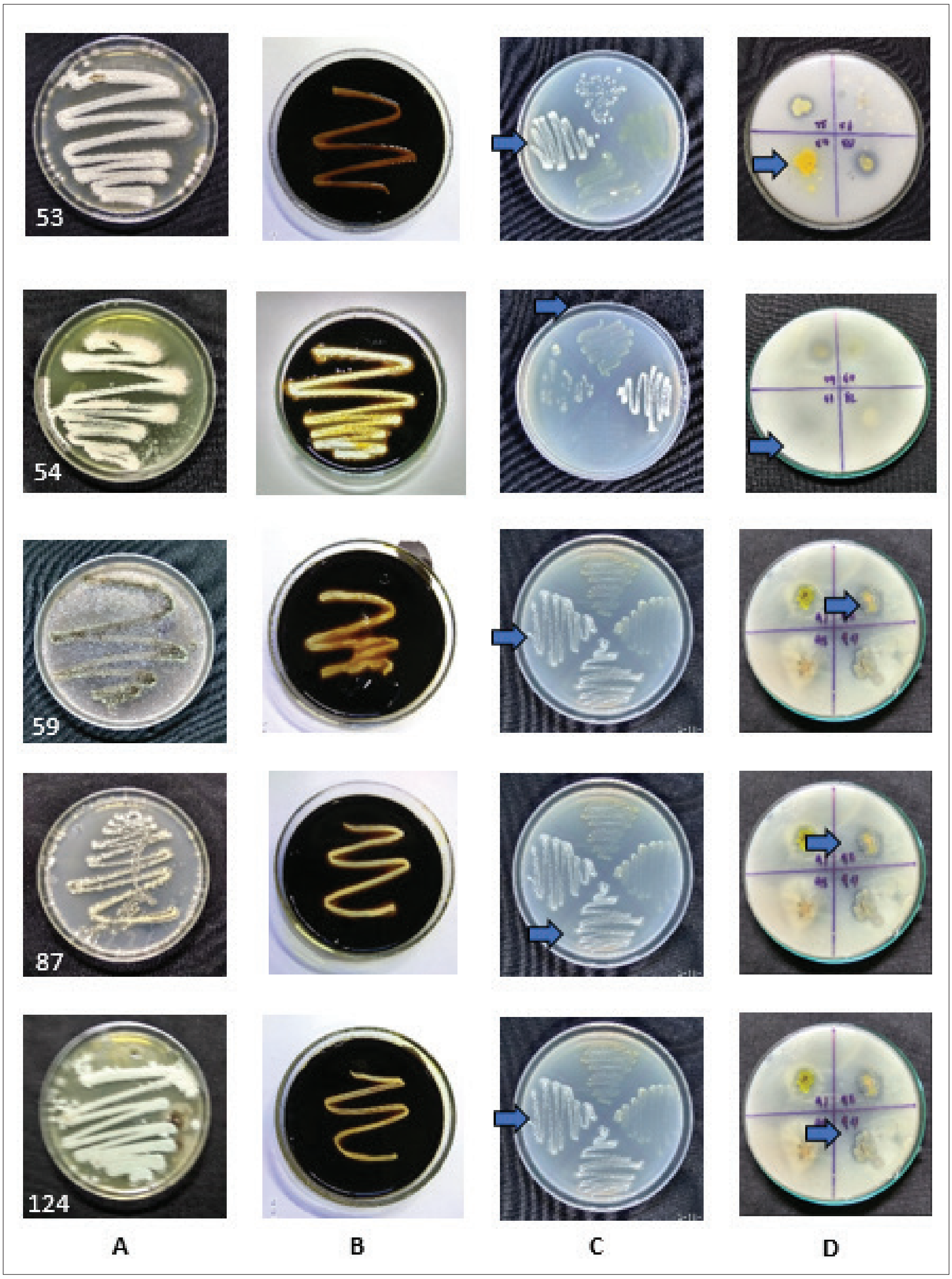

Figure 1. Growth-promoting activities of selected (a) bacterial isolates: (b) starch hydrolysis, (c) ACC deaminase production, and (d) phosphorus solubilization.

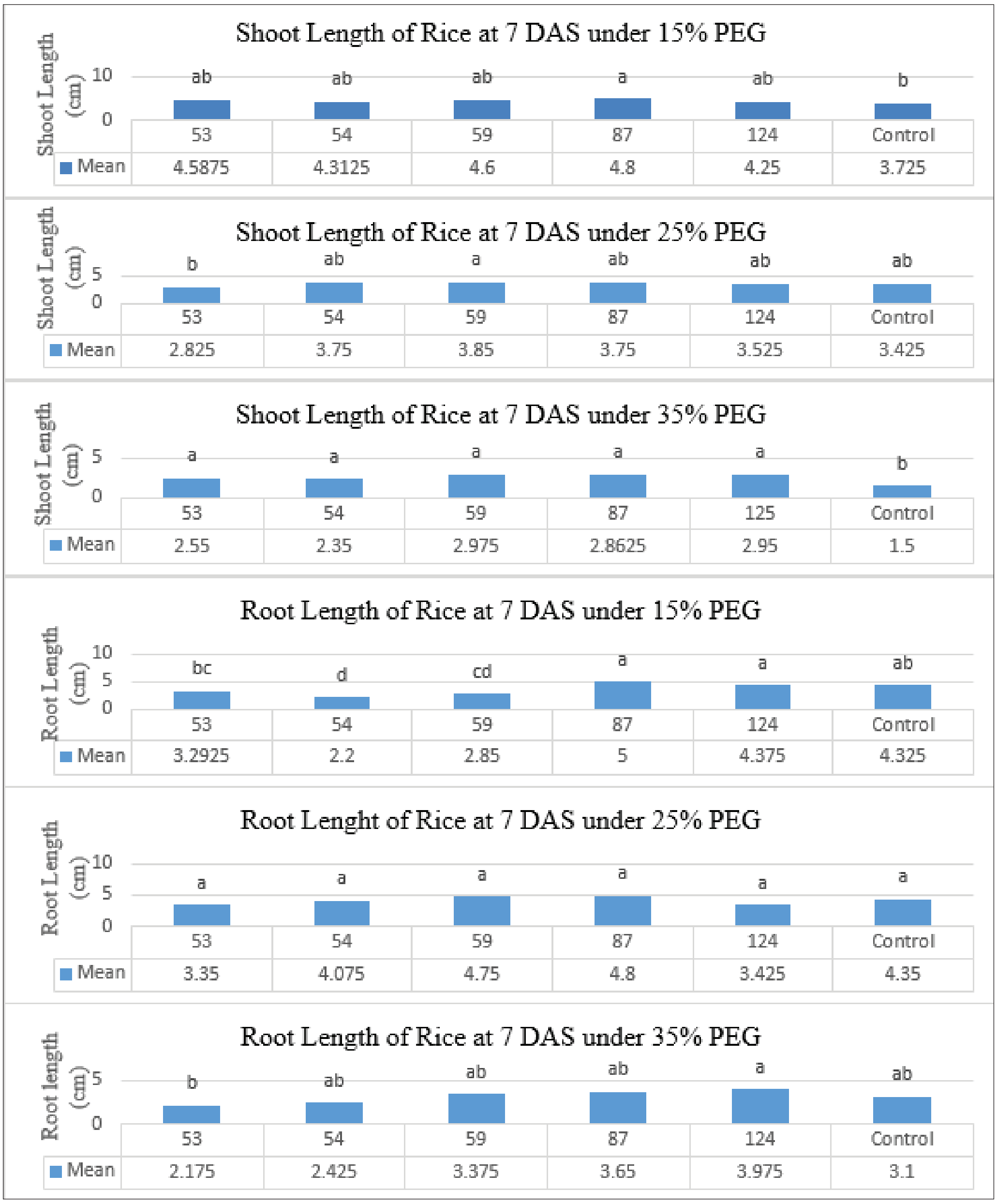

Figure 2. Shoot length and root length (cm) of rice at 7 DAS under 15%, 25%, and 35% PEG. *letters represent mean comparison, means followed by a common letter are not significantly different at the 5% level by Fisher's (LSD).

Table 1. Shoot length, root length, fresh weight, and dry weight of rice seedlings at 14 DAS under 15%, 25%, and 35% PEG.

Isolate Number	Shoot Length			Root Length			Fresh Weight			Dry Weight		
	15% PEG	25% PEG	35% PEG	15% PEG	25% PEG	35% PEG	15% PEG	25% PEG	35% PEG	15% PEG	25% PEG	35% PEG
53	7.90ab	5.75a	2.38a	3.73a	4.93ab	2.38a	0.045a	0.043d	0.050a	0.024a	0.025bc	0.035a
54	7.68ab	6.73a	2.88a	4.08a	4.68ab	2.88a	0.053a	0.060ab	0.050a	0.026a	0.0355ab	0.032a
59	8.83a	7.98a	3.58a	5.08a	3.35b	3.58a	0.044a	0.058abc	0.054a	0.023a	0.0360a	0.036a
87	8.73a	6.4a	3.38a	4.7a	3.43ab	3.75a	0.042a	0.045dc	0.060	0.024a	0.023c	0.029a
124	7.83ab	7.6a	3.5a	4.23a	3.98ab	3.5a	0.050a	0.064a	0.068a	0.028a	0.037a	0.037a
Control	5.95b	6.3a	2a	3.65a	5.48a	2a	0.045a	0.048bcd	0.048a	0.028a	0.037a	0.029a

*Letters represent mean comparison, means followed by a common letter are not significantly different at the 5% level by Fisher's (LSD).

87, and 124 at 35% PEG showed an increase in dry matter percentage, demonstrating the effectiveness of bacteria with growth-promoting ability to enhance seedling growth even in drought stress (Figure 3). The ACC deaminase of rhizospheric bacteria hydrolyzes ACC, which is the direct precursor of the hormone ethylene that decreases plant growth in drought stress (Husen et al., 2011). Tip burning and leaf rolling are symptoms of drought intolerance in plants (Cruz et. al., 2015). Table 2 shows that seedlings treated with bacterial isolates were able to tolerate drought stress of up to 25% in all levels of drought stress induced by PEG. These results demonstrate the potential of bacterial isolates to enhance drought tolerance in seedlings.

Identification of Selected Isolates

The GEN III MicroPlate™ test panel is a widely used method for profiling and identifying bacteria based on their phenotypic patterns. It consists of 94 biochemical tests that analyze the utilization of carbon sources and resistance to inhibitory chemicals (Bochner, 1989). The results are analyzed using BiOLOG's Microbial Identification Systems software such as the OmniLog® Data Collection, which can identify the bacterium from its phenotypic pattern in the GEN III MicroPlate.

However, in this particular study, all assays using the GEN III MicroPlate resulted in no identification. This could be due to several factors, such as the bacterial strain being novel or rare, or the sample being contaminated. Further testing using other identification methods may be necessary to determine the identity of the bacterium.

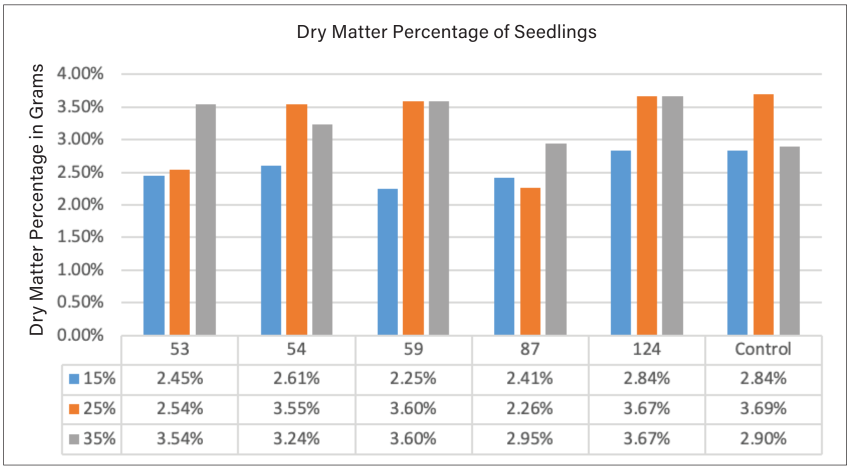

Figure 3. Percentage of dry matter of rice seedlings at 15%, 25%, and 35% PEG.

Table 2. Drought intolerance observation in rice seedlings at 14 DAS.

Isolate Number	Tip Burning			Leaf Rolling		
	15% PEG (%)	25%PEG (%)	35% PEG (%)	15% PEG (%)	25% PEG (%)	35%PEG (%)
53	25	25	50	25	75	0
54	0	0	100	0	0	25
59	25	0	25	0	0	0
87	75	25	25	25	0	0
124	25	0	50	25	25	25
Control	50	75	25	25	0	50

Summary and Conclusion

The study found that the five selected bacterial isolates can enhance the growth and improve the tolerance of rice seedlings under drought-stress conditions induced by PEG. The study also showed that rhizospheric bacteria possess growth-promoting abilities that can enhance growth and improve the tolerance of rice seedlings in drought-stress conditions. The results indicate that the use of PGPB is a promising approach to controlling drought stress and improving plant growth. However, the bacterial isolates used in the study were not identified using the BiOLOG system. The authors recommended employing 16S rDNA analysis for bacterial identification. In addition, the study provides valuable insights into the use of PGPB for improving drought tolerance in rice. Further research is needed to identify the bacterial isolates and to explore their potential for enhancing the growth and tolerance of other crops under various stress conditions.

Supplemental Figure 1. Photo documentation of bacterial isolates.

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FULL PAPER

QUANTITATIVE TRAIT LOCI (QTL) ASSOCIATED WITH PLASTICITY IN ROOT HARDPAN PENETRATION AND DEEP ROOT SYSTEM DEVELOPMENT UNDER SOIL MOISTURE FLUCTUATION IN RICE

Dinh Thi Ngoc Nguyen[1,3], Roel Rodriguez Suralta[1,4*], Mana Kano-Nakata[1,2], Shiro Mitsuya[1], Stella Owusu-Nketia[1,5], and Akira Yamauchi[1]

[1]Graduate School of Bioagricultural Sciences, Nagoya University, Nagoya 464-8061, Japan
[2]International Cooperation Center for Agricultural Education, Nagoya University
[3] Faculty of Agronomy, Vietnam National University of Agriculture, Gialam, Hanoi, Vietnam
[4]DA-Crop Biotechnology Center, Philippine Rice Research Institute
[5]Crop Science Department, School of Agriculture, College of Basic and Applied Sciences, University of Ghana
P.O. Box LG 44, Legon-Accra, Ghana
*Corresponding Author:rrsmfs@yahoo.com

Abstract

The plasticity in nodal root hardpan elongation during rewatering after drought and deep root system development below hardpan during transient drought are important for rice adaptation to rainfed lowland conditions. This study aimed to identify the quantitative trait loci (QTLs) associated with root plasticity under soil moisture fluctuation (SMF) stress. A panel consisting of 108 F_2 mapping population derived from Sasanishiki and SL39 backcrosses were used to analyze eight substituted chromosome regions with "Habataki" allele for association with root plasticity under SMF. Results showed that all QTLs were detected on chromosome 12. At seedling stage, one QTL (q*TRL*-12) near marker RM6905 was associated with plasticity in total root length during rewatering after drought. At vegetative stage, one QTL each namely: q*TRLW*-12, q*TRLB*-12, q*TLRB*-12, and q*TNRB*-12 co-located at marker RM3813 was associated with plasticity of whole root system, total root length, total lateral root length, and number of nodal roots below the hardpan, respectively. During SMF, one QTL near marker RM2197 for total lateral root length at the hardpan and one QTL near marker RM1986 for total nodal root length of whole root system were associated with plasticity. The results indicate that the Habataki genome contributed the corresponding alleles for the increases in the mentioned root traits which contributed to the increase shoot dry matter production under SMF. The QTLs detected in this study are associated with and/or contributed to the increased total root length of whole root system in response to SMF.

Keywords: *Artificial hardpan layer, Chromosome Segment Substitution Lines (CSSLS), Deep root development, Quantitative Trait Loci, Rice, Root plasticity*

Introduction

In rainfed lowland (RFL), rice plants are grown in bundled fields, in which soil moisture fluctuates from flooded to drought and aerobic conditions (Serraj et al., 2011). Correspondingly, rice plants develop their root systems constitutively and or as an adaptive response to the prevailing soil moisture conditions during these transitions. In rice, constitutive root traits are developed under normally flooded and anaerobic conditions, while adaptive root traits are developed in response to water stress and/or soil physical and chemical barriers (Shoaib et al., 2022). Phenotypic plasticity is the ability of a genotype to alter its phenotype in response to changing environmental conditions (Kato and Katsura, 2014; Suralta et al., 2018). In RFL, a soil physical barrier in the form of hardpan a layer with high bulk density at 20 cm depth below the soil surface, is present (Samson et al., 2002; Yano et al., 2006; Clark et al., 2008; Bengough et al., 2011). This hardpan hinders the penetration of roots to deeper soil layers to access whatever available water in the deep as well as the movement of water between soil layers during drought (Cairn et al., 2011). The majority of rice roots are generally present in the shallow layers (Islam et al., 2021), but genotypic differences in root growth in deeper layers were also evident (Samson and Wade, 1998; Kamoshita et al., 2008). Hence, deep rooting could be one of the key traits for improving drought avoidance of rice under RFL (Manschadi et al., 2006; Rich and Watt, 2013). During the period of limited rainfall, the soil starts drying from the surface leaving the deeper soil layer to have a relatively more available water, which could be accessed by the roots for its continued growth (Kameoka et al., 2015, 2016). Hence, the plasticity of roots to penetrate to hardpan layer and and continue to develop root system at deep layer during soil moisture fluctuation (SMF) is necessary for adaptation to RFL with a prominent hardpan.

Recently, the development of molecular markers has facilitated the genetic mapping of quantitative trait loci (QTLs). Root traits are typically governed by multiple QTLs or genes, and these root QTLs often exhibit a relatively low LOD value, due to low heritability and environmental interactions (Horii et al., 2006; Niones et al., 2015). The technique of applying a thin-wax layer to create an artificial hardpan layer has revealed extensive genotypic variations in root system development in both rice (Clark et al., 2002) and wheat (Acuña and Wade, 2005; Kubo et al., 2004), which account for differences in field performance (Acuña et al., 2007). In fact, several QTLs associated with root penetration through hardpans have been mapped in rice (Ali et al., 2000; Price et al., 2000; Zheng et al., 2000; Nguyen et al., 2004) and wheat (Acuña et al., 2014) using this technique. However, the artificial hardpan using the wax-petroleum layer has constant hardness, regardless of the prevailing soil moisture. Under natural soil conditions, penetration resistance, including that of hardpans, is inversely related to prevailing soil moisture (Cairn et al., 2011); as soil moisture increases, hardpan penetration resistance decreases and vice versa (Bengough et al., 2011; Nguyen et al., 2018; Suralta et al., 2018b).

Under SMF, the periods of rewatering decrease the penetration resistance of the hardpan layer. (Suralta et al., 2018b).

Root system development is controlled by a constitutive intrinsic pathway that determines the genetic potential of the accessions for root development, and by response pathways that modulate its development in response to water stress. This could possibly include SMF and contribute to root developmental plasticity (Malamy, 2005; Kano-Nakata et al., 2019). The adapted genotypes that performed better under SMF can take advantage by responding sharply to rewatering, promoting nodal root elongation through the hardpan and continuing root system development below the hardpan layer during drought (Suralta et al., 2018b; Nguyen et al., 2018).

The QTLs associated with plasticity in lateral root development (Niones et al., 2015) and aerenchyma formation (Niones et al., 2013) have been mapped under SMF on Chromosome 12 using chromosome segment substitution lines (CSSLs). However, QTLs related to plasticity in root elongation through the hardpan during SMF have yet to be reported.

With the development of the rootbox hardpan experimental system, which can simulate hardpan interactions with changes in soil moisture, we showed that the plasticity in nodal root elongation through the hardpan occurred during rewatering rather than during drought under SMF (Suralta et al., 2018b). Therefore, it is important to focus on detecting QTLs associated with root plasticity in response to rewatering after drought. This could subsequently promote deep root development below the hardpan layer during the succeeding progressive drought.

So far, we have identified one CSSL, SL39, that exhibits a greater ability to promote nodal root elongation through the hardpan and extensive deep root development under SMF (Nguyen et al., 2020). SL39 has substituted segments from the Habataki allele on two chromosomes; (3 and 12). We hypothesized that the QTLs associated with the plasticity associated with root plasticity in nodal root hardpan penetration and deep root development under SMF may be located on one or both of these chromosomes; 3 and 12. Therefore, this study aimed to map the QTL associated with root plasticity responses to rewatering during SMF.

Materials and Methods

Plant materials

An F_2 mapping population consisting of 108 lines derived from Sasanishiki x CSSL439 (SL39) backcrosses was used in this study. SL39 was chosen from a set of 39 CSSLs that were derived from a cross between Sasanishiki and Habataki. This selection was due to SL39's superior plasticity in nodal root hardpan penetration and deep root development below the hardpan in response to soil moisture fluctuation (SMF) (Nguyen et al., 2020). This may be largely attributed to one or more of the eight chromosome segments substituted from the Habataki allele in the Sasanishiki genetic background (Figure 1). Sasanishiki is a standard *japonica* irrigated lowland cultivar, which is the recurrent parent of the CSSL population developed by the Rice Genome Research Centre of the National Institute of Agrobiological Sciences, Tsukuba, Ibaraki, Japan. The F_2 mapping population, on the other hand, was developed at the Graduate School of Bioagricultural Sciences, Nagoya University, Japan.

Cultural management

Thirty-two lines were evaluated during the seedling stage in hydroponic culture, while 76 lines were assessed during the vegetative stage using soil-filled tubes. These methods facilitated destructive sampling of plants for root measurements and analyses at each developmental stage.

For the transient SMF at the seedling stage, pre-germinated seeds from each of the 32 lines were sown, and the seedlings were subjected to drought conditions from sowing up to 7 days. Drought treatment was induced by adding polyethylene glycol 6000 (PEG 6000; 4% w/v) to the hydroponic solution to achieve a water potential of -0.13 MPa (Suralta et al., 2008). PEG has no toxic effects under well-watered conditions (Suralta et al., 2008; Kano et al., 2011; Matsunami et al., 2016) but can mimic the drying effects of the soil environment. After 7 days, seedlings were transferred to new hydroponic solutions without PEG (non-stress, control condition) for another 7 days. Subsequently, plants were collected for various measurements.

Transient SMF at vegetative stage: The pre-germinated seeds of each of the 76 lines were sown in tubes (4 cm in diameter and 50 cm in height) filled with soils and divided into three layers (above hardpan - 20 cm soil depth from the soil surface) (1.25 g cm^{-3} bulk density (BD), hardpan (5 cm in depth) (1.70 g cm^{-3} BD), and below the hardpan (25 cm in depth) (1.25 g cm^{-3} BD). The soil used was an air-dried sandy loam soil sieved through a 3 mm mesh and mixed thoroughly with complete fertilizer (14-14-14) at the rate of 60 mg per kg soil. The hardpan layer (5 cm thick) was filled up with a soil mixture composed of 96.36 g of dry soil containing 45% sandy loam and 45% sandy soil premixed with 10% kaolinite. The mixture was gradually filled into a rootbox with the addition of a small amount of water while compacting it to achieve a 5-cm thick and 1.70 g cm^{-3} bulk density (Nguyen et al., 2018; Suralta et al., 2018b).

The plants were subjected to either well-watered (WW) or SMF conditions. In WW, the soil moisture content (SMC) was maintained at 30% (w/w) from 5 days after sowing (DAS) to 45 DAS, the day the experiment was terminated, using a time domain reflectometry probe (TDR; Tektronix Inc., Wilsonville, OR, U.S.A). The parent plants (SL39 and Sasanishiki) were only evaluated under well-watered (control) conditions.

In the SMF condition, plants were subjected to 20% SMC. At sowing, a small amount of water was added to the soil to facilitate optimal seedling growth for 5 days. During the experiments, the plants experienced several cycles of SMF: progressive drought down to 10% (w/w) (6 - 20 DAS); rewatered back to WW level (21 - 28 DAS); progressive drought down to 10% (29 - 35 DAS); rewatered back to WW level (39 - 41 DAS), and progressive drought down to 10% SMC (42 - 45 DAS). The plant samplings were done at 45 DAS.

Shoot and root growth measurements

Shoots were cut and placed in a paper bag and oven dried at 70°C for 72 h to record the shoot dry weight (SDW). The roots from each plant were collected in both experiments. In the soil-filled tube, roots were extracted from each soil layer (above hardpan, hardpan, and below hardpan layers). The extracted roots were washed carefully under running water. For root length measurements, each root sample was spread on a transparent plastic sheet with minimal overlapping. Digital *tiff* files were taken using an image scanner (EPSON Expression 10000XL) with a solution of 600 dpi. Scanned images were analyzed for total root length (TRL) using WinRhizo 2016 (Regent Instrument Inc.) with a pixel threshold value of 230. The total lateral root length (TLRL) was estimated as the total length of roots with less than ≤0.2 mm in diameter. The total nodal root length (TNRL) is the difference between the TRL and TLRL (Kato and Okami, 2011; Nguyen et al., 2015).

Genotyping and marker selection

Marker selection. SL39 had eight substituted genomic segments from Habataki distributed across two chromosomes in the Sasanishiki background (Figure 1). These substituted segments are found on chromosome 3 (RM5442) and chromosome 12 (between loci RM6905 and RM2197) (Yamamoto et al., 2008). Primer pairs were selected or designed based on the substituted segments from Habataki segments. A polymorphic analysis was done using 8 SSR markers: one in chromosome 3 (RM5442) and 7 in Chromosome 12 (RM6905, RM6973, RM7344, RM1986, RM3813, RM1300, RM2197) from the Gramene website (http://www.gramene.org/) for QTL mapping analysis.

DNA extraction. Three-centimeter-long rice leaf segments of F2 population and their parents were ground with liquid nitrogen and put into the DNA extraction buffer (pH 7.5) containing 0.2 M Tris-HCl, 0.25 M NaCl, 25 mM EDTA-2Na and 0.5% (w/v) sodium dodecyl sulfate. After incubation for 15 min, the extract was mixed with an equal volume of a mixture of chloroform and isoamyl alcohol (24:1) and centrifuged. Then, the DNA was rescued from the supernatant by mixing with 2-propanol and used for genotyping (Hironori, 2005).

The PCR was conducted in a reaction volume of 20 µl containing 1 µl of template DNA, 10 µl Go Taq Green master mix, 0.4 µl of both forward and reverse primer and 8.2 µl of distilled water. The samples were prepared in a 96-well amplification plate for PCR amplification using the TaKaRa PCR Thermal Cycler.

The PCR conditions were as follows: 2 min at 95ºC; 35 cycles of 30 sec at 95ºC, 30 sec at 55ºC annealing temperature and 30 sec to 1 min at 72ºC; and a final extension step at 72ºC for 5 min. The amplified PCR product was separated by electrophoresis on 4% agarose gel in 0.5 x TBE buffer and stained with ethidium bromide. DNA bands were visualized under UV light using an electronic UV trans-illuminator (Nippon Genetics Co. Ltd., Tokyo, Japan).

Statistical and QTL analyses

Statistical analysis. The experiment was laid out in completely randomized design for only parents (Sasanishiki and SL39). The statistical significance between the two parents in each soil moisture condition was determined using *t*-test.

QTL mapping. Quantitative trait loci was analyzed on the set of 32 and 76 F_2 individuals at seedling and vegetative stage, respectively, with phenotypic data for length of the whole root system and root length at and below the hardpan layers. R/qtl software (http://www.rqtl.org/; Broman et al., 2003) was used to detect QTLs (markers) associated with root plasticity traits. A critical threshold value (LOD score) of 2.0 was set to detect a QTL. In this study, less stringent significance thresholds were used because QTLs for root traits have a relatively low LOD value, presumably due to low heritability (Horii et al., 2006). The LOD value was calculated by conducting 1000 permutation test at 0.05 significant level. The phenotypic variance explained by each QTL (R^2) was estimated at maximum LOD score. The naming of QTLs followed QTL nomenclature system defined by McCouch et al. (1997).

Results and Discussion

Phenotypic variation in root traits

Adapting to drought and recovering quickly in response to rewatering after drought are complex processes related to several morphological and physiological traits. Therefore, identifying the key traits that contribute to plant growth and grain yield under water-stressed conditions is crucial for an effective breeding program. QTL mapping plays a significant role in modern breeding by enabling marker-assisted selection (MAS) and gene discovery (Price, 2006). Recent advancements in molecular marker technologies have facilitated the mapping of major genes for biotic and abiotic stresses in rice.

Following this development, the genetic architecture of the rice root system has been extensively studied to improve drought resistance, including root plasticity responses to soil moisture fluctuation in rice. QTLs for a large number of root parameters in several populations and different growth conditions in rice under drought have been identified (Courtois et al., 2009). These include root plasticity in lateral root development (Niones et al., 2015), root aerenchyma formation (Niones et al., 2013), and different component root traits (Suralta et al., 2015) under fluctuating soil moisture stress. However, our understanding of the QTLs associated with plasticity in root hardpan penetration and deep root development below the hardpan in response to SMF is still limited. Under RFL conditions, SMF and the presence of a hardpan in the soil are two of the main limiting factors that significantly reduce rice yield (Suralta et al., 2018a, 2018b). The use of CSSLs derived from genetically diverse rice cultivars provides a valuable genetic resource for identifying potential QTLs or genes controlling agronomic traits such as roots. These have been extensively used in identifying QTLs associated with root plasticity in response to SMF (Niones et al., 2015; Suralta et al., 2015; Owusu-Nketia et al., 2018).

In the present study, we examined the function of the QTL region and the root and shoot growth characteristics by comparing SL39 with its recurrent parent, Sasanishiki, under well-watered conditions at the seedling stage in hydroponics and at the vegetative stage in soil with an artificial hardpan layer (Table 1). Both genotypes, along with their F_2 genotypes, were also grown under transient soil moisture stress (drought and then rewatering) and SMF conditions. The results showed that without stress, both SL39 and Sasanishiki had similar root and shoot growth at the seedling and vegetative stages (Table 1). Under transient soil moisture stress, SL39 and Sasanishiki also had similar shoot dry weight (SDW) and other root parameters during the seedling stage (Table 2). At the vegetative stage, shoot dry weight and the total root lengths of the whole root system were also similar between SL39 and Sasanishiki (Table 2). However, plant height as well as the root lengths below the hardpan were larger in SL39 than in Sasanishiki under transient soil moisture stresses (Table 2).

Phenotypic variations in total root length (TRL) among genotypes at the seedling stage were wide which range from 141.8 to 356.6 cm per plant. At the vegetative stage, phenotypic variations among F2 genotypes in TRL of the whole root system and TRL below the hardpan were also wide-ranging from 3327.8 to 7882.4 cm per plant and 0 - 2299.8 cm per plant, respectively (Table 2, Figure 2b, f).

The SL39 possesses a QTL allele associated with increased deep root development after penetrating the hardpan, located in one of the eight substituted chromosome segments (Figure 1). Therefore, we quantified deep root development in SL39 under SMF using the saturated and high-resolution map of the CSSL derived from Sasanishiki x Habataki. Using

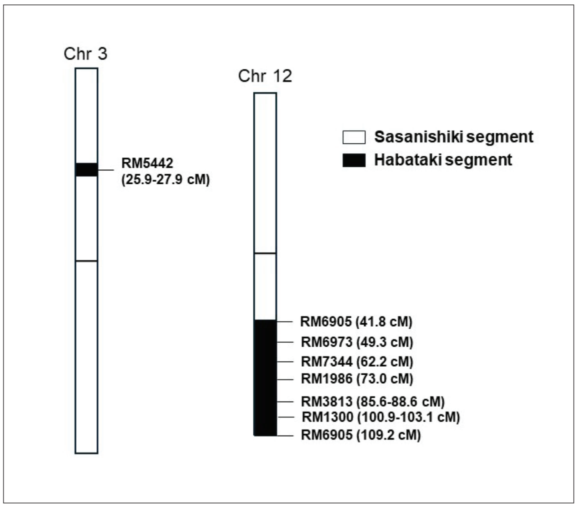

Figure 1. Graphical map of SL39, which shows the Sasanishiki background with substituted chromosome segments from the Habataki genome (NIAS, 2012). The solid white square represents the Sasanishiki segment while the solid black square represents the Habataki segment. The designation on the right of the substituted segments includes the name of the flanking genetic marker with the chromosome position in parenthesis.

Table 1. Shoot and root traits of Sasanishiki and SL39 genotypes under well-watered condition at seedling (14 DAS) and vegetative (45 DAS) stages in hydroponic and soil cultures with an artificial hardpan soil layer, respectively.

Traits	SL39	Sasanishiki	P value
Seedling stage (14 DAS)			
Plant height (cm/plant)	34.75	36.10	ns
Leaf age	6.04	5.96	ns
Tiller number	1.40	1.40	ns
SDW (g)	0.09	0.09	ns
NRN	15.60	17.00	ns
SMRL (cm)	20.60	19.30	ns
TRL (cm/plant)	722.80	834.80	ns
Vegetative stage (45 DAS)			
Plant height (cm/plant)	63.50	70.30	ns
Tiller number	6.70	4.00	ns
SDW (g)	1.99	1.83	ns
TRLW (cm/plant)	5835.80	6200.90	ns
TRLA (cm/plant)	4231.60	3819.70	ns
TRLH (cm/plant)	526.10	782.90	ns
TRLB (cm/plant)	1085.60	1598.30	ns

DAS, days after sowing; SDW, shoot dry weight; TRL, total root length; TRLW, total root length of whole root system; TRLA, total root length above hardpan layer; TRLH, total root length at hardpan layer; TRLB, total root length below the hardpan layer; ns, not significantly different between genotypes.

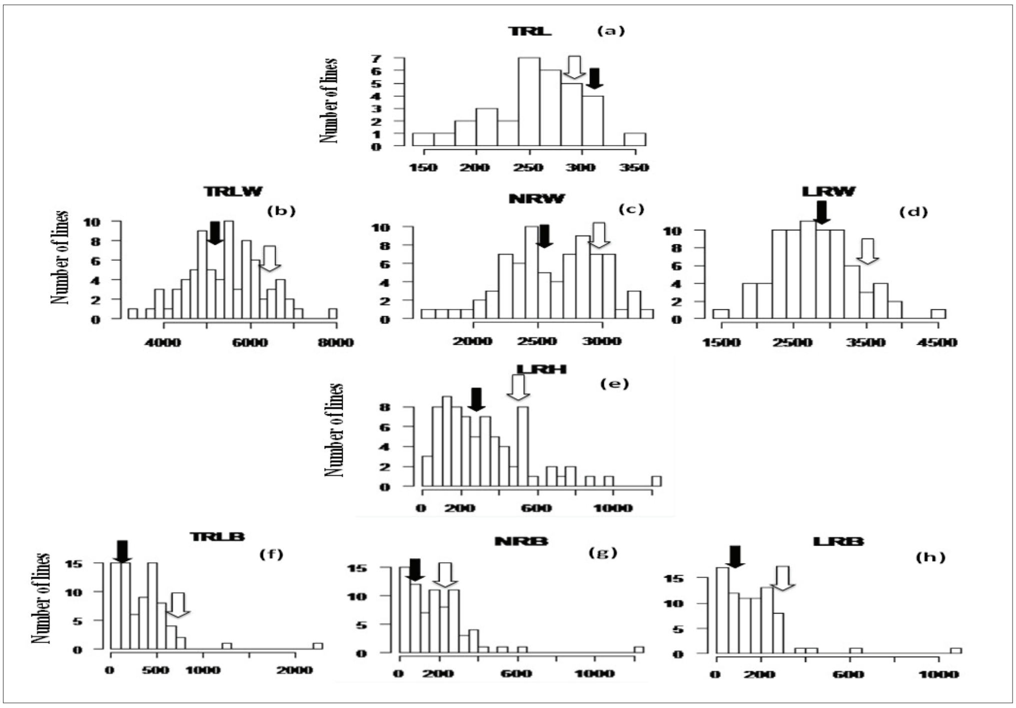

Figure 2. Frequency distribution of total root length(a) at seedling stage and total root length of whole root system (b), total nodal root length of whole root system (c), total lateral root length of whole root system(d), total lateral root length hardpan soil layer (e), total root length below hardpan layer (f), total nodal root length below the hardpan (g), total nodal root length below the hardpan (h), and total lateral root length below the hardpan layer (i) at vegetative stage of F_2 mapping population under soil moisture fluctuation condition. The values above the bars are the means of Sasanishiki (solid arrow) and SL39 (open arrow).

Table 2. Shoot and root traits of Sasanishiki and SL39 genotypes under transient soil moisture stress conditions (drought and then rewatered) at seedling stage (14 DAS) and under soil moisture fluctuation conditions at vegetative stage (45 DAS).

Traits	SL39	Sasanishiki	F_2 Population	
			Mean	Range
Seedling stage (14 DAS)				
Plant height (cm)	27.4	25.9^{ns}	27.4	20.1-32.3
SDW (g)	36.2	34.4^{ns}	34.1	24.2-43.2
Nodal root number	13.3	15.5^{ns}	14.2	10.0-20.0
SMRL	15.4	13.3^{ns}	13.5	8.0-16.5
TRL (cm/plant)	288.9	312.9^{ns}	257.8	148.1-356.6
Vegetative stage (45 DAS)				
Plant height (cm)	**66.5**	**61.9***	64.3	56.0-74.0
Tiller number	5.7	4.5^{ns}	4.6	2.0-8.0
SDW (g)	1.88	1.71^{ns}	1.60	1.19-2.03
TRLW (cm/plant)	6329.4	5375.3^{ns}	5398.3	3327.8-7882.4
TLRLW (cm/plant)	3248.4	2697.2^{ns}	2798.2	1511.2-4546.0
TNRW (cm/plant)	2912.3	2515.4^{ns}	2614.8	1666.5-3335.3
TRLA (cm/plant)	4683.3	4379.9^{ns}	4414.8	2868.6-5713.7
TRLH (cm/plant)	1050.7	826.3^{ns}	668.7	0-1932.3
TLRLH (cm plant^{-1})	482.3	330.1^{ns}	325.8	0-1237.5
TNRLH (cm/plant)	431.4	333.8^{ns}	323.7	0-960.3
TRLB (cm/plant)	**595.3**	**169.0***	339.8	0-2299.8
TLRB (cm/plant)	**266.5**	**89.6***	156.2	0-1066.6
TNRB (cm/plant)	**297.1**	**79.3***	187.9	0-1233.0

DAS, days after sowing; SDW, shoot dry weight; TRL, total root length; TRLW, total root length of whole root system; TLRW, total lateral root length of whole root system; TNRW, total nodal root length of whole root system; TRLA, total root length above hardpan layer; TRLH, total root length at hardpan layer; TLRH, total lateral root length at hardpan layer; TNRH, total nodal root length at hardpan layer; TRLB, total root length below the hardpan layer; TLRB, total lateral root length below the hardpan layer; TNRB, total nodal root length below the hardpan layer; ns, *, indicate no significant and significant differences at P0.05 between the two genotypes, respectively.

Table 3. List of QTLs detected for root traits by composite interval mapping under transient soil moisture conditions (drought and then rewatered) at seedling stage (14 DAS) in hydroponics and under soil moisture fluctuation at vegetative stage (45 DAS) in soil culture with the artificial hardpan layer.

Traits	Stage	QTL	Chr	Nearest Marker	Marker Position (cM)	LOD	AE	R^2 (%)	Direction of phenotypic effect	Condition
TRL	Seedling	*qTRL-12*	12	RM6905	41.8	2.4	41.8	29.3	SL39	Hydroponics
TNRW	Veg	qTNRW-12	12	RM1986	73.0	2.1	187.9	11.8	SL39	Soil
TRLW	Veg	qTRLW-12	12	RM3813	86.5-88.6	2.3	160.4	13.1	SL39	Soil
TLRW	Veg	qTLRW-12	12	RM3813	86.5-88.6	2.4	103.9	13.5	SL39	Soil
TRLB	Veg	qTRLB-12	12	RM3813	86.5-88.6	3.3	41.0	18.3	SL39	Soil
TLRB	Veg	qTLRB-12	12	RM3813	86.5-88.6	3.2	22.9	17.8	SL39	Soil
TNRB	Veg	qTNRB-12	12	RM3813	86.5-88.6	3.2	20.5	17.3	SL39	Soil
TLRH	Veg	qTLRH-12	12	RM2197	109.2	2.0	1.5	11.5	SL39	Soil

Chr, chromosome; *qTRL*, QTL of total root length; *qTRLW*, QTL of total root length of whole root system; *qTLRW*, QTL of total lateral root length of whole root system; *qTNRW*, QTL of total nodal root length of whole root system; *qTLRH*, QTL of total lateral root length at hardpan soil layer; *qTRLB*, QTL of total root length below the hardpan soil layer; *qTLRB*, QTL of total lateral root length below the hardpan soil layer; *qTNRB*, QTL of total nodal root length below the hardpan soil layer; Sdlng, seedling stage; Veg, vegetative stage. LOD, value of each marker in the interval analysis; QTL was detected when LOD score is greater than 2.0; AE, additive effect with positive value indicates that Habataki allele increased the respective trait. R^2, percentage of phenotypic variation explained by the QTL.

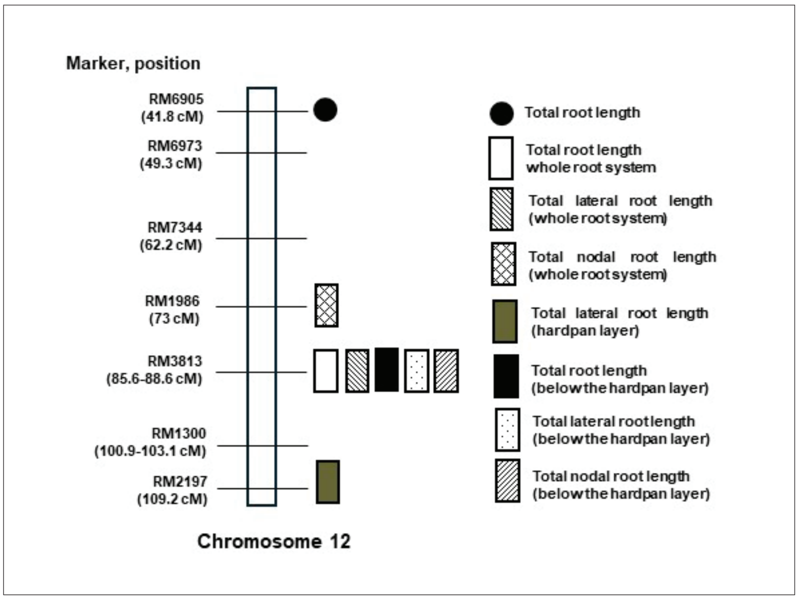

Figure 3. Molecular linkage map of F_2 population derived from a cross between SL39 x Sasanishiki and the possible location of the QTLs on the chromosome 12. The LOD threshold value was set at 2.0 to detect QTLs that are associated with specific traits. Symbols on the right indicate the approximate location of the QTLs that were identified at seedling stage (circle) and vegetative stage (rectangular). The designation on the left refers to the marker's name and its position.

eight molecular markers (Simple Sequence Repeats, SSR), we saturated the target regions of interest in SL39, which were on chromosomes 3 and 12 where the major Sasanishiki backgrounds were substituted with Habataki segments. A molecular linkage map was constructed using phenotypic and genotypic root data derived from the F2 mapping population (Figure 3). Four QTLs related to root plasticity were detected on chromosome 12 under SMF at both seedling and vegetative stages (Table 3).

During seedling stage, one QTL (*qTRL-12*) associated with TRL of the whole root systems with LOD value of 2.4 was detected at RM 6905 marker in the short-arm of chromosome 12. This QTL was contributed by Habataki allele (SL39 allele) (Table 3). During the vegetative stage, another QTL *(qTNRW-12)* associated with TNRL of the whole root system with LOD value of 2.1 was detected near RM1986 marker on chromosome 12, which was contributed from Habataki allele (SL39 allele). One QTL each for the TRL of the whole root system (*qTRLW-12; LOD=2.3)*, TLRL of whole root system (*qTLRW-12; LOD=2.4)*, TRL below the hardpan (*qTRLB-12; LOD=3.3),* and TLRL and TNRL below the hardpan *(qTLRB-12 and qTNRB-12; LOD= 3.2)* were detected in RM3813 locus on chromosome 12. These QTLs were also contributed by Habataki allele (Table 3). Furthermore, one QTL for TLRL at the hardpan layer was detected near marker RM2197 locus on chromosome 12 (LOD= 2.0) also contributed by Habataki allele (Table 3). The effect of the introgressed segment of Habataki allele on chromosome 12 enhanced the TRL of both the whole root system and below the hardpan layer by 17.7% and 252.2%, respectively, relative to Sasanishiki under SMF. One minor QTL for SDW (LOD= 0.92) was detected near marker RM2197 on chromosome 12, which was also contributed from the Habataki allele. This QTL contributed to the increase SDW of SL39 by 5.23 and 9.94 % relative to Sasanishiki under SMF during seedling and vegetative stages (Table 2).

Overall, we found four putative QTLs associated with root plasticity expressions were detected on chromosome 12 (Table 3, Figure 3). One QTL was detected at the seedling stage while three QTLs at the vegetative stage (Table 3) at different marker positions. This suggest that the expression of QTLs associated with root plasticity varies with different growth stages in rice in response to SMF similar to the findings reported by Niones et al. (2015). These differences could be well explained by the influence of QTL x environment interaction (Qu et al., 2008; Price et al., 2002; Kamoshita et al., 2002). Furthermore, QTLs identified in this study likely control more than one root trait. At the vegetative stage, QTLs for TRL and TLRL of the whole root system co-located with QTLs for deep root development such as TRL, TNRL, and TLRL below the hardpan at the marker region RM3813 contributed by the Habataki allele (Table 3, Figure 3).

Interestingly, the observed clustered QTLs correlated with multiple root plasticity traits, making the genetic locus or marker region RM3813 a genetic hotspot (Price et al., 2000; Champoux et al., 1995; Niones et al., 2015). This is considered very promising for potential use in marker-assisted breeding to improve the adaptation of rice varieties to RFL conditions experiencing SMF and the presence of a hardpan layer.

Generally, QTLs are controlled by several sets of genes (Comas et al., 2013; Wade et al., 2015), and co-locations of QTLs may be inevitable due to genetic interactions. Still, this genetic region may serve as a starting point for further mapping and for genetic and molecular characterization to better understand plasticity control.

In the present study, a chromosome region associated with TRL of the whole root system and deep root development below the hardpan under SMF was detected in the same marker region RM3813 on chromosome 12. This suggests that QTLs from SL39, which were responsible for the increased TRL of the whole root system and the TRL, TNRL, and TLRL below the hardpan layer, were co-located and/or interacted during their response to SMF.

Our previous studies showed that SL39 had similar responses in hardpan penetration and deep root development to its donor parent, the Habataki variety, under SMF (Nguyen et al., 2018; Nguyen et al., 2020). SL39 contains QTLs that enhance TRL of the whole root system and deep root development below the hardpan, contributed by the Habataki allele.

However, further study is needed to understand the differences in the characteristics of root system development such as morphological and anatomical differences among Sasanishiki, Habataki, and SL39 under actual rainfed lowland rice field conditions with a prominent hardpan.

Previously, QTLs associated with plasticity in L-type lateral root number (Niones et al., 2015) and aerenchyma development (Niones et al., 2013), which significantly contributed to greater root system development, water use (Suralta et al., 2010), and maintenance of dry matter production (Niones et al., 2012), were also detected on chromosome 12. Other QTLs associated with root thickness and root number at the deep soil layer were also detected on chromosome 12 (Price et al., 2002). However, these QTLs did not overlap with the QTLs on chromosome 12 detected in the present study, possibly due to differences in the nature of the water stress imposed (progressive drought stress versus waterlogged versus SMF conditions).

On the other hand, another QTL for TRL (41.8 cM) at the seedling stage identified in this study overlapped with the QTLs associated with plasticity in aerenchyma development (26.7 - 42.7 cM) and the number of L-type lateral root per cm nodal root axis (28.2 - 42.2 cM) detected on chromosome 12 (Niones et al., 2013, 2015; Suralta et al., 2018a) using different mapping populations. This suggests that this QTL may also be responsible for enhancing aerenchyma formation during rewatering after a transient drought, facilitating O2 diffusion into root tips for root system development during a period of sudden waterlogging in SMF.

Furthermore, the QTLs for root plasticity in this study did not overlap with any QTLs for root plasticity in TLRN (Niones et al., 2015; Owusu-Nkekia et al., 2018), TNRL, and nodal root number at 0 - 10 cm depth (Suralta et al., 2015) detected on chromosome 12. This indicates that these QTLs are distinct from those that were identified in previous studies.

The genetic regulation of root growth is strongly influenced by soil properties (Cairns et al., 2009). In the present study, the QTLs mapped in SL39 could enhance TRL of whole root systems in hydroponics and in soil culture in response to drought, rewatering, and SMF. This suggests that these QTLs may enhance penetration under compacted soils.

Furthermore, in soil with a hardpan experiencing SMF, one QTL for TRL of the whole root system was detected near marker RM3813 on chromosome 12. This is where QTLs for deep root development below the hardpan, contributed from SL39 alleles, were also present. These QTLs would be crucial for breeders to manipulate the rice root system to promote growth into deeper soil layers and improve resource acquisition when hardpans are present in the target fields prone to drought conditions (Ramalingam et al., 2017).

A QTL detected near the marker region RM 6905 on chromosome 12 from the Habataki allele might be responsible for the increase in TRL during rewatering after transient drought (Table 3). This QTL could also enhance nodal root penetration through the hardpan when the soil penetration resistance of the hardpan layer is reduced due to rewatering (Nguyen et al., 2018; Suralta et al., 2018b). This QTL could be a candidate for improving rice adaptation in rainfed lowlands with a prominent hardpan. Furthermore, no QTLs for TRL and Total Nodal Root Length (TNRL) were detected at the hardpan layer, but only a QTL for TLRL contributed by the SL39 allele near marker region RM1986 (Table 3). These findings suggest that Habataki may not have QTLs that could enhance penetration directly into the hardpan, especially during drought periods, but only QTLs that enhance sharp response to rewatering in preparation for continued deep root development below the hardpan when the next drought period occurs.

Moreover, the QTLs associated with the increase in TRL of the whole root system during seedling and vegetative stages contributed to the enhancement of nodal root elongation through the hardpan during rewatering and continued elongation and branching at the deep soil layer below the hardpan. This increases water availability and uptake during subsequent drought periods in SMF (Nguyen et al., 2018; Suralta et al., 2018b), consequently maintaining greater dry matter production (Kameoka et al., 2015). These QTLs played significant roles in plant adaptation to Rainfed Lowland (RFL) conditions with SMF and the presence of a hardpan (Yamauchi et al., 1996; Wang and Yamauchi, 2006).

Conclusion

We have shown that Habataki possesses the ability to express plasticity in nodal root elongation through the hardpan during rewatering, which subsequently promotes deep root development below the hardpan during subsequent droughts. In this study, genetic regions associated with various root plasticity traits such as the promotion of TRL and TLRL of the whole root system and deep root development (i.e., TRL, TNRL, and TLRL) below the hardpan, were identified. These regions were mostly co-located in the region of marker RM3813 on chromosome 12. These root plasticity traits expressed in SL39 were generally contributed by the Habataki allele and are essential for improving the adaptive capability of rice plants under RFL rice fields with a prominent hardpan.

The development of near-isogenic lines is currently underway. These lines will be used for fine mapping to enhance our understanding of the genetic mechanisms controlling root plasticity in root system development based on total length, as well as deep root development below the hardpan in response to fluctuating soil moistures and the presence of hardpans.

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FULL PAPER

SUITABILITY OF RICE WINE LEES AND CHILI PEPPER *(Capsicum annuum* L.*)* LEAVES IN THE PRODUCTION OF NUTRIENT-ENRICHED DRIED WHEAT NOODLES

Lynnden C. Lucas[1], Amelia V. Morales[1], Rogelie B. Orga[2], Aldrian Loi M. Velayo[2], Camille A. Buenaventura[2], Geraldine G. Tayag[2], and Rosaly V. Manaois[1*]

[1]Rice Chemistry and Food Science Division, Philippine Rice Research Institute
[2]Department of Food Science and Technology, College of Home Science and Industry
Central Luzon State University, Science City of Muñoz, 3119 Nueva Ecija, Philippines
*Corresponding Author: rvmanaois@philrice.gov.ph

Abstract

Wheat noodles are among the world's most popular food items and there is an increasing trend in improving their nutritive value. Lees is a by-product of Philippine rice wine (*tapuy*) production that has been previously shown to possess high levels of protein and dietary fiber. Partial replacement of wheat flour with *tapuy* lees flour (TLF) was evaluated to develop dried wheat noodles with superior nutritional quality by utilizing lees. The noodle formulation was optimized by testing different substitution levels of TLF: 0 (control), 15, 20, and 25% (w/w). The optimum level was identified based on the results of sensory descriptive analysis employing 13 semi-trained panelists (male=7, female=6; age ≥20 years). Results indicated that the noodles with 15% TLF had comparable general acceptability to the control. Higher TLF percentages resulted in products with heightened off-odor and off-taste, grainier mouthfeel, and lower acceptability. Further nutritional enrichment of noodles with 15% TLF was tested using different levels of powdered chili pepper leaves (CPL). Sensory results indicated that up to 1% addition of CPL was acceptable. The physical and nutritional properties (protein and dietary fiber [DF] content) and microbial load of raw and/or cooked noodles with 15% TLF and 1% CPL were then assessed. All raw noodle samples had <10% moisture content and <0.6 water activity, indicating low susceptibility to microbial spoilage and potentially long shelf life. No coliform and *Escherichia coli* were detected in the cooked samples. Cooked noodles with 15% TLF had considerably higher crude protein content than the control, while the overall quality and consumer acceptability of the products were comparable. With the addition of 1% CPL, the DF level was slightly improved but consumer acceptability was reduced. TLF could be used as partial substitute for wheat flour in dried noodles at the specified level to enhance the product's protein content.

Keywords: *Lees, Noodles, Protein content, Rice wine, Sensory evaluation*

Introduction

The conversion of agricultural wastes and food processing by-products into other useful and high-value products has been explored primarily to address ecological problems associated with the processes. This includes the production of biofuels, fertilizers/soil conditioners, animal feeds, food, cosmetics, and pharmaceutical products. One by-product that has been tested in some foods is rice wine lees. Lees is the residue obtained after the fermentation of rice into wine. In the manufacture of Philippine rice wine (*tapuy*), lees constitutes about 27% by weight of the raw material. As rice wine production scales up, the generation of large volumes of lees are anticipated. Lees is typically discarded, prompting investigations into its potential uses in food for a more sustainable and eco-friendly rice wine production process. By determining the properties of lees and its suitability for use in food products, rice wine manufacturers could gain an additional income source from their production process.

It has been previously demonstrated that rice wine lees contains high levels of fiber and protein (Manaois and Morales, 2014), suggesting a huge potential for improving the nutritional and overall quality of food products. This was made possible through the production of a shelf-stable product called *tapuy* (Philippine rice wine) lees flour (TLF). TLF was found to be a suitable replacement for wheat flour in various baked and non-baked products such as polvoron (Manaois and Morales, 2014), butterscotch (Manaois and Morales, 2018), cookies, and brownies. It improved the protein and/or DF levels of these products while maintaining their sensory acceptability.

Noodles are among the world's most popular food items, particularly in Asia, owing to their versatility and convenience. Noodles are mainly made of wheat, rice, and flours from potato and other starchy food, and other minor ingredients. After processing of these ingredients, the resulting noodle strands could be packed directly and marketed as fresh noodles or could be further processed by drying, steaming, frying, boiling, freezing, or a combination of these (Fu, 2008). Regardless of the form, wheat noodles serve as excellent mediums for nutrient enrichment, given that wheat lacks essential nutrients such as protein and dietary fiber (DF), which are lost during the refinement of wheat flour (Ganga et al., 2019). Protein, a vital macronutrient, is required by the body for growth, tissue repair, and various crucial metabolic processes. Conversely, DF aids in healthy digestion, weight maintenance, and reducing the risk of obesity and related health conditions. The intake of DF among Filipinos has been reported to be lower than recommended levels (Angeles-Agdeppa and Custodio, 2020), potentially leading to non-communicable diseases that have persistently posed serious health concerns in the country. Given its high protein and DF content, TLF could effectively supplement nutrients in dried wheat noodles.

Plants have served as nutrient-rich sources for a variety of food products. In noodles, various leafy plant foods have been utilized to boost the nutritional quality and even make the product more palatable. The use of Moringa (*Moringa oleifera*) leaf powder has been shown to enhance the protein content and increase the levels of micronutrients, specifically calcium, iron, and beta-carotene (Abilgos, 1996); enhance the DF level and lower the *in vitro* glycemic index (Ganga et al., 2019); and improve the antioxidant properties of noodles while retaining an acceptable sensory quality (Kim and Chung, 2017). Partial substitution of instant noodles with *Amaranthus* leaf powder, on the other hand, increased a product's fat content (Qumbisa et al., 2022) while the use of *alugbati* (*Basella alba* L.) leaves resulted in egg noodles with higher protein, fiber, ash, and total carotenoid content (Soriano et al., 2020). Chili pepper (*Capsicum annuum* L.) leaves (CPL) have been identified as rich sources of nutrients. When incorporated at a 0.5% level in powdered form into salt bread (pandesal), CPL enhanced the bread's dietary fiber, iron, beta-carotene, and folate content (Abilgos-Ramos et al., 2015). However, information regarding the use of CPL in other foods remains limited. CPL could potentially be utilized to further enrich the nutrient content of dried noodles. Such an application would not only benefit consumers but could also provide additional income for farmers.

This study evaluated the potential of TLF as a food ingredient and, in combination with CPL, as a source of protein and fiber in producing dried wheat noodles. Wheat flour was replaced with TLF and supplemented with CPL. The physical properties, sensory characteristics, microbiological quality, and consumer acceptability of the enriched products were all determined.

Materials and Methods

Lees from the glutinous local rice variety NSIC Rc 15 was obtained from the Rice Wine Manufacturing Plant of the Philippine Rice Research Institute (PhilRice), Maligaya, Science City of Muñoz, Nueva Ecija, Philippines. Ingredients for dry wheat noodles were procured from a local supermarket. All chemicals used in the laboratory analysis are of analytical grade.

Preparation of TLF

The procedure of Manaois and Morales (2014) was followed in the preparation of lees flour. The sample was packed in a polyethylene (PE) plastic bag and stored at 4 - 5^{o}C until further processing.

Preparation of powdered CPL

The procedure of Abilgos-Ramos et al. (2015) was followed in the preparation of powdered CPL. Healthy leaves were selected and thoroughly washed under running potable water, rinsed twice with distilled water, laid in sterile trays, air-dried for several minutes, and oven-dried at 40^{o} for 12 h. The dried leaves were powdered using a food grinder.

Preparation of dried noodles

Noodles were prepared using 100 g all-purpose/wheat flour, 46 mL water, and 2 g salt (pre-dissolved in water). TLF was partially substituted by weight to wheat flour at different levels: 0%, 15%, 20%, and 25%. The ingredients were thoroughly mixed until a uniform dough was achieved. This dough was then allowed to rest for 30 min. The dough was rolled into sheets with a thickness of 1.6 mm and subsequently made into noodle strands using a manual noodle maker machine. The noodles were steamed for 40 min, allowed to cool, packed in PE bags, and refrigerated overnight. The steamed noodles were dried using a cabinet dryer (electrical thermostatic blasting dryer) for 7 h at 50^{o}C. Noodles were identified as cooked enough by repeated evaluations until there was no white line visible at the center of the crushed piece and no raw taste. For the noodles with TLF, lees was substituted to all-purpose flour at different levels (0%, as unsubstituted control; 15%; and 20% w/w).

The noodle samples were screened by sensory evaluation. The most acceptable noodle treatment with TLF was further incorporated with CPL at different levels (0, 0.5, 1, and 2%). The best CPL incorporation level was determined by a trained sensory panel. Lastly, the final products with optimum TLF and TLF+CPL levels, along with the control, were subjected to consumer sensory tests, physical, microbial, and nutritional analyses.

Analysis of dried wheat noodles

Sensory evaluation

The dried wheat noodles (350 g) were boiled in chicken stock (35 g chicken cubes in 2.5 L water) for 5 min. The noodles were separated from the chicken stock and dispensed into paper cups. The hot stock was added to the cups immediately before the sensory evaluation.

Laboratory. Sensory evaluation of the optimized noodles with TLF was carried out using a 15-cm unstructured scale scorecard with 10-13 semi-experienced PhilRice staff (age ≥20 years) as panelists. The panelists were all consumers of dried noodles. They had undergone a 3-h refresher training and lexicon development to familiarize themselves with the sample and reference food products and to prepare the scorecard to be used for the descriptive sensory tests.

Sensory evaluation sessions were conducted in individual booths with controlled white light. Each panelist was given three coded samples and water for rinsing in between sample tasting. The attributes that were evaluated are aroma, off-odor (lees-like), appearance (external color of cream to light brown), off-taste (lees-like), firmness, adhesiveness, and mouthfeel. The panelists were also asked to rate the general acceptability to help determine the final formulation. Ratings for off-odor, off-taste, and general acceptability that differed significantly from the control were considered unacceptable.

The most acceptable noodle formulation with TLF was incorporated with different levels of CPL and the resulting products were further subjected to laboratory sensory evaluation. Ten (10) of the trained panelists above evaluated the products using a 15-cm unstructured scale scorecard as above, with the inclusion of off-odor (grassy) and off-taste (grassy/bitter-like) attributes.

Consumer. The two enriched noodle products (TLF, TLF+CPL) that received the highest ratings in the descriptive sensory test, along with the control, were subjected to a consumer sensory evaluation. A preference test was conducted with 50 untrained PhilRice staff (age ≥20 years) as panelists using a 9-point hedonic scale scorecard, with the following ratings: 1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like or dislike, 6=like slightly, 7=like moderately, 8=like very much, and 9=like extremely. The product characteristics evaluated included aroma, color (external), taste, mouthfeel, and overall acceptability. The panelists also ranked the samples with 1 as the highest, and without tied ranking.

Analysis of physical properties and microbial load

Moisture content (MC). Noodles were cooked by boiling in distilled water for 5 min (350 g dry wheat noodles: 2.5 L distilled water). The cooked noodles were spread in net bags and dried in an air-drying oven at 30ºC for 12 h. The raw and cooked dry wheat noodles were powdered using Cyclotec 1093 Sample Mill (Tecator, Höganäs, Sweden). The powdered samples were packed in PE plastic bags and stored at 4 - 5°C until further processing.

MC analysis was done following the AOAC Method 925.10 standard methods (AOAC, 1990). About 1.0 g of powdered noodle sample was added into a tared aluminum pan and then dried in an oven for 1 h at 130ºC. Samples were cooled in a desiccator for 30 min and then reweighed. MC was calculated using the equation below:

$$MC(\%) = \frac{wt.\,of\ dried\ sample}{wt.\,of\ sample} x100$$

Water activity. The water activity (A_w) of raw dried noodles was determined using Rotronic Hygropalm HP-23 following the manufacturer's instructions. The measurement was done in triplicate.

Color. The noodles were cooked as described in the MC analysis After boiling, the water was drained and sampling was done immediately before analysis. The color was measured as CIE *L*, *a*, and *b* color values using a Konica Minolta CM-5 spectrophotometer. Before use, the reflectance was calibrated using the 100% white calibration plate. *L* pertains to the measure of the lightness of the color with 100 as white and 0 as black, *a* for redness (+) or greenness (–), and *b* for yellowness (+) or blueness (–).

$$\Delta E^* = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2}$$

Where:

ΔE* = total color difference

ΔL* (L* sample minus L* standard) = difference in lightness and darkness (+ = lighter, - = darker)

Δa* (a* sample minus a* standard) = difference in red and green (+ = redder, - = greener)

Δb* (b* sample minus b* standard) = difference in yellow and blue (+ = yellower, - = bluer)

Volume expansion. To determine the volume expansion of noodle samples, the water displacement method was adopted (Yalcın and Basman 2008). Briefly, a 5.0-g sample was added into a 150-mL graduated cylinder filled with 90 mL water, and the volume of water displaced was measured. The volume expansion, expressed in percentage, was calculated by getting the difference between the volume of cooked noodles and the volume of raw noodles.

Nutritional analysis

Protein content. Crude protein content was determined following the 984.13 official method of AOAC (1990) by the Kjedahl method. About 0.3 ±0.0050 g of powdered noodle sample, prepared as described in the MC analysis, was placed into a digestion tube and added with Kjeldahl tablet (catalyst) and 5 mL of concentrated sulfuric acid. The samples were digested for 2 h and allowed to cool until the color changed from dark green to light blue. The digested solution was added with 25 mL distilled water and the total nitrogen content of samples was directly measured using Kjeltec Autoanalyzer (Kjeltec 2100, Foss). The total nitrogen was computed as follows:

$$Total\ Nitrogen(\%) = \frac{(Vs - Vb)xNacidx0.014}{wt.of\ sample}x100$$

Where:

Vs= Volume of acid used in the sample

Vb= Volume of acid used in the blank

Nacid= Concentration of sulfuric acid in normality

The protein content of the rice sample was estimated using the formula below:

$$\text{Protein content (\%)} = \text{\% total nitrogen} \times 6.25 \text{ (protein factor)}$$

Dietary fiber (DF). The DF level was measured using the enzymatic-gravimetric method (AOAC Method 985.29, 1990).

Microbial load

The microbial load was determined immediately after sample preparation by standard plate count technique. Ten grams of noodle sample was blended with 90 mL of 0.1% peptone solution for 1 min. Successive dilutions were made by transferring 1 mL of the suspension medium to 9 mL of 0.1% peptone solution. The components were plated in duplicate using dilutions from 10^{-2} to 10^{-4} for aerobic plate count (APC) and 10^{-1} to 10^{-2} for coliform and *E. coli* counts by transferring 1 mL on 3M™ petri-film plates. Plated Petri film plates were incubated and colonies were counted based on procedures provided by the manufacturer (3M™ Food Safety, 2017). The microbial count was computed by multiplying the total number of colonies by the dilution factor.

Statistical Analysis

Analysis of variance and subsequent comparison of means using Tukey's HSD (Honesty significant difference) was determined using SPSS statistical software (Version 20.0, SPSS Inc.) at p<0.05. Data were based on three measurements unless otherwise stated.

Results and Discussion

Screening of noodle preparation and percent TLF

Two sets of screenings were conducted to ascertain the optimal level of TLF substitution in wheat flour. The first set included 0, 15, 30, and 40 (w/w) flour, based on substitution levels previously tested in other food products (Manaois and Morales, 2014, 2018). These were evaluated for their sensory properties.

In general, all treatments were similar in aroma, taste, and adhesiveness. However, a grainy mouthfeel and lees-like off-odor were noticeable in all samples containing TLF. Notably, noodle strands with 30 and 40% TLF disintegrated easily and had a more discernible lees-like off-taste.

TLF has been found to be a suitable nutrient-enhancing ingredient in some snack foods up to around a 30% wheat substitution level (Manaois and Morales, 2014; Manaois and Morales, 2018). However, this was not feasible in noodles due to their mild flavor, which makes the addition of ingredients with strong flavors challenging.

Tapuy lees has a noticeable bitter taste, similar to brewer's spent grain (BSG), a major by-product of the brewing industry (Nocente et al., 2019) that has been repurposed as a food ingredient. However, its bitter taste has limited its use in food. Dried noodles with 30 and 40% TLF also had a grainy mouthfeel and received low acceptability scores (data not shown). Therefore, lower levels of lees substitution were subsequently tested (Figure 1).

Table 1 presents the results of the sensory evaluation screening performed by 13 trained panelists. Among treatments, no significant differences in aroma, taste, and adhesiveness scores were observed. However, color, lees-like off-odor, and off-taste were perceivable in all noodles with TLF. TLF possesses a distinct brown color, and it was observed that the hue of the noodles became progressively darker with the increase in TLF levels (Figure 1). Similar to *tapuy* lees, the powdered lees

Figure 1. Cooked dried wheat noodles with different levels of TLF.

Table 1. Sensory scores of cooked dried wheat noodles with different levels of TLF.

Sensory Attribute	Substitution Levels of TLF (%w/w flour)[1]			
	0	15	20	25
Aroma[2]	3.05^{a}	2.45^{a}	2.41^{a}	2.10^{a}
Off-odor (lees-like)[3]	0.00^{b}	2.26^{a}	2.36^{a}	3.00^{a}
Appearance (Color)[4]	2.62^{c}	6.83^{b}	9.36^{ab}	10.97^{a}
Taste[2]	2.61^{a}	3.20^{a}	2.82^{a}	3.17^{a}
Off-taste (lees-like) [3]	0.00^{b}	1.72^{ab}	3.34^{a}	3.70^{a}
Firmness[5]	7.77^{a}	6.65^{ab}	5.33^{ab}	4.23^{b}
Adhesiveness[6]	3.18^{a}	4.19^{a}	4.58^{a}	4.12^{a}
Mouthfeel[7]	0.25^{c}	3.34^{b}	4.35^{ab}	6.01^{a}
General acceptability[8]	9.88^{a}	7.44^{ab}	6.09^{b}	4.72^{b}

[1]Data with same letter within the same row are not significantly different (p<0.05; n=13).
[2]0=none, 15=very intense; [3]0=none, 15=very perceptible; [4]0=cream, 15=light brown; [5]0=soggy, 15=firm; [6]0=non-adhesive, 15=very adhesive; [7]0=smooth, 15=very grainy; [8]0=dislike, 15=like very much

of *Takju*, or Korean turbid wine, also resulted in a darker noodle color when substituted for wheat flour in noodles at 2% and 4% (Kim et al., 2007). Also, darker color and grainier mouthfeel were observed as the TLF levels increased. The noodles with 15% and 20% TLF had comparable firmness, while the general acceptability score of the product with 15% TLF was similar to that of the control. Hence, the sample with 15% TLF was used in subsequent CPL incorporation.

The noodle sample with 15% TLF was subjected to further nutrient enrichment by the addition of CPL at different levels (0, 0.5, 1, and 2%). Based on sensory evaluation (n=10), noodles with CPL were comparable with the control in terms of aroma, lees-like off-taste, firmness, adhesiveness, mouthfeel, and overall acceptability (Table 2). Grassy off-odor and off-taste, and green color were amplified as CPL levels increased. However, using more than 1% CPL in noodles resulted in noticeable lees-like and grassy off-odors, an intense color, and a grassy or bitter off-taste. Given these results, the noodle sample with 1% CPL was chosen as one of the final products (Figure 2) for consumer sensory evaluation and subsequent laboratory analysis.

Table 2. Sensory properties of noodles with 15% TLF and different percent CPL powder.

Sensory attributes	CPL Powder Incorporation Level (% w/w flour)[1]			
	0 (Control)	0.5	1.0	2.0
Aroma[2]	2.36^{a}	0.99^{a}	0.81^{a}	0.46^{a}
Off-odor (lees-like)[3]	1.80^{b}	3.35^{b}	3.60^{ab}	3.56^{a}
Off-odor (grassy)[3]	0.27^{b}	1.45^{b}	2.95^{ab}	4.94^{a}
Appearance (color)[4]	6.16^{b}	7.74^{b}	9.69^{ab}	11.53^{a}
Off-taste (lees-like)[3]	1.79^{a}	2.62^{a}	3.50^{a}	3.64^{a}
Off-taste (grassy/bitter-like)[3]	0.02^{b}	1.28^{b}	2.24^{b}	5.22^{a}
Firmness[5]	6.88^{a}	6.55^{a}	6.27^{a}	6.28^{a}
Adhesiveness[6]	2.89^{a}	3.52^{a}	2.87^{a}	2.49^{a}
Mouthfeel[7]	2.66^{a}	2.82^{a}	4.04^{a}	4.18^{a}
General Acceptability[8]	9.10^{a}	7.57^{a}	7.27^{a}	5.89^{a}

1Data with same letter within the same row are not significantly different (p<0.05; n=10)
[2]0= none,15= very intense; [3]0=none, 15= very perceptible; [4]0=cream, 15= light brown for 0%, light green to green for 0.5-2% as identified by the panelists;
[5]0= soggy, 15= firm; [6]0=non-adhesive, 15= very adhesive; [7]0= smooth, 15= very grainy; [8]0= dislike, 15= like very much

Figure 2. Raw dried wheat noodles with optimum levels of TLF and CPL.

In developing innovative ingredients and designing new products, consumer needs, expectations, and reactions toward the product must be determined to ensure a quality product that will be successful in the market (Świąder and Marczewska, 2021). Table 3 summarizes the result of the consumer test comparing the control (T_0), noodles with 15% TLF (T_1), and noodles with 15% TLF + 1% CPL (T_3) using a 9-point hedonic scale scorecard. The panelists considered noodles with 15% TLF acceptable and gave them ratings comparable with the control in terms of aroma, taste, mouthfeel, and overall acceptability. Use of 1% CPL in noodles with 15% TLF received lower ratings. Overall acceptability of the control and T_1 fell in the "moderate liking" rating, while T_2 was neither liked nor disliked. Ranking the samples, the panelists gave comparable ratings for T_0 and T_1, while T_2 received lower scores. While noodles with 15% TLF alone generally received comparable scores as the control, the addition of CPL in dried wheat noodles resulted in decreased overall acceptability.

Table 3. Consumer sensory evaluation of cooked dried wheat noodles with 15% TLF and 1% CPL.

Sensory Attribute	Treatment (% w/w)[1]		
	T_0 (Control)	T_1 (15% TLF)	T_2 (15% TLF + 1% CPL)
Aroma[2]	6.96^{a}	7.02^{a}	6.04^{b}
Color (External) [2]	7.92^{a}	7.08^{b}	5.25^{c}
Taste[2]	7.12^{a}	7.10^{a}	5.64^{b}
Mouthfeel[2]	7.16^{a}	6.92^{a}	5.32^{b}
Overall acceptability[2]	7.27^{a}	7.02^{a}	5.44^{b}
Rank[3]	1.62^{b}	1.70^{b}	2.68^{a}

[1]Data with same letter within the same row are not significantly different (p<0.05; n=50)
[2]1= dislike extremely, 2- dislike very much, 3= dislike moderately, 4= dislike slightly, 5= neither like nor dislike, 6= like slightly, 7= like moderately, 8= like very much, 9= like extremely; [3]1= highest, 3= lowest

Laboratory Analysis

Food quality and safety are of utmost consideration. Food quality comprises all characteristics and attributes demanded by consumers. These include the sensory attributes, physical characteristics, functional properties, and nutritional content (Mihafu et al., 2020). Food safety, on the other hand, concerns the preservation of quality and prevention of physical, chemical, or microbiological contamination of a food product before it is made available for consumption (Mihafu et al., 2020; Oyarzabal and VanRenterghem, 2020). The different properties of raw and cooked noodle products are summarized in Tables 4 and 5, respectively. MC refers to the amount of water in a food product, which impacts the product's taste, texture, appearance, weight, and shelf life (Appoldt and Raihani, 2017). MC values ranged from 6.89 to 8.59%, which fell within the acceptable MC range for dried noodles, typically between 8 - 12% (Gulia et al., 2013). Beyond this value, texture will be adversely affected. Microorganisms can also easily and multiply in the food, which will negatively impact the product's shelf life (Qing, 2016).

The A_w of a food product, or free water, provides valuable information about its quality, particularly microbiological growth on the surface. A_w is important for food stability, chemical and microbial reactions, and spoilage processes (Safefood 360, Inc., 2014). All raw dried noodle samples had A_w below 0.6, but the use of TLF and CPL even reduced this value (Table 4). At A_w of less than 0.75, bacterial growth is inhibited, although some yeasts and molds may still grow. However, all growth is inhibited if the value is less than 0.6 (Safefood 360, Inc., 2014). Foods with A_w below 0.6 and dried foods with MC ranging from 5 to 15% are less susceptible to microbial spoilage (deMan, 1999), indicating that the dried noodles had good storage quality.

Table 4. Properties of raw dried wheat noodles with TLF and powdered CPL.

Property	Treatment (% w/w)[1]		
	T_0 (0%, control)	T_1 (15% TLF)	T_2 (15% TLF + 1% CPL)
Moisture content (%)	8.59±1.59^a	7.24±0.10^a	6.89±0.35^a
Water activity (A_w)	0.426±0.01^a	0.385±0.00^b	0.364±0.00^c
Microbial count (CFU/g)			
Aerobic plate count	1.63 x 10^{5c}	1.52 x 10^{6c}	1.66 x 10^{6a}
Coliform and E. coli	ND	ND	ND

[1]Data with same letter within the same row are not significantly different (p<0.05); ND = not detected

Table 5. Properties of cooked dried wheat noodles with TLF and powdered CPL.

Property	Treatment (% w/w)[1]		
	T_0 (0%, control)	T_1 (15% TLF)	T_2 (15% TLF + 1% CPL)
Crude protein (%)	16.46±0.23^b	21.23±0.07^a	21.14±0.13^a
Dietary fiber (%)	8.42±0.27^b	6.80±0.22^c	9.82±0.45^a
Color: *L*	72.38±1.08^a	65.43±0.18^b	52.36±0.65^c
a	3.80±0.19^b	6.39±0.04^a	1.66±0.05^c
b	28.81±0.07^a	25.01±0.17^b	17.09±0.30^c
ΔE	0.00^c	8.35^b	23.30^a
Volume expansion (mL/g)	0.67±0.29^a	0.50±0.00^a	0.57±0.40^a
Microbial count (CFU/g)			
Aerobic plate count	8.00 x10^{4b}	1.55 x 10^{5a}	1.85 x 10^{5a}
Coliform and *E. coli*	ND	ND	ND

[1]Data with same letter within the same row are not significantly different (p<0.05); ND = not detected

Table 5 shows the different properties of the cooked noodles. The protein content of cooked noodles considerably increased from 16.46 to 21.23% and 21.14% in T_1 and T_2, respectively, or about a 28 - 29% improvement. This is due to the TLF's high protein level of about 45% (Manaois and Morales, 2014). Similar to *tapuy* lees, Brewer's Spent Grain (BSG) has been used in food products, and even commercialized for this purpose. Cuomo et al. (2022) utilized the dried powder form of a protein-rich BSG fraction, which had a protein content of 32.2%, in pasta. The addition of the same level (15%) to semolina flour resulted in an 18% increase in the pasta's protein content.

Additional incorporation of the dried noodles with CPL, however, did not show substantial difference in the protein content between T_1 and T_2 (Table 5). The level of CPL added to the product may be too low to cause any change in the protein level. Partial substitution of wheat flour with TLF resulted in a slight reduction in DF, but the addition of CPL augmented its value. The increase in fiber content for T_2 was from 8.42% to 9.82%.

In salt bread, the incorporation of crushed CPL at 0.5% slightly increased the bread's DF content from 1.68% to 2.42%; however, the powdered form did not have the same effect (Abilgos-Ramos et al., 2015). Various crop leaves have also been investigated for their potential to enrich noodles and other food products, addressing issues of food security and nutritional deficiencies, increasing the utilization of neglected crops (Zula et al., 2021), or aiding in waste management (Wani et al., 2016; Hussain et al., 2020).

Ganga et al. (2019) utilized Moringa leaves to enhance the fiber content of noodles at higher levels of 3, 4, 5, and 6%, finding that a 3% addition showed significant improvement. Zula et al. (2021) used an even higher level (20%), achieving protein and fiber enhancements of up to 10.86% and 42.2%, respectively. The use of spinach and artichoke at a 2.5% level did not significantly improve the protein content of noodles, but it did increase their DF level by about 14.2% and 72.6%, respectively (Ahmed et al., 2010).

With a 15% addition of powdered alugbati leaves, egg noodles showed slight enhancements in both protein (10% increase) and DF values (62%) (Soriano et al., 2020). In this study, CPL was used at only a 1% level, but this still resulted in a significant increase (16.6%) in the DF level of the noodles.

In a study by Abilgos-Ramos et al. (2015) on salt bread, CPL was shown to also increase the micronutrient content, specifically iron, beta-carotene, and folate content, in addition to DF. These findings, combined with the result of the DF content evaluation in this study, suggest that CPL can be a promising nutrient resource in foods and is therefore worth further exploration, especially in the absence of other nutrient-enhancing ingredients. This includes testing the effect of CPL on improving the micronutrient content in foods commonly consumed by vulnerable groups or those prone to micronutrient deficiencies.

The color of food is an important characteristic that influences consumer acceptability. In terms of color, the cooked noodles with TLF and CPL (T_1 and T_2) had a darker color than the control, as expected (Table 5). They had brownish colors with a lesser intensity of yellowness than the control, as indicated by their L and b values, respectively. Significant changes in color characteristics of noodles can be ascribed to the brown color of TLF. Also anticipated, T_2 had a light green color as indicated by its lower a value. There was a significant color change among treatments from 0 to 8.35 and 23.30 in T_1 and T_2. In terms of volume expansion, the noodle products did not exhibit significant differences.

The APC significantly increased by 1 log both for raw and cooked noodles with TLF and CPL as compared with the control (Tables 4 and 5, respectively). However, the cooking of noodles decreased the APC by 1 log from 10^5 to 10^4 CFU/g for the control (T_0) and 10^6 to 10^5 CFU/g for T_1 and T_2 (Table 5). Despite the marked increases in APC in the treatments, no pathogenic organisms, particularly coliform and *E. coli*, were detected in all samples, both raw and cooked.

In summary, this study corroborates previous findings that lees can be upcycled or transformed into a new product of higher value, specifically as a nutrient-enhancing ingredient in foods, particularly dried wheat noodles. In this product, up to 15% TLF can be used to replace wheat, resulting in a significant enhancement in protein content with minimal changes in sensory quality.

The incorporation of lees in foods could therefore add value to rice wine production, as this by-product may also serve as an additional source of income. Moreover, it offers a potential locally sourced and cost-effective alternative to wheat. Wheat is a crucial commodity in the country but is imported, making its supply and price potentially unpredictable. The use of wheat alternatives could therefore have significant impacts on food security and the economy (Wang et al., 2021).

However, in dried noodles, TLF was not effective in increasing the DF level. Conversely, CPL showed promise as an ingredient for enhancing the DF level of dried noodles but could still be further explored, particularly for its micronutrient-enriching property.

Conclusion and Recommendation

Rice wine lees can be repurposed or upcycled as an ingredient in noodle production. TLF can replace all-purpose/wheat flour up to a level of 15% in dried wheat noodles, enhancing the protein content of the product by up to 29% without impacting its overall sensory quality and acceptability. However, DF content was only slightly increased through the use of 1% CPL, and not by TLF. The product with CPL was less favored by the consumer panelists**.**

Further research is needed to improve the texture, aroma, and taste of TLF to expand its applicability in various products and provide nutritional benefits to more consumers. Additionally, exploring the use of CPL as a standalone nutrient-enhancing ingredient in foods is recommended.

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FULL PAPER

DEVELOPMENT AND TESTING OF A CONDUCTION, CONVECTION, AND FAR INFRARED RADIATION PADDY DRYER

Manuel Jose C. Regalado*, Marvelin L. Rafael, Alexis T. Belonio, and John Jeric A. Batanes

Rice Engineering and Mechanization Division, Philippine Rice Research Institute
*Corresponding Author: mjcregalado@philrice.gov.ph

Abstract

The Philippines has an annual grain drying capacity deficit of almost 9 million tons, which requires over 24,000 units of mechanical dryer. Thus, drying in the sun on roads is still prevalent. Consequently, improper drying alone accounts for rice postharvest losses amounting to 4.5% of total national paddy production. Hence, through a DOST/PCAARRD-funded project, we have developed a rapid paddy drying technology employing combined conduction, convection, and far infrared radiation heat transfer modes and using a rice husk gasifier as heat source to rapidly reduce paddy moisture for safe storage. This new drying technology could rapidly dry paddy from 21 - 16% moisture content (MC) through conduction and convection drying in a rotary drum dryer and grain cooler, respectively, and from 16 - 14% MC through the far infrared dryer. Both the rotary and far infrared dryers have grain throughput rates of 600 - 800 kg/h. Test results conducted at farmers' cooperative show a promising breakthrough in crop drying technology; however, this novel dryer needs further improvement before commercialization.

Keywords: *Combined conduction, Convection, Far infrared radiation drying, Paddy dryer, Rice husk gasifier*

Introduction

With the introduction and current popular use of the imported rice combine harvesters in the Philippines, drying of the high volume of paddy harvested during the harvest season has become a difficult challenge.The situation is further exacerbated during the wet season, as the harvested paddy tends to have a higher moisture content and the opportunities for sun-drying are limited due to frequent rainfall. In their study and analysis of the Philippine rice value chain covering the top 20 rice-producing provinces, Mataia et al. (2020) found that majority of the farmers (71%) sold their paddy in fresh form owing to limited access to postharvest facilities and immediate need for cash to pay for crop production loans. Palis et al., (2015), in their rice farmers' needs assessment study in six rice-producing provinces in Luzon, Visayas, and Mindanao, found that aside from paying off debts, other reasons for selling freshly harvested paddy right away include: (1) farmers in general need cash immediately; (2) buyers would still take out 7 kg for every bag of fresh paddy as discount (locally known as "resiko") to the buyers, which is equivalent to the amount lost if the grains were dried; (3) lack of drying facilities; and (4) do away with labor cost for drying. Philippine Statistics Authority (PSA, 2021) data show that from 2018 - 2020, 57.7 - 59.1% of the country's total annual paddy production was sold while from 19.4 - 21.9% was utilized for home consumption. This implies that, given an annual average national paddy production of 19.069 million metric tons (Mmt) from 2018 - 2020, based on 2021 PSA data, an average of 11.1 Mmt per year would be dried by traders, millers, and other processors. Meanwhile, farmers would need to handle the drying of an average of 3.95 Mmt per year.

Most farmers tend to sell their paddy immediately after harvest while paddy traders and processors might cease purchasing the fresh or wet produce due to their limited drying capacity, especially during the wet season. Given the large volume of paddy that they need to dry and their limited mechanical drying capability, traders and processors often resort to sun-drying on roads and even highways. This practice risks re-wetting the dried paddy due to sudden downpours, invariably resulting in poor quality dried paddy which ultimately leads to lower milling recoveries.

Based on DA-PHilMech's 2015 database, the Philippines has a total annual grain drying capacity of 9.36 Mmt (Tolentino et al., 2017). However, considering the total national paddy production of 18.15 Mmt in 2015 (PSA, 2016), there is a national deficit in drying capacity of 8.79 Mmt per year. This translates to a need for over 24,000 units of 6-ton flatbed or batch recirculating dryers.

Methods of grain convection drying use air as the heat transfer medium because air is handled easily and does not contaminate the grain (Brooker et al., 1974). However, air does not have a high heat transfer coefficient and coupled with high resistance to moisture diffusion, results in extended drying times. Hence, the process of air-drying, regardless of the type of dryer, is relatively an inefficient process (Lapp and Manchur, 1974). As an alternative to convection drying, researchers have investigated and tried conduction heating to accelerate drying rates and increase drying efficiencies. The term conduction heating for grain drying is used when heat is supplied to a solid medium, which comes into contact with the grain rather than the heating of air (Raghavan et al., 1988).

Two types of conduction heat transfer systems were previously studied. In the first system, solid heat transfer media such as salt, sand or molecular sieves were used. Heated sand was tried by Khan et al. (1974) as a heat conduction medium to dry wet paddy. Raghavan et al. (1988) compared the use of sand and molecular sieves (synthesized zeolites) for drying corn in terms of moisture removal and found that molecular sieves were better than sand and moisture removal was more pronounced at higher residence (retention) time. Other systems wherein, instead of using particulate media, the grain was mechanically rolled on a heated surface appeared to be more practical in providing simple means of applying heat in a direct manner (Jindal and Reyes 1988). Kelly (1938) was probably one of the first researchers who used the latter system for drying wheat by heating it in a drum rotating inside an oven and then cooling with unheated air afterward. Conduction drying of paddy in a rotary drum dryer has been employed to reduce the moisture of paddy (Belonio, 1993). Results of parallel studies on the rotary dryer of International Rice Research Institute showed that moisture removal was abetted by aerating the heated grains (Espanto, 1987; Jeon et al., 1987). Woods and Gupta (1988) referred to a second stage of drying that may take the form of a cooling process as “dryeration.” This process of heat and moisture transfer to the air, which brings about grain drying and cooling, is possible on a thermodynamic basis with the reversible process but with hysteresis effect (Boyce, 1965).

Regalado and Madamba (2000) developed a combined conduction and convection rotary drum paddy dryer and found that fresh ambient air forced inside the drum in a counter-flow direction at 1-2 m/s “dryerated” the heated paddy. Studies on far-infrared drying of paddy showed that it is effective in reducing grain moisture even at lower initial moisture content levels, without significant loss in the grain’s milling quality (Bekki, 1991; Hidaka et al., 2004; Pan et al., 2008; Pan et al., 2011). In this research project, we postulated that combining the principles of conduction, convection, and far-infrared drying of paddy as heat transfer modes in a single dryer will further increase the rate of mechanical drying. Moreover, adopting the rice husk gasification technology to supply the heat needed would significantly reduce the drying cost and dependence on imported fossil fuel.

Philippine Rice Research Institute (PhilRice) produced its first working prototype of the combined conduction, convection, and far infrared radiation paddy dryer (Figure 1) in 2016 (Regalado et al., 2017). The main components of this new drying technology include the rotary drum dryer, grain cooler, far infrared radiation dryer, and rice husk gasifier. The producer gas burner of the rice husk gasifier heats the rotary drum dryer which, through conduction heating of grain upon contact with the hot inner cylinder surface, removes free moisture from the paddy. Heated grains from the rotary dryer are passed through an oscillating screen grain cooler to lower the grain temperature resulting in evaporative cooling or “dryeration.” Partially dried paddy is then conveyed by a bucket elevator to the far infrared radiation (FIR) dryer. Its main component is an FIR emitter slab made of a mixture of white sand and cement. When heated to a temperature of about 130°C, the slab emits far infrared rays, which can further reduce the moisture content of grains conveyed underneath by an oscillating tray. The rotary drum and FIR slab are directly heated by burners fueled with producer gas generated by a continuous flow rice husk gasifier.

This research project, which was funded by DOST-PCAARRD and PhilRice, was conducted from October 2017 to December 2022 at PhilRice Central Experiment Station in the Science City of Muñoz, Nueva Ecija and at the Sto. Nino Multi-purpose Cooperative in Butuan City, Agusan del Norte. This research validated under actual field conditions the performance of the combined conduction, convection, and far-infrared radiation paddy dryer; modified the dryer based on the results of actual field performance vis-à-vis the design parameters and prospective adopter’s preference in terms of operation; and identified socio-economic factors that can either enhance or hinder the utilization of the new dryer.

Materials and Methods

Project Conceptual Framework

The project was implemented following a conceptual framework shown in Figure 2. It made use of the initial CCFIR dryer prototype developed in a previous project. A modified design for a pilot test unit was produced after optimization tests. The modified design was fabricated by a local manufacturer and installed at a farmers’ cooperative for field verification and testing. Improvements resulting from the actual drying tests, as well as suggestions from the intended users, will be incorporated to finalize a design for pre-commercialization.

Optimization Tests

Further drying trials were conducted at the PhilRice Central Experiment Station (CES) using the prototype of the combined conduction, convection, and far infrared radiation (CCFIR) paddy dryer developed in 2016 (Figure 1). The aim was to optimize design parameters such as grain throughput capacities, gas flow rates in gasifier burners that affect burner temperatures, as well as the temperatures of the rotary drum surface and far infrared radiation emitter/slab surface.

Redesign of the Dryer Components

The main components of the CCFIR dryer for installation at the pilot test site were redesigned to attain an overall grain throughput of 800 - 1000 kg/h. The design also considered the use of locally available materials and fabrication skills and technology's easy use and operation. Technical drawings were prepared for the fabrication of component parts.

Selection of Field Validation Site

Criteria were set in selecting the test site. The CCFIR paddy dryer pilot unit was planned to be validated in a region that does not have a dry season but experiences a pronounced wet season from November to January. Presence of mechanical dryers must also be necessary in the region to maintain the quality of the paddy harvest.

The site should ideally be located near a PhilRice branch station to facilitate data gathering and monitoring. Additionally, the partner farmers' cooperative should be willing to provide an area suitable for the installation and operation of the CCFIR dryer. The cooperative's aggregate paddy field area should also be 50 ha or more.

If the cooperative does not operate a rice mill, then a sufficient quantity of rice husks should be available from nearby rice mills. The cooperative members should also be open to having their paddy dried using the dryer. Furthermore, the cooperative could provide

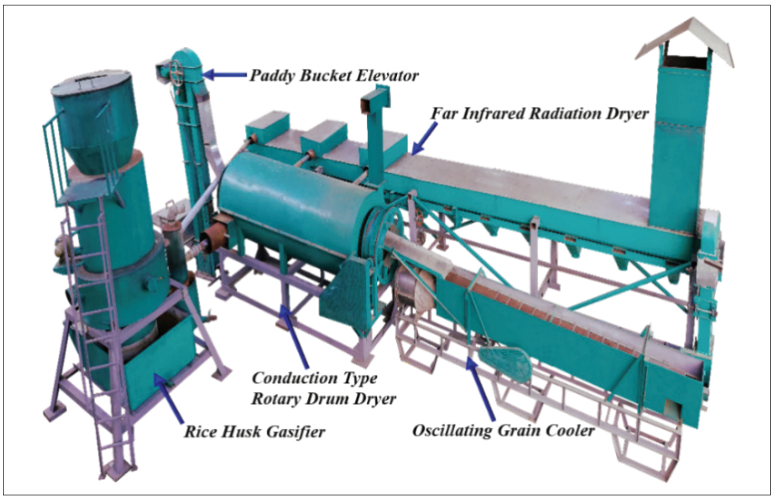


Figure 1. Combined conduction, convection and far infrared radiation paddy dryer at PhilRice Central Experiment Station, Science City of Muñoz, Nueva Ecija.

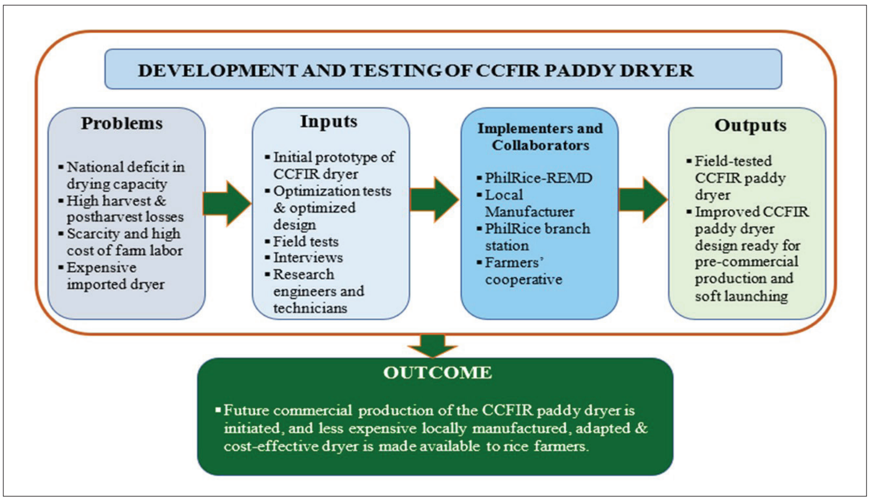


Figure 2. CCFIR dryer development and testing the project conceptual framework.

workers who would be trained in the operation, maintenance, and simple repair or troubleshooting of the dryer.

Finally, there should be a manufacturer or assembler within the selected region who is willing to be accredited in the fabrication, assembly, and maintenance of the dryer.

Fabrication of CCFIR Dryer Pilot Unit for Field Validation

A pilot unit of the CCFIR dryer, based on the revised design of the optimized prototype installed at the PhilRice Central Experiment Station, was fabricated and installed at the identified and selected site, the Sto Niño Multi-purpose Cooperative in Butuan City, Agusan del Norte.

The fabrication of the pilot unit adhered to the revised design of the working and functional CCFIR dryer. Local manufacturers from the selected pilot test area were identified, visited, and evaluated. The chosen manufacturer was trained and guided in the fabrication and assembly of the dryer. The fabrication process of the dryer components was regularly monitored, with technical assistance provided to the manufacturer as needed.

A commissioning test of the fabricated and installed dryer pilot unit was conducted by the selected fabricator to debug or check and ensure the functionality of the dryer components.

Field Performance Testing

The research team adhered to the standard procedure for testing mechanical grain dryers (BPS PAES 202:2015). Performance data such as dryer throughput, dryer capacity, drying ability or percent moisture content reduction per hour, rice husk fuel consumption, initial and final paddy moisture contents, initial and final paddy temperatures, electric power consumption, and temperatures of the gasifier reactor, producer gas burners, and FIR surface emitter were gathered during the actual operations.

Paddy samples with varying moisture contents, ranging from partially dry to very wet paddy, were used to determine and make necessary adjustments to further optimize the drying process onsite. These tests were conducted on the initial prototype for two seasons (wet and dry), and on the pilot unit for two seasons in the following year.

Improvement and Modification

Operational problems encountered during the drying season were evaluated and necessary modifications were incorporated in the pilot unit to improve dryer operation. Machine parts that wear out and need periodic replacement were listed and replaced. These activities will be carried out until the final prototype is accepted by the partner farmer cooperative.

Results and Discussion

Initial Prototype Optimization Test Results

In the series of tests carried out to determine the CCFIR dryer's optimum settings, freshly harvested and partially dried paddy samples of mixed varieties were used. Results showed that the average grain throughput was 878.4 kg/h, average rice husk consumption by the gasifier was 120 kg/h (about 10 sacks/h), and elapsed time for producer gas or combustible gas production in the gasifier reactor ranged from 5 - 10 min with a mean of 6.25 min. The time to heat the concrete slab to 130 - 150°C was about two hours on the average. Based on the relationship (Equation 1) given by Hall (1962), which shows that the absolute temperature T^o, in degrees Celsius of a radiating body is associated with the maximum wavelength, λ, in microns, the slab would be emitting at the stated range of temperatures far infrared radiation with a wavelength of about 8 µm. Figure 3 shows that far infrared wavelengths used in industry is from 2.5 - 30 microns (JIRA, 2016). According to Bekki (1991), the normal infrared absorption spectrum of moisture in a rice kernel is 2.9 µm. However, to produce infrared rays with this wavelength would require tremendous heat and extremely high temperature (1300°C), which would scorch the grains. Hence, Bekki (1991), in his rough rice drying experiments using a far infrared panel heater, worked with wavelengths from 3.3 - 8µm, which heated to much lower than 250°C.

$$\lambda_{max}(T) = 5205 \qquad \text{(Equation 1)}$$

Grain Residence Time

Single pass of a grain through the dryer from the loading bin to the bagging section after the FIR dryer took about 6 min. Grain residence or retention time in the loading bin and bucket elevator was 5 s, about 2 min and 11 s in the rotary drum dryer, 22 s in the grain cooler, 3 s in the second bucket elevator to the FIR dryer, and about 3 m and 9 s in the FIR dryer.

Grain Layer Depth and Temperature

The depth of the grain layer was maintained all throughout on the grain cooler oscillating tray and FIR dryer oscillating tray, averaging at 8 mm and 6 mm, respectively. This resulted in effective evaporative cooling and uniform grain drying. Grain temperature at the loading bin elevator was 32°C; after going through the rotary drum, 64°C; after passing through the grain cooler, 50°C; at FIR bed, 53°C; and after

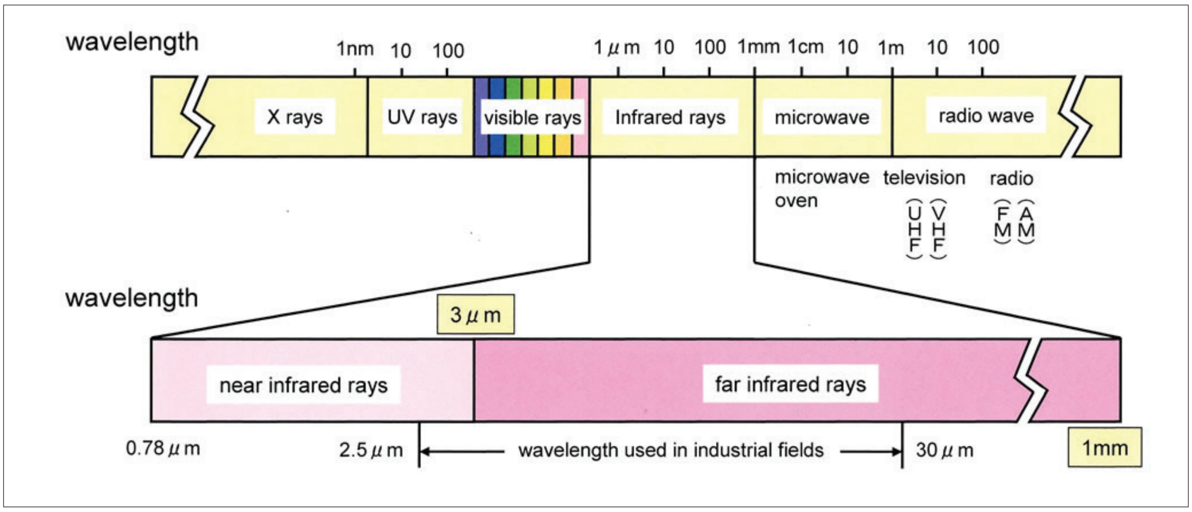


Figure 3. Far infrared rays in the electromagnetic wave spectrum and range of FIR wavelengths (2.5 – 30 μm) used in industrial fields (Source: JIRA, http://www.jase-w.eccj.or.jp/technologies/pdf/factory/F-18.pdf).

the FIR bed at the outlet hopper, 45°C. By replacing the air duct of the grain cooler with a larger one, the 14-degree temperature drop was observed.

Moisture Content Reduction

Freshly harvested paddy was used as sample for the first pass, while the partially dried grain sample was used for the second pass. After going through the CCFIR dryer for the first pass, the fresh samples were dried to an average moisture content (MC) of 16.6%, and were bagged and stored. For the second pass, these partially dried samples were used and after going through the dryer for the second time, these were dried to about 13% MC, which is in the range of recommended MC for milling. Figure 3 illustrates the grain moisture reduction trend during the first and second passes and after going through the rotary drum dryer, grain cooler, and FIR dryer. During the first pass, the grain samples with an average initial MC of 22.6% are dried to an average MC of 20.3% after going through the rotary drum dryer and further dried to 18.6% MC after being cooled on the oscillating cooler tray. Then, these were dried furthermore to 16.6% MC after passing through the FIR bed, resulting in an overall MC reduction of 6 percentage points during the first pass. During the second pass, moisture reduction through each of the dryer components was relatively less in magnitude and also slower, as shown by the relatively flat (red) moisture reduction curve in Figure 4. Unlike during the first pass when drying occurs at what Hall (1980) calls the first falling rate stage or "unsaturated surface drying", drying during the second pass occurs at the second falling rate period, wherein the moisture movement within the grains is the controlling factor and the drying rate is slower rate (Hall, 1980; Henderson et al., 1997).

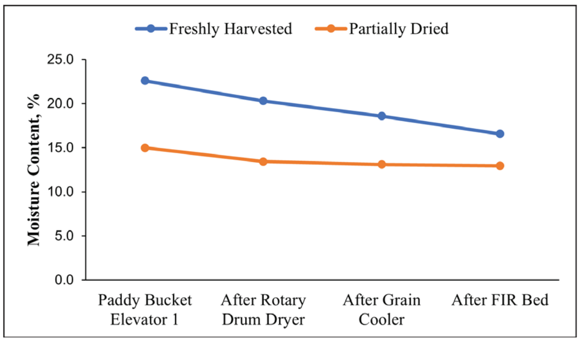


Figure 4. Paddy MC curves during the first and second drying passes.

Design of the Pilot Unit for Field Validation

Based on the observations and results of the optimization tests, the CCFIR dryer unit for pilot testing (Figure 5) was designed. The rotary dryer, with an 80-cm diameter drying cylinder or drum heated by a rice husk gasifier burner, would reduce paddy moisture from an initial moisture content of 21% down to 17 - 18% in a single pass. Paddy is fed into the rotary dryer by a screw conveyor with feeding capacity of 0.75 - 1.0 t/h. The rotary drum has a speed of 16 rpm, and is driven by a 2.24-kW (3-hp) electric motor. Average grain retention time inside the rotary dryer is 1 min and 17 s and the grain throughput is 20 bags (50 kg/bag) of paddy per hour (1 t/h).

Heated grains from the rotary dryer would be passed through an oscillating screen grain cooler to lower the grain temperature resulting in evaporative cooling. Driven by 0.75-kW (1-hp) electric motor, the grain cooler had an oscillation speed of 285 strokes per minute. Grain retention time at the cooler is 2 min and 20 s. The modifications and improvements applied during the optimization tests were selectively incorporated for the pilot test unit with the following design features:

1. Rotary dryer and grain cooler stacked on top of FIR bed to save space and eliminate one grain conveyor to save on electricity (one electric motor eliminated);
2. Single main heat supply entry point via jet burner to provide more efficient heat transfer, reduce heat loss, and eliminate three burners, which heated the FIR bed;
3. Pre-fabricated FIR emitter slabs could be installed by inserting and checked through side hinges for ease of replacement;
4. Dryer temperature could be regulated via butterfly valves installed in the jet burner and exhausts in rotary and FIR dryers;
5. Addition of one elevator for rice husk for uniform and intermittent supply of fuel all throughout the operation (same design with paddy grain bucket elevator);
6. Modular design: use of flanges for ease of repair and maintenance; and
7. Control panel for individual panels with safety emergency shut-off button.

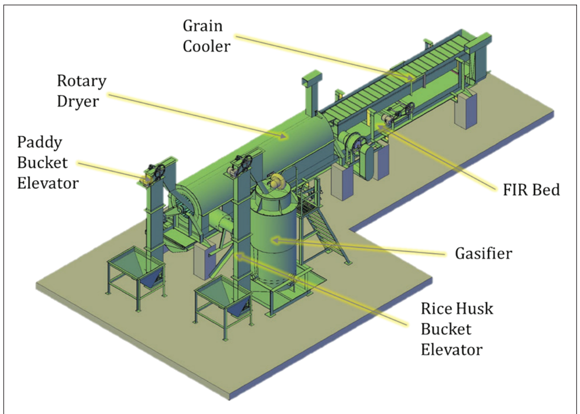


Figure 5. 3D model of the CCFIR dryer pilot test unit.

Establishment of the Pilot Site

Region 13 is characterized by a Type IV climate, which lacks a dry season and experiences a pronounced wet season from November to January. Three farmers' cooperatives in the vicinity of the PhilRice Agusan Branch Station were visited, surveyed, and evaluated. Based on the set criteria for partner-cooperative selection, the Sto. Niño Multi-purpose Cooperative (MPC) ranked first and was consequently chosen.

Established in 1991 and registered with the Cooperative Development Administration, Sto. Niño MPC is a farmers' cooperative that engages in rice milling, grain drying, paddy and milled rice trading, and agricultural lending. Currently chaired by Ms. Marilyn Aranas, Sto. Niño MPC serves 385 farmer-members across an aggregate rice production area of 630 ha. A Memorandum of Agreement between PhilRice and Sto. Niño MPC was signed and became effective on October 1, 2018.

Demonstrating its full commitment as a willing partner in this project, the cooperative constructed a steel and concrete shed extension (20 m length x 11 m width x 4 m height), worth PhP400,000 for the CCFIR dryer. This site is conveniently located along the Pan-Philippine Highway and is just 3.7 km from the PhilRice Agusan station situated in RTR (Remedios Trinidad Romualdez).

Selection of Manufacturer and Fabrication of the CCFIR Dryer Pilot Unit

Three agricultural machinery manufacturers in Agusan del Sur and two in Butuan City were identified, visited, and evaluated in June 2018. An evaluation of the three prospective manufacturers, based on a set of criteria for their capability to fabricate the dryer, resulted in the selection of Torralba Metalcraft, Inc (TMI) of Butuan City. In March 2019, PhilRice signed a contract with TMI for the fabrication, delivery, and installation of the dryer at a cost of PhP970,000.

TMI fabricated components such as the rotary drum, rice husk gasifier, grain cooler, bucket elevators, and FIR oscillating tray at their workshop. Meanwhile, the dryer support columns and FIR bed (concrete slab) were constructed at the pilot site. However, due to the COVID-19 pandemic and the nationwide lockdown beginning in March 2020, the fabrication of the components and the assembly and installation of the CCFIR dryer (Figure 6) at Sto. Niño MPC could only be completed in November 2020.

Functionality test of CCFIR Dryer Components

In 2021, a series of tests was carried out to check if the CCFIR dryer components were functioning properly. The rice husk gasifier with 90-cm diameter reactor was incorporated with a pocket char discharger, which noticeably facilitated manual discharging of rice husk char by swinging the discharge rod 45^{o}. Results of the gasifier performance trial, which were found satisfactory, are shown in Table 1.

Figure 6. The CCFIR dryer pilot test unit installed at the dryer shed of the Sto. Niño Multi-Purpose Cooperative, Butuan City in November 2020.

Table 1. Performance test results of the CCFIR dryer's rice husk gasifier.

Parameter	Value	Unit
Rice husk consumption rate	108	kg/h
Gas production time	≤10	minutes
Reactor external temperature, maximum	≤60	°C
Char discharging interval	15	minutes
Char discharged per cycle (2 swings)	8	kg
Char production rate	32	kg/h
Air velocity (5" blower), 100% opening	9.86	m/s
Air velocity (5" blower), 50% opening	9.16	m/s
Air velocity (5" blower), 25% opening	6.74	m/s

The chain-and-sprocket driven rotary drum dryer with 24 internal fins rotated at 20 rpm. The grain cooler with 35 cm diameter blade blower, functioned as designed during the performance tests with flow rate of 12.6 m/s with blades rotating at 1625 rpm, and power consumption of 1.25kW. The 110 cm wide by 11 m long FIR tray that advances grain through mechanical oscillation. Based on a few sacks of paddy run through the dryer, the projected (calculated) paddy throughput capacity was 920 - 1000 kg/h. All electric motors used (single phase, 220 v) could be safely switched on or off through a control panel.

Commissioning Test and Modification of the CCFIR Dryer

When the pandemic health and safety restrictions began to ease, the commissioning of the CCFIR dryer was finally carried out in June 2022. However, before running an actual drying trial, several modifications had to be carried out, namely:

1. Angle of inclination of the rotary drum was raised to 70 to achieve the desired grain throughput of 800 - 1000 kg/h;
2. A new and modified oscillating mechanism for the grain cooler was fabricated and installed to improve the flow of grains on the oscillating tray; and
3. A 2.4-m extension was added to the FIR dryer chimney to enhance draft suction of the producer gas and burner flame passing through the FIR slab to heat it.

Based on initial drying trial results using freshly harvested paddy, the CCFIR dryer achieved only an average grain throughput capacity of 451 - 474 kg/h and could dry only the first few sacks from 24.8% to 13.3 - 15.1% MC in one pass. But the other batch of samples, which were dripping wet, MC could be reduced to only 19.5 - 24.1%. The CCFIR paddy dryer did not properly function because the FIR slab at the portion of the FIR dryer closest to the single burner heating the rotary drum could only be heated to 60 - 100°C, and the other farther half of the FIR slab to only 32 - 52°C. This showed that using only one main heat supply entry point via the single jet burner to heat both the rotary drum and the FIR slab did not work out as expected even if the FIR dryer chimney was increased in height. It was then recommended that an extension pipe be installed to channel producer gas to a second jet burner, which would heat the FIR slab directly.

Paddy Drying Tests

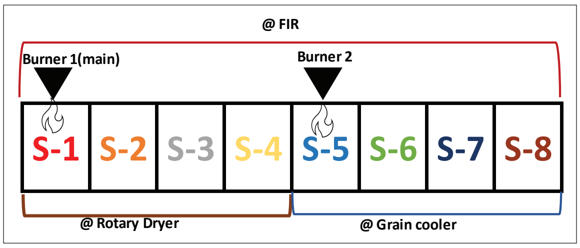
After installing the second burner to heat the FIR slab directly, a drying trial was carried out in September 2022 using freshly harvested paddy with an initial MC of 20.3%. Moisture reduction curves (Figure 7) show that the initial MC of 20.3% could be brought down to 13.2 % only after three drying passes. The drying curves indicate that minimal drying occurred when the paddy sample passed through the FIR dryer in all three passes. The temperature profile (Table 3) of the FIR slab shows that the required slab temperature range from 130 - 150°C was not achieved even at the portion, which was nearest the main burner (S-1) and the portion of the slab where the secondary burner was located (S-5). After a review of the several video footage of the secondary burner, it was decided to enhance the flow of producer gas to the second burner during the initial stage of the heating the slab and to improve the firebox of the second burner such that the burner flame would be directed on the slab. Other test results given in Table 2 show that grain throughput for the first and second passes: 547 kg/h and 591 kg/h, respectively, was lower than expected. Moreover, the drying capacity for the first and second passes: 426 kg/h and 443 kg/h, respectively, was also below the design target of 800 kg/h. However, it was only during the third pass when the paddy sample was already almost relatively dried at 15.7% that design targets were achieved with throughput at 988 kg/h and drying capacity at 898 kg/h.

Table 2. Performance test results of the CCFIR dryer, September 2022, Sto. Niño MPC, Butuan City.

Parameters		Drying Pass		
		First	Second	Third
Weight of Paddy, kg	Initial	1927	1773	1631
	Final	1173	1631	1489
Moisture Content, %	Initial	20.3	17.9	15.7
	Final	17.8	15.7	13.2
Time of Operation, h	Rotary and FIR bed Pre-heating time	1	1	0.17
	Drying of paddy	3.52	3	1.65
	Discharging of paddy @ Paddy elevator	3.21	2.95	1.47
Rice husk consumption rate, kg/h		85	72	
Throughput capacity, kg/h		547	591	988
Drying capacity, kg/h		426	443	898
Discharge capacity of paddy elevator, kg/h		600	601	1110

Table 3. Far infrared emitter slab temperature profile after heating during each drying pass (slab positions are shown in the diagram below); drying test in September 2022.

Slab Position*	Temperature (°C) Profile During Each Pass at the FIR dryer		
	1st	2nd	3rd
S-1	26.3 - 60	29.8 - 92.9	71- 99
S-2	26.1 - 67	29.5 - 74	59-81.6
S-3	26.4 - 40.6	28.7 - 50.5	51.4-55
S-4	26.5 - 41	28.8 - 45	46-53.4
S-5	27.1 - 72	28.4- 86.5	70-76
S-6	26.5 - 49	29.4 - 38.9	37-41
S-7	27.1 - 42	29 - 35.9	34-37
S-8	26.8 - 41	28.8 - 35.8	34-35



After the installation of a producer gas flow controller at the main burner to enhance the gas flow to the second burner during the initial stage of heating the FIR slab, and improvements to the firebox of the second burner, another drying trial was conducted in December 2022. The test results, as shown in Table 4, indicate that the modifications improved the drying performance of the CCFIR dryer. Now, only two drying passes are needed, and the MC reduction increased from 0.7% per hour during the previous test to 0.9% per hour.

The temperature profile of the FIR slab, detailed in Table 5, also improved. The portion of the slab from the second burner to the end of the slab where grains from the grain cooler are delivered (S-5 to S-8) saw an increase in temperature from 28 - 199°C.

Table 4. Performance test results of the CCFIR dryer, December 2022, Sto. Niño MPC, Butuan City.

Parameters		Drying Pass	
		First	Second
Weight of paddy, kg	Initial	1918	1809
	Final	1809	1773
Moisture content, %	Initial	20.0	17.0
	Final	17.0	15.3
Time of operation, h	Rotary and FIR Bed Pre-heating time	2.2	1
	Drying of paddy	3.2	1.9
Moisture reduction rate (%/h)		0.9	0.9
Rice husk consumption rate, kg/h		98	102
Throughput capacity, kg/h		603	952
Drying capacity, kg/h		358	624
Paddy elevator loading capacity, kg/h		567	1005

Table 5. Far infrared emitter slab temperature profile after heating during each drying pass; drying test in December 2022.

Slab Position*	Temperature (°C) Profile During Each Pass at the FIR dryer	
	1st	2nd
S-1	27-92	29-85
S-2	27-76	28-63
S-3	28-49	28-47
S-4	28-44	28-44
S-5	28-155	30-199
S-6	29-191	30-175
S-7	29-135	31-187
S-8	28-160	30-117

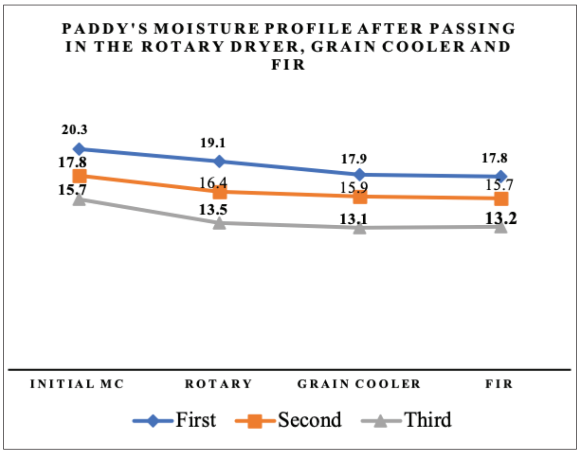


Figure 7. MC reduction curves of freshly harvested paddy dried in three passes through the CCFIR dryer installed at Sto. Niño MPC, Butuan City, September 2022.

Conclusion and Recommendation

The results suggest a promising breakthrough in crop drying technology that combines conduction, convection, and radiation heat transfer modes, as demonstrated by the recent development of the CCFIR dryer. While the optimized initial prototype functioned satisfactorily, the pilot unit's revised design and its test results need to be thoroughly reviewed to identify modifications that could enhance the performance of the unit installed at a farmers' cooperative.

Suggestions for improvement from the cooperative officers and members such as providing a holding bin for temporary storage and tempering of dried paddy prior to bagging, and mechanically conveying the dried paddy into the holding bin to save on labor and operating time, should also be seriously considered and implemented.

Acknowledgment

We thank the DOST Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (PCAARRD) for funding the field validation and pilot testing of the CCFIR dryer, as well as the initial project on the development of the CCFIR paddy dryer. We also appreciate the Sto. Nino Multi-purpose Cooperative for agreeing to be our partner in CCFIR paddy dryer pilot testing. The valuable technical support and services of the late Jan 11 dela Cruz, our smart, creative, resourceful, able, and diligent research assistant who passed away in 2021, and the PhilRice REMD workshop technicians are gratefully acknowledged.

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FULL PAPER

DIVERSITY OF INSECT PESTS AND THEIR NATURAL ENEMIES IN FOUR SITES OF THE PARTICIPATORY PERFORMANCE TESTING AND VALIDATION (PPTV) TRIAL OF RICE VARIETIES IN ORIENTAL MINDORO

Perfecto S. Ramos Jr.* and Oliver E. Manangkil

Philippine Rice Research Institute
*Corresponding Author: perfectojrramos@gmail.com

Abstract

Studying biodiversity of insect pests and their natural enemies is extremely important to assess their status in the rice ecological system without any disturbances, specifically the application of their control. Diversity of insect pests and their natural enemies for new rice varieties were determined and compared using the Shannon Diversity Index (SDI or H) for their species incidence, population, richness, and relative abundance. Six orders specifically *Homoptera*, *Hemiptera*, and *Orthoptera* for insect pests and their natural enemies (*Coleoptera*, *Hymenoptera*, and *Araneae*) were identified in four sites of the participatory performance testing and validation (PPTV) trial in Oriental Mindoro. Furthermore, four species of insect pests were also observed and recorded in the same sites, namely, *Nephotettix virescens, Nephotettix nigropictus, Leptocorisa oratorius,* and *Oxya hyla intricata* and eight species of their natural enemies:*Micraspis crocea, Tetrastichus schoenobii, Dinocampus coccinellae, Charops brachypterum, Tetragnatha maxillosa, Oxyopes lineatipes, Callitrichia formosana,* and *Lycosa pseudoannulata*. The H values of the four PPTV trials of the rice agroecosystem ranged from 1.54 to 2.74 H values; majority of the sites (3 of 4) had higher percent relative abundance in natural enemies than the insect pests. The relative abundance in four PPTV trial sites had a range of 34.8 - 58.5% for insect pests and from 41.5 - 65.2% for natural enemies. Environmental conditions such as temperature, humidity, and other factors create differences in biodiversity. High presence of natural enemies indicates that biodiversity in the area is abundant.

Keywords: *Biological control, Integrated pest management, Rice ecosystem*

Introduction

Organisms that may be harmful to rice including pathogens and insects are referred to as pests. Specific pest management strategies have been developed to address a range of rice production situations, but not all rice pests are covered. This is due to the vast and diverse range of rice production situations worldwide, as well as the wide variety of pests. The diversification of rice production is occurring at an unprecedented rate in response to environmental, climatic, social, and economic drivers. Lastly, plant protection in rice cultivation faces emerging crop health challenges that continually call for new solutions in different contexts (Savary et al., 2012).

Biodiversity plays a crucial role in the management of tropical irrigated rice pests. This includes the variation within rice plants, rice fields, groups of rice fields, and rice-associated ecosystems. In the unique cropping conditions and stable water supply of tropical irrigated rice, manipulating a relatively few manageable components of diversity can confer stability, such that pests are mostly kept at levels which do not justify the use of insecticides. Resistant rice varieties, including those with moderate resistance and the ability to compensate for insect pest damage, are considered successful biological control measures alongside natural enemies of insect pests.

Reliable or consistent natural enemy action is linked to the all-year-round continuity of prey or hosts made possible by asynchronous planting or short fallow periods due to three rice cropping periods annually. This also includes certain non-rice habitats such as the bunds, levées, and surroundings of the rice field (Way and Heong, 1994).

One of the most important processes in agroecosystems is pest regulation because biodiversity is closely related to host-plant resistance, pest management attributes, natural biological control agents and their impacts, and stability as the ecological basis for pest management. Intensive rice cultivation has led to a substantial increase in yield, but it has also caused significant damage to biodiversity, resulting in the spread of insect pests and other plant diseases. Solid evidence has shown that biodiversity is closely related to pest incidence in rice ecosystems and is strongly affected by the application of nitrogen fertilizer (Zhong-Xian et al., 2006).

Based on the PalayCheck System of the Philippine Rice Research Institute (PhilRice), natural enemies or beneficial organisms are considered natural engineers of biodiversity because they minimize the damages caused by insect pests that can significantly reduce rice crop yields. By avoiding pesticide usage, especially insecticides, the population of natural enemies or beneficial organisms can significantly increase, along with a high and dominant biodiversity of these organisms in the rice agroecosystem (PhilRice, 2021).

This study determined and compared the incidence, population, and biodiversity of species and relative abundance of rice insect pests and their natural enemies in four sites of the PPTV trial in Oriental Mindoro. The biodiversity of insect pests and their natural enemies in rice ecological systems without insecticide application served as the basis for decision-making to employ integrated pest management in these four sites.

Materials and Methods

Collection Sites, Time, and Place of the Study

The sampling was conducted in four PPTV trial sites in Oriental Mindoro, namely, (1) Brgy. Malabo, Victoria, Oriental Mindoro (13.1650° N, 121.3055° E); (2) Brgy. Zone 1, Socorro, Oriental Mindoro (13.0622° N, 121.3313° E); (3) Brgy. Alma Villa, Gloria, Oriental Mindoro (12.9616° N, 121.4384° E); and (4) Brgy. Kawit, Gloria, Oriental Mindoro (12.9599° N, 121.4775° E). Map of the four sites in three municipalities of Oriental Mindoro was illustrated and provided by Google Map (Figure 1).

This study was conducted in April 2022 dry season. The collected samples were identified and analyzed at PhilRice Central Experiment Station (PhilRice CES) in Maligaya, Science City of Muñoz, Nueva Ecija.

Site Composition of the PPTV Trial

The PPTV trial was composed of eight new rice varieties as entries. The PPTV trial had a total experimental area of 500 m^2. Each entry was transplanted in a plot with an area of 20 m^2 (4 m x 5 m). No pesticides were applied in the PPTV trials for the screening of insect pests and diseases resistance. The fertilizer rates were at 120N-60P_2O_5-90K_2O kg/ha.

Sampling Collection

Insect pests and their natural enemies including the arachnids (spiders) were collected and sampled at maturity. Samples were collected between 6:00 - 6:30

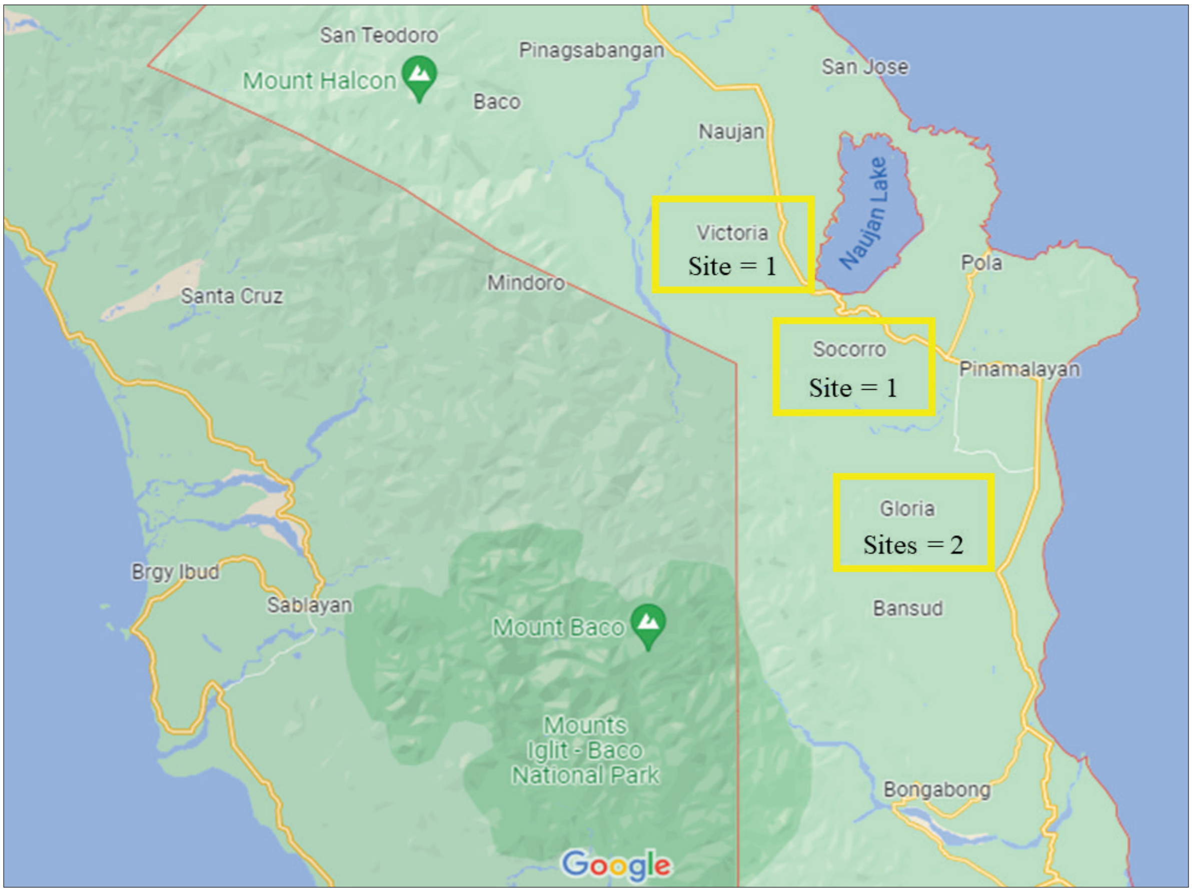

Figure 1. Map showing the locations of the four sites of PPTV trial in three municipalities of Oriental Mindoro, Philippines (source: Google Map).

a.m. Light and strong insect net (32 cm diameter) were used for catching the insect pests and their natural enemies. The mesh is open for ease in sweeping and trapping the insects. Insects were sampled by sweeping the net on established plots in diagonal pattern with 20 sweeping strokes.

Insect Samples

The killing jar was filled with potassium cyanide, saw dust, and plaster of paris with 1:2:1 ratio to quickly kill insects. Insects and spiders were then placed in a killing jar for 5 min and waited until all the insects died. Dead insects were transferred in glass vials with labels and preserved in 99.9% ethanol.

Sorting and Identification

Collected samples were sorted, identified, and counted. Specimens were identified using references such as the PhilRice field guide on harmful and useful organisms in the Philippine ricefields (Arida and Joshi, 2012), Friends of the rice farmer: Helpful insects, spiders, and pathogens (Shepard et al., 1987), Devices and techniques (Arida and Tiongco, 2010), and with the assistance of PhilRice entomologist.

Data Gathered

Species incidences (SI) of the insect pests (IP) and their natural enemies (NE) were calculated using the formula:

SI of IP = (Total species of IPs) – (Total species of IPs and NEs)

SI of NE = (Total species of NEs) – (Total species of IPs and NEs)

On the other hand, the species populations (SP) of the insect pests (IP) and their natural enemies (NE) were calculated using the formula:

SP of IP = (Total no. of IPs) – (Total SP of IPs and their NEs)

SP of NE = (Total no. of NEs) – (Total SP of IPs and their NEs)

The percent relative abundance (RA%) of the insect pests and their natural enemies was calculated using the formula below:

$$RA\% = \frac{\text{Total no. of each species}}{\text{Total no. of all species}} \times 100$$

Data Analysis

To determine and compare the biodiversity of four sites of PPTV trials, the SDI or H were used to calculate the biodiversity for their species richness and relative abundance using the formula:

Shannon Diverity Index (H) $= -\sum_{i=1}^{S} pi \ ln \ pi$

In the Shannon diversity index (H), p is the proportion (n/N) of individuals of one species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and **s** is the number of species.

A higher value of H indicates a more diverse community. Typical values are generally between 1.5 and 3.5 in most ecological studies. Index is rarely greater than the value of 4. The H increases as both the richness and the evenness of the community increase.

Results and Discussion

Species incidence

Six orders of insect pests and their natural enemies were observed in the four study sites, namely, the Orders of *Homoptera*, *Hemiptera*, and *Orthoptera* for insect pests; *Coleoptera*, *Hymenoptera*, and *Araneae* for natural enemies. In addition, 11 more insect families were observed and recorded such as the four families of natural enemies (*Coccinellidae*, *Eulophidae*, *Braconidae*, and *Ichneumonidae*); four families of arachnid (spiders) (*Tetragnathidae*, *Oxyopidae*, *Linyphiidae*, and *Lycosidae*); and the three families of insect pests (*Cicadellidae*, *Alydidae*, and *Acrididae*) (Table 1).

In terms of species level, 12 insects were obtained. Four for insect pests, which include *Nephotettix virescens*, *Nephotettix nigropictus*, *Leptocorisa oratorius*, and *Oxya hyla intricate*; while eight for natural enemies: *Micraspis crocea, Tetrastichus schoenobii, Dinocampus coccinellae, Charops brachypterum, Tetragnatha maxillosa, Oxyopes lineatipes, Callitrichia formosana,* and *Lycosa pseudoannulata* (Table 1).

The rice plant is an ideal host for many insect pests. Aside from direct damage, many insects also act as vectors of dreaded diseases (Dale, 1994) including two kinds of tungro viruses known as *rice tungro spherical virus* (RTSV) and *rice tungro bacilliform virus* (RTBV). These tungro viruses are vectors of two species of green leaf hopper (GLH), the *Nephotettix virescens*, *Nephotettix nigropictus,* which were present in the four PPTV trials (Jones et al., 1991; Dale, 1994).

Table 1. Species incidence of insect pests and their natural enemies recorded at the maturity phase of the rice plants in four sites of PPTV trial in Oriental Mindoro.

Common Name	Order	Family	Species
Insect Pests			
Green leaf hopper	*Homoptera*	*Cicadellidae*	*Nephotettix virescens*
Green leaf hopper	*Homoptera*	*Cicadellidae*	*Nephotettix nigropictus*
Rice bug	*Hemiptera*	*Alydidae*	*Leptocorisa oratorius*
Short-horned grasshopper	*Orthoptera*	*Acrididae*	*Oxya hyla intricata*
Natural Enemies			
Lady Beetle	*Coleoptera*	*Coccinellidae*	*Micraspis crocea*
Parasitoid wasp	*Hymenoptera*	*Eulophidae*	*Tetrastichus schoenobii*
Parasitoid wasp	*Hymenoptera*	*Braconidae*	*Dinocampus coccinellae*
Parasite larvae-wasp	*Hymenoptera*	*Ichneumonidae*	*Charops brachypterum*
Long-jawed spider	*Araneae*	*Tetragnathidae*	*Tetragnatha maxillosa*
Lynx spider	*Araneae*	*Oxyopidae*	*Oxyopes lineatipes*
Dwarf spider	*Araneae*	*Linyphiidae*	*Callitrichia formosana*
Wolf spider	*Araneae*	*Lycosidae*	*Lycosa pseudoannulata*

The rice bug, *Leptocorisa oratorius*, is a rice pest that feeds on developing rice grains, reducing the yield and quality of rice (Torres et al., 2010). Both adults and nymphs of paddy bugs suck out the sap from the developing rice grains until they are emptied. All soft milky grain is susceptible to attack. Rice bugs are usually attracted to young crops with early grains and feed on succulent young shoots and leaves until grain formation (Pathak and Khan, 1994).

The short-horned grasshopper, *Oxya hyla intricata*, is a rice pest in Southeast Asia (Li et al., 2011) that can damage rice at all stages of crop growth. Both nymphs and adults can feed on leaves by cutting the edges of leaves. Large numbers of this pest can feed even on the midribs and total leaves, causing extensive defoliation (Akhtar et al., 2012).

Natural enemies, also known as beneficial insects and arachnids, are one of the habitats in the rice ecosystem. According to Shepard and Rapusas (1989), the lady beetle *Micraspis crocea* is a voracious feeder of leafhoppers, brown plant hopper or BPH (*Nilaparvata lugens*), and other small insect pests of rice. They are abundant in rice plants and can help suppress populations of several insect pests. Despite their positive effects on rice, many farmers incorrectly identify them as pests and apply insecticides to eliminate these lady beetles.

Parasitoid wasps, a very large evolutionary group of hymenopteran insects, are well-known biological control agents for arthropod pests in agricultural and forest ecosystems. Biological control is a safe and sustainable approach that takes advantage of natural enemies such as predators, parasitic insects, or pathogens to manage pests in agroecosystems (Wang et al., 2019). This parasitoid wasp (*Tetrastichus schoenobii*) parasitizes on stem borer's pupae (*Chilo* spp.). Meanwhile, female parasitoid wasps (*Dinocampus coccinellae*) are known to parasitize male and female coccinellid pests. Also, the parasite wasp (*Charops brachypterum*) searches the rice foliage for larvae of leaf folders, green semiloopers, and yellow stem borers to parasitize. The wasp first locates the larvae, then pierces the stem with its ovipositor, and lays an egg near the host larva. The legless parasite larva hatches and then wiggles to the larvae (Shepard et al., 1987).

Species population

The highest population of natural enemy species across the four sites was recorded in site 2 (Zone 1, Socorro) with 19 species, compared with the 13 species of insect pests. Conversely, the highest population of insect pest species was recorded in site 3 (Alma Villa, Gloria) with 24 species vs. the 17 species of natural enemies. On the other hand, the lowest population of insect pest species was recorded in site 1 (Malabo, Victoria) and site 4 (Kawit, Gloria), each with 15 species. The lowest population of natural enemy species was recorded in Site 1 at Malabo, Victoria with eight species (Figure 2).

The absence of insecticide application resulted in a higher and richer population of natural enemy species compared to insect pests. Beddington et al. (1978) explained that a strong reduction in the insect pest population is characterized by the voracious and dominant population of natural enemies.

Sites 1, 2, and 4 had a higher species population of natural enemies than insect pests, except for Site 3 in Alma Villa, Gloria, where the insect pests' population was higher than their natural enemies. A higher species population of natural enemies indicates that biological control in these three sites is abundant. The insect pests' population cannot progress in the area. Moreover, if the rice crop is not affected by the insect pests' population as compared to the natural enemies' population, there is no economic yield loss to the rice varieties because of the complexity of the other natural enemies, especially the arachnids, which are voracious and consistent predators of rice insect pests (Sigsgaard, 2000).

In Site 3, the species populations of insect pests were higher than natural enemies but no crop damage was observed because of the response of the rice varieties used in the study and the presence of natural enemies (Figure 2).

The highest incidence was observed in natural enemies compared with the insect pests at the maturity phase of rice plants across the four PPTV trials in Oriental Mindoro. The proliferation of natural enemies over the insect pests in the area indicates that they are predominant in the rice ecosystem. In addition, the natural enemies were more prominent than the insect pests because of no application of insecticides in the area. This can be associated with the employment of integrated pest management (IPM) in the area. In IPM, an insecticide is used only when needed and in combination with other approaches for more effective long-term control. Insect pests cannot progress in the rice ecosystem because of the significant presence of their natural enemies and as being dominant predators. Also, a high presence of natural enemies indicates that biodiversity in the area is abundant. The study by Biradar et al. (2011) indicated that the peak of insect pests and their natural enemies was based on season, month, and growth stages or phases of plants or crops.

Prakash et al. (2014) explained that IPM is a knowledge-intensive sustainable approach for managing pests through a combination of compatible cultural, biological, chemical, and physical tools while minimizing its economic, health, and environmental risks with the help of pest scouts. Pests also co-evolve and adapt quickly to single control tactics through natural selection; simultaneously utilizing multiple methods or an integrated approach are mostly effective for long-term sustainable management programs. There are hundreds of insects that can cause serious damage to crops; Ahmad and Rasool (2014) defined that insect pests are the main source of biotic stress on crops. The majority of these insects are controlled by chemical pesticides which are also major sources of pollution, resulting in several animal and human health problems.

Biodiversity using Shannon Diversity Index

Based on the Shannon diversity index (H), the highest biodiversity was observed at Site 2 (Zone 1, Socorro) with a value of 2.74 H. This was among four sites where insect pests and their natural enemies were collected during the maturity phase. Site 2 (Kawit, Gloria) had the second highest biodiversity with a value of 1.86 H, followed by Site 1 (Malabo, Victoria) with a value of 1.74 H. The lowest biodiversity was observed at Site 3 (Alma Villa, Gloria) with a value of 1.54 H (Figure 3).

Biodiversity can be influenced by conditions such as temperature and humidity that may favor one species of insect pests over natural enemies resulting in biodiversity differences. A high index value suggests a stable site with many different niches and low competition (high richness and evenness), while a low index value suggests a site with few potential niches where only a few species dominate or there is low richness and evenness (He and Hu, 2005).

Biodiversity indices are commonly used for ecological analysis as they are classic scalar ecological indicators. Recent findings suggest that species diversity indicates the status of the ecosystem or

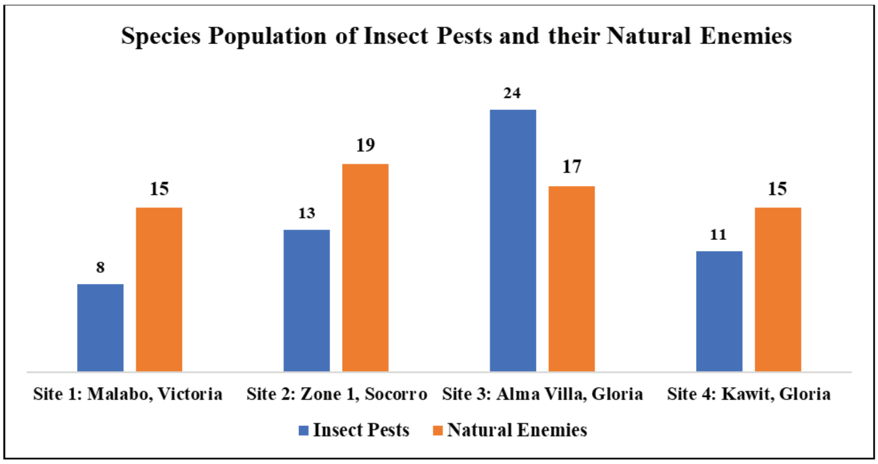

Figure 2. Population of insect pests and their natural enemies at the crop's maturity phase in the four sites of the PPTV trial.

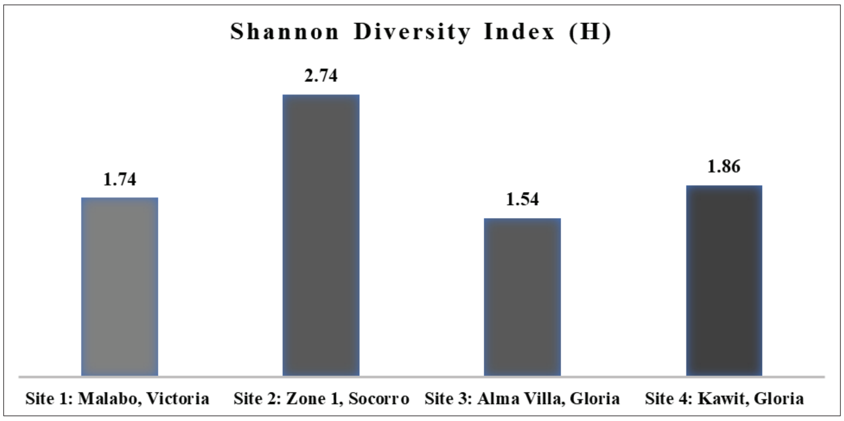

Figure 3. Shannon diversity index (H) analyses of the four sites of the PPTV trial in Oriental Mindoro at maturity phase of rice plants.

community (Izsák, 2007). Nolan and Callahan (2006) explained that species richness, which is simply the number of species present in an area, can be quantified using the Shannon-Weiner Species Diversity Index (H). A higher H value indicates greater biodiversity in the sampling site. Normal values generally range between 1.5 and 3.5 in most ecological studies, and it is rare for H to exceed 4. In this study, the H values of the four PPTV trials in the rice agroecosystem ranged from 1.54 to 2.74 H, indicating normal richness and evenness between insect pests and their natural enemies. An increase in evenness may strengthen the effect of species richness by promoting the abundance of natural enemies over insect pests.

Relative abundance

The highest percent relative abundance (RA%) across the four sites of the PPTV trial was observed at site 1 (Malabo, Victoria), with natural enemies and insect pests accounting for 65.2% and 34.8% RA, respectively. However, site 3 (Alma Villa, Gloria) had a higher RA of insect pests at 58.5%, compared with the 41.5% RA of natural enemies, indicating a higher prevalence of insect pests.

In general, the RA% of insect pests across the four PPTV trial sites ranged from 34.8% to 58.5%, while the RA% of natural enemies ranged from 41.5% to 65.2%. It's important to note that insecticides and other pesticides were not used in these trials. As a result, natural enemies had a higher RA% than insect pests in three sites (Malabo, Victoria; Zone 1, Socorro; and Kawit, Gloria), with the exception of Alma Villa, Gloria (Figure 4).

The RA%, or percent relative abundance, is defined as follows: (1) a distinction is made between opportunistic and equilibrium species; (2) there is limited ecological interest in the relative abundances of opportunistic species. However, the abundances of such species often follow a log-normal distribution; and (3) the RA% of equilibrium species are of significant ecological interest. It is often assumed that

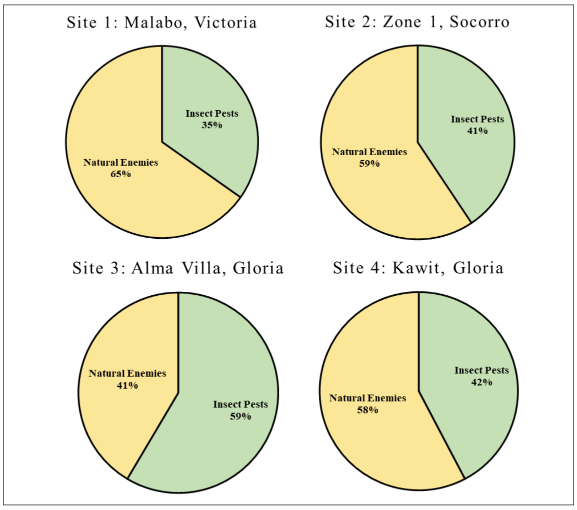

Figure 4. Relative abundance (RA) percentage in four sites of the PPTV trial in Oriental Mindoro at maturity phase of rice plants.

an increase in the population of one species results in a roughly equal decrease in the populations of other species (MacArthur, 1960).

Conclusion

In species incidence, six orders of insect pests and their natural enemies were observed in four sites, namely, Orders *Homoptera* (*Nephotettix virescens*, and *N. nigropictus*), *Hemiptera* (*Leptocorisa oratorius)*, and *Orthoptera* (*Oxya hyla intricate)* for insect pests and Orders *Coleoptera* (*Micraspis crocea*), *Hymenoptera* (*Tetrastichus schoenobii, Dinocampus coccinellae,* and *Charops brachypterum*), and *Araneae* (*Tetragnatha maxillosa, Oxyopes lineatipes, Callitrichia formosana,* and *Lycosa pseudoannulata*) for natural enemies. Environmental conditions in four PPTV trial sites such as temperature and humidity have favored a single species of insect pests over natural enemies that created differences in biodiversity. The values of insect pests and their natural enemies ranged from 1.54 to 2.74 H. In RA%, three of the four trials had higher percent in natural enemies over the insect pests. The RA% of the four PPTV trials for insect pests ranged from 34.8 to 58.5% while 41.5 - 65.2% for natural enemies.

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DEVELOPMENT OF A SMALL-SCALE HYDROUS BIOETHANOL PRODUCTION FACILITY USING SUGARCANE MOLASSES AS FEEDSTOCK

Katherine C. Villota[1], Alexis T. Belonio[1], Marvelin L. Rafael[1], Amelia V. Morales[2], Phoebe R. Castillo[1], Neil Caesar M. Tado[3], and Manuel Jose C. Regalado[1]*

[1]Rice Engineering and Mechanization Division and
[2]Rice Chemistry and Food Science Division, Philippine Rice Research Institute
[3]Caraga State University, Butuan City, Agusan del Norte
*Corresponding Author: manueljoseregalado@yahoo.com

Abstract

The escalating prices of petroleum-based fuels necessitate the investigation of renewable liquid fuel sources such as hydrous bioethanol (90 - 95% v/v ethanol), particularly as an alternative biofuel for agricultural machinery. A small-scale, farm-level hydrous bioethanol production facility was developed and assessed using sugarcane molasses as feedstock to determine its technical and economic viability. Our findings revealed that a combination of one part sugarcane molasses, three parts water, and 1-g active dry yeast per 140 mL of the mixture resulted in the highest alcohol concentration of 10.53% v/v after fermenting for 5 days. In scaled-up experiments, 140 L of the optimized mixture in a polyethylene plastic tank produced the highest alcohol content of 11.19% v/v after four days. Distiller tests indicated that 400 L of fermented feedstock could yield 29.2 - 41.1 L of hydrous bioethanol (93 - 96% v/v) within a timeframe of 3.5 - 6.0 h. Distillation rates ranged from 6.0 - 8.3 L/h, with an alcohol recovery rate of 93 - 99%. The biomass gasifier, which heated the boiler, consumed between 35 - 38 kg of rice husks per hour. Hydrous bioethanol proved to be a suitable fuel for retrofitted single-cylinder, spark-ignition engines used to power various mobile and stationary rice farm machines. The facility successfully fermented sugarcane molasses and produced hydrous bioethanol at a cost of PhP 93.90/L (USD 1.71/L). Based on the economic analysis results, it is recommended to upscale the unit to a feedstock capacity of 1,000 L and operate it at two batches per day to produce hydrous bioethanol at a projected cost comparable to the current local gasoline pump prices.

Keywords: *Distillation, Hydrous bioethanol production facility, Liquid biofuel, Rice husk gasifier, Sugarcane molasses fermentation*

Introduction

Recent global increases in food, fuel, and fertilizer prices, largely driven by the ongoing conflict between Ukraine and Russia, have accelerated rapidly (Diao et al., 2022). Taghizadeh-Hesary et al. (2019) demonstrated the interconnectedness of energy and food security through price volatility, advocating for a diversification of energy consumption in the food sector away from over-reliance on fossil fuels towards an optimal mix of renewable and nonrenewable energy resources.

In the Philippines, the enactment and implementation of Republic Act No. 9367, also known as the Biofuels Act of 2006 (Official Gazette, 2007), and RA No. 9513 or the Renewable Energy Act of 2008 (Official Gazette, 2008) reflect the country's proactive response to global energy and climate change concerns. The Philippine Department of Agriculture and Department of Energy (DA and DOE, 2021) issued a joint memorandum circular (JMC-2021-02-001) for the development and implementation of a renewable energy program for the agri-fishery sector (REPAFS). Section 3 of the JMC promotes existing renewable energy technologies, including a community-level hydrous bioethanol fermentation and distillation facility that produces hydrous bioethanol as a fuel source for farm machinery and other applications.

The DOE and DA conducted a public consultation in January 2022 to finalize the REPAFS. Its Component 2: Research and Development—Enhancement of Existing Technologies section discussed biofuels, specifically: (1) improving and scaling up bioethanol and biodiesel production facilities to empower farmers' cooperation on using local and renewable resources for powering farm machinery; and (2) using bioethanol and biodiesel as fuel for spark-ignition and compression-ignition engines for farm and fishery machinery such as power tillers, boat tractors, combine harvesters, seeders and transplanters, and crop haulers (Mojica-Sevilla, 2022).

Ethanol, also known as ethyl alcohol or grain alcohol, is a type of alcohol that is an important industrial chemical. It is used as a solvent, an additive to automotive gasoline, and as the intoxicating ingredient in many alcoholic beverages like beer, wine, and distilled spirits (Encyclopedia Britannica, 2023). Among other fuel alcohols, ethanol is considered more suitable as an alternative fuel for spark-ignition engines due to its lower toxicity than methanol, lower production cost, and superior evaporation and combustion characteristics compared to butanol (Thangavelu et al., 2016). Ethanol can be classified into two grades: anhydrous ethanol (99.5% v/v), also known as absolute ethanol, is considered the best substitute for gasoline in engines; however, since it requires more energy to produce than hydrous ethanol, it is beneficial to use ethanol in its hydrous form (Loyte et al., 2022). Hydrous ethanol (90 - 95% v/v), also known as azeotropic ethanol, is the most concentrated grade of ethanol that can be produced by simple distillation without further dehydration necessary to produce anhydrous ethanol (Agrupis et al., 2017). Various studies have shown that hydrous ethanol can be used directly as fuel without mixing with gasoline for spark-ignition engines (Costa and Sodre 2010; Sileghem et al., 2014; Lanzanova et al., 2016; Loyte et al., 2022).

Bioethanol, produced through the fermentation process by various microorganisms such as *Saccharomyces cerevisiae* (Raharja et al., 2019), is widely used in Brazil as a biofuel in flexible-fuel light vehicles. Due to its cost competitiveness with gasoline and growing public concern over environmental and energy security issues, its production and sales have increased rapidly, a trend expected to continue (De Medeiros et al., 2017). The use of hydrous bioethanol has significant potential to address energy costs and global warming concerns associated with the use of petroleum-based fuels.

However, in the Philippines, there are currently only 13 registered local bioethanol producers for commercial use (SRA, 2023a). These bioethanol companies produce anhydrous bioethanol to enhance and supplement gasoline fuel at 10% (E10 blend) used in transport vehicles. This limited number of local producers had a combined production capacity of 425.5 million liters (ML) in 2020, which could only supply half of the annual requirement of ethanol for gasoline blending. This falls short of the projected annual local bioethanol demand of more than 400 ML (Mojica-Sevilla, 2021). This significant deficit necessitates the exploration of other sources for bioethanol production, particularly for fueling farm machinery.

In 2013, the Philippine Rice Research Institute (PhilRice) began developing a hydrous bioethanol distilling unit aimed at enabling Filipino farmers to produce fuel for their engines using resources available on their farms. Initially, PhilRice explored the use of nipa sap as feedstock for hydrous bioethanol production as fuel (Gagelonia, 2014). The design, development, and pilot testing of crude bioethanol and hydrous bioethanol distillation equipment using fermented nipa sap was carried out in Infanta, Quezon (Regalado et al., 2018). The distiller successfully produced crude bioethanol (40 - 60% v/v) and hydrous (90 - 95% v/v) bioethanol using rice husks as fuel. Dispensing the hydrous bioethanol directly into the intake manifold of a spark-ignition engine retrofitted with an alcohol fuel feeding device similar to the one developed by Belonio et al. (2014) was found to successfully run the engine without any mixture of gasoline (Regalado et al., 2017).

Inedible sugarcane molasses, a by-product of sugarcane processing found in areas where rice is grown, is another potential feedstock for hydrous bioethanol production, in addition to nipa sap. Morales et al. (2013) reported that the alcohol yields of fermented sugarcane molasses, ranging 6.09 - 10.73% v/v, were comparable to those of nipa sap, which varied from 6.24 - 10.13% v/v. However, the production of molasses is significantly greater, i.e., 888,200 in 2021-2022 (SRA, 2023b), compared with nipa, which production area is limited to coastal regions. Moreover, molasses can be stored for a longer period without degrading its ethanol potential, unlike nipa sap, which requires immediate processing as it naturally ferments, turning sugar into acid within hours and resulting in low ethanol yield (Morales et al., 2013). According to Pérez (1997), the quantity of molasses that could be derived from 100 mt of fresh sugarcane is 3 - 7 mt or 3 - 7% of its weight. Hence, based on this about 4 t of fresh sugarcane would be required to produce an average quantity of 200 kg of molasses. Paturau (1989) stated that with fair quality molasses, some 240 L of ethanol should be obtained from 1 mt of sugarcane molasses. Considering this, a hydrous bioethanol production facility could be designed to produce, say 50 L of bioethanol from 200 kg of molasses. In crop year 2021-2022, the Philippines milled 20.916M mt of sugarcane (SRA, 2022). Of this annual sugarcane production, some 888,200 mt of molasses was produced in 2021-2022 (SRA, 2023b). This quantity of molasses as feedstock could potentially produce over 21 ML of bioethanol.

Producing fuel-grade alcohol directly on the farm is an innovative approach to helping rice farmers become more resilient by making them independent from expensive imported fuel. DOE (2023) showed that unleaded gasoline prices in NCR ranged from PhP76.45 - 97.40/L by the end of June 2023, up from PhP76.45 - 88.05/L at the end of June 2022. In the event of a fossil-based fuel shortage, having hydrous bioethanol produced on the farm and readily available, accessible, and affordable would allow farmers to continue their farming activities using their farm machines in preparing their field and producing rice for their families and country. Without liquid fuels to run farm engines, rice mechanization would be severely constrained, resulting in increased production costs and reduced crop yields.

We hypothesized that with the continual increase in the prices of fossil-based fuels, it would then be technically and economically feasible to develop a decentralized farm-level hydrous bioethanol production facility using renewable sources of feedstock such as sugarcane molasses and equipped with a biomass gasifier using rice husks as solid biofuel to heat the boiler of the distillation facility. To ascertain the technical and economic feasibility of producing hydrous bioethanol as an alternative farm fuel, this study was conducted to design, fabricate, and test a 400-liter capacity hydrous bioethanol distiller using fermented sugarcane molasses as feedstock; test and compare the use of hydrous bioethanol as fuel for selected rice farm machines with conventional gasoline fuel; and determine the distillation and production costs of hydrous bioethanol using molasses as feedstock.

Materials and Methods

Prior to the design of the hydrous bioethanol production facility, laboratory and actual fermentation tests were conducted using active dry yeast to determine the optimal proportion of sugarcane molasses and water that would yield the highest percentage of alcohol from the feedstock samples. Following this, the distiller was constructed and its performance was evaluated using the optimal mixture identified in the fermentation study.

Fermentation Tests

Laboratory fermentation tests were conducted at PhilRice's Rice Chemistry and Food Science Division to determine the optimal mixing proportion of sugarcane molasses, water, and yeast. Molasses were sourced from a sugar factory in Tarlac City. The fermentation media was prepared by diluting sugarcane molasses with sterile distilled water in 1:1, 1:2, 1:3, 1:4 ratios (molasses: water) based on Osunkoya and Okwudinka (2011).

Samples of 140-mL diluted sugarcane molasses were pasteurized at 60°C for 10 min (Lay et al., 2010) using a steamer (Figure 1a). After cooling, active dry yeast (Red Star, China) was added to the molasses medium (Figure 1b) at 1, 2, 3, and 4 g. The active dry yeast was reactivated directly in the molasses medium. The inoculated medium was thoroughly mixed in a sterile Erlenmeyer flask, covered with a cotton plug, and incubated at ambient temperature (Figure 2a).

After 24 h, the cotton plug in the flasks was replaced with a fermentation lock (Figure 2b), which is a single-hole rubber stopper with a bent glass tube dipped into a test tube two-thirds full of distilled water. This allowed the carbon dioxide produced during fermentation to escape. The fermentation process continued for up to 5 days to optimize fermentation and maximize the alcohol conversion of yeast in the samples.

During the tests, the physicochemical properties of the fermented samples were determined. These included total soluble solids and refractive index using an Abbe Refractometer (Leica Mark II, IKA) (Figure 3a), pH using a pH/Conductivity/TDS/ °C/m instrument (Eutech Instruments pc 510, Singapore) (Figure 3b), and percent alcohol content using a digital rotary evaporator with an integrated HB10 heating bath (RV10, IKA) (Figure 3c and 3d), based on AOAC methods (Helrich, 1990).

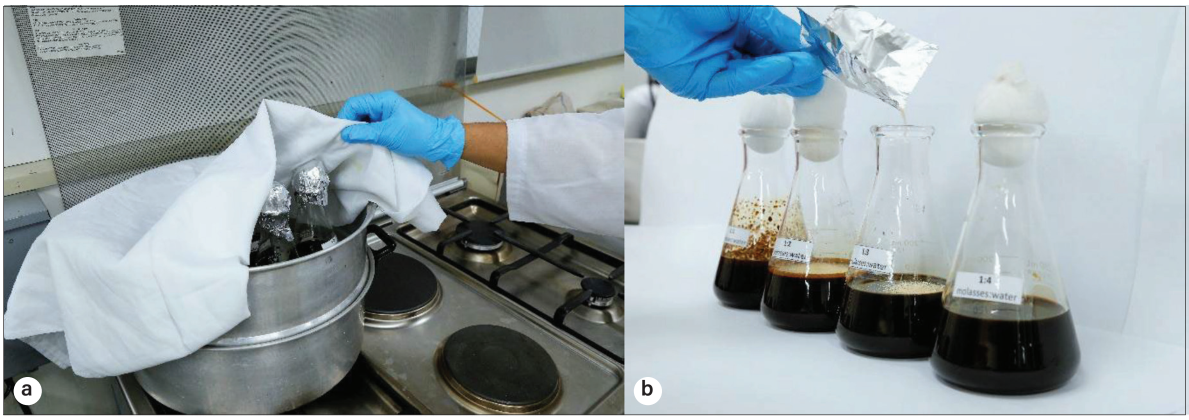

Figure 1. Fermentation medium consisting of sugarcane molasses diluted with distilled water was sterilized by steaming (a) and after cooling, active dry yeast was added into the medium (b).

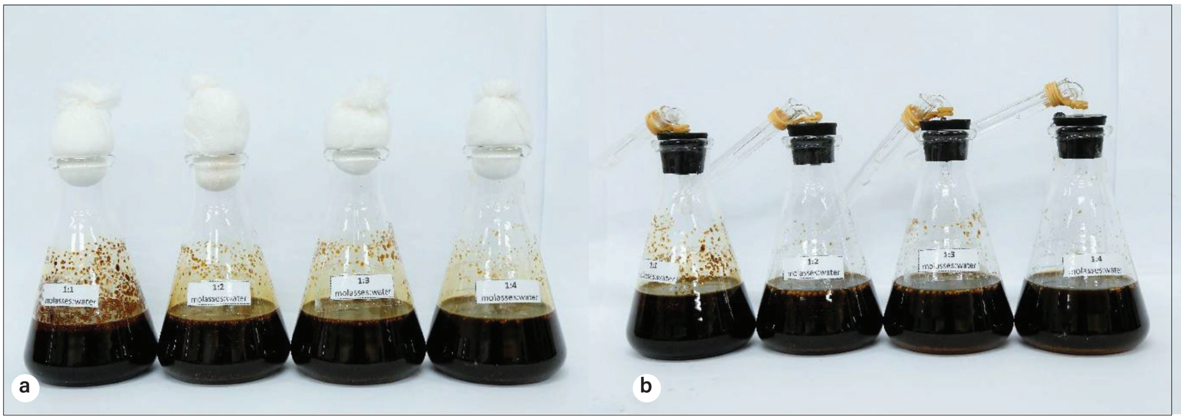

Figure 2. Fermentation media consisting of sugarcane molasses diluted with distilled water and inoculated with active dry yeast was incubated for 24 h at ambient temperature (a). Fermentation was continued for 5 days in the flask with fermentation lock (b).

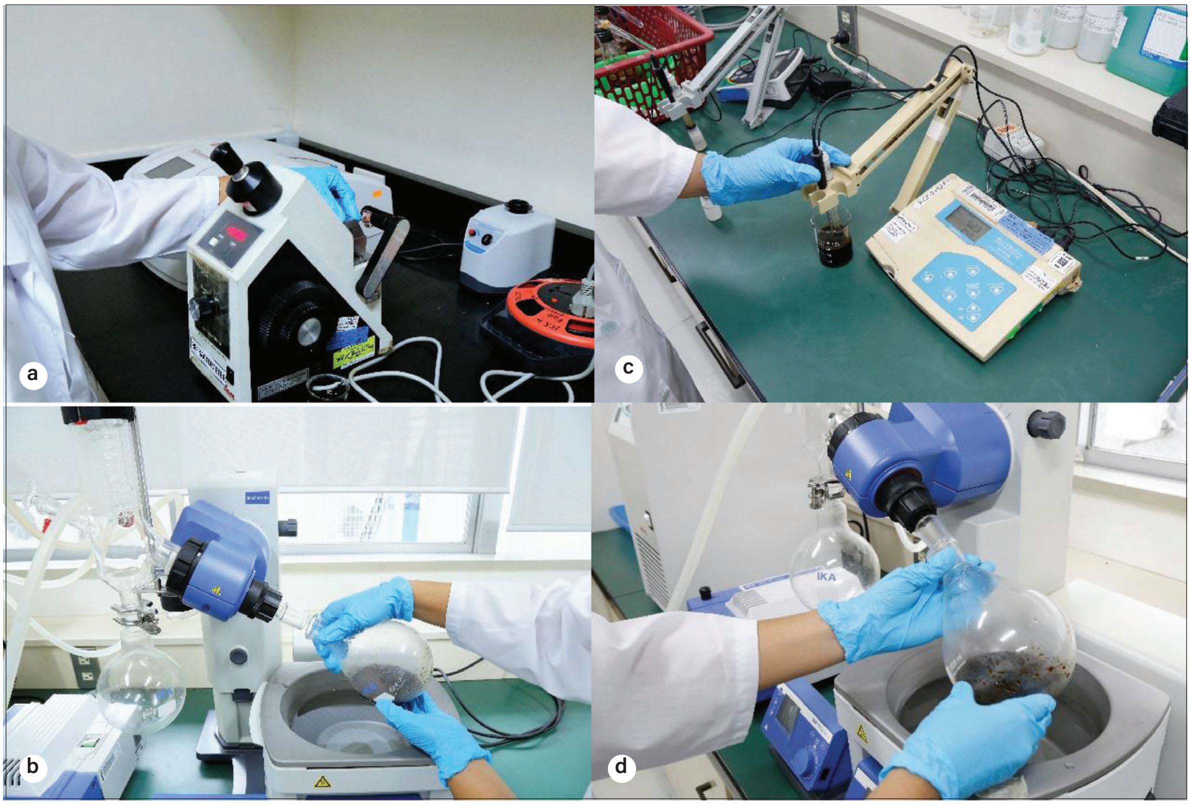

Figure 3. Physicochemical properties of the fermented samples such as total soluble solids (a), pH (b), and percent alcohol content (c) and (d) are determined.

Scaled-up Fermentation Tests

Following the laboratory experiment, actual fermentation tests were conducted on a larger scale using polyethylene plastic (Figure 4a) and stainless-steel fermentation tanks (Figure 4b). In the plastic tank, 140 L of the optimal mixture was used, while in the stainless-steel tank, 180 L was used. Both the plastic and stainless-steel tanks were equipped with a cover and a breather to facilitate the release of CO_2 generated during the fermentation process. A sugarcane molasses to water ratio of 1:3, with 7 g of active dry yeast per liter of the mixture, was used in the tests. The mixture was allowed to ferment for 4 - 6 days. Similarly, the physicochemical properties such as pH, TSS, and percent alcohol content of the samples, including the ambient conditions, were determined.

Design of Distiller

In designing the distiller, the following criteria were considered:

1. Feedstock – Fermented sugarcane molasses with alcohol content of 5 - 10%.

Figure 4. Fermentation tests: (a) mixing of sugarcane molasses with water and (b) plastic and stainless-steel tanks used during fermentation.

2. Capacity – 400 L enough to produce approximately 35 - 40 L of hydrous bioethanol per load.
3. Quality of alcohol to be produced – Hydrous bioethanol with 90 - 95% alcohol concentration.
4. Construction Materials – Locally-available such as metal plates (mild steel and stainless steel), bars, and pipes.
5. Number of operators – One to prepare in advance the fermented samples, to load the feedstock into the boiler, to load rice husks into the gasifier, and monitor the operation of the distiller.
6. Investment cost – Not more than half million pesos for the entire distilling plant including readily available plastic and stainless-steel fermentation tanks.

A modified version of the 200-L capacity hydrous bioethanol distiller previously developed at PhilRice (Rafael et al., 2015) was considered based on the aforementioned criteria. The distiller comprises an internally-heated boiler capable of containing 400 L of feedstock, a distilling column with a water heater that is twice the length of the previous model, and a 60 cm-diameter reactor rice husk gasifier that supplies heat to the boiler. The major revision incorporated in the design of the 400-L distiller was the use of a counter-flow heat exchanger pipe, replacing the trickling-type condenser used in the 200 L capacity distiller.

Fabrication of Distiller

The distiller and other components of the hydrous bioethanol production facility were fabricated and assembled at the REMD machine prototyping workshop of PhilRice (Figure 5). Fabrication drawings were provided to the assigned welders/technicians for guidance. Monitoring was conducted during the fabrication process to ensure strict adherence to the specified materials and dimensions. The actual cost of materials and labor used in the fabrication of the distiller was determined upon completion of the unit.

Performance Testing

Functional tests of each component were conducted until the unit performed in accordance with design objectives. Preliminary trials were carried out to verify whether the rice husk gasifier could supply the necessary heat to vaporize water and whether the condenser could convert the vapor into liquid. After gathering all the necessary information, four test runs were conducted using fermented sugarcane molasses as feedstock. The samples were prepared using a 1:3 ratio of sugarcane molasses and water, i.e., 100 L of sugarcane molasses for every 300 L of water. Seven grams of active dry yeast was added per liter of the mixture, which was then placed in three 140-L capacity plastic tanks to ferment for 4 - 6 days. The tanks were equipped with a breather to separate carbon dioxide from the samples being fermented.

During the tests, the volume of fermented samples in the boiler was measured. The percentage alcohol content of the feedstock used was analyzed at the RCFSD laboratory (Figure3c and 3d). The time it took to reach the temperature at which the alcohol/water mixture starts to evaporate was recorded using a 150°C-max bimetallic thermometer and an Extech digital stopwatch. The volume of distillate collected at the discharge spout of the condenser was measured for each run using a 2 L-capacity graduated cylinder. The weight of rice husk consumed as fuel for the gasifier was measured using a 20 kg-capacity spring-scale balance. The time from when the distillate started to trickle into the graduated cylinder until no more distillate came out of the condenser was also recorded for each run. To determine the profile and operating condition of the distiller, the temperature at its different components was measured using

Figure 5. Fabricating a (a) rice husk gasifier reactor and (b) stainless-steel distiller boiler and assembling a (c) hydrous bioethanol production facility at PhilRice's REMD.

a bimetallic thermometer and an Extech digital thermometer with type-K thermocouple wire sensors at 20-minute intervals. The alcohol content of the distillate collected from the samples was measured using a glass-bulb alcohol meter.

After all data were gathered, parameters were determined and analyzed: (a) distillation rate, (b) fuel consumption rate, (c) alcohol/fuel ratio, (d) alcohol recovery, and (e) overall thermal efficiency.

The operational characteristics of the distiller were closely observed during the tests such as difficulty in loading feedstock into the boiler and rice husk fuel into the gasifier, adjusting water flow into the condenser, collecting distillate, and other factors that affect distiller operation.

Samples of hydrous bioethanol (Figure 6) produced from the distiller were also tested using 0.75-, 3.5-, and 6.5-hp four-stroke cycle spark-ignition (SI) engines to power various equipment: (1) grass cutter, (2) 3-inch water pump, (3) 0.8 m-wide microtiller, (4) 50 kg-capacity micromill, and (5) power tiller hauler, with the last three farm machines powered by a 6.5-hp SI engine.

Figure 6. The distilled hydrous bioethanol (a) tested as alternative fuel for retrofitted gasoline engine (b).

Results and Discussion

Physicochemical Properties of Samples

Table 1 presents the results of the physicochemical analysis of the feedstock samples. It was discovered that the amount of yeast used did not affect the pH and alcohol content of the samples at 1:1 and 1:2 sugarcane molasses/water mixtures, as well as the alcohol content of the 1:4 mixture. Additionally, it was observed that a 1:3 sugarcane molasses/water mixture with 1-g active dry yeast produced the highest alcohol content of 10.53% v/v.

Furthermore, we noted that the 1:1 sugarcane molasses to water mixture with 1-g active dry yeast had the highest total soluble solid of 41.60oBrix. Conversely, the same mixture but with 2-g active dry yeast had the lowest alcohol yield. This could be attributed to the high sugar concentration in the sugarcane molasses, which reduces yeast viability due to the high osmotic pressure of the medium that reduces water activity and inhibitory substances in sugarcane molasses (Bajaj et al., 2003).

Table 2 presents the results of the physicochemical analysis conducted during the actual fermentation tests using the optimal mixture of sugarcane molasses and water, which was a 1:3 ratio with 7-g active dry yeast per liter of the mixture. Fermentation of sugarcane molasses in a polyethylene plastic tank for 6 days yielded an alcohol content of 10.55% v/v, while an alcohol content of only 8.82% v/v was obtained in a stainless-steel tank for the same fermentation period. However, using the plastic tank for a shorter fermentation period of 4 days resulted in a higher alcohol content of 11.19% v/v. It was observed that plastic tanks operate best at lower relative humidity

Table 1. Physicochemical analysis[1] of sugarcane molasses after 5-day fermentation with different amounts of active dry yeast (laboratory condition).

Physicochemical Analysis	Active Dry Yeast (g)		
	1	2	3
1:1 Sugarcane molasses: water*			
pH	4.47^{a}	4.44^{a}	4.46^{a}
Total soluble solids (°Brix)	41.60^{a}	40.60^{c}	41.10^{b}
Alcohol content (% v/v)	6.23^{a}	6.09^{a}	6.62^{a}
1:2 Sugarcane molasses: water*			
pH	4.47^{a}	4.50^{a}	4.50^{a}
Total soluble solids (°Brix)	25.30^{a}	24.70^{b}	24.00^{c}
Alcohol content (% v/v)	8.77^{a}	9.49^{a}	9.48^{a}
1:3 Sugarcane molasses: water*			
pH	4.32^{c}	4.38^{b}	4.41^{a}
Total soluble solids (°Brix)	12.45^{c}	12.75^{a}	12.60^{b}
Alcohol content (% v/v)	10.53^{a}	10.08^{ab}	9.72^{b}
1:4 Sugarcane molasses:water*			
pH	4.23^{c}	4.30^{b}	4.34^{ab}
Total soluble solids (°Brix)	10.20^{b}	10.60^{a}	10.60^{a}
Alcohol content (% v/v)	8.13^{a}	7.95^{a}	8.16^{a}

[1]Mean values with the same letter within a row are not significantly different at p=0.05 (n=2).
*140 ml total volume of diluted molasses

Table 2. Physicochemical properties of fermented sugarcane molasses in the different kinds of fermentation tank.

Fermentation Days	Total Volume (L)	Tank Used	Relative Humidity (%)	Ambient Temperature (°C)	Before Fermentation		After Fermentation		Alcohol Content (%)
					pH	TSS (°Brix)	pH	TSS (°Brix)	
6	140	Plastic	51 to 71	19.5 to 29.7	5.46	18.57	3.89	12.76	10.55
4	140	Plastic	55 to 79	23.5 to 30.1	5.41	21.20	4.83	13.75	11.19
6	180	Stainless	80 to 91	30.5 to 26.0	5.45	15.05	4.80	13.20	8.82

levels ranging 51 - 79% and at ambient temperatures ranging 19.5 - 30.1°C, compared with stainless steel tanks. After six days of fermentation, the pH value and TSS of the feedstock were generally lower in the plastic tank than those in the stainless-steel tank.

Description of the Distiller

The 400-L capacity hydrous bioethanol distiller, depicted in Figure 7, comprises the following major components: (a) boiler, (b) distilling column, (c) condenser, (d) water cooling bin, and (e) rice husk gasifier. The boiler is where the feedstock is heated to vaporize the alcohol/water mixture and push the vapor into the distilling column. It has a diameter of 0.8 m and a height of 1.2 m. At its center is a 20-cm diameter by 1.2-m high cylinder, which serves as the heater for the boiler. Fins are provided on the surface of the boiler's inner cylinder to enhance heat transfer from the hot flue gas passing through the cylinder and to induce boiling and vaporization of the feedstock.

A chimney was added to the boiler outlet to facilitate the discharge of flue gas and to pre-heat the water for the distilling column. The distilling column, coupled to the boiler, was designed to refine alcohol vapor in order to produce 90 - 95% v/v alcohol. This unit consisted of a double-walled cylinder with a 7.5-cm diameter and 135-cm height. The inner cylinder was filled with chrome tubes (6-mm diameter x 12-mm long) that served as a filter for the gas by separating the vapor from the liquid. Hot water obtained from the boiler's chimney was used to heat the column, maintaining the alcohol in its vapor form and the water in its liquid state.

Vapor alcohol from the distilling column passed through the condenser, which was made of a 7.5-cm diameter by 5-m long pipe serving as a heat exchanger, condensing the alcohol vapor into liquid. Water flowed through the condenser from outside of the pipe in a counter-flow manner.

To heat the boiler, a 60 cm diameter moving-bed rice husk gasifier equipped with a 3-inch, 220 v electric blower was used. Rice husk was converted into producer gas which, when ignited, produced hot flames causing alcohol to vaporize from the feedstock.

The water bin supplied water to the condenser using a 0.5-horsepower electric pump at a rate of 33 L/min. The pump was movable so it could also be used to pump feedstock from the fermentation tanks into the boiler.

Performance of the Distiller

A series of preliminary tests were conducted until the distiller achieved its designed performance. During these preliminary tests, adjustments were made to the chimney and the column, as well as to the operation of the gasifier. After achieving satisfactory operating performance for the distiller, four test runs were conducted using fermented sugarcane molasses as feedstock to measure various parameters relevant to the distiller's performance.

Inedible sugarcane molasses samples were obtained from a sugar mill in Tarlac City, Central Luzon, Philippines. The samples were mixed with water at a ratio of 1:3; that is, 1 part of sugarcane molasses to 3 parts of water. A total of 2.86 kg of Baker's yeast was directly poured and dissolved in the mixture (Figure 8a). The mixture was then placed in plastic tanks and allowed to ferment for 4 - 6 days. In each run, 400 L of fermented sugarcane molasses, with an alcohol content of 7.3 - 10.0% v/v, were pumped into the boiler of the distiller (Figure 8b). The producer gas generated from rice husks was used to heat the boiler (Figure 8c). Water was pumped into the condenser to cool the alcohol vapor leaving the condenser. The water, already hot upon leaving the condenser, was then diverted to the heat exchanger at the chimney and at the packed-bed column of the distiller.

Figure 9 shows the temperature trend at various components of the distiller: boiler, water inflow and outflow, distilling column, condenser, and distillate coming from the condenser (Figure 8c). The collection of bioethanol started when the boiler temperature reached 92°C, which took 2.7 - 3 h from the time the rice husk gasifier started heating the boiler. It was further observed that the distillate comes out of the condenser after an hour upon reaching a temperature range of 40 - 60°C for water entering the distilling column and 50 - 65°C for water leaving it. At this

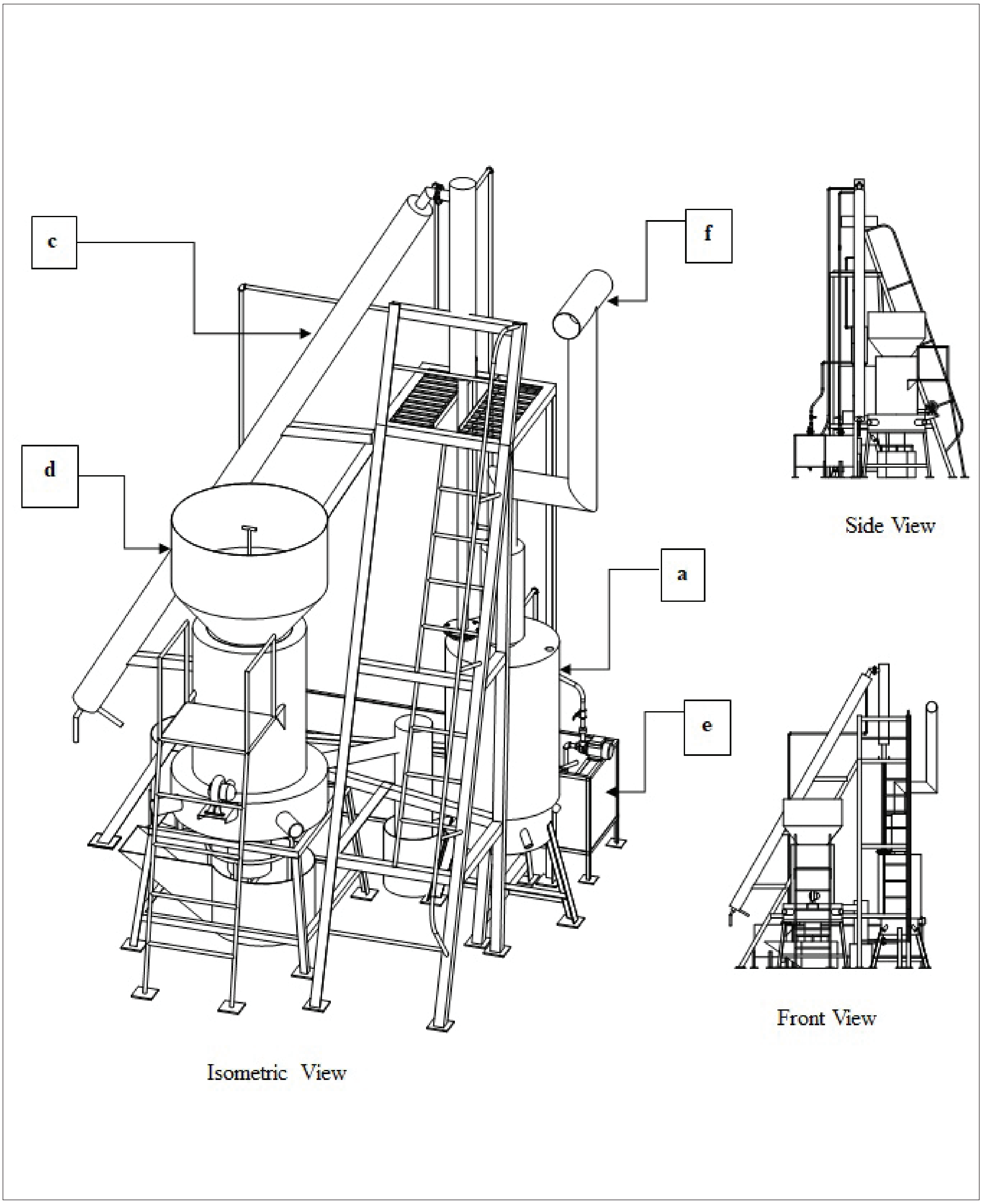

Figure 7. Parts of the 400-l capacity Hydrous Bioethanol Distiller: (a) boiler; (b) distilling column; (c) condenser; (d) rice husk gasifier; (e) water cooling bin, and (f) chimney.

Figure 8. Hydrous bioethanol distiller during performance tests: (a) preparation of molasses to be fermented, (b) loading of fermented molasses, and (c) heating and collection of distillates.

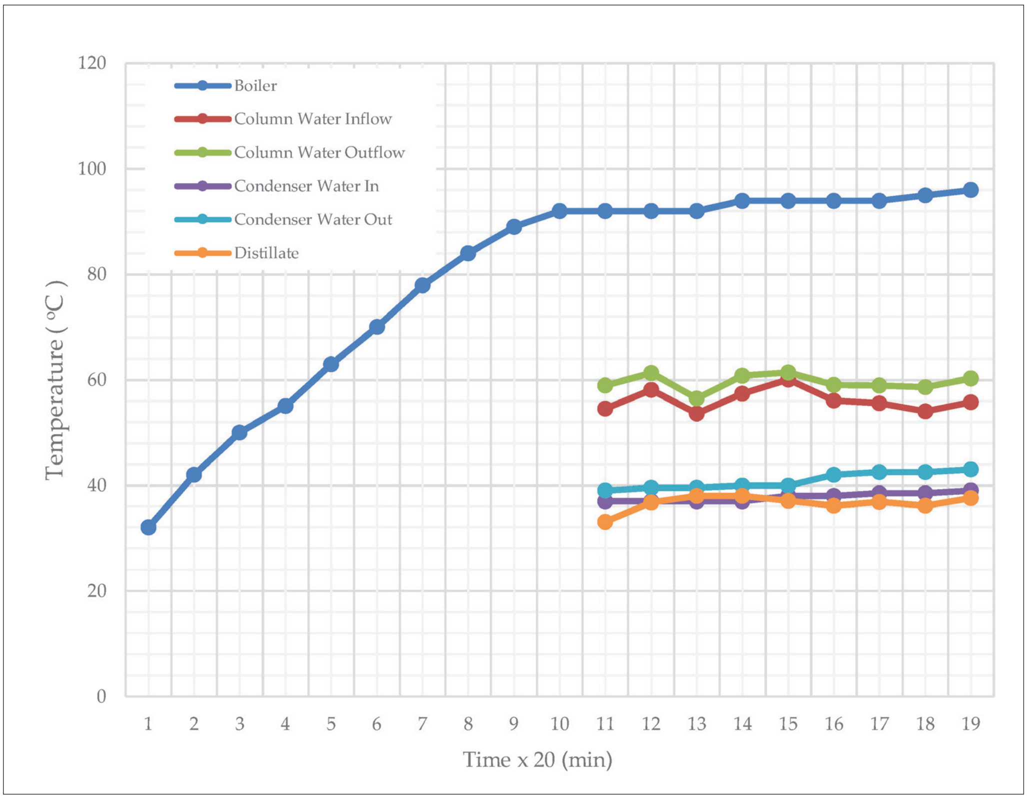

Figure 9. Temperature trend of feedstock, column and condenser, water inflow and outflow, and distillate while in operation.

temperature range, the water coolant entering the condenser is measured at 30 - 38°C and leaving at 35 - 42°C; while the temperature of the distillate ranges from 28 - 38°C.

Table 3 shows the results of performance tests of the distiller. The boiler required 2.7 - 3 h of heating using rice husk gasifier before vapor alcohol was produced. For a feedstock load of 400 L of fermented sugarcane molasses having an alcohol content of 7.3 - 10.0% v/v, between 29.2 - 41.1 L of distillate were obtained for four runs. The alcohol content of these distillates varied from 93.0 - 96.0% v/v over a collection period of 3.5 - 6 h. The amount of rice husk consumed from starting up the gasifier until its operation ended varied from 233.1 - 321.3 kg.

The stillage, calculated by subtracting the volume of distillates obtained, ranged from 361.0 - 368.7 L for four test runs. Also shown in Table 3 are calculated distillation rates for producing hydrous bioethanol in the distiller ranging from 6.0 - 8.3 L/h; alcohol recovery varied from 93 - 99% v/v; rice husk consumption rate by gasifier ranged from 35.6 - 38 kg/h; and overall thermal efficiency ranged from 4.2 - 5.6%. It was observed that the distiller functioned satisfactorily as expected. Hydrous bioethanol fuel was produced from fermented sugarcane molasses using producer gas from rice husk as a heat source. The internally-heated boiler was able to raise the temperature of the 400-L feedstock within three hours of heating. The distilling column produced alcohol vapor of sufficient purity suitable for fueling retrofitted spark-ignition engines. The alcohol vapor was converted into liquid distillate upon passing through the condenser in the opposite direction to the coolant.

Hydrous Bioethanol as Fuel for Retrofitted Engines

Hydrous bioethanol fuel was used as fuel for 0.75-hp, 3.5-hp, and 6.5-hp spark-ignition engines (Figure 10) retrofitted with the hydrous bioethanol fuel-feeding device developed by Belonio et al. (2019). This device was installed on the engine, bypassing the carburetor, allowing hydrous bioethanol to be directly injected into the intake manifold. The engine has a separate stainless-steel tank and the fuel line, made of polyurethane material, is connected to the tank and to the injector.

Table 4 shows the performance of hydrous bioethanol as fuel for various farm machines compared with gasoline fuel. As shown, the retrofitted engine is used as a power source for a 3-inch water pump (Figure 10a) and is successfully tested for irrigating a rice field. The average hydrous bioethanol fuel consumed by the engine is at 1.8 L/h for a discharge of 15.5 m^3/h. A 0.75-hp grass cutter or power scythe (Figure 10b), with a retrofitted engine, is also tested with hydrous bioethanol fuel in cleaning the levees of a 2.5-ha rice farm. The engine consumed 0.7 L of hydrous bioethanol per hour against 0.5 L/h when using gasoline. A retrofitted 6.5-hp engine, which was tested in powering a microtiller (Figure 10c) using the variable-feed hydrous bioethanol fuel injector, consumes 2.0 L of hydrous bioethanol per hour in tilling a 1,500 m^2 farm tilled in three passes compared with 1 L/h when using gasoline only.

Table 3. Test performance of the 400-L capacity Hydrous Bioethanol Distiller.

Parameter	Test Run			
	1st	2nd	3rd	4th
Loading capacity (L)	400	400	400	400
Heating period (h)	2.7	3.0	3.0	2.9
Alcohol content of feedstock (% v/v)	7.3	8.0	10.0	8.8
Volume of distillate collected (L)	29.2	33.0	41.1	35.8
Alcohol content of distillate (% v/v)	93.0	96.0	95.0	95.0
Rice husk used (kg)	233.1	230.0	320.0	321.3
Collection period (h)	3.5	5.2	6.0	5.6
Stillage (L)	368.6	368.7	361.0	362.9
Distillation rate (L/h)	8.3	6.3	6.0	5.6
RH consumption (kg/h)	37.6	38.0	35.6	37.8
Alcohol/fuel ratio	0.13	0.14	0.13	0.11
Alcohol recovery (%)	93.0	99.0	97.5	96.5
Overall thermal efficiency (%)	5.4	5.6	4.4	4.2

Figure 10. Hydrous bioethanol used as fuel for farm machines: (a) water pump, (b) microtiller, (c) micromill, (d) power tiller hauler, and (e) grass cutter.

Table 4. Performance of hydrous bioethanol as fuel for farm machines.

Farm Machine	Engine (hp)	Operation	Hydrous Bioethanol [HB] (L/h)	Gasoline [G] (L/h)	Ratio HB/G
Water pump	3.5	2 in. @ 15.5 m^3/h	1.8	1.3	1.4
Grass cutter	0.75	Cleaning 2.5 ha	0.7	0.5	1.4
Microtiller	6.5	Tilling 1,500 m^3 for 3 passes	2.0	1.0	2.0
Micromill	6.5	Milling 50 kg paddy	1.8	1.0	1.8
Power tiller Hauler	6.5	Traversing 1.6 km on rough road	3.9	1.6	2.4

The retrofitted engine that was tested performed well in powering a micromill (Figure 10d) which milled rice at a rate of 50 kg of paddy per hour. The retrofitted engine consumed about 1.8 L of hydrous bioethanol in milling rice as against a consumption rate of 1.0 L/h when using gasoline. Tested on a power-tiller hauler (Figure 10e), the retrofitted engine consumed 3.9 L traveling a distance of 6.4 km on a rough road with an average fuel consumption rate of 1.6 L/h. It was generally observed that using hydrous bioethanol required between 0.5 - 2.4 times more fuel, depending on the size of the engine and load, than using gasoline to operate farm machines to perform the same task. The higher consumption for hydrous bioethanol could be attributed to its lower heating value (24.90 MJ/kg) compared with that of gasoline (43.45 MJ/kg) (Regalado et al., 2018).

3.5 Distillation and Production Cost Analyses

Table 5 presents the details of the distillation and production cost analyses for the distilling facility using sugarcane molasses as feedstock. The total investment cost (IC) for the 400-L capacity distilling facility was PhP465,000.0. This included the distilling unit amounting to PhP356,000.0, the fermentation tanks at PhP20,000.0, and the shed, which would require an area of about 50 m^2 or 5 m x 10 m, at PhP89,000.0. The cost of the land was excluded as it would be provided by farmers' cooperatives intending to build and process hydrous bioethanol as fuel for their members. The cost of retrofitting the engine should also be covered by the farmers since they would be able to make and install them on their own using locally-available parts.

Table 5. Distilling and production cost analyses for the distiller (as of May 2023).

Item	Amount (PhP)	
Investment cost (PHP) [1/]		
Distilling unit (400-liter capacity)	356,000.00	
Fermentation tanks	20,000.00	
Shed	89,000.00	
Sub total	465,000.00	
Fixed cost (PhP/day)		
Depreciation [2/]	163.80	
Interest on investment [3/]	305.75	
Repair and maintenance [4/]	127.40	
Insurance [5/]	38.22	
Sub total	635.17	
Variable costs (PhPday)	Distilling	Production
Sugarcane molasses [6/]		1,530.00
Yeast[7/]		714.00
Fuel [8/]	304.00	304.00
Electricity [9/]	144.00	144.00
Labor [10/]	430.00	430.00
Sub total	878.00	3,122.00
Total costs (PhP/day)	1,513.17	3,757.20
Cost per liter (PhP)	37.83	93.90

[1/] Complete set: 7 years life span
[2/] Straight line with 10% salvage value
[3/] 24% of the investment cost
[4/] 10% of the investment cost
[5/] 3% of the investment costs
[6/] 400 L of fermented sugarcane molasses (100 L molasses + 300 L of water)
[7/] PhP220 per kg of yeast
[8/] PhP1.0 per kg of rice husks @ 38 kg/h consumption for 8 h per day operation
[9/] 1.5 kW for 8 h @ PhP12/kW-hr
[10/] One operator at PhP430/8-h day
[11/] Operation: 6 days per week, 4 weeks per month, and 10 months per year

The total fixed cost, which included depreciation (PhP163.80), interest on investment (PhP305.75), repair and maintenance (PhP127.40), and insurance (PhP38.22), amounted to PhP635.17. On the other hand, the variable costs, which included the cost of fermented sugarcane molasses, rice husk fuel, electricity for the blower, pump, and bulbs for lighting, and labor, was PhP1,513.17 per day.

The calculated total cost of operating the distiller in processing the feedstock is PhP1,513.17 per day. If costs of sugarcane molasses and yeast are included, production cost is PhP3,757.20. At a 400-L/d production capacity, the distilling cost is PhP37.83/L and production cost is PhP93.90/L of hydrous bioethanol.

Results of the cost analysis showed that this cost of hydrous bioethanol would be higher than the prevailing PhP76.45 - 97.40/L retail prices of unleaded gasoline in Metro Manila (DOE, 2023) and therefore not practical to use. However, based on our projections, if the distiller could be scaled up to have a feedstock capacity of 1000 L and operated at two batches per day, it could reduce the production cost by 27.5%, i.e., from PhP93.90 - 68.10/L. At this projected reduced cost, using hydrous bioethanol produced from this facility would be viable.

Moreover, at this capacity, the projected investment cost of PhP697,500, which is 1.5 times the cost of the existing distiller, could be recovered after 2.3 years.

Conclusion and Recommendations

The results of the prototype 400-L hydrous bioethanol production facility demonstrated satisfactory performance based on the design specifications. The facility could be constructed locally at the farm level using readily available materials for the fermentation tanks and distiller, and employing local skills and labor in the fabrication and construction of the facility. Therefore, it is technically feasible to develop a decentralized farm-level hydrous bioethanol production facility using renewable sources of feedstock, such as sugarcane molasses, and equipped with a biomass gasifier using rice husks as solid biofuel to heat the boiler of the distillation facility.

In the fermentation of sugarcane molasses, a mixture of one part sugarcane molasses to three parts water with 7-g active dry yeast per liter of the mixture should be used for the highest alcohol content yield within 5 days of fermentation. Locally available and less expensive 200-L plastic tanks or drums would be more suitable than stainless-steel tanks for use as containers in the fermentation process.

The hydrous bioethanol obtained from the distiller could be effectively used as fuel for retrofitted spark-ignition engines in powering farm machines. However, there is a need to improve the design of the fuel injector, specifically its feeding mechanism, for a more accurate supply of fuel to the carburetor to reduce the amount of bioethanol consumption in powering farm machines.

As the cost of producing hydrous bioethanol from sugarcane molasses is higher than the current pump prices of gasoline, it is necessary to scale up the facility to at least a 1000-L capacity and carry out distillation in two batches per day. This would reduce the production cost from PhP93.80/L to a projected PhP68.10/L. A study on optimizing the design of the boiler and distilling column that will allow for a shorter period of heating feedstock and collection of distillates is also recommended to further increase its economic viability.

Acknowledgment

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FULL PAPER

ACUTE CONTACT TOXICITY OF LANZONES (*Lansium domesticum* Correa) LEAF EXTRACT AGAINST ADULT BROWN PLANTHOPPER, *Nilaparvata lugens* (Stål)

Aerl Jave M. Enriquez*, Stephen E. Mariñas, Anne Mae Francine P. Mesina, Jesamel A. Gamit, and Erickson F. Del Mundo

Caloocan City Science High School
P. Sevilla Street cor. 10th Avenue Grace Park West, Caloocan City, Philippines 1406
*Corresponding Author: aerl.enriquez@gmail.com

Abstract

Nilaparvata lugens (Stål), a major threat to rice production in Asia, has been traditionally combated using synthetic chemicals. However, the environmental impact, potential harm to human health, and the development of resistance in brown planthopper (BPH) necessitate alternative solutions. This study determined the acute contact toxicity of lanzones (*Lansium domesticum*) leaf extract against *N. lugens*. *L. domesticum* leaves, totalling 2 kg, were processed to obtain the extract through maceration and water bathing. The extract was then formulated into varying concentrations (0.25, 0.50, 0.75, and 1%) and applied to *N. lugens* in three replicates with each replicate consisting of 15 hoppers. The mortality count of the treated BPHs was recorded every hour for 6 h. The results demonstrated a direct relationship between the concentration of *L. domesticum* leaf extract and the mortality count of *N. lugens*, with higher concentrations having a more pronounced effect compared with the negative control and lower concentrations. The LC50 and LC90 of *L. domesticum* leaf extract were found to be 0.55% and 1.80% respectively. These findings suggest that *L. domesticum* leaf extract could potentially serve as an effective botanical control against *N. lugens*.

Keywords: *Abbott's formula, Alkaloid, Saponin, Mylar cage, Probit linear regression*

Introduction

Insects pose a significant threat to agricultural crops, particularly rice. The International Rice Research Institute (IRRI) conducted a study revealing that in Asia, the brown planthopper (BPH) *Nilaparvata lugens* (Stål) (*Hemiptera: Delphacidae*) severely damages rice crops. The damage is inflicted through direct sucking of rice stems, often resulting in hopper burn, oviposition, and virus disease transmission due to its long distance migration. Outbreaks of *N. lugens* have become increasingly common in China and other Asian countries. The damage caused by *N. lugens* to rice production in Asia is estimated to exceed $300 million annually, and susceptible rice varieties can suffer significant output losses (Wu et al., 2018). According to IRRI, farmers lose approximately 40% of their rice crops to pests with *N. lugens* being one of the most destructive. In the province of Samar, Philippines alone, about 4,000 ha of rice fields have been infested by BPH (Fernandez, 2017).

For many years, synthetic chemicals have been the primary method of BPH control. However, due to the widespread and extensive use of pesticides, BPH has developed significant resistance to several major types of insecticides including organophosphates, carbamates, pyrethroids, neonicotinoids, insect growth regulators, and phenylpyrazoles (Wu et al., 2018). Moreover, synthetic chemicals can cause health issues, harm non-target organisms, contaminate agricultural products including water, soil, air and breed insecticide-resistant insects.

Plant extracts do not pose these problems as they are biodegradable (Visetson et al., 2002 as cited in Bullangpoti et al., 2006), and do not have toxic effects on humans (Udomchoak, 1985 as cited in Bullangpoti et al., 2006). Therefore, there is a growing interest in developing natural insecticides such as botanical insecticides that are safer and more environmentally friendly than synthetic insecticides for BPH control (Nuryanti et al., 2018). This has led to an increased interest in using *Lansium domesticum* leaf extracts as an alternative to synthetic biocides.

L. domesticum (Langsat, Meliaceae) is a tropical fruit predominantly found in Southeast Asian countries including Thailand, Malaysia, Indonesia, and the Philippines (Abdallah et al., 2022). In the Philippines, lanzones seeds are used for deworming and ulcer treatment by pounding them and mixing with water (Alfonso et al., 2017). A study by Subahar et al. (2020) screened and assayed five species of Philippine plants, including *L. domesticum*, for their larvicidal potential against *Aedes aegypti* (L) and *Culex quinquefasciatus* (S). The extracts of lanzones and sugar apple demonstrated the most effective insecticidal activity against the larvae of *Aedes aegypti* after 48 h of exposure (Monzon et al., 1994).

The main bioactive compounds of *L. domesticum* leaves are alkaloids and saponins (Subahar et al., 2020). Further studies using the seeds and rind (peel) of *L. domesticum* revealed the presence of bioactive compounds such as alkaloids, flavonoids, saponins, and polyphenols. Indole alkaloid structures such as strychnine and quinine function as insect repellents (Subahar et al., 2020). Solidum's study in 2012 showed that the fruit peel has high intensity for sugars and alkaloids. Among other fruit trees tested (mangosteen, ponkan, dalandan, pomelo, longgan, and rambutan), only lanzones showed positive results to all tests related to alkaloids. This proved to be an effective insecticide against both larvicidal and adulticidal forms of insects in a test.

However, there is a scarcity of studies investigating the potential insecticidal activity of *L. domesticum* leaf extract against adult *N. Lugens*. Therefore, this study utilized *L. domesticum* leaf extract to investigate its acute contact toxicity against adult *N. Lugens* and expand our knowledge.

This study determined the acute contact toxicity of *L. domesticum* leaf extract against adult N. lugens without causing harm to plants, soil, or biodiversity surrounding rice crops. It seeks to identify the lethal or effective concentration of *L. domesticum* leaf extract required to kill 50% (LC50) and 90% (LC90) of the *N. lugens* population. It also aims to understand the significant differences in mortality count among the positive control, negative control, and experimental groups. This study will be beneficial to farmers, crop consumers, and future researchers who can use it as a reference for future experiments.

Materials and Methods

Plant materials

In this study, *L. domesticum* leaf extracts were used as natural insecticides, serving as the independent variable, while the mortality count of rice pests was the dependent variable. The analysis primarily focused on the mortality count of rice pests, specifically the adult stage of BPH. The adult stage of *N. lugens* was chosen for testing due to its availability and proximity to the researchers. The study did not cover other developmental stages of BPH as they fall under a different topic. The egg stage was excluded because the eggshell has been shown to be an excellent barrier to insecticides, fungal pathogens, and some fumigants (Campbell et al., 2016). Another limitation of the study was that it did not examine the growth stages of rice, soil quality, or the status of the rice crop after biocide treatment.

Research Design

The experiment employed a quantitative research design with a post-test-only group to explore the potential of *L. domesticum* ethanolic extract as an insecticide against *N. lugens*. The study was structured in a Completely Randomized Design (CRD) with four experimental groups and two control groups. Each treatment used three replicates with each replicate containing 15 adult BPH.

Collection of Materials

Samples of *L. domesticum* plant leaves, totalling 2 kg, were collected from San Agustin, Laguna. Samples of *N. lugens* were acquired from the Institute of Weed Science, Entomology and Plant Pathology (IWEP) at the University of the Philippines - Los Baños.

Preparation of Lanzones Leaf Extract

The leaves of *L. domesticum* were thoroughly washed with tap water, air-dried, and weighed. Twelve nylon nets were prepared, each containing 200 g of leaves, and air-dried. The leaves were mixed daily to prevent any insect infestation and mold growth. After drying, the leaves were powdered using an electric blender. The powdered leaves were then placed in clean, dry containers and sent to the Institute of Pharmaceutical Sciences, NIH-University of the Philippines-Manila for maceration and water bath extraction methods. The leaf extract was stored in a refrigerator prior to the formulation of the treatments.

Preparation of Treatments and Controls

The study formulated Lanzones crude extract concentrations of 0.25, 0.5, 0.75, and 1% as treatments. To achieve these concentrations of *L. domesticum* extract, 0.25 g of extract was added to 99.75 ml of distilled water, 0.5 g of extract to 99.5 ml of distilled water, 0.75 g of extract to 99.25 ml of distilled water, and 1 g of extract to 99 ml of distilled water, each mixture totaling a 100 ml solution. The solutions were thoroughly agitated until the extract was fully mixed with the water.

For the positive control, 0.28 ml of Cypermethrin (a commercial insecticide) was diluted in 100 ml of distilled water. The negative control consisted of pure distilled water (100 ml). Both the treatments and controls were then transferred into small bottles.

Preparation of Nilaparvata lugens

The *N. lugens* were acclimatized for 2 days to adapt to the new environment. They were kept in mylar cages or in an insect incubator with rice seedlings serving as their food source (Caugma et al., 2020) and were fed for 2 days (Li et al., 2019). The tops of the mylar cages were covered with organza fabric to confine the insects while allowing air circulation within the cages. *N. lugens* were collected using a mouth aspirator through a slit in the mylar cages (Heinrichs et al., 1981).

Acute Contact Toxicity of Lanzones leaf Extract to BPH

The exposure method utilized a circular filter paper (Qualitative Filter Paper 102 Moderate, 9 cm diameter). Filter papers were moistened with 2 ml of the different treatment concentrations and impregnated using a syringe in a spiral configuration to ensure homogeneous distribution towards the center. Once the carrier solvent had evaporated, each treated filter paper was placed in a plastic container (diameter: 9 cm; height: 7 cm) with an organza fabric on top. This setup prevented the *N. lugens* from escaping while allowing air to circulate within the containers.

Fifteen insects of a 7-day-old adult *N. lugens* were placed onto the dried filter paper inside the plastic container for time intervals of 1, 2, 3, 4, 5, and 6 h. The mortality count was recorded at each interval.

Data Collection and Analysis

The treated *N. lugens* were monitored for mortality count every hour over a 6-h period after each treatment was applied. The dead *N. lugens* were identified by gently prodding them with a non-sharp stick to check for movement. Dead hoppers were immediately removed at each data collection point. Data on the mortality count of dead *N. lugens* were tested for normal distribution (Shapiro-Wilk Test) and homogeneity of variances (Levene's Test).

Data were analyzed through One-way ANOVA, as this study contains one independent variable, and to find the significant difference between the mortality count of BPH groups treated with four concentrations of lanzones leaf extract and the groups treated with control (distilled water and Cypermethrin). The treatments were compared using Tukey HSD, as the sample sizes are equal, at a 5% significance level using Jamovi.

The percentage mortality of the insect was corrected using Abbott's formula (Abbott, 1925 as cited in Wititsiri, 2011). These corrected percent mortalities of the insect were used in estimating the LC (LC50 and LC90) values of the plant extracts. Lethal concentrations were determined using probit analysis (Finney, 1997 as cited in Nuryanti et al., 2018), and it was performed in Microsoft Excel at a 5% significance level (Caugma et al., 2020).

Results and Discussion

Table 1 presents the mortality of *N. lugens* following a 6-h exposure to various treatments. The mortality percentages varied among different concentrations of *L. domesticum* leaf extract with the highest mortality rate of 76% observed in a 1% concentration treatment. At 0.25% concentration, there was a 22% mortality rate; at 0.50%, the mortality rate was 51%; and at 0.75%, it reached 62%. The negative control resulted in a 4% mortality rate, while the positive control exhibited a substantial 82% mortality rate. Notably, even the negative control group showed a low mortality rate. The experiment used Abbott's correction method to determine the percent corrected mortality of *N. lugens* (Figure 1), providing an accurate assessment of the acute contact toxicity of *L. domesticum* leaf extract.

Table 1. Percent mortality of *Nilaparvata lugens* in response to varying concentrations of *Lansium domesticum* leaf extract.

Treatments (%)	Mortality (%)
0.25	22 a
0.50	51 ab
0.75	62 bcd
1	76 bd
Control (-)	4 a
Control (+)	82 d

The mortality of *N. lugens* when subjected to varying concentrations of *L. domesticum* leaf extract may be attributed to the presence of tannins, phlobatannins, saponins, flavonoids, alkaloids, steroids, and glycosides (Evans, 1989 as cited in Silva et al., 2019). It was confirmed that alkaloids and saponins are the main bioactive compounds of *L. domesticum* leaves that act as an insect repellent by inhibiting acetylcholinesterase (Subahar et al., 2020). This inhibition prevents acetylcholine from being hydrolyzed, resulting in prolonged binding of acetylcholine to its postsynaptic receptor and causing excessive neuroexcitation (Rajashekar et al., 2014).

One-way ANOVA showed that the variance of concentrations of *L. domesticum* had an F-statistic value of 34.5, which is higher than the F critical value of 3.11, and a p-value of <0.001 indicating very strong evidence against the null hypothesis. This favors the alternative hypothesis that there is a significant difference between the control groups (positive and negative), and experimental groups (*L. domesticum* leaf extract) when it comes to the mortality count of *N. lugens*.

As the results of the p-value in one-way ANOVA are significant, Tukey HSD was used to determine if there is a significant difference between variables. Tukey's HSD test results (Figure 2) showed significant differences among several groups but comparable effects between others.

This suggests that Cypermethrin (positive control) has a stronger impact than various *L. domesticum* leaf extract concentrations because organic pesticides are less persistent and can be more selective than synthetics (McCoy and Frank, 2020). However, it is better to use organic pesticides, which kill pests without causing any side effects to plants (Kalkura et al., 2021). The post-hoc test further implies that higher *L. domesticum* leaf extract concentrations have a greater impact than the negative control and lower concentrations.

Ideally, an effective insecticide should be applied at a concentration high enough (following label directions) to kill all individuals in a population (Pundt, 2020), which supports our findings.

Table 2 and Figure 3 present the lethal concentrations required to kill 50 and 90% of the *N. lugens* population, along with the findings of the regression analysis between the different concentrations of *L. domesticum* leaf extract. The regression line equation is displayed to estimate the lethal concentrations needed to kill 50 and 90% of the population. In the regression equation $y = 2.4948x + 5.6437$, the concentration of *L. domesticum* leaf extract and the corrected percent mortality of *N. lugens* are represented by X and Y variables, respectively. This suggests that for every increase of 2.5 units in concentration (X), the mortality of *N. lugens* rises by 5.6 units.

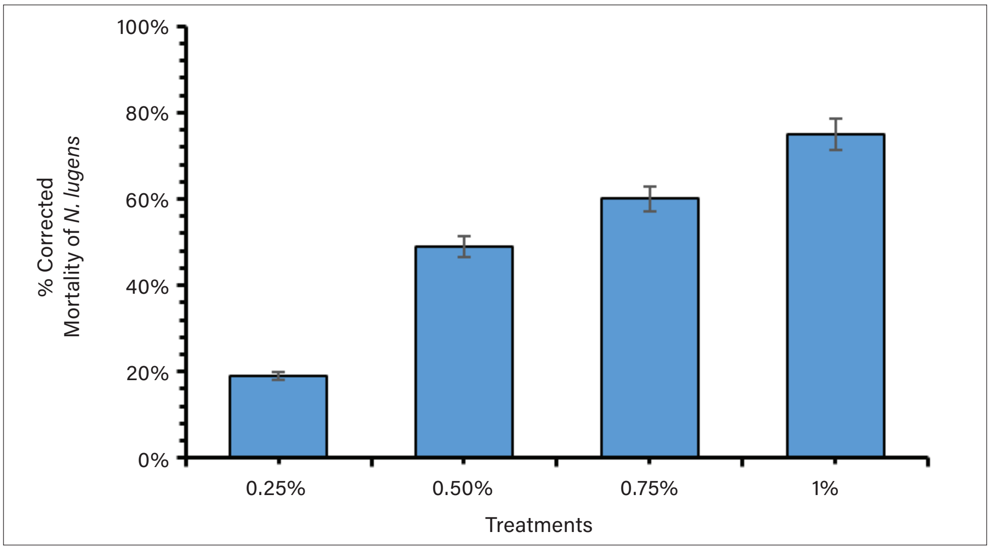

Figure 1. Quantifying the corrected mortality percentage of *Nilaparvata lugens* using Abbott's formula.

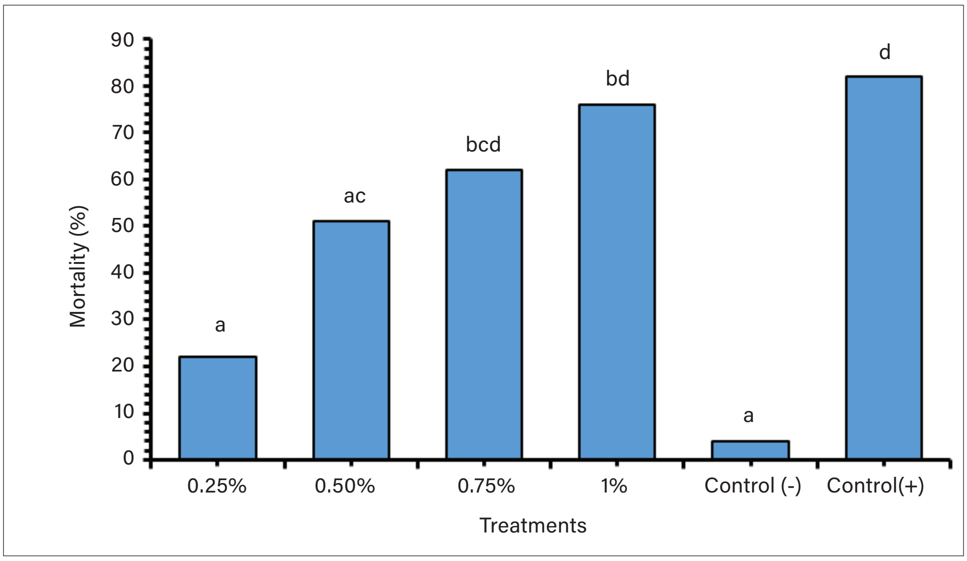

Figure 2. Post-hoc comparison of treatment means for *Nilaparvata lugens* mortality.

Note: Treatment groups with the same letter do not exhibit statistically significant differences at a 5% level of significance, as determined by Tukey's Honestly Significant Difference (HSD) test.

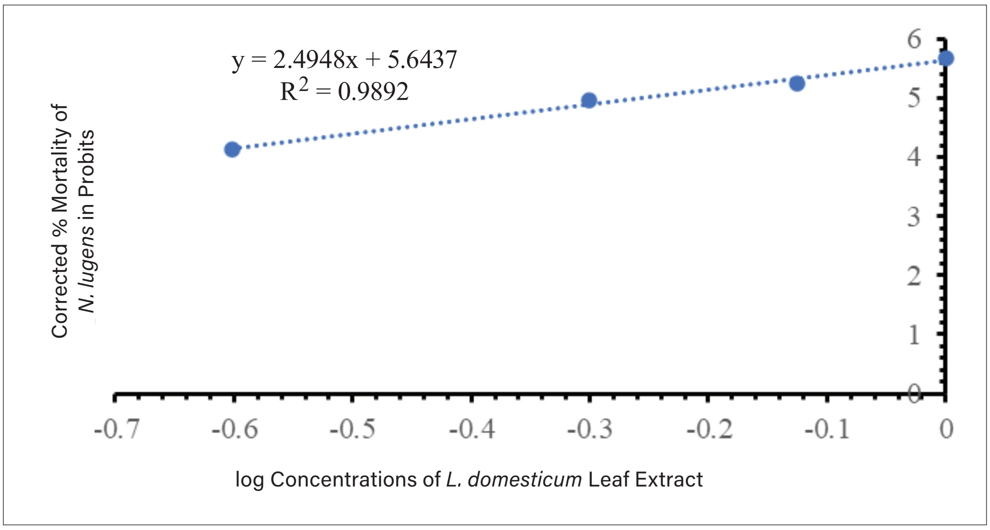

Figure 3. Probit linear regression line equation of the insecticidal activity of *Lansium domesticum* leaf extract against *Nilaparvata lugens* after 6 h.

Table 2. Calculated LC50 and LC90 of *Lansium domesticum* leaf extract against *Nilaparvata lugens.*

LC50 (%)	LC90 (%)	Regression Line Equations	R
0.55%	1.80%	y = 2.4948x + 5.6437	0.9892

The coefficient of determination, which measures the degree to which concentration (X) predicts the mortality of *N. lugens* (Y), was found to be 98.92%. Ideally, mortality levels should increase as the insecticide concentration increases (Miller et al., 2010). Thus, insect mortality has a direct relationship with the concentration of the solution, indicating that an increase in concentration will yield an increase in corrected percent mortality.

Moreover, regression analysis revealed that a 0.55% concentration of *L. domesticum* leaf extract may control LC50, and a 1.80% concentration of the extract may control LC90. This finding aligns with the study by Villa et al. (2012) as cited in Caugma et al. (2020), which showed that an increase in concentration of C. microcarpa extract leads to higher mortality of A. aegypti (Linn.) through log-probit analysis.

Conclusion

The results demonstrated that an increase in the concentration of *L. domesticum* leaf extract leads to a higher percent mortality of *N. lugens*. The LC50 and LC90 may be controlled by *L. domesticum* leaf extract at concentrations of 0.55% and 1.80%, respectively. Therefore, it can be inferred that *L. domesticum* leaf extract has potential as a botanical insecticide against *N. lugens*.

However, there were limitations in this study such as using only three replicates per treatment due to constraints on the number of BPH obtained. The BPH was collected as adults and was not reared due to time constraints.

This research has shed light on the effectiveness of *L. domesticum* leaf extract as a botanical insecticide against adult *N. lugens*. Future research could explore the stomach mode of action of lanzones leaf extract, test other parts of lanzones (such as peelings, stem, and seed) against BPH, and assess the effectiveness of *L. domesticum* leaf extract against the insect's different developmental stages (egg, nymph, adult).

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WHAT IS THE CURRENT THINKING ON YOUTH AND AGRICULTURE IN THE PHILIPPINES?

Teresa Joi P. de Leon*, Louie Gerard F. Orcullo, and Jaime A. Manalo IV

Socioeconomics Division, Philippine Rice Research Institute
*Corresponding Author: deleontj917@gmail.com

Abstract

This paper reviews literature on youth engagement in agriculture from 2011 to 2021. In decades, there has been no comprehensive review on youth engagement in agriculture in the Philippines and in Southeast Asia covering academic scholarship and the gray literature. Given the challenges faced by Philippine agriculture due to an aging population of food producers and the departure of young individuals from rural farming communities, this review aims to provide insights on enhancing youth engagement in agriculture. The search involved using ProQuest and Google Scholar, yielding a final list of 21 articles from an initial pool of 284. The mixed-method approach has gained popularity for its ability to provide comprehensive insights through quantitative and qualitative research methods. Educational institutions initiated most of the studies reviewed. The schooled youth appear to be the foci of inquiries resulting in the underrepresentation of the out-of-school-youth in the academic literature. A significant finding is the disconnect between the reasons for youth disinterest in agriculture and the strategies employed to engage them. This misalignment could lead to long-term issues. Furthermore, literature that delves into the youth's perspective on the intersection of agriculture and their lives remains limited.

Keywords: *Youth, Agriculture, Philippines*

Introduction

The aging population of farmers poses a threat to food security in the Philippines. The Rice-based Farm Household Survey (RBFHS) conducted by the Philippine Rice Research Institute (PhilRice) confirms this pattern. It reveals that the average age of farmers has risen by one increment every five years, climbing from 53 years old in 2006 to 56 years old in 2017 (PalayStat, 2017). During this period, discourses in the mainstream media have referred to the current farmers as "the last generation farmers" and "a dying breed". In 2020, a study conducted among Filipino rice farmers found that most of them do not want their children to follow in their footsteps and become farmers (Palis, 2020). Instead, outmigration from the rural areas and from farming was encouraged. Several studies have observed a phenomenon where the youth are less interested in agriculture, fisheries, and forestry (AFF) programs compared to non-AFF programs in some universities. Additionally, some young people perceive agriculture as an unprofitable career choice (Aquino et al., 2018; Gaboy et al., 2021). Currently, there are legislations aimed at addressing these issues such as the *Young Farmers and Fisherfolk Challenge Act of 2021* (18th Congress House Bill 9575) and the *Magna Carta of Young Farmers Act of 2020* (18th Congress Senate Bill 1422).

Amidst the 2020 COVID-19 pandemic, the state of Philippine agriculture experienced a favorable shift, reversing the trend of outmigration (Briones, 2021). Urban migrant workers returned to the rural areas due to economic fallout, and urban residents turned to agriculture for subsistence. The agriculture sector proved its resilience and significance. Farmers became highly regarded for being frontline-heroes along with medical workers. In 2021, Philippine production of the staple food of the country, rice, was a record-breaching 19.96 Mmt; a 3.4% increase from the 2020 production outcome (PNA, 2022).

Over time, and as seen in recent years, the view that young people no longer want to be engaged in agriculture has increasingly been challenged as evidenced by the number of youth and agriculture initiatives that have emerged. For example, Manalo et al. (2013, 2015A, 2016) established that the children of rice farmers can effectively serve as infomediaries or information mediators. Care for their parents' learning was seen as the primary motivation for this. The Commission on Higher Education (CHED) data on enrollment by discipline group from 2010 to 2020 showed a generally increasing trend on the number of enrollees for the AFF discipline group. A policy note in 2021 by the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) showed that youth interest in agriculture was rekindled during the COVID-19 pandemic, motivated by the need for economic security, food security, and community-oriented advocacies. The School-Plus-Home Gardens Project (S+HGP) collaboration project between the Department of Education (DepEd) and SEARCA resulted in improved nutrition among the students while successfully influencing their families to embrace sustainable food lifestyles (Calub et al., 2019). The home gardens also served as alternative sources of income for them. These initiatives indicate a shift in perspective, where numerous organizations now view youth as interested in agriculture and are actively devising strategies to involve them in this field. This stands in stark contrast to previous decades when discussions about youth and agriculture seemed less prominent, likely due to the prevailing belief that young individuals were not interested in pursuing agricultural engagements.

Currently, substantial efforts are being dedicated to emphasizing the necessity of generating enough food for the global population. The UN's Sustainable Development Goals, specifically the Zero Hunger objective, exemplify this commitment, with food security, enhanced nutrition, and sustainable agriculture being key success indicators (UN, 2016). The convergence of the pandemic and other global disruptions has created a pressing need for action in food production, as recently highlighted (News5, 2022). Given this context, it is evident that maintaining consistent involvement in agriculture is imperative from a policy perspective. The aging demographic of the country's food producers and the limited engagement of young people in agriculture are understandably concerning aspects. Based on the Philippine Statistics Authority (PSA) data from October 2022, the labor force participation rate for youth stands at 34.2% (PSA, 2022). Young individuals wield significant potential across various domains, including agriculture. In the literature focusing on community youth and development, the perspective is that young people are assets to be mobilized rather than problems to be solved (DFID-CSO, 2010; USAID 2013).

This paper reviews research literature from the last decade regarding youth involvement in Philippine agriculture. This review is essential to gain insights into the current state of youth engagement in agriculture and to formulate impactful policies based on this assessment. This paper is novel in that it provides a comprehensive review of the literature on youth and agriculture in the Philippines, which has not been done in decades. As such, it is well-positioned to provide valuable insights for future initiatives aimed at engaging young people in agriculture in the Philippines and Southeast Asia.

Materials and Methods

A systematic literature review was conducted to meet the paper's objectives. Articles were selected based on their comprehensiveness and availability of institute access, and the review covered research studies conducted in the Philippines from 2011 to 2021 as well as the initiatives during the same period. Google Scholar and Proquest were the utilized databases, and two Boolean queries were generated for Google Scholar to keep the highest fidelity of the parameters with Proquest. The search strings used are shown in Table 1.

Table 1. Boolean Query.

Database	Boolean Query	Results
Google Scholar	("youth" OR "young*") AND ("Initiative*" OR "Project*" OR "Program*" OR "Engagement*" OR "Participat*" OR "Polic*" OR "involv*") AND ("Farm*" OR "Agricultur*") AND "Philippine*" AND (intitle:agriculture AND youth)	124
Google Scholar	youth~ AND involvement~ AND Agriculture~ AND "Philippine*" AND (intitle:youth AND agriculture)	142
Proquest	NOFT("youth" OR "young*") AND NOFT("Initiative*" OR "Project*" OR "Program*" OR "Engagement*" OR "Participat*" OR "Polic*" OR "involv*") AND NOFT("Farm*" OR "Agricultur*") loc("philippines")	18

Following these, the 284 total shortlisted articles were narrowed down to 21. Duplicates were removed from the total shortlisted articles. The abstracts were then reviewed according to the following inclusion/ exclusion criteria:

1. written in English or with English translations,
2. with open access to the full article,
3. about initiatives or perspectives on youth in agriculture,
4. published between 2011-2021, and
5. with the Philippines as a country of focus or project area.

To ensure validity, the authors read the final list of articles in its entirety. The first reading aimed to identify the recurring themes across the articles, which were then used to sort and analyze the literature for this review. Three main themes emerged: (a) school-based vs. out-of-school-youth (OSY)-based literature, (b) youth engagement strategies, and (c) factors affecting staying in or straying from the agriculture sector. Gray literature was also explored in addition to the review as initiatives on youth engagement in agriculture are rarely documented in scholarly literature. The search was limited to interventions relating to youth and agriculture in the past decade. A series of workshops was then conducted to further sort the literature, with deliberations conducted to deal with differences in coding the articles. Overall, 65 initiatives were reviewed.

Results and Discussion

Overview

The final list of articles included research sites located throughout the Philippines. Figure 1 illustrates the provinces explicitly mentioned by the articles as their research sites, with Isabela, Nueva Ecija, Laguna, Bukidnon, and Davao Oriental being the most frequently cited research areas in the literature. Additionally, we found that the authors of the studies were affiliated with 16 academic and research institutions (Figure 2), with the Philippine Rice Research Institute (PhilRice) and University of the Philippines Los Baños (UP Los Baños) being the top institutions producing the most studies on youth in agriculture in the Philippines.

In terms of literature type, 13 empirical papers were classified, where four of these were student reports, two were project reports, and one each of conference papers and popular articles (Figure 3). In terms of research methods employed, there were more qualitative than quantitative studies, with the majority employing both methods (Figure 4). As regards the research focus, Figure 5 shows that the youth in agriculture research studies over the past decade were mostly focused on youth who attend school or university.

The marked tendency towards using mixed methods as shown in Figure 4 is one of the most notable findings of this study. It is a remarkable development in youth research as quantitative approaches have always dominated the literature. This development is important because qualitative research is able to deal with the intangible variables, which are often difficult to investigate quantitatively. Examples of these are perception, experience, or feeling of youth towards farming. Having greater appreciation for qualitative research and mixed methods, the chance is high for more context-specific and narrative-laden inquiry. Emphases on contexts and narratives provide powerful inputs to more impactful policy interventions.

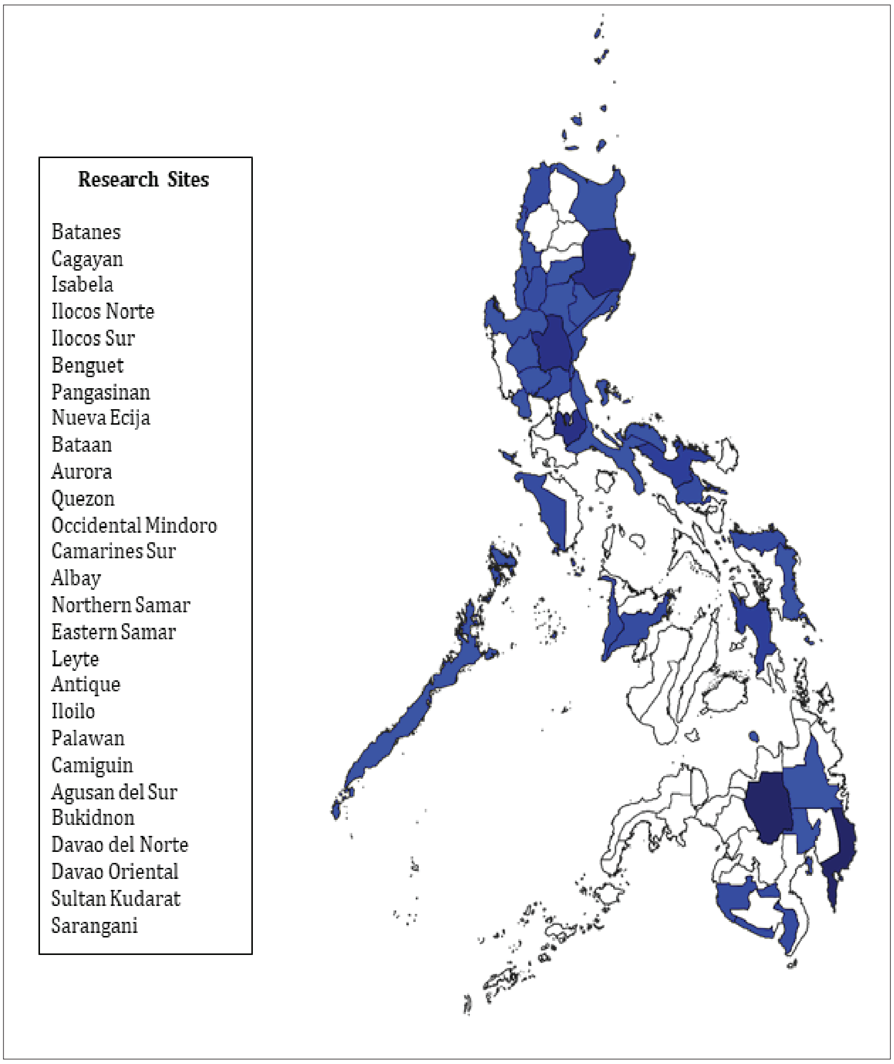

Figure 1. Map showing the research sites of the reviewed literature.

Factors for staying and straying

The literature generally depicts the youth as having less interest in agriculture against a backdrop of a retiring generation of farmers (Aquino et al., 2018; Lumen, 2020; Guerrero et al., 2021). This mindset had impacted the engagement approaches towards the youth, which are centered on encouraging them to return to agriculture and make it their career choice, mostly through the agricultural entrepreneurship or agripreneurship education track as endorsed in and supported by several policies such as the *Magna Carta for Young Farmers*, the *Young Farmers and Fisherfolk Act*, and the *Young Farmers Program Act* (Santiago and Roxas, 2015, 14th Congress SB 3053, 18th Congress HB 9575, 18th Congress SB 1422). Only a few have engaged the youth in their current state by working with them as infomediaries and as producers of their own food (Manalo et al., 2013, Lai 2016, Altamarino et al., 2019; Calub et al., 2019; Pasiona et al., 2021).

One palpable observation is that scholars tend to overlook the multitude of factors surrounding staying or straying away from agriculture. We contend that decision-making is complex rather than linear. Hence, in the succeeding section, we examine the reasons why young people seem to show disinterest towards agriculture.

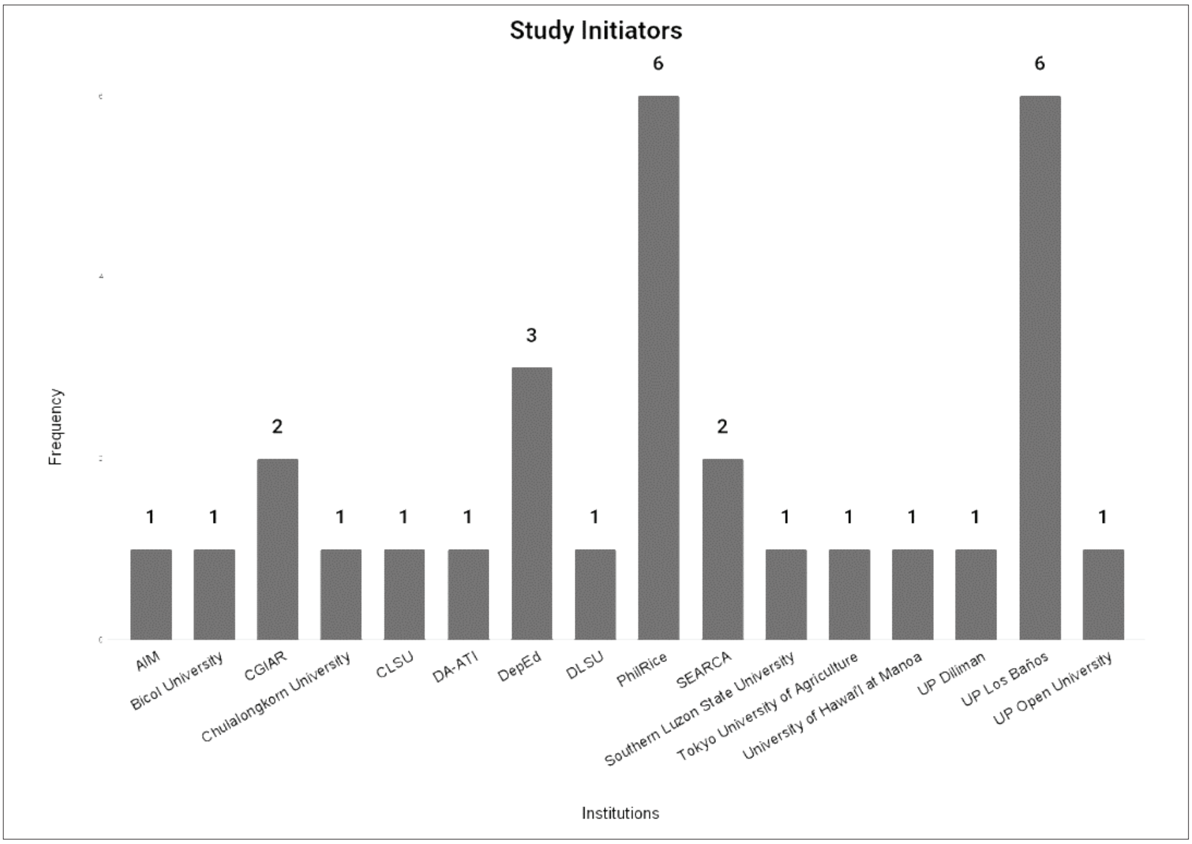

Figure 2. Initiators of studies on youth in agriculture in the Philippines.

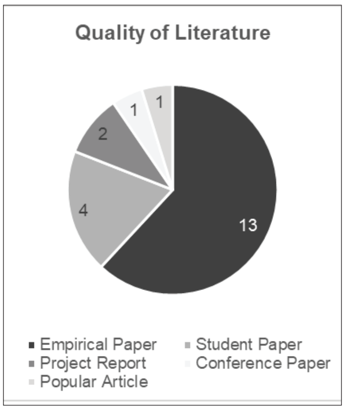

Figure 3. Literature type.

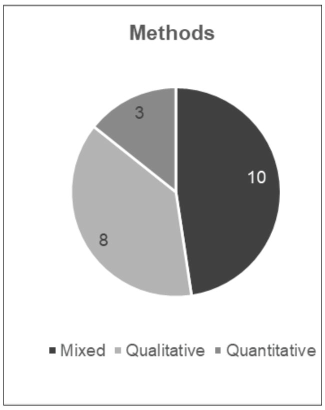

Figure 4. Research methods used in the literature.

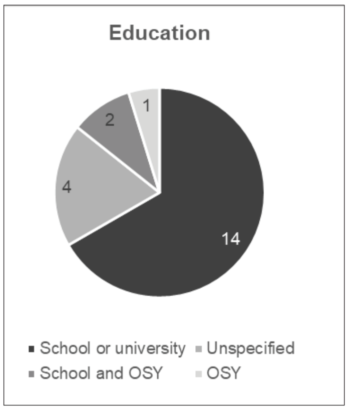

Figure 5. Research focus based on education.

The factors affecting the judgment of youth whether to stay or stray from agriculture relate to employment, education, three states of perception, and culture (Table 2). The factors for staying provide evidence of effective efforts that work for the youth at present. At a glance, it can be observed that four of the six aspects, namely employment, status of agriculture, status of agricultural producers, and culture, are the least balanced with factors that might encourage the youth to stay. The engagement efforts are observably centered on education and addressing youth perception. Agriculture is being advocated as a career choice. Examining the youth's state of perception, the four aspects capture what they hope to be addressed so that they may respond to the invitation to take an interest in agriculture and become the next generation of farmers.

One interpretation of the data is that the youth are not disengaged from agriculture as generally perceived. Rather, they cannot appreciate agriculture because they interact with it at a distance. They are sensitive to public statistics and perceive that the sector is underinvested, receiving inadequate support

Table 2. Factors for staying in or straying from agriculture based on the 21 reviewed articles.

Engagement Aspects	Year Detected	Factors for Straying	Factors for Staying
Employment	2000-2010	▪ Aging population ▪ Engagement to agriculture is due to lack of resources ▪ Underemployment	
	2011-2021	▪ Decreasing new farmers and fisherfolk ▪ Limited opportunities ▪ Low board passing rate ▪ Lucrative opportunities in non-agricultural careers ▪ Male-dominated career	▪ OSY-inclusive skills and capacity development
Education	2000-2010	▪ Smaller proportion to AFF to non-AFF enrollees ▪ Lack of career counseling, informational services, and network	
	2011-2021	▪ Advocacy-based curricula due to lack of policy guidelines ▪ AFF-allied fields reformed into independent disciplines ▪ Low priority on curriculum revision ▪ Politicized scholarship grants ▪ Underinvested institutions as indicated by old facilities	▪ Agripreneurship programs and scholarships ▪ Complementing alliance of AFF and non-AFF programs ▪ Learning gardens in schools as stimulants of children's interest ▪ First-hand agricultural activities and exposure programs ▪ Membership in youth groups with agriculture-related advocacies ▪ Openness of school administrators to curriculum enhancement ▪ RA 10618 Rural Farm School Act ▪ Technical, cognitive, and entrepreneurial skills development
Status of agriculture	2000-2010	▪ Low productivity Limited diversification ▪ Lags in research spending ▪ Scant support for research and development ▪ Uncompetitive wages	
	2011-2021	▪ Decreasing arable land ▪ Decreasing labor ▪ Decreased share in Philippine GDP and government funding ▪ High climate risk ▪ Limited infrastructure, social amenities, and technical support ▪ Inconsistencies in the GVA and labor productivity growth rates ▪ Perceived as an insecure and vulnerable rural occupation ▪ Underutilized research from higher education institutions ▪ Vulnerable to climate shocks	▪ Food and economic security need during the COVID-19 pandemic ▪ Sector resilience during the COVID-19 pandemic

Engagement Aspects	Year Detected	Factors for Straying	Factors for Staying
Status of agricultural producers	2011-2021	▪ Aging ▪ Economically marginalized, i.e. low wages and few support services ▪ Landless ▪ Less schooled ▪ Limited execution of modern farming methods	
Status of youth	2000-2010	▪ Outmigration for employment	
	2011-2021	▪ Agriculture learning is through secondary and tertiary sources ▪ Extant plans on pursuing non-agriculture careers ▪ Income from agriculture is not sufficient ▪ Lack of access to resources e.g. land and capital ▪ Lack of participation in governance and decision-making platforms ▪ Lack of rural youth groups ▪ Lack of time and motivation ▪ Limited entrepreneurship knowledge ▪ Low exposure to non-production aspects of agriculture ▪ Non-agriculture aligned education ▪ Not keen on being farmers like parents ▪ Outmigration for employment as a global trend ▪ Working youth comfortable with their non-agricultural profession	▪ Access to resources, education, and opportunities ▪ Active local community involvement in agricultural projects ▪ Advocacy for community and environmental health and wellness ▪ Appreciation for food security frontliners ▪ ATI's adopt-a-farm-youth-program ▪ Availability of infrastructure, social amenities, and technical support ▪ Care for parents' learning ▪ Communicating to and with the youth ▪ Determination ▪ DIY agriculture promoted through vlogging in social media ▪ Farmer-trainer role ▪ First-hand learning, e.g. visitation to agricultural techno-research centers ▪ Gardening as a mental health coping strategy ▪ ICT/IT-applied agricultural projects ▪ Opportunity to serve as infomediaries ▪ Participation in policy and decision-making platforms ▪ SEARCA's #Y4AGRI initiative ▪ Support of family
Culture	2011-2021	▪ Farmer parents encourage college degree for stable employment ▪ Low political will on addressing issues ▪ Mindset that agriculture is farming only ▪ Outmigration from agriculture ▪ Parents discourage children from engaging in agriculture ▪ Perception that agriculture is a poor man's job ▪ Poor general access to internet for digital shift in agriculture ▪ Rapid urbanization of rural areas	▪ Educating parents and community through engagement programs ▪ Farmer-first movement ▪ Mainstreaming of DIY agriculture during the COVID-19 pandemic ▪ Next in line to the management of family business and land

and rewards for all its contributions. Additionally, literature provides evidence that living in agricultural areas, awareness of agricultural production, and belonging to a household of agricultural producers do not automatically put the youth in a position of action or investment in agriculture (Coronacion, 2015; Gaboy et al., 2021). Based on the identified points under "stray" as affected by culture, it can be discerned that much of cultural opinion stems from a production understanding of agriculture and not an entire value chain. Yet because the youth lack exposure, they engage passively towards agriculture.

Recent statistics on wage rates in the Philippines report that a farmer worker earns around PhP350 (USD6.2) a day or roughly PhP10,500 (USD186.3) a month (PSA, 2020) — a reckoning classified as below the 2018 poverty threshold estimated at PhP10,727 (USD190.3) (PSA, 2019). Indeed, a repugnant return for spending full days under the heat of the sun and doing much risk-bearing and back-breaking work to produce food (Secretario, 2021). In a study on agriculture employment opportunities in Davao, the wage statistics were also found to be low (Lumen, 2020). It is not surprising then that even the AFF professionals themselves (including farmers) would discourage their children or other youth from engaging in agriculture (Clemente, 2014; Gaboy et al., 2021; Secretario, 2021). On a societal level, this depiction of agricultural producers causes a societal low regard for farming. This is also institutionalized by national primary education modules showing farming as a second-class profession that is indeed as anti-beauty, manual, and traditional. In Lumen's (2020) study, it was found that the respondents agreed with the statement: "Public perception of the agricultural profession as a poor man's job is true." Other factors that the respondents of Lumen's (2020) study agreed with include "agriculture is susceptible to undesirable climate conditions." Manalo and van de Fliert (2013) elucidated these climate risks in their study on the push and pull factors that affect rural Filipino youth's outmigration, stating that destructive natural events indeed sometimes result in total crop failure, fear, and even death. Lumen's respondents also reported that "there were many readily available and accessible non-agricultural opportunities."

While the state of agriculture may seem discouraging with noncompetitive wages, high risks, and low contribution to the Philippine economy relative to other sectors, the youth balanced these with determining other benefits that add to their personal development and to community development, often manifested by improved infrastructure, social amenities, and technical support (Lumen, 2020). Empirical evidence shows that when the youth are given first-hand opportunities to engage in agriculture, their negative perception on agriculture shifts to a positive mindset. Examples of these are visiting agricultural technology and research centers, participating in agriculture-related camps, giving them roles such as being infomediaries and being farmer trainers, involving them in producing their own food, and providing familiar avenues for them to channel their agricultural knowledge such as IT-applied agricultural projects and vlogging. As such, it can be said that the chance is high that young people are likely to stay well within the agriculture sector if their issues with it are being addressed.

Youth engagement strategies

Advocacy is the crux of the messaging of reviving the youth's interest in agriculture; hence, the need to present to the youth a deeper purpose to agriculture than taking over the work of the retirement-qualified farmers. This is evident in the way agriculture is often portrayed as the opposite of what the youth and society generally consider it to be. Analyzing the literature, we identified three main ways that agriculture was packaged to align with the advocacies that young people take interest in.

Package 1: Agriculture is the solution to achieving food security (Calub et al., 2019; Pasiona et al., 2021; Guerrero et al., 2021). It is not entirely the anti-glam that the youth consider it to be. It has modernized and mechanized work processes and it is conducive to becoming a lucrative business career via the agripreneurship path. Usual descriptions include that of a millionaire farmer or an ultra-successful agripreneur.

Package 2: Agriculture is pro-health. It promotes health awareness for the family and for the self through school programs such as vegetable gardening. For example, the beneficiary students and families of the DepEd and SEARCA's School-Plus-Home Gardens Project (S+HGP) observed improved nutrition when they participated in the program and produced their own food (Calub et al., 2019).

Package 3: Agriculture is a community-building and economy-boosting endeavor. The youth could be ambassadors of campaigns that are pro-environment and support local (Coronacion, 2015; Pasiona, 2021). Typical examples include school gardening, community gardening, sustainable food production.

The engagement efforts reflected in Table 2 are summarized in Figure 6. Based on the reviewed literature, we observe that most strategies are towards sensitizing the youth on agricultural education and employment prospects beyond farming. These are achieved by conducting exposure activities, promoting agripreneurship degree tracks, and carrying out skills and capacity development. At the policy level, there are scholarship programs for agriculture and fisheries students.

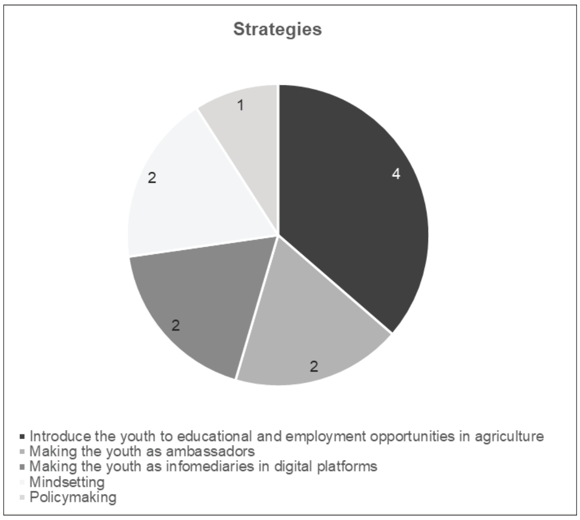

Figure 6. Youth engagement strategies.

To this end, the strategies appear to be responsive to pressing concerns on access to resources and limited knowledge on the career opportunities in agriculture. However, these do not address the remaining of the youth's concerns on employment, the flat inclusion of out-of-school youth in development plans, the status of agriculture in the country, and the low cultural regard for the profession. For the implementers of education, their concerns on the lack of policy implementation guidelines also remain unresolved. Moreover, while there are advocacy packages in place to which the youth are receptive, the strategies do not provide clear blueprints on the ways these advocacies help in addressing the rest of their concerns.

Examining the factors for straying in Table 2 and the identified strategies in Figure 6, it appears that the youth have issues on the capacity of the agriculture sector to provide adequate monetary compensation that meets their basic needs. This is despite the knowledge that there are ways for agriculture to be a decent career through entrepreneurial opportunities (Gaboy et al., 2021). As such, it can be said that there is a mismatch between the focus of engagement strategies and the factors awaiting to be addressed. There is a chance that this mismatch may pose a risk towards the desire to engage the youth in agriculture if not revisited and strengthened. It is likely that in the next decades, the same issues will be reported because they have yet to be adequately addressed from the outset.

The literature presents numerous opportunities that can help advance the agricultural agenda with the youth. However, many of these have remained as opportunities in the past decade and require further research for action. On employment, Macaranas (2016) presented that food security is part of the Philippine Development Plan, and that there is projected increase in the demand for sustainable, nutritious, and safe agricultural products. Lai (2016) provided initial information on how the out-of-school youth might also be engaged, aside from the schooled youth; establishing empirical evidence that they have potential for entrepreneurship. On the aspect of education, the DepEd had already explored the inclusion of agriculture in the K-12 curriculum (Lumen, 2020). The literature also suggests that non-agriculture students can be agriculture advocates, and that the alliance of AFF programs and non-AFF programs was beneficial in building the image of agriculture as a multi-relevant discipline. Several policies can also significantly increase the investment on youth including the *Youth Entrepreneurship Act* and the *Young Farmers Program Act*.

For these matters, the strategy of meeting the youth where they are at is salient. It already engages the youth in agriculture without the need for curriculum or the vision of making it their career. Being tech-savvy netizens, several projects tapped the youth to partake in agricultural work as infomediaries or information mediators. The Infomediary Campaign of PhilRice was one such project where the student-participants bridged to their immediate families the agricultural advisories they received through short message service (SMS) (Manalo et al., 2015B, 2019). There is also the #Y4AGRI campaign of the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) where the youth entered an agricultural vlogging contest (Pasiona et al., 2021). The vlog platform allows the youth to engage experts and all types of audiences (Pamplona, 2020). These examples make youth engagement widely inclusive.

On improving the state of agriculture, the insights from the study of Lai (2016) suggest that massive promotions and subsidies by credit and financial agencies will address concerns on limited access to resources. Moreover, there is a suggestion for communication experts to generate interest in the public concern for agriculture (Macaranas, 2016). Research studies lodged at the undergraduate may also be further investigated so that they do not remain underutilized (Gaboy et al., 2021). Developing different policies for different types of farmers is also seen as a potential stay factor. On the state of youth perception on agriculture and the cultural stigma surrounding the discipline, there is a call towards recognizing that the youth are not totally uninterested in farming and that they perceive that agriculture is a noble job. In addition to the youth, their families and immediate communities should be provided with more opportunities to participate in agricultural and agriculture-related activities. This approach aims to dispel the perception that agriculture is solely about farming. Firm advocacies and adequate reinforcement that build on existing policies such as the *Magna Carta of Young Farmers*, the *Youth in Nation-Building Act*, and the *Young Farmers and Fisherfolk Challenge Act* are seen as enablers of more positive mindsets that can encourage the youth to stay.

Youth engagement initiatives

As projects centered on youth engagement are seldom documented in scholarly articles, we have taken the initiative to explore gray literature sources such as news articles, project reports, and similar resources, to gain insights into actual initiatives and projects. This approach allows us to gain a broader perspective in identifying youth and agriculture initiatives in the country.

Most of the initiatives we found are not focused on a single area and are implemented nationwide. However, for those initiatives where areas were specified, we find Mindanao to be targeted more than Luzon or Visayas as shown in Figure 7. Lai (2016) explained that the region is noted for its particular vulnerability of the youth to unemployment due to inequality in resource access. This observation also helps explain the conspicuous presence of employment generation initiatives in the area such as the University Partnership Linking Out-of-School Youth to Agri-Entrepreneurship and Development

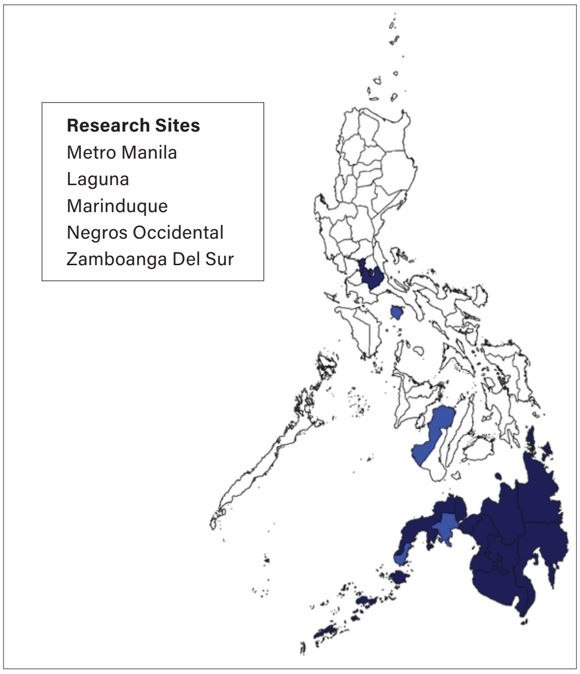

Figure 7. Intervention sites based on reviewed gray literature.

to promote Job Opportunities and Business Scale-up (UPLOAD JOBS) program of the United States Agency for International Development (USAID).

The initiatives that we found are initiated usually by the government, with a smaller number initiated by local and international nonprofit organizations. This implies the role of the government as the primary initiator for youth engagement in agriculture. From our compiled list of initiatives from the articles reviewed and supplemented with gray literature, we find 43 out of 65 to be initiated by the government as shown in Figure 8. Some of the NGO- and INGO-initiated initiatives include the Kaneshige Farm-Rural Campus Foundation (KFRC), Good Food Co. (GFC), Zagana, UPLOAD JOBS, The Scarecrow PH, 4-H Club of the Philippines, and For our Farmers PH, Inc.

We identified nine types of initiatives on youth and agriculture. The top three most popular initiatives are: (1) organizations that are formed by, for, or involving youth in agriculture; (2) financial assistance such as grants and scholarships; and (3) training or skills development programs (Figure 9).

The organizations from our list work on disaster and relief assistance for farmers affected by the COVID-19 situation; opening opportunities for agricultural innovation and policy making; youth empowerment; and community development (Figure 10).

The National Association of Community Development Extension Professionals (NACDEP) defines community development as "a discipline that promotes participative democracy, sustainable

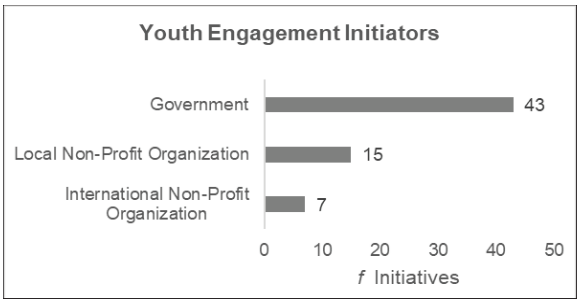

Figure 8. Initiators of youth engagement in agriculture projects.

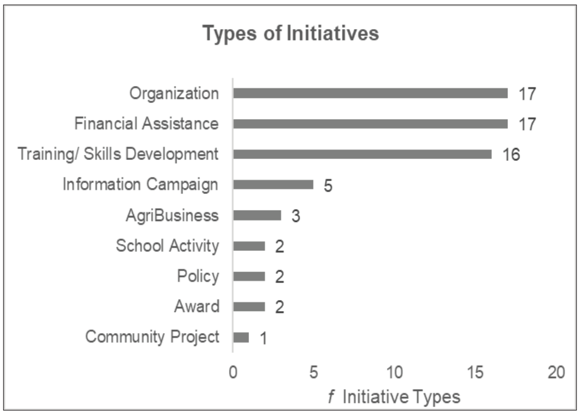

Figure 9. Interventions for the youth.

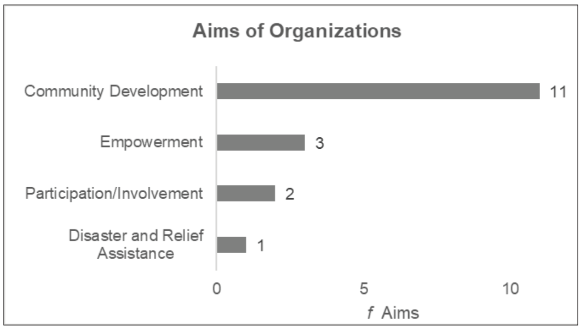

Figure 10. Aims of organizations.

development, rights, equality, economic opportunity, and social justice, through the organization, education, and empowerment of people within their communities, whether these be of locality, identity or interest, in urban and rural settings" (n.d.). Community development, which is the most common aim of the organizations in our list, is manifested through improving the relationships between local community members and people in positions of power. The Organization for Industrial, Spiritual and Cultural Advancement (OISCA) in Lucban, the Pag-Asa Youth Farmers Association (PAYFA), The Student Technologists and Entrepreneurs of the Philippines (STEP), and The Young Professionals for Agricultural Development (YPARD) are some of the organizations working in the area of community development. They engage various groups of the community through activities such as technology sharing to out-of-school youth; mangrove planting activities involving ethnic groups; and opening of international discussion platforms for agricultural development for the youth. On our list, the majority of financial assistance are scholarships (Figure 11). Examples of these are the Agricultural Competitiveness Enhancement Fund (ACEF) Scholarship Program, and the Commission on Higher Education Student Financial Assistance Program (CHED-StuFAP). Empowerment is a broad goal that could focus through aspects of individual, gender, social, educational, economic, political, psychological, physical, educational, and economic aspects. Santosa (2014) describes it as a "continuum"; a process of transformation requiring holistic participation of the society and changes in all societal elements. In our review, we found that organizations for youth in agriculture aim to empower in two aspects: educational and economic. They are empowered by the provision of high-quality educational resources and of solutions to financial barriers with mentoring through entrepreneurship.

Most of the financial assistance offered for the youth in agriculture are provided by the government (Table 3). These are consistent with the earlier findings that most of the interventions were government-initiated and education-oriented.

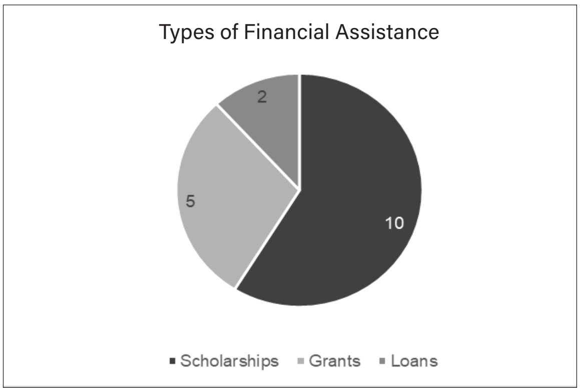

Figure 11. Types of financial assistance.

Initiatives that focus on training and skills development offer a combination of skills to impart in their program covering the following skill areas: communication, analytical, management, technological, problem solving, and organizational (Figure 12). Examples of these initiatives include exposure interventions, seminars for high school students, and internship programs like the DA-Management Internship Program, UPLOAD JOBS, Young Entrepreneurs from School to Agriculture Program (YESAP), Young Filipino Farm Leaders Training Program in Japan, and the Young Southeast Asian Leaders Initiative (YSEALI). Consistent with the discussion with respect to factors for staying in agriculture, capacity development helps the youth see agriculture beyond food production in the farm. They become exposed to the possibilities of AFF and non-AFF program alliances as well, which can translate to more diversified agriculture-related research studies, funding, agripreneurial opportunities, and career paths. It should be noted, however, that among the youth's concerns are the lack of capital resources. Hence, these capacity development initiatives may be boosted with increased financial assistance post-programs and especially post-agripreneurship programs. This may also help address the challenges on underemployment and enable the youth to perceive that the encouraged engagement in agriculture is supported beyond schooling.

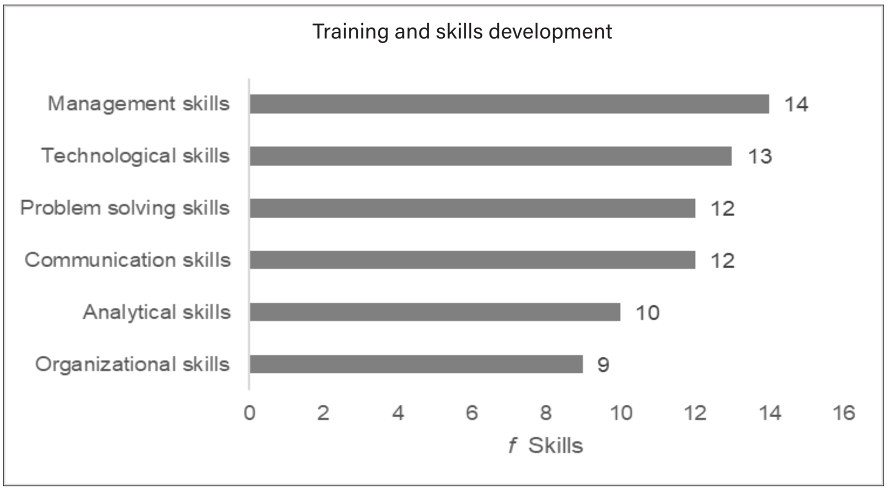

Figure 12. Training and skills development.

Table 3. Financial assistance benefactors and beneficiaries.

Financial Assistance	Benefactor	Beneficiaries
"*Kabataang Agribiz* Grant Assistance Program"	Government – Department of Agriculture	Young agripreneurs
Agri-Negosyo	Government – Department of Agriculture	Filipino farmers' cooperatives, associations, and young agripreneurs
Agricultural Technology Business Incubation (ATBI) program	Government – Department of Agriculture	Filipino millennials and agripreneurs
Cropital	Private investors	Smallholder farmers
Micro and Small Entrepreneurship Loan Program (MSELP)	Government – Department of Agriculture	Filipino millennials
P1B Kapital Access for Young Agripreneurs (KAYA)	Government – Department of Agriculture	Young agripreneurs
Young Agripreneurs Loan Program (YALP)	Government – Department of Agriculture	Young agripreneurs

Conclusion

This review delved into published and gray literature from the past decade regarding youth involvement in Philippine agriculture. This examination is essential as it serves as a crucial step toward formulating impactful policies by assessing the current state of youth engagement in agriculture. To the best of our knowledge, there has not been a comprehensive review on youth and agriculture encompassing academic scholarship and gray literature in decades, not only in the Philippines but also in Southeast Asia**.**

There are four major findings that we wish to highlight. First, the decision to stay or stray away from agriculture is complex. Based on our review, the chance is high that young people may stay well within the sector if their issues with it such as employment and income will be addressed. Second, and perhaps the most important finding, is that there is a mismatch between the current youth engagement in agriculture strategies and the reasons for straying away from the sector. This mismatch is likely to result in disastrous consequences given that there are major issues such as the cultural perceptions on agriculture that are not really being addressed. Three key advocacies appeal to young people: food security, health and wellness, and community building. Third, there are many youth engagement initiatives in the country that have been reported from 2011 to 2021. Mindanao appears to be the favored site of intervention, and the government is the main initiator of youth and agriculture initiatives with programs spanning from scholarships to community development initiatives. Fourth, in terms of scholarly contributions, mixed methods seem to be the dominant approach, which optimizes insights from both the qualitative and quantitative traditions of research. PhilRice and UPLB are the top institutions producing knowledge on youth and agriculture in the country. The out-of-school youth is underrepresented in the literature.

Drawing on the findings of this research, we are inclined to advance the following research questions to guide future inquiries relating to youth engagement in agriculture:

1. What other types of interventions must be put in place to ensure that the issues surrounding youth in agriculture are adequately addressed?
2. How can interventions by the public and private sector alike be sustained?
3. What other methods can be explored to properly investigate the issue on youth and agriculture?
4. How can we increase the number of players– both in scholarly discourse and actual interventions– in this area?
5. What are the policy imperatives on youth and agriculture?
6. What are other forms of youth empowerment and how can these be appropriated in engaging youth in agriculture?
7. How can we move beyond agripreneurship so we are able to tackle other forms of youth empowerment?
8. What do we know about youth and agriculture in the context of our ethnic minorities?
9. Most reviewed literature tackled youth and agriculture from the perspective of the researcher or the donor – What does youth and agriculture mean to young people themselves?
10. What else do we not know about youth and agriculture from the perspective of the OSY?
11. How can we increase our presence (in terms of research and actual interventions) in the underserved parts of the country?

It is hoped that these questions would be able to shed more light on the discourses surrounding youth engagement in agriculture. By advancing these questions, we are one with the scholars working in the area of community youth development in arguing that indeed young people are assets that must be mobilized, not problems that must be solved.

Acknowledgment

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TECHNICAL PERFORMANCE AND ECONOMIC EVALUATION OF A LOCALLY DEVELOPED TRACTOR-DRAWN RICE STRAW ROUND BALER

Elmer G. Bautista* and Virsus L. Galdonez

Rice Engineering and Mechanization Division, Philippine Rice Research Institute
*Corresponding Author: egbautista@exchange.philrice.gov.ph

Abstract

In the Philippines, rice straw is often viewed as waste. This by-product of rice production has yet to be fully utilized due to the labor-intensive process of collection, particularly with the prevalent use of combine harvesters. These machines have made the collection of loose straws more problematic. Faced with these challenges, many farmers choose to either burn the rice straws in the field or incorporate them into the soil during land preparation. However, rice straws could be valuable if used for mushroom cultivation, as feedstock for cows and carabaos, and for energy production, as suggested by various global studies. The use of mechanized options such as a rice straw baler can make the process more efficient and improve the handling and transportation of rice straw. To reduce labor costs and increase capacity in straw collection, a locally developed rice straw round baler was fabricated in partnership with a local manufacturer. This was based on STAR MRB0850B, an imported round rice straw baler available in the market. The technical performance and economic aspects of the locally developed baler were evaluated under actual field conditions to determine its competitiveness with STAR MRB0850B. Field-testing data on actual field capacity, fuel consumption, labor requirement, and other cost items were collected. The actual field capacity is 0.3 ha/h or 2.39 ha/day with a bailing rate of 0.39 t/h. The cost of baling rice straw using this machine is PhP1,278.2 per ton (US$ 22.7 per ton) while STAR MRB0850B's cost per ton is US$110.64 (PhP6,629) per ton with the same days of operation per year. The locally fabricated rice straw baler will be financially feasible at a service fee of PhP3/kg when operated 60 days per year. A farmers' group could adopt the localized baler for custom service provisions, which can earn a minimum PhP50,000 per year income at 60 operation days per year.

Keywords: *Locally developed baler, Rice straw collection, Technical and economic evaluation*

Introduction

The Philippines annually produces a significant quantity of rice straws, estimated to be around 18 million tons (Mt), which is equivalent to the country's grain production. However, this biomass is largely considered waste in many parts of the country. Many farmers dispose of their rice straw through open field burning, a practice that negatively impacts human health and the environment. Rice stubbles, or the straw left in the field, are often left to decompose and are incorporated into the soil during the first plowing for the subsequent rice crop.

Open-field burning has become a common method of straw management (Launio et al., 2014), prompting stakeholders to address the issue. While incorporation returns nutrients to the soil and improves its condition (Liu et al., 2014), it significantly contributes to methane emissions from rice production, negatively impacting the climate (Conrad, 2007). This leads to increased carbon footprints, environmental constraints, and poor rice straw management practices compared to rice straw burning (Bautista and Saito, 2015). However, other studies have found these emissions to be overestimated (Jiang et al., 2019).

Rice straw can also be used as a soil ameliorant to improve soil or as feed for livestock (Shara et al., 2017) where it is considered a major feedstock (Kadam et al., 2000). In the Philippines, it can be used as mulching material in onion production (November-March), and as a medium to grow mushrooms (Gadde et al., 2009). A study by Suramaythangkoor and Gheewala (2008) using life cycle assessment to evaluate the potential of rice straw power plant implementation in Thailand concluded that a rice straw power plant could be a high potential alternative for electricity generation as well as an incentive for utilization instead of field burning.

In Vietnam, outdoor rice straw mushroom (RSM) growing is a traditional practice with low investment costs but generates low yield and incurs a high risk as it is strongly affected by changes in weather. However, indoor RSM growing has higher investment costs but greater productivity and lower risks due to its environment being well controlled (Thuc et al., 2020).

In Nueva Ecija, carabao owners were seen collecting rice straws for feeds, and others were buying it on a per bag or stockpile basis (Figure 1[2]). The demand for rice straw is increasing nowadays, making it an additional source of farmers' income.

Figure 1. Rice straws are incorporated in the field during land preparation and are used as animal feedstock.

Farmers traditionally collect rice straw manually using rakes and transport it in sacks. This method is labor-intensive and results in higher costs. The widespread use of combine harvesters in recent years has made the collection of loose straws even more challenging. According to Balingbing et al. (2020a), manual rice straw collection on combined harvested crops is laborious and tedious, requiring about 17 people to collect from an area of one hectare in a single day. Figure 2 illustrates the current situation of rice straw burning in the Philippines.

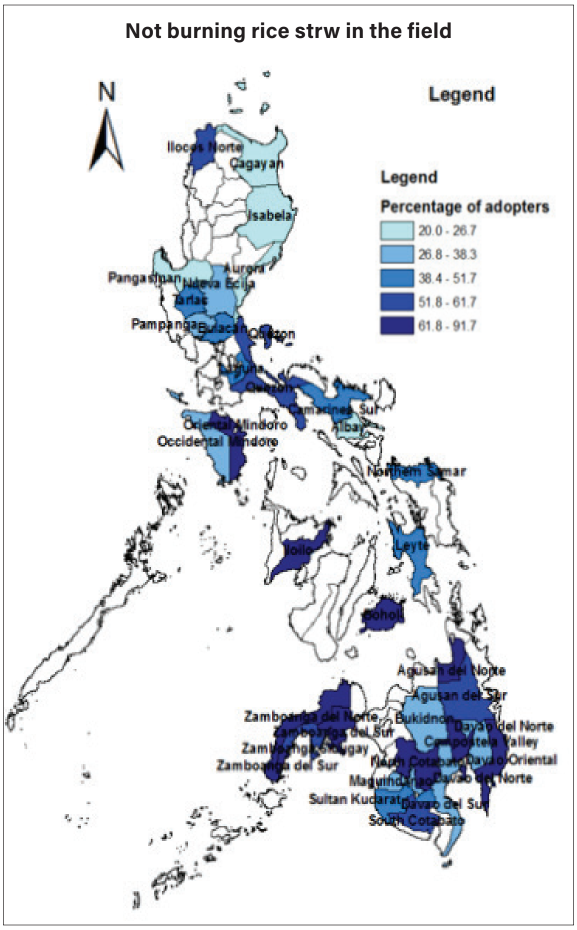

Figure 2. Rice straw burning in the Philippines (Philippine Statistics Authority).

Mechanized options such as a baler make the process more efficient, requiring only one or two skilled individuals to operate the machine. The duration of rice straw gathering is reduced by 1 - 4 h per unit hectare depending on the size and capacity of the baling machine used. Mechanized rice straw collection has become essential to increase capacity and reduce transportation costs. Baling machines can collect and compact rice straw in various forms. Compacted rice straw, compared to loose rice straw, has a lower weight-to-volume ratio of about 50 - 100%, significantly decreasing the cost of handling and transportation (Balingbing et al., 2020a).

The RiceStrawPH project, funded by the Department of Agriculture-Bureau of Agricultural Research (DA-BAR) in 2017, conducted several demonstrations of rice straw balers throughout the Philippines. This sparked interest among farmers in rice straw collection for animal feeds and rice straw mushroom production (Figure 3). This demand led to the development of a locally fabricated baler to minimize repair and maintenance issues and reduce initial investment costs.

As part of the project, a locally fabricated rice straw round baler was developed in collaboration with AgriComp Corporation, a local manufacturer in Isabela. The principle of operation for the locally fabricated rice straw round baler was based on an imported round baler, STAR MRB 0850B. This is a tractor-mounted baler powered by a PTO and uses sets of rollers to compress rice straws into bales, which are then ejected using an independent hydraulic system. The baler needs to stop to tie the bale with twine and eject the bale.

The locally fabricated baler is composed of around 80% local parts, utilizing available materials and the fabrication capability of a local manufacturer (Figure 4). The imported round baler, STAR MRB 0850B (Figure 5 [2]), available in the market, was reverse-engineered (Figure 5[1]). The aim was to localize all

Figure 3. The rice straw baler is demonstrated to farmers in Isabela, Philippines.

Figure 4. Fabrication of localized rice straw baler by AgriComp: (1) the fabricated mainframes, (2) metal springs, and (3) bearings and hydraulic system.

Figure 5. The localized rice straw baler (1) and STAR MRB0850B round baler (2).

parts completely, but manufacturing limitations were encountered, leaving some parts such as hydraulic systems, plastics, and spring metals still in place. The main body, bearings, rollers, metal covers, tires, bolts, nuts, chains, and sprockets were locally fabricated.

Balingbing et al., 2020b tested the technical and economic performance of STAR MRB0850B at the IRRI Zeigler Experiment Station in Los Baños, Laguna. The results of their study served as a benchmark for assessing the technical and economic performance of the machine.

This study evaluated the technical performance and economic aspects of the locally developed baler under actual field conditions. It further assessed if this local machine can compete with STAR MRB0850B in terms of technical and economic performance. Furthermore, it verified whether using this locally developed baler could be economically viable for farmers providing services.

Materials and Methods

The new round rice straw baler, a localized version of the imported MRB0850B, was fabricated using materials and techniques available to our local manufacturer.

The localized rice straw baler has the following specifications:

- overall dimension: 115 cm long x 130 cm wide x 120 cm
- 330 kg weight
- tire size: 16 x 6.50 x 8 x 4 ply rating
- 80 - 120 bales per hour under optimum field conditions
- picking width: 80 cm
- bale size: 50 cm diameter, 70 cm long, and 14 - 16 kg weight
- power source: 4W Tractor (20 - 50 hp) with match PTO speed of 540 - 600 rpm

Figure 6. The localized rice straw baler and the baled rice straw.

Details of the STAR MRB0850B round baler include the following:

- overall dimension: 115 cm long x 130 cm wide x 120 cm
- 390 kg weight
- tire size: 16 x 6.50 x 8 x 4 ply rating
- 80 - 120 bales per hour
- picking width: 80 cm
- bale size: 50 cm diameter, 70 cm long
- power source: 4W Tractor (18-50 hp) with PTO speed of 540 rpm

Site Description

The field tests were conducted at the Rice Engineering and Mechanization Division (REMD) model farm at the Philippine Rice Research Institute (PhilRice) in Science City of Muñoz, Nueva Ecija. The GPS coordinates for this location are Latitude 15.675491 and Longitude 120.864332. The testing was carried out on three field plots with areas of 2,379 m², 2,175 m², and 2,018 m² in April 2022 during the dry season harvest. The rice variety planted on all plots was NSIC Rc 222, and the fields were harvested by a combine harvester, leaving the rice straw scattered. The actual test was conducted three days after combine harvesting to allow the rice straw to dry and be suitable for baling.

Figure 7. The MRB0850B round baler and the baled rice straw.

Data Gathering

The locally developed rice straw baler was powered and drawn by a four-wheel drive (4WD) tractor (Figure 5 [1]). During the actual field tests, the 4WD tractor with the attached rice straw baler moved along the scattered rice straws, which were left in the path of the combine harvester during harvesting. The operation time started when the rice straw baler began to collect rice straws and ended when the baled rice straws were released from the machine.

During baling, the rake-like fingers at the front of the baler collected the rice straws and lifted them to a roller. The roller then combined all these rice straws until a firm bale was produced (Figure 8). A busher sound was produced when sufficient hardness was attained, signaling the operator to release the bale. A rope was then pulled to open the door, and the baled rice straw came out of the baler.

For each field plot, the baling time (in minutes) was recorded from the start of operation until all scattered rice straws were collected. The number of bales was counted, collected, and weighed (Figure 8). The average stubble height was measured using a meter stick by randomly measuring nine stubbles for each plot. The fuel consumed on each field plot was also recorded using the full tank method. The average of the data gathered (baling time, number of bales, weight of bales) on all plots was used to calculate the actual field capacity (AFC) of the rice straw baler and rice straw yield (Nguyen et al., 2015).

Rice straw yield varies depending on the rice variety planted, paddy yield, and the stubble cutting height during harvesting. The average rice straw yield of the field was first evaluated at 1.347 t/ha or an approximated 103 bales/ha. The variety planted was NSIC Rc 222 with an average stubble height of 34.4 cm.

Figure 8. Counting and weighing bales; (1) baled rice straw, (2) weighing rice straw.

The cost of the rice straw baling operation was calculated considering factors such as the depreciation of the machine, maintenance, sheltering, interest rate, fuel consumption, manpower, twine, and baler's AFC.

1. Total cost = IC + RM +S +Int +fuel cost + labor cost + CT

   Where: IC – acquisition cost of machine
   RM - cost of maintenance
   S - cost of shelter
   int - interest on investment
   FC - fuel cost
   Labor costs - cost for labor
   CT - cost of twine

Internal rate of return (IRR), benefit-cost ratio (BCR), and payback period (PP) were the parameters considered in deciding the financial profitability of the locally developed rice straw baler.

2. BCR = B/C

   Where: BCR - benefit-cost ratio
   B - income generated during baling
   C - cost of operation

3. IRR = ((CF)/(1+i)^t) - IC

   Where: IRR - Internal Rate of Return-benefit-cost ratio
   CF - cash flow in the time period
   IC - Investment cost
   i - discount rate
   t - time period

4. PP = IC/ACF

   Where: PP - payback period
   IC - investment cost
   ACF - annual cash inflow

Results and Discussion

Technical evaluation

The baler's AFCwas determined to be 0.3 ha/h or 2.39 ha/day (Table 1) with a baling rate of 0.39 t/h of scattered rice straw collected. In comparison, Balingbing et al., 2020b found that the imported baler (STAR MRB0850B) had an AFC of 0.38 ha/h and a baling rate of 0.28 t/h. Although the localized baler has a slightly lower field capacity, it has a higher baling rate. The imported baler's AFC is higher by 26.67%; however, the baling rate of the localized baler is higher by 39.28%.

Each round bale consumed an average of 8 m of twine per bale. The baling operation only required one laborer who was also the tractor operator. The average fuel consumption of the 4W tractor during actual rice straw baling was 3 L/h.

During testing, it was observed that the tractor needed to stop to eject each baled straw, which increased the total baling time per unit area. This observation was also made by Balingbing et al. (2020b) during their field test.

The improved components used locally available materials and the manufacturer's fabrication techniques of the baler performed similarly to the imported machine without any trouble occurring. The throttle of the tractor was also at normal speed and no untoward incidents occurred.

Economic Evaluation

The data gathered from the technical evaluation of the baler's AFC served as the basis for the computation of the economic evaluation. Fixed costs include interest, depreciation, and maintenance, while operating costs include labor, fuel, and twine.

Table 1. Technical results of the testing of locally developed rice straw baler.

Field plot	Area, ha	Number of bales	Average weight of bales, kg	Time, min	Bales /ton	RS yield, kg/ha	Collection time, hr	Actual Field Capacity, ha/h	Baling rate, ton/ hr
1	0.2379	28	14.5	62	69.0	1706.6	1.03	0.23	0.39
2	0.2175	18	13.66	45	73.2	1130.5	0.75	0.29	0.23
3	0.2018	22	11.07	33	90.3	1206.8	0.55	0.37	0.44
Ave.	**0.22**	**22.67**	**13.08**	**46.7**	**77.50**	**1347**	**0.78**	**0.30**	**0.39**

The initial investment cost for the localized rice straw baler was PhP250,000. In contrast, the purchase price of STAR MB0850 is US$ 8,000 (Balingbing et al., 2020b), approximately PhP450,000, which is 1.8 times higher than that of the localized baler. The investment cost for the four-wheel drive (4WD) tractor was not included as it is not solely used for baling operations and can be further optimized for different farm operations. These tractors are assumed to be owned by the farmers, especially the recipients of the Rice Competitiveness Enhancement Fund Mechanization Program.

Rice straw baling operation was assumed to occur over 30 - 60 days per cropping season with two cropping seasons per year, resulting in 60 - 120 days of operation per year.

The investment cost and assumptions used in calculating financial and economic parameters are presented in Table 2. Among the cost items, fuel and twine costs had the largest percentage contribution at 35% and 29%, respectively, and are directly proportional to the AFC of the baling operation (Figure 9). Depreciation and maintenance costs contributed 15% and 5%, respectively (Figure 8).

The locally developed rice straw baler will cost PhP1,278.2 (approximately US$ 22.7) per ton or (PhP1.278/kg) when used in baling scattered rice straw and operating for 60 days per year. In comparison, the cost per ton when operating STAR MB0850, as computed by Balingbing et al., 2020b, amounted to US$110.64 (approximately PhP6,629) per ton with the same number of days of operation per year.

Balingbing et al., 2020b cited Nguyen et al. 2015, who calculated a cost of US$19/t in their study on a similar round baler in Vietnam. Balingbing et al., 2020b attributed the significant difference in cost to the higher field capacity of the unit tested in Vietnam (0.5 ha/h) compared with the unit they tested (0.38 ha/h).

Balingbing et al. (2020a) also noted that their baler twine usage is US$ 12.36 (approximately PhP695) per ton of rice straw bales, which already accounts for 54% of the cost per ton of the locally fabricated baler in this study.

Table 2. Investment cost and assumptions for the locally developed round baler.

Particulars	Cost, PhP
Investment cost (IC), PhP	250,000.00
Sheltering cost, PhP/yr	6,250.00
Useful life, years	6.00
Salvage value, 10% of IC, PhP	25,000.00
Use: days/year	60.00
hours/day	8.00
hours/year	480.00
Field capacity:	
ha/day	2.40
ha/hour	0.30
ha/year	144.00
bales/hour	30.37
tons/ha	1.35
tons/year	194.11
Fuel consumption, liters/h	3.00
Fuel cost (diesel/gasoline), PhP/L	60.00
Number of workers required	1.00
Labor rate for operator, PhP/day	400.00
Repair and maintenance, 5% of IC	12,500.00
Interest on investment	6,875.00
Fixed cost	
Shelter, PhP/year	6,250.00
Depreciation, PhP/year	37,500.00
Interest, PhP/year	6,875.00
Total fixed cost	
PhP/year	50,625.00
PhP/hour	105.47
PhP/bale	3.47
PhP/ton	260.80
Variable cost	
Fuel cost, PhP/year	86,400.00
Oil/lubricant, PhPyear	2,592.00
Repair and maintenance, 5%, PhP/yr	12,500.00
Operator, PhP/year	24,000.00
Twine, PhP/year	72,000.00
Total variable cost	
PhP/year	197,492.00
PhP/hour	411.44
PhP/bale	13.55
PhP/ton	1,017.41
Total bailing cost	
PhP/ton	1,278.22
PhP/year	248,117.00

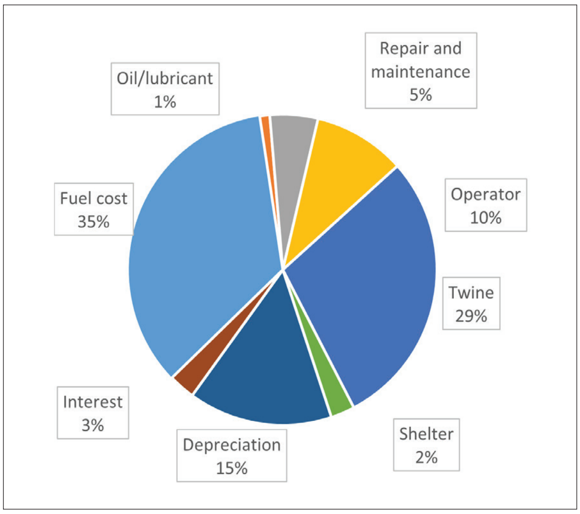

Figure 9. Distribution of cost during rice straw baling PhP/year.

The economic analyses in Table 3 show the financial parameters at different service fees (PhP/kg) and working days (days/year) of baling rice straw. Four service fees and three working days per year were considered in the calculation, 2.8, 3, 3.3, and 3.5 PhP/kg and 60, 90, and 120 days, respectively. It can also be observed in Table 3 that increasing the working days from 60 - 120 days directly affects the computed financial parameters. The benefit-cost ratios (BCR) of service fees of 3-3.5 PhP/kg and 60 - 120 working days were greater than 1, which indicates that baling service by the locally developed rice straw baler will be profitable. IRR also indicates that at PhP3/kg or higher, the lowest IRR value is 26%. The payback period will be 2.9 years when rice straw is marketed at PhP3/kg. Service fee can further be lowered to PhP2.8/kg but working days per year should be more than 60 days. This is lower compared with Vietnam farmers' usage in Mekong Delta who sell their baled rice straw at PhP3.7/kg (The Phnom Penh Post, 2020).

Table 3. Financial parameters at different service fees and working days per year.

Service Fee,PhP/kg	Working Days, days/year	IRR (%)	BCR	Net Profit, PhP/yr	PP, yrs	Cost, PhP/ton
	60	4	0.97	47,279.60	5.29	1278.22
2.80	90	49	1.19	134,044.40	1.87	1169.82
	120	86	1.33	220,809.20	1.13	1115.62
	60	26	1.09	86,102.00	2.90	1278.22
3.00	90	74	1.34	192,278.00	1.30	1169.82
	120	118	1.49	298,454.00	0.84	1115.62
	60	53	1.28	144,335.60	1.73	1278.22
3.30	90	111	1.56	279,628.40	0.89	1169.82
	120	165	1.73	414,921.20	0.60	1115.62
	60	70	1.41	144,335.60	1.36	1278.22
3.50	90	134	1.70	279,628.40	0.74	1169.82
	120	197	1.89	492,566.00	0.51	1115.62

The use of the localized rice straw round baler resulted in a significantly lower cost per ton when collecting scattered rice straw, being 4.8 times less expensive compared to the imported baler. This difference can be attributed to the investment cost of the machine, which is almost double that of the imported baler. Twine cost is also a differentiating factor; the imported baler's twine cost per ton is US$ 12.36, whereas the locally manufactured baler only costs US$ 6.54 (~PhP371) per ton.

Twine cost per bale is directly related to the number of bales per ton. STAR MB0850 produces 130 bales/t at an average weight of 10.8 kg/bale, whereas the locally manufactured baler only produces 77.5 bales/t, at an average weight of 13.1 kg/bale of rice straw. This may be due to differences in the rice variety and larger bales produced.

It can also be observed that the cost per ton for the localized rice straw round baler is similar to that of Nguyen et al's result in 2015.

Conclusion

Improving the design of the imported STAR MB0850 using local materials and local fabrication techniques is indeed possible. This approach significantly lowered the manufacturing cost, even though only 80% of the parts were localized, while maintaining a comparable technical performance in terms of actual field capacity and baling rate of 0.3 ha/h and 0.39 t/h, respectively.

It is recommended that the localized baler be further modified to improve the tying mechanism and ejection process. Currently, the tractor needs to stop when tying and ejecting each baled rice straw. Although this also occurs in the imported model, it increases the baling time per unit area, which decreases the machine's actual field. Improving the release system without stopping will increase the resulting rice straw bales per unit of time.

The cost of baling a ton of scattered rice straw per hour also decreased significantly by 38% in the locally fabricated rice straw baler. This proves that the localized baler will be a more viable option to use compared with STAR MB0850 when baling scattered rice straw as the cost per ton determines the minimum service fee that can be offered while still generating profit. The locally fabricated rice straw baler will be financially feasible at a service fee of PhP3/kg operated 60 days per year. This can still be lowered to PhP2.8/kg but is only feasible when operating more than 60 days per year.

This is a promising technology for a farmers' group to venture into custom services such as straw collection which can earn a substantial income per year. This locally designed rice straw baler could have promising income for farmers in the future as studies on feedstock, mushroom production, and energy utilization of rice straw further progress.

It is recommended to further improve the manufacturing techniques and local materials so that 100% of the baler parts could be localized. Further study can be devoted to further simplifying its tying mechanism to fit the locally produced abaca fiber.

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Central Experiment Station
Maligaya, Science City of Muñoz, 3119 Nueva Ecija

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