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RESPONSE OF PROMISING RICE CSSL IAS66 AND ITS PARENTS UNDER DIFFERENT NITROGEN LEVELS

Nguyen Hong Hanh[1], Pham Van Cuong[1,2]*, Tang Thi Hanh[1] and Nguyen Van Hoan[2]
[1]Faculty of Agronomy, Vietnam National University of Agriculture (VNUA), Vietnam
[2]Center of International Plant Research Vietnam and Japan, VNUA, Vietnam
*Corresponding author: pvcuong@vnua.edu.vn

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ABSTRACT

Pot experiments were conducted on rice to estimate the relationship among dry weight, translocation of non-structural carbohydrates (NSC), and grain yield in IAS66, a chromosome segment substitution line (CSSL) derived from a cross between the *indica* cultivar IR24 and the *japonica* cultivar Asominori, in comparison with its parental cultivars (IR24 and Asominori) under non-nitrogen (N0), normal nitrogen (N1), and high nitrogen (N2) conditions in the spring season 2017 in a greenhouse at the Faculty of Agronomy, Vietnam National University of Agriculture, Vietnam. Increasing the nitrogen level increased the photosynthetic rate in terms of the CO_2 exchange rate (CER) and leaf area, which lead to both greater dry weight and NSC transportation from culms and leaves sheaths (stem) to panicles in all genotypes. However, the rate of increase in dry weight and NSC in the panicles at the maturing stage observed in IAS66 was higher than that in its parental cultivars. As nitrogen increased from the N1 to N2 levels, the grain yield significantly increased because the number of panicles per plant increased, but the other yield components including the number of spikelets per panicle, grain-filling, and 1000-grain weight were not significantly different. Grain yield of IAS66 was 11.4% higher than that of the recurrent parent IR24 at the same high nitrogen levels and the rate of grain yield increase in IAS66 was significant higher than that of its parental cultivars.

Key words: dry weight, non-structural carbohydrates, grain yield, nitrogen use efficiency

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INTRODUCTION

Rice is the staple food grain for more than half of the world's population. It was estimated that the world will have to produce 40% more rice per year, equivalent to 852 million tons, by 2035, indicating that the yield potential of rice will need to increase from 10 to 12.3 tons per hectare to satisfy the growing demand without affecting the resource base adversely (Khush 2013). Crop yield mainly depends on both the formation and translocation of carbohydrates before flowering, and the partitioning of the accumulated assimilates during the grain filling period (Yoshinaga et al. 2013). Additionally, the photosynthesis activity of sources (leaves) and storage ability of the sinks (grains) impacts carbohydrate remobilization from the stem and also affects the final grain weight. Katsura et al. (2007) suggested that the grain yield of rice was affected primarily by large amount of biomass accumulation before heading stage, while Takai et al. (2006) and Tang et al. (2008) reported that grain yield is mainly determined by carbohydrates supplied from photosynthesis after heading and partly by reserve carbohydrates in the culm and leaf-sheaths accumulated before heading stage. Therefore, further studies are required to clarify whether the roles of the reserve carbohydrates and biomass accumulation are different among the genotypes.

Nitrogen plays an important role in increasing photo-assimilates during the ripening period, contributing to the size of the sink by decreasing the number of degenerated spikelets and enhancing the rate of grain filling. Increasing nitrogen application has been shown to increase nitrogen content in leaves which leads to an enhanced photosynthetic capacity and increased dry weight (Mae 1997; Nagata et al. 2001). Thus, it was concluded that the supply level of nitrogen greatly regulates dry weight production and non-structural carbohydrate (NSC) transportation in rice genotypes.

Recently, chromosome segment substitution lines (CSSLs) that cover the whole genome have been constructed in rice and contain target genes that aid molecular marker techniques (Kubo et al. 2002; Ebitani et al. 2005). CSSLs can be used as a good source of genetic material for breeding programs based on the performance of interested traits from donor chromosome segments. Kubo et al. (2002) developed 70 CSSLs in a cross IR24 x Asominori with IR24 genetic background called IAS. Among these lines, IAS66 was shown to be a promising rice line with good phenotypic traits such as having green leaves, thicken roots and long panicle (Nguyen et al. 2017). Therefore, this study was conducted to examine the dry weight (DW), transportation of NSC, and relationship among DW and NSC on the grain yield of IAS66 compared to its parental genotypes under three nitrogen levels. Several physiological characteristics and yield components were identified to learn more about the cause of higher DW and grain yield in IAS66.

MATERIALS AND METHODS

Plant materials. IAS66, a chromosome segment substitution line developed from a cross between IR24 and Asominori at BC_2F_3 (Kubo et al. 2002), was used in this study along with its two parental genotypes. The maternal cultivar, IR24, belongs to the *indica* subspecies, and the paternal cultivar, Asominori (ASO), belongs to the *japonica* subspecies.

Experimental design. The green house experiment was arranged in Randomized Complete Block Design (RCBD). Each genotype was replicated four times and exposed to three nitrogen application levels.

Plant growth and fertilizer application. The pot-experiment was conducted during the spring season from February to June in 2017 in a greenhouse at the Faculty of Agronomy, Vietnam National University of Agriculture, Vietnam. IAS66, IR24, and ASO were sown on different dates (January 17 for IR24, January 22 for IAS66, and January 30 for ASO) in order to synchronize heading times. Thirty-day-old seedlings from wet-bed nurseries were transplanted with one seedling per hill into each pot. All crop management practices were in accordance with standard cultural practices (IRRI, 2002). The plants were grown in the pots and supplied with chemical fertilizer at the treatment rates of non-nitrogen (0 g N pot^{-1}), normal nitrogen (1 g N pot^{-1}), and high nitrogen levels (2 g N pot^{-1}). The amount of fertilizer applied is shown in Table 1. The nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) used in the present study were urea (46% N), super phosphate (16% P_2O_5), and potassium chloride (60% K_2O), respectively. ‘Song Gianh’ micro-organic fertilizer (relative humidity 30%, effective phosphorus 1.5%, organic matter 15% and effective microorganism $1x10^6$CFU g^{-1}) was applied at a rate of 10 g pot^{-1} and a basal dressing of all the chemical fertilizers was applied to the alluvial soil in the $0.03m^2$ pots containing 5.5 kg of soil one day before transplanting. Additional nitrogen was applied during the active tillering and panicle initiation stages (PI). Water, weeds, insects, and diseases were controlled as necessary to avoid yield loss.

Table 1. Rate of fertilizer applications

Nitrogen levels	Nitrogen (g N pot^{-1})				Phosphorus (g P_2O_5 pot^{-1})				Potassium (g K_2O pot^{-1})			
	Basal	Tillering	PI	Total	Basal	Tillering	PI	Total	Basal	Tillering	PI	Total
N0	0	0	0	0	0.5	0	0	0.5	0.1	0.25	0.15	0.5
N1	0.2	0.5	0.3	1.0	0.5	0	0	0.5	0.1	0.25	0.15	0.5
N2	0.4	1.0	0.6	2.0	0.5	0	0	0.5	0.1	0.25	0.15	0.5

PI: panicle initiation stage

Sampling and Measurements

Physiological characteristics. Photosynthetic rates were measured in terms of carbon dioxide exchange rates (CER) at tillering, heading, and dough-ripening stage (14 days after heading (DAH)) by the use of a LICOR-6400 portable photosynthesis system (USA) at the CO_2 concentration of 360-370 ppm, light intensity of 1500 µmol m^{-2} s^{-1}, and varied relative humidity. Four plants of each rice genotype (i.e. IAS66, IR24, and ASO) were randomly selected for the measurement and each plant was considered as one replication. The flag leaf of the main culm of each rice plant was used to measure the CER between 9:00 and 13:00 hours on sunny days. After the CER measurement, the green leaves were cut to measure leaf area (LA) using a LICOR-3100 Area Meter. Plant samples were divided into: leaves, culms plus leaf sheaths, and panicles, then oven-dried at 80^0C for at least 72 hours to determine dry weight (DW). The dried flag leaves were powdered and then analyzed for the flag leaf nitrogen content (FLNC) by the Kejldalh method.

$$\text{Biomass nitrogen use efficiency (BNUE)} = \frac{Dry\ weight}{FLNC} \quad \text{(BNUE - g mg}^{-1}\text{N)}$$

The non-structural carbohydrate content (NSC) of stems and leaf sheaths, and the panicles at both the heading and maturing stages were measured using the gravimetric method (Ohnishi and Horie 1999).

Yield components and grain yield. At the ripening stage, 4 plants in each treatment were selected to determine the yield components and grain yield by measuring the number of panicles, number of grains per panicle, percentage of filled-grain, and 1000-grain weight. Grain yield was measured after threshing, cleaning, and drying.

The formulas used for calculating the nutrient use efficiency are as follows (Fageria *et al.*, 2010):

$$\text{Agronomic nitrogen use efficiency (ANUE)} = \frac{\text{Grain yield at N1 or N2} - \text{grain yield at N0}}{\text{quantity of nitrogen applied}} \ \text{(ANUE - g g}^{-1}\text{)}$$

Statistical analyses. Analysis of variance (ANOVA) was performed using 'Minitab 16' (Meyer and Krueger 2004), according to (RCBD) to assess genotypes differences, nitrogen levels and genotypes × nitrogen levels interactions. The significance of mean values was analyzed using Tukey's test (0.05).

RESULTS AND DISCUSSION

Photosynthesis, leaf area, and dry matter accumulation. As shown in Figure 1, the photosynthetic rate, in terms of CO_2 exchange rate (CER), increased significantly under high nitrogen conditions in IAS66 and the recurrent parent IR24 at all stages, but the rate of increase was significantly higher in the CSSL than in IR24. In the N0 level, there were no significant differences in CER between IAS66 and its parental cultivars at the tillering, heading, or dough-ripening stages. At the tillering stage, the CER of ASO in the N1 level was higher than that of IAS66 and IR24, but when nitrogen increased to the N2 conditions, the CER of IAS66 was as high as that of ASO with values of 25.0 and 25.9 µmol CO_2 m^{-2} leaf s^{-1}, respectively. At the heading stage, the CER of the ASO at N1 level still had similar trends to that of tillering stage, the highest value being 28.3 µmol CO_2 m^{-2}leaf s^{-1}, but no significant differences were observed between Asominori and IAS66 at N2 level with CER values of 27.0 and 25.9 µmol CO_2 m^{-2} leaf s^{-1}, respectively (Fig. 1). However, the rate of increase in CER in IAS66 from the N0 to the N2 level was significantly higher than that in its parental cultivars. At the dough-ripening stage, the paternal parent, ASO maintained a high photosynthetic rate at N1 levels, whereas the photosynthetic rate of IAS66 was not significantly different to that of the IR24 cultivar. There was no significant difference in CER between N2 and N1 level of all genotypes at all stages.

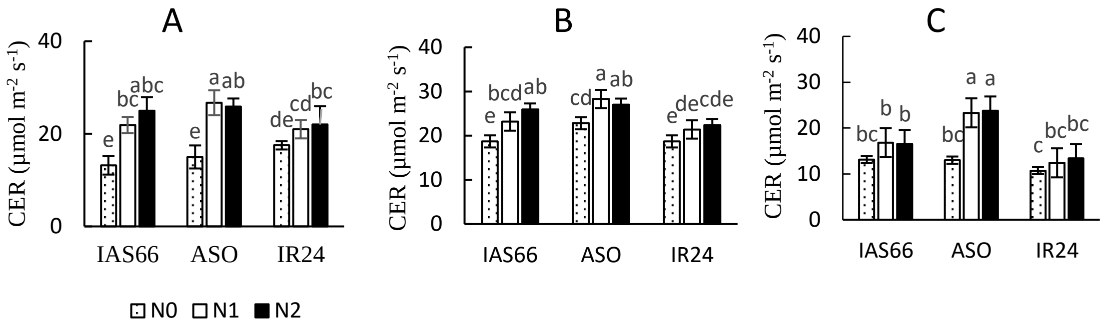

Fig. 1. CO_2 exchange rate (CER) of the promising line IAS66 and its parental cultivars grown under different nitrogen conditions at the tillering stage (A), heading stage (B), and dough-ripening stage (C). Vertical bars show the standard error of four replications. Mean values followed by the same letter are not significantly different at each stage ($P \leq 0.05$) by Tukey's test.

Leaf area (LA) per plant significantly increased when nitrogen increased from N0 to the N2 conditions in IAS66 and both parental cultivars (Fig. 2). The rate of increase in IAS66 was significantly higher than that of its parental cultivars at the tillering and heading stages. The observed values of LA of IAS66 were 16.5 and 34.4% higher than that of IR24 and ASO, respectively at the heading stage. However, at the dough-ripening stage, there were no significant differences in LA of IAS66 compared to its parent under all nitrogen levels.

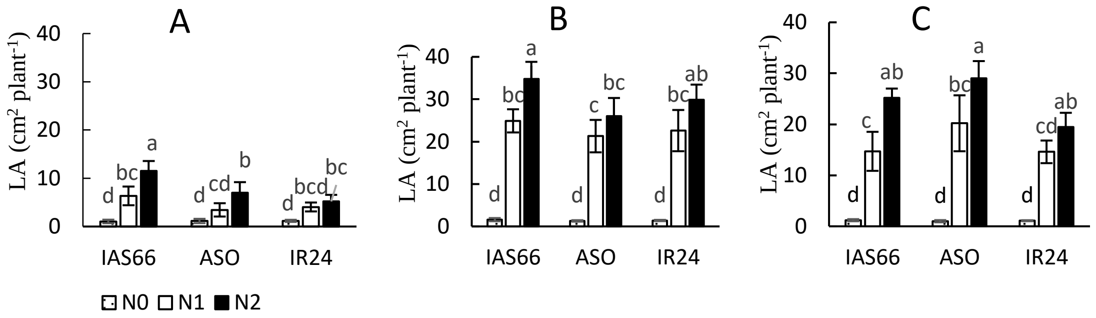

Fig. 2. Leaf area (LA) of the promising line IAS66 and its parent cultivars grown under different nitrogen conditions at the tillering stage (A), heading stage (B), and dough-ripening stage (C).

Aboveground dry weight also increased throughout the growth stages as N levels increased in IAS66 and both parental cultivars (Fig. 3). In the N0 treatment, there were no significant differences in dry weight among genotypes. Increasing nitrogen to the N1 conditions, dry weight of IAS66 also increased to 45.6 g plant^{-1}, and increased again to 56.5 g plant^{-1} in the heading and maturing stages, but no significant differences were measured in comparison to IR24 at the ripening stage. Under the N2 conditions, the dry weight of IAS66 was significantly higher than that of its parent at all stages and also 13 and 23% greater than that in the N1 conditions in both the heading and maturing stages, respectively (Fig. 3). The rate of increase was higher in IAS66 than that in its parental cultivars.

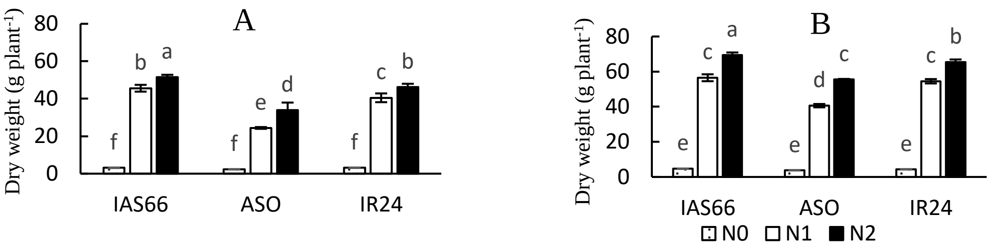

Fig. 3: Dry weight of the promising line IAS66 and its parental cultivars grown under different nitrogen conditions at the heading stage (A) and maturing stage (B).

Non-structural carbohydrate (NSC) mobilization. The total carbohydrates in grain are derived from both the accumulated carbohydrates in the culm and leaf sheaths before heading, and the photosynthetic products during grain filling (Nakano et al. 2017). In general, accumulated NSC in the culms and leaf sheaths (stem) increased from the tillering to heading stage, and then decreased during the ripening period (Yoshida 1981). In contrast to the NSC in the stems, NSC in the panicles of all genotypes showed an increasing trend with increased nitrogen application, from the heading to mature stages. There was a large decrease (8.9g hill^{-1}) of accumulated NSC in the stems of IAS66 from the heading to mature stages under N1 conditions (Table 2). However, as the nitrogen level increased, the amount of NSC reserved in the stems of the IAS66 and IR24 genotypes decreased. Under the N2 condition, the NSC of IAS66 panicles had the highest average (31.5 g hill^{-1}) at the mature stage, but was not significantly different to that of IR24 (28.8 g hill^{-1}). High nitrogen application led to a significant increase in the amount of NSC reserved in the panicles from the heading to mature stages, however the percentage of increase of NSC in the panicles at the mature stage of IAS66 was 39.4 and 9.4% higher than in ASO and IR24, respectively.

Table 2. Non-structural carbohydrates (g hill^{-1}) in stems and panicles of the promising line IAS66 and its parent cultivars grown at different nitrogen conditions

Genotype	Nitrogen	Stems			Panicles		
		Heading	Mature	Decrease	Heading	Mature	Increase
IAS66	N0	0.7^{d}	0.3^{d}	0.4^{d}	0.1^{bc}	2.0^{f}	1.9^{e}
	N1	12.4^{a}	3.5^{ab}	8.9^{a}	1.7^{a}	27.0^{bc}	25.3^{ab}
	N2	9.9^{b}	3.0^{bc}	6.9^{b}	2.3^{a}	31.5^{a}	29.2^{a}
	Average	7.7^{A}	2.3^{B}	5.4^{A}	1.4^{A}	20.2^{A}	18.8^{A}
ASO	N0	0.6^{d}	0.3^{d}	0.2^{d}	0.1^{c}	1.8^{f}	1.6^{e}
	N1	4.1^{c}	3.3^{bc}	0.8^{d}	2.0^{a}	18.2^{e}	16.2^{d}
	N2	5.7^{c}	4.3^{a}	1.4^{cd}	1.4^{ab}	22.6^{d}	21.1^{c}
	Average	3.5^{C}	2.6^{A}	0.8^{C}	1.2^{A}	14.2^{B}	13.0^{B}
IR24	N0	0.7^{d}	0.2^{d}	0.5^{d}	0.1^{bc}	1.8^{f}	1.7^{e}
	N1	9.3^{b}	3.2^{bc}	6.1^{b}	1.8^{a}	25.5^{cd}	23.7^{bc}
	N2	6.1^{c}	2.6^{c}	3.5^{c}	2.4^{a}	28.8^{ab}	26.6^{ab}
	Average	5.4^{B}	2.0^{B}	3.4^{B}	1.4^{A}	19.1^{A}	17.6^{A}

Values within a stage for each treatment followed by the same uppercase letter and lowercase letter are not significantly different at the 0.05 probability level by Tukey's test.
Decrease refers to the amount of NSC decrease in the stems = NSC at heading – NSC at mature
Increase refers to the amount of NSC increase in the panicles = NSC at mature – NSC at heading

Table 3. Yield and yield components of the promising line IAS66 and its parental cultivars under different nitrogen conditions

Genotype	Nitrogen	Number of panicles hill^{-1}	Number of spikelets panicle^{-1}	Percentage of filled-grain (%)	1000-grain weight (g)	Grain yield (g hill^{-1})
IAS66	N0	2.0^{f}	81^{d}	84.6^{c}	25.3^{b}	2.9^{f}
	N1	17.3^{d}	155^{b}	93.3^{ab}	26.3^{a}	40.1^{c}
	N2	21.0^{bc}	153^{b}	94.2^{ab}	26.3^{a}	47.9^{a}
	Average	13.4^{B}	130^{B}	90.7^{B}	26.0^{B}	30.3^{A}
ASO	N0	2.5^{f}	34^{e}	95.7^{a}	26.5^{a}	2.4^{f}
	N1	22.0^{b}	91^{cd}	92.6^{ab}	27.0^{a}	25.1^{e}
	N2	31.0^{a}	96^{cd}	94.1^{ab}	27.0^{a}	32.8^{d}
	Average	18.5^{A}	74^{C}	94.1^{A}	26.8^{A}	20.1^{C}
IR24	N0	1.5^{f}	111^{c}	83.3^{c}	23.5^{c}	2.8^{f}
	N1	13.2^{e}	245^{a}	90.8^{b}	23.9^{c}	37.3^{c}
	N2	17.5^{cd}	240^{a}	90.7^{b}	24.0^{c}	43.0^{b}
	Average	10.7^{C}	199^{A}	88.3^{C}	23.8^{C}	27.7^{B}

Values within a stage for each treatment followed by the same uppercase letter or lowercase letter are not significantly different at the 0.05 probability level by Tukey's test.

Yield components and grain yield. Nitrogen levels had a significant effect on the number of panicles per hill of IAS66 and both the parental cultivars. The highest number of panicles hill^{-1} was in the ASO cultivar subjected to the high nitrogen treatment, followed by IAS66 and IR24 cultivars, respectively (Table 3).

Increasing the nitrogen application level from the N1 to N2 conditions did not affect the number of spikelets per panicle, the percentage of filled-grain and the 1000-grain weight. The number of spikelets per panicle in IR24 was much higher than that of IAS66 with about 240 spikelets per panicle at both nitrogen levels. However, the percentage of filled-grain of IAS66 was higher than in IR24 with 93.3% and 94.2% at the N1 and N2 levels, respectively. The 1000-grain weight of IAS66 was significantly different than that of IR24, and this could be induced by a segment of chromosome derived from the ASO cultivar.

Large variations among genotypes were observed in the grain yield as nitrogen levels increased. Grain yield was not significantly different among all cultivars under the N0 condition, except for ASO under the N1 conditions. However, there was a significant difference in grain yield of IAS66 compared to its parental cultivars under the N2 conditions. The increase in grain yield from N0 to N2 conditions was significantly difference with 45, 30.4 and 40.2 g hill^{-1} in IAS66, Asominori, and IR24, respectively. In addition, the rate of increase in grain yield for IAS66 was 20 and 32% higher than that of IR24 and ASO, respectively.

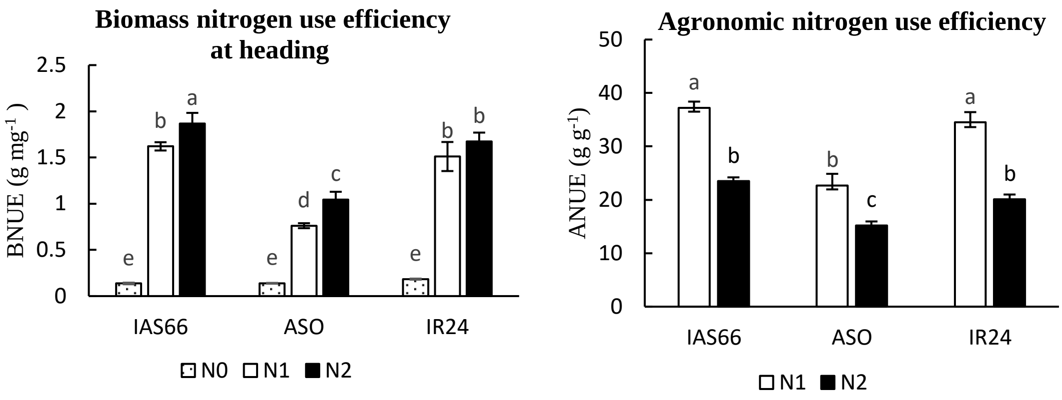

Fig. 4. Biomass nitrogen use efficiency **(**BNUE) and agronomic nitrogen use efficiency (ANUE) of the promising line IAS66 and its parental cultivars grown under different nitrogen conditions.

Nitrogen use efficiency (NUE). One of the strategies to improve yields is to choose genotypes with high nitrogen use efficiencies (NUE) that can produce higher economic yields under limited conditions. The biomass nitrogen use efficiency (BNUE) of IAS66 at heading stage was significantly higher than in its parents under high nitrogen conditions (N2) (Fig. 4). The rate of increase in BNUE in the IAS66 from the N0 to N2 conditions was 15 and 92% higher than in IR24 and ASO, respectively. In contrast to BNUE, the agronomic nitrogen use efficiency (ANUE) of all-genotypes decreased when increasing nitrogen from N1 to N2 conditions. The ANUE of IAS66 was higher than that of its parental cultivars, but it was not significantly different to IR24 in the N1 level. These results are in agreement with previously published data demonstrating that under high N concentrations, both absorption nitrogen use efficiency (aNUE) and agronomical nitrogen use efficiency (ANUE) decrease gradually (Nguyen et al. 2014). This indicates the plants are able to acquire adequate nutrition from the normal nitrogen applications.

The main objective of this study was to examine the ability of production of dry weight and translocation carbohydrates of promising chromosome segment substitution line (CSSL) in comparison to its parental cultivars. The different nitrogen application levels were provided to evaluate the response of the genotypes over growth stages. Under the N1 condition, the NSC had the highest values in the culm and leaf sheaths (stems) at the heading stage. Increasing the nitrogen levels to the N2 condition resulted in a decrease in the amount of NSC reserved in stems. The high nitrogen conditions increased the number of spikelets m^{-2} but did not increase the amount of reserved NSC (Table 3 and Table 2), resulting in lower amounts of reserved NSC compared with the larger sink size in the high nitrogen application conditions (Nagata et al. 2001). However, in the high nitrogen treatment, the NSC reserved in the panicles at the maturing stage was higher than that under normal nitrogen conditions. Sources of the carbohydrates can be separated into two components: those assimilated during the ripening period and reserved in the culms and leaf sheaths before heading stage. Many previous studies indicated that a higher grain yield of rice was due to reserve carbohydrates in the culms and leaf-sheaths accumulated before heading (Takai et al. 2006). Other studies stated that dry matter production after heading is more important than the reserved carbohydrates before heading because the fraction of carbohydrates from assimilates after heading is usually larger than that those reserved before heading (Nagata et al. 2001). The results of the present study showed that the carbohydrates from the assimilates of IAS66 after the heading stage had the highest values under the N2 conditions. There was a close relationship between the increase of NSC in panicles at the ripening stage and grain yield with r = 0.99** in all genotypes (Fig. 5A). Additionally, high rate of decrease of NSC in the stems of IAS66 could lead to a higher grain-filling ability (Li et al. 2012, Zheng et al. 2010). Higher NSC accumulation under the high nitrogen conditions promoted the translocation of labeled ^{13}C from the culms and leaf sheaths to the grains, and increased sucrose synthase enzyme activity in the grains enhanced the duration of higher activity

(Zheng et al. 2010). However, the rate of increase of NSC in the panicles of IAS66 was higher than that of its parental cultivars.

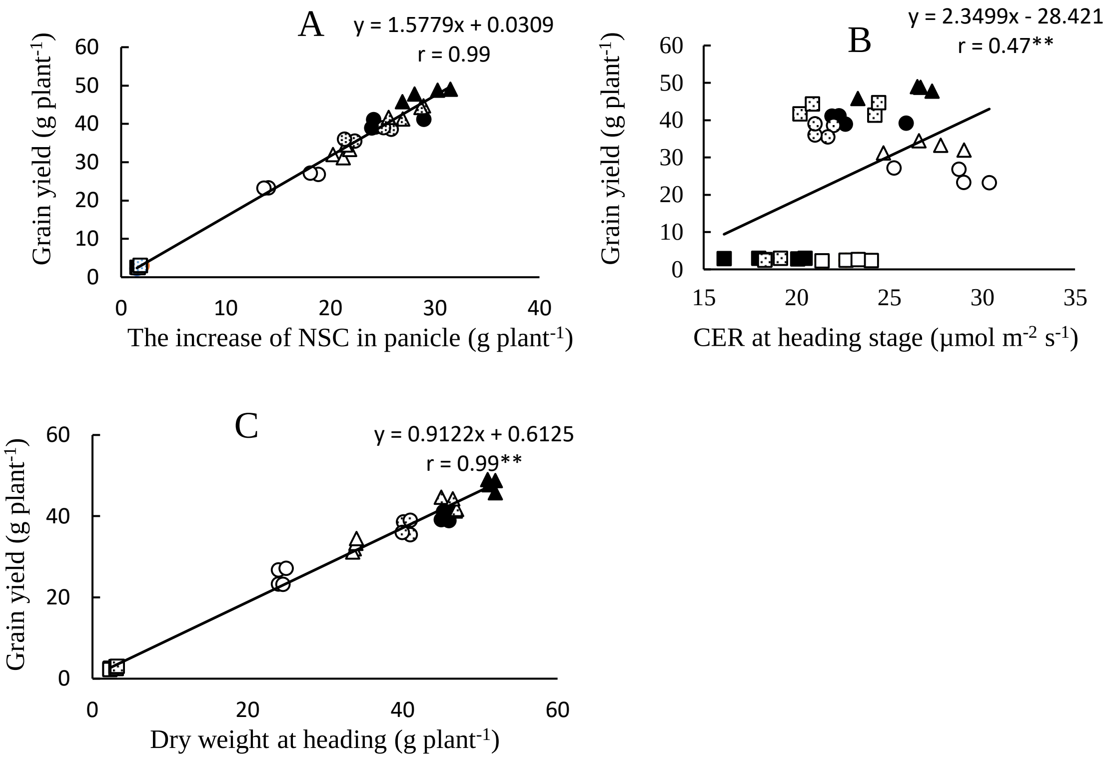

Fig. 5. Correlation between the increase of NSC in the panicles from heading to maturing stage with grain yield (A), CER at heading stage with grain yield (B) and dry weight at the heading stage with grain yield (C) in IAS66 (closed symbol), Asominori (open symbol), and IR24 (meshed symbol) rice cultivars grown under the N0 (square symbol), N1 (circle symbol), and N2 (triangle symbol) conditions.
ns: not significant; *, ** significant difference at $P<0.05$, 0.01, respectively.

The higher grain yield of IAS66 relative to the parent should be the result of higher contributions of biomass at the heading and mature stages. Nakano et al. (2017) showed evidence that larger dry weights might be attributed to higher source activity. In our study, the dry weight production of IAS66 had the highest values at the heading and mature stages under the N2 conditions due to higher leaf areas (Fig. 3) and CER at heading (Fig. 2). These results agree with Nakano and co-workers (2017) who indicated that high-yielding cultivars originating from a cross between *indica* and *japonica* sub-species have a higher sink capacity than *indica* high-yielding cultivars, and a higher grain yield of F_1 hybrid rice was attained by greater DM production at heading (Pham et al. 2003). There was a significant correlation between CER at the heading stage and grain yield of IAS66 and its parent cultivars with r = 0.47** (Fig. 5B). A positive correlation between dry weight and grain yield at the heading stage was also observed with r = 0.99** (Fig. 5C). These results suggest the importance of maintaining dry weight and that the translocation of NSC could be contributing to the high grain yield of IAS66 during the mature stage under high nitrogen conditions.

CONCLUSION

A high level of nitrogen application is a critical factor in IAS66 for greater increase in grain yield compared to the parents. Increasing the nitrogen level resulted in an increase in the rate of dry matter production and number of panicles per plant compared to its parental cultivars. IAS66 under high nitrogen condition had higher CER values before heading, a higher dry weight, and higher levels of carbohydrates from assimilates after the heading stage in the panicles, which consequently contributed to the higher grain yield of the promising CSSL IAS66 relative to its parental cultivars.

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ESTABLISHING SOIL PHOSPHORUS CRITICAL LEVEL FOR POTATO (*SOLANUM TUBEROSUM* L.) IN ANDISOL OF LEMBANG, INDONESIA

Gossaye Hailu Debaba, Arief Hartono*, Untung Sudadi, Lilik Tri Indriyati
Department of soil science and land resources, Faculty of Agriculture,
Graduate School of Bogor Agricultural University, Indonesia
Jl. Raya Kampus IPB Darmaga 16680, Indonesia
*Corresponding author: hartono@apps.ipb.ac.id

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ABSTRACT

A greenhouse experiment on soil diagnosis on phosphorus (P) fertilizer trial was conducted for potato in Andisol of Lembang district at Assessment Institute for Agricultural Technology (BPTP) from February to June 2018 in Indonesia. The treatments consisted of seven level of P fertilizer amount (0, 25, 50, 75, 100, 125, and 150 kg ha^{-1}) with three replications for low and high P soil arranged in completely randomized design. Bulk soil samples were collected from agricultural land and categorized as low and high P soil with respect to the soil's native fertility status. Soil test P was extracted by Olsen method. The result showed that P fertilizer significantly affected tuber yield. Correlation and calibration result of Olsen soil test P with relative tuber yield result indicated that 68.8 mg P kg^{-1} and 191 mg P kg^{-1} was critical level for potato production in Andisol for low and high P soils respectively. Result showed that at values less than these critical level of extractable P, P fertilizer should be applied to increase potato tuber yield. The application of phosphorus fertilizer at different amount increased tuber yields of potato by 21.8-40.1% and 15.3-28.4% for low and high P soil respectively as compared to the control yield. Available soil test phosphorus extracted by Olsen method three weeks after planting significantly responded to P fertilizer rate.

Key words: agricultural land, calibration, correlation, fertilizer rate, Olsen P, tuber yield

INTRODUCTION

Indonesia has 56.5 million ha of agricultural land comprised of various soil types (Syuaib 2016). In some parts of the country low fertilizer efficiency due to coated method of fertilizer application restrain agricultural profitability. Thus, low agricultural profitability especially for subsistence farming community is an indicator of low fertilizer efficiency. Agricultural development strategy of the country to improve crop productivity through increasing utilization of agricultural technology such as improved varieties and chemical fertilizer in conjunction with proper soil management is an essential tool to increase fertilizer use efficiency. In developing countries like Indonesia, phosphorus (P) fertilization efficiencies are highly important due to the lack of funding for fertilization (Hartono et al. 2018). Hence, evaluation of fertility status of the soil based on its nutrient supplying ability can help to improve productivity and increase fertilizer use efficiency and reduce environmental risk (Nafiu et al. 2012). Soil diagnosis is a method of evaluating soil fertility status in order to know the level of nutrient availability for a certain crop in a given soil type (Dahnke et al. 1990). Soil diagnosis to determine nutrient status of soils and calibrated to crop response is a major tool for improving and sustaining productivity through site-specific nutrient management (Agegnehu et al. 2015). However, Soil test P (STP) measures the quantity of P nutrient that is extracted from a soil by a particular extractant (Corey 1987). The measured quantity of extractable STP later correlated and calibrated to percent relative yield by assessing crop response in plots or greenhouse experiment to establish critical limits for a certain crop and soil type which may help to make fertilizer recommendation. The major purpose of diagnosing soils for P is to determine the quantity of supplemental P required to prevent economic loss of crop value because of P deficiency (Fixen et al. 1990). Soil test correlation is the process of determining whether there is relationship between plant uptake of a nutrient or yield and the amount of nutrient extracted by a particular soil diagnosis (Corey 1987), while calibration is a means of establishing a relationship between a given STP value and the yield response from adding nutrient to the soil as fertilizer (Admasu 2016, Dahnke et al. 1990).

Andisol is one of the 12 soil orders in Soil Taxonomy and defined taxonomically by the presence of andic soil properties (Soil Survey Staff 1998) formed from volcanic ejecta and has high P retention and Al saturation are limiting factors for plant growth (Yatno et al. 2008). Volcanic ash soils are among the most fertile soils in the world (Shoji et al. 2002), but in volcanic ash soil P is strongly sorbed by non-crystalline aluminum and iron materials. Phosphate retention by allophanic soils can reduce P availability for plant uptake (Stevenson et al. 1999). In turn, the applied P fertilizer readily react with weathering products of monocrystalline aluminum and iron materials, resulting formation of insoluble metal-phosphorus compounds (Shoji et al. 2002). However, the high retention of phosphate on Andisol causes the majority of P cannot be used by plants (Sembiring et al. 2017). Andisol covers appreciable area in Lembang district, West Java, Indonesia. Hence, inadequate P concentration in soil influences plant growth and development in the study area. It is estimated that 30–40% of global agricultural soils are limited by P availability and it is second only to nitrogen in limiting agricultural productivity (Vance et al. 2003). Thus, P is one of essential plant nutrients (Tisdale et al. 1985, Tan 2011) available in soil and plants can absorb in the form of primary orthophosphate ($H_2PO_4^-$) mostly at low soil pH and secondary orthophosphate (HPO_4^{2-}) at high soil pH. However, after application of mineral P fertilizers to soils the major portion of P (80-90%) cannot be absorbed by plants due to adsorption by soil particles (Fe, Al, Ca) (Daoui et al. 2014).

In the study area farmers grow intensively agricultural crops including potato. However, farmers apply chemical fertilizer while P fertilizer application is not based on soil diagnosis for potato is commonly practiced. It does not consider the spatial and temporal soil fertility variations and farmers apply the same P fertilizer amount to their fields regardless of fertility difference. As a result, profitability of potato production is restrained by low phosphorus fertilizer efficiency. Potato requires high P nutrient for optimum growth and yield, thus, when grown on P deficient soils, considerable yield losses are apparent (Dechassa et al. 2003). In addition method of P fertilizer application that is not based on soil diagnosis increases production cost and environmental risk. Currently there is no information on P requirements of potatoes in the study area while interpretations do available for other types of soils and crop but these may not applicable for potato in Andisol because (Fixen et al. 1990) calibrations are specific for each crop type, soil type, soil pH, climate, plant species, and crop variety. Hence, soil P diagnoses are useful to identify soils deficient in P and provide a guide to determine P requirement as to the magnitude of the crop's response to applied P. Once critical nutrient level established and crop requirement are worked out, farmers and producers could use this relatively simple tool to increase fertilizer profitability (Admasu 2016). In turn, it allows for the growers to have efficient utilization of P fertilizer. The basic aim of soil testing is to assess nutrient status, thereby identifying current and potential need for fertilization (Dahnke et al. 1990). Sound soil test based and site specific nutrient management therefore reliable and accurate method to identify the nutrient rates required to attain a desired level of plant growth and yield (Admasu 2017). Therefore, the objective of this study was soil diagnosis phosphorus calibration to establish phosphorus critical level for potato (*Solanum Tuberosum* L.) in Andisol of Lembang, Indonesia by Cate and Nelson (Cate and Nelson 1965) graphical method in order to determine a relationship between soil test and response to added P nutrient.

MATERIALS AND METHODS

Experimental site. P response trial for potato was conducted in greenhouse from February – June 2018 at Assessment Institute for Agricultural Technology (BPTP) in Lembang. Lembang is in West Java province, geographically located between 6º45'- 6º50' south latitude and 107º30'-107º40' East longitude. Potato is grown by farmers for local markets with other agricultural crops in Lembang district. Altitude of the study area is 1235 m above sea level and receives average annual rain fall 3047 mm.

Thirty soil samples (0-15 cm depth) were collected before the onset of the trial from the upper 0-15 cm because P from fertilizers stays in this layer due to strong sorption and precipitation. Soil samples were air-dried, sieved <2 mm and stored in sealed plastic bags at ambient laboratory temperature prior to analyses. Soil samples were analyzed for pH using in a ratio of 10 g of soil to 25 ml of water (1:2.5). Soil particle size distribution was analyzed by the hydrometer method (Bouyoucos 1962) using sodium hexametaphosphate (Calgon) as a dispersing agent. Soil textural class names were determined following the textural triangle of USDA system (Rowell 1994). Available P was determined by Olsen method (Olsen et al. 1954). Organic carbon content was determined using the Walkley and Black method (Walkley and Black 1934), total nitrogen using Kjeldhal digestion, distillation and titration method as described by Blake (Blake 1965), exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method (Chapman 1965).

Greenhouse experimental setup. The soil analysis was carried out at Department of Soil Science, Faculty of Agriculture, Bogor Agricultural University. 11 kg field soil was filled to 14 litter pots and the pots were arranged in complete randomized design with seven levels of P (0, 25, 50, 75, 100, 125 and 150 kg P ha^{-1}) each have three replications. The mean soil P analytical results of the study site soil were interpreted as low and high using Olsen available P in the range < 10 , 10 – 25, 26-45, >46 mg kg^{-1} categorized in very low, low, medium and high STP respectively. The plant materials used for the experiment were sprouted tubers of median potato variety obtained from local farmers. This variety was selected due to local agro climatic condition adaptability and its availability in the area. The soil media used for growing potato was prepared from low P soil (21 pots) and high P soil (21 pots) filled with 11 kg of experimental site field soil with a total of 42 pots. The sprout was planted on April. The sources of nitrogen (N), P and potassium (K) were urea (46% N), triple super phosphate (TSP 45% P_2O_5), and KCl (60% K_2O) respectively. The P and KCl (135 kg ha^{-1}) fertilizers were applied at planting while the recommended N fertilizer (100 kg ha^{-1}) was applied in two dozes, half at planting and half after 45 days of planting. The amount of N and K fertilizers applied based on local farmers practice and also farmers in the study area apply 100 kg ha^{-1} of P fertilizer for potato. One sprouted tubers of size between 85-100g weights of tubers were planted at 10 cm depth after watering the media well. Every two days interval after watering the pots, the pot soil was mixed to the depth of 5 cm in order to make sure that the P fertilizer distribute uniformly at the top soils of pot without damaging the planted sprout until three weeks. Three weeks after planting soil samples were taken from all pots (5 cm depth) in order to give enough time to dissolve P fertilizer in the pot to analyze soil test P by Olsen extraction method (Olsen et al. 1954). Olsen extractant used because of the soil initial pH was 6.2 such that acid extractant the results correlate better with plant response in soil with pH less than 6.0. Holford (1980) found that acid extractants extracts large amounts of non-labile P in soils with pH greater than 6.0 results over estimation of available P in soil. In addition Maghanga et al. (2012) suggested that the Olsen extractant is useful for both acid and calcareous soils. In calcareous soils, increased P solubility is as a result of decreased Ca concentration by high CO_3^{2-} to form $CaCO_3$. In acid or neutral soils, the solubility of the Al and Fe phosphates increases as OH^- concentration decreases. The type of fertilizers application used in this study was band method around the planted sprout. All of the other cultural practices used throughout the growing season were similar to those that were practiced by regular farmers. Agronomic parameter collected was total tuber yield after crop maturity.

Determination of critical P concentration (Pc). To correlate relative yield versus soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each pot using Olsen method and three replications for each treatment. The Cate-Nelson graphical method (Cate and Nelson 1965) used to determine the critical P value using relative yields and soil test P values obtained from P fertilizer trials conducted in greenhouse, to assess the relationship between tuber yield response to nutrient rates and soil test P values, relative potato tuber yields in percent were computed for both high and low P soil separately by the formula below:

$$\text{Relative yield (\%)} = \frac{Yield}{Maximum\ Yield}\ x\ 100$$

Where yield stands for tuber yield obtained from all treatment with their respective replication, and maximum yield stands for the maximum yield obtained among replications.

The scatter diagram of relative yield (Y-axis) versus soil test value (X-axis) was plotted and the range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P fertilizer requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting line was moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). It was divided according to the probability (high or low) that potato respond to fertilization. Then, the soil- test value where the vertical line crosses the x-axis is selected as the soil critical level of extractable P concentration for potato. Thus, the vertical line separates the point between nutrient deficiencies to sufficiency range.

Statistical Analysis. The effect of P treatments on potato yield and three weeks after planting soil test P was evaluated by analyses of variance (ANOVA), using the statistical analysis system version 9.1 (SAS 2004) software. Means for the main effects were compared using the means statement 5% significance level in order to separate the treatment means. Tukey's test at 5% levels of significance was used to separate the treatment means.

RESULTS AND DISCUSSION

Initial soil physical and chemical properties. The soil medium prepared for growing potato was Andisol with pH 6.20, 0.72 g cm^{-3} bulk density, EC 0.50 ds m^{-1} and other soil physical and chemical properties analyzed (Table 1) based on respective methods. The mean textural class of the study site was categorized under silt loam. The mean soil pH was under the range of slightly acidic class (4.3-6.7). The lowest soil pH was recorded from low P soil but at high P soil the soil pH recorded higher than low P soil. This is because on high P soil farmers apply high amounts of organic materials in addition to chemical fertilizer that may raise the soil pH, because organic materials raise soil pH either by mineralization of organic anions to CO_2 and water thereby removing H^+ or the alkaline nature of organic materials (Helyar 1976). The mean value of organic carbon (5.02%) and total nitrogen (0.47%) were under the range of medium (2.59 – 5.17%) and very high (>0.25%) status respectively according to ratings developed by Tekalign (1991). Extractable P content extracted by Olsen method for low P soil a mean of 23.4 mg kg^{-1} and high P soil 118 mg kg^{-1}. This indicates a high variation in P content among low and high P soil. This is because on high P soils farmers were applied high amount of organic material for crop production complementary to chemical P fertilizer, while in low P soil farmers were not used organic matter.

Table 1. Summary of soil physical and chemical properties of trial site

Selected soil properties	Average	±SE	Range
pH (10:25 H_2O)	5.57	0.12	4.30-6.70
Total N (%)	0.47	0.01	0.29 - 0.55
Olsen-extractable P(mg kg^{-1}) for high P soil	118	5.26	115-121
Olsen-extractable P (mg kg^{-1}) for low P soil	23.4	1.64	22.1-25.0
Organic carbon (%)	5.02	0.07	4.20-5.60
Exchangeable K (cmolc kg^{-1})	0.58	0.04	0.13-1.08
Exchangeable Ca (cmolc kg^{-1})	3.53	0.47	0.90-10.14
Exchangeable Mg (cmolc kg^{-1})	0.52	0.08	0.19-1.42
Exchangeable Na (cmolc kg^{-1})	0.05	0.001	0.04-0.07
CEC (cmolc$_{(+)}$ kg^{-1})	27.8	0.35	26.1-31.0
Soil texture			
- Sand (%)	42.4		36.2-50.2
- Silt (%)	52.6		43.2-54.6
- Clay (%)	5.07		3.21-6.74
- Texture	Silt loam		

Note: CEC, Cation Exchange Capacity; SE, Standard Error

Yield responses to P fertilizer. The analysis of variance of the experiment result indicated that there were significant ($P < 0.05$) responses of tuber yield to P fertilizer rates. The highest mean tuber yield (15,336 kg ha^{-1}) was recorded from 75 kg P ha^{-1} with mean relative yield response of about 91% on low P soil (Fig. 1), while on high P soil the highest mean tuber yield (16,211 kg ha^{-1}) was recorded from 50 kg P ha^{-1} with mean relative yield response of about 92% (Fig. 2). The application of P fertilizer at different rates increased tuber yields of potato by 21.9-40.1% and 15.3-28.4% for low and high P soil respectively as compared to the control yield (Table 2).

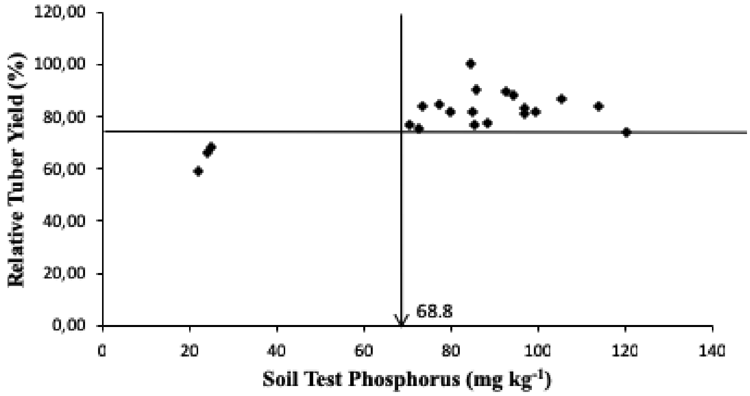

Fig. 1. Effect of available soil test phosphorous value analyzed three weeks after planting to P fertilizer rate for low P soil as determined by Cate-Nelson graphical method. The arrow indicates the phosphorus critical level for potato on low P Andisol.
Note: Soil Test Phosphorus (STP in mg kg^{-1}) available phosphorus extracted by Olsen method 3 weeks after planting with respect to each treatment (each pot soil).

Critical P concentration (Pc). The correlation between relative tuber yield response and soil P measured with Olsen method is indicated that the critical level of extractable P concentration for potato using data of soil available P and corresponding relative tuber yield for all treatments, extracted by Olsen extraction method was 68.8 mg P kg^{-1} (Fig. 1) and 191 mg kg^{-1} (Fig. 2) for low and high P soils respectively determined by Cate-Nelson graphical method (Cate and Nelson 1965).

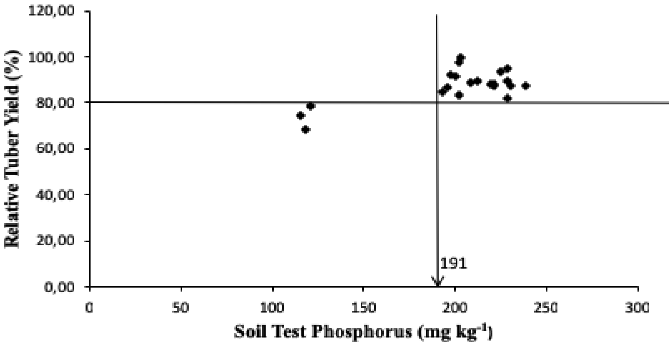

Fig. 2. Effect of available soil test phosphorous value analyzed three weeks after planting to P fertilizer rate for high P soil as determined by Cate-Nelson graphical method. The arrow indicates the phosphorus critical level for potato on high P Andisol.
Note: Soil Test Phosphorus (STP in mg kg^{-1}), available phosphorus extracted by Olsen method 3 weeks after planting with respect to each treatment (from each pot soil).

The increase in soil P response to P fertilizer applied was linear up to 75 kg P ha^{-1}, but the increase in yield was not significantly different beyond 75 kg P ha^{-1}; on low P soil, on the other hand the increase was linear up to 50 kg P ha^{-1}, but the increase in yield was not significantly different beyond 25 kg P ha^{-1} on high P soil (Table 2), a slight decline in yield was even observed at the greatest P rate. This suggests that the magnitude of potato response to P might be limited by supply of other nutrients, particularly N, because nitrogen deficiency causes a marked reduction in uptake of P, K, Ca, Mg, Mn, Cu, and Zn (Mengel et al. 2001). In addition (Fixen et al. 1990) suggested that the extractable soil P level is only one of several factors influencing plant response to P fertilizer. At soil test phosphorus values of less than 68.8 mg kg^{-1} and 191 mg kg^{-1} critical levels of extractable P on low and high P soils respectively, P fertilizer should be applied to increase potato tuber yield at values of greater than or equal to 68.8 mg kg^{-1} on low P soil the crop achieved about 75% of its maximal yield (Fig. 1) and at values of greater than or equal to 191 mg kg^{-1} on high P soil the crop achieved about 80% of its maximal yield (Fig. 2). This implies that P fertilizer application could be recommended for a buildup of the soil P to this critical value, or maintaining the soil P concentration at this level.

Results showed some yield responses from P fertilizer application had soil test levels above the critical level. Hence, to protect potential potato tuber yield loss, at least a maintenance application of 25 kg ha^{-1} P for both low and high P soil may be required depending on yield goal and profitability. Conversely, P fertilizer application is not likely to increase tuber yield of potato at soil P concentration above the critical level. Agegnehu et al. (2015) suggested that to increase P beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of additional yield. Thus, farmer's economic return may also reduce. Therefore, in soils with available P status below 68.8 mg kg^{-1} on low P soil and 191 mg kg^{-1} on high P soil, potato tuber yield could show a significant response to application of P fertilizers. Observations showed that plant heights were taller in pots treated with P fertilizer than untreated ones on low P soil. Susila et al. (2010) in line with the result of this study reported that critical Olsen Phosphorus values of 117 mg kg^{-1} and 267 mg kg^{-1} for low P and high P soil respectively for Yard Long Bean on Ultisols in Nanggung-Bogor district, Indonesia. The correlation analysis (Fig. 1 and Fig. 2) indicated that there is significance correlation between soil test P and potato tuber yield. Application of P fertilizer could be recommended to raise soil P to the critical value and maintain it there. The analysis of variance also indicated that soil with low initial P concentration, response of crop to fertilizer application was also higher than high P soil (Table 2). This implies that potato grown on soil with initially high P concentration can get more available P nutrient for growth and development than low initial P soil.

Table 2. Yield response to phosphorus fertilizer at low and high P soil

	Soil P status	
Amount of P fertilizer (kg ha^{-1})	**Low P**	**High P**
	Tuber yield (kg ha^{-1}) Mean ±SE	
0	10,946 ± 470a	12,622 ± 493a
25	13,338 ± 455ab	14,550 ± 176ab
50	13,497 ± 436ab	16,211 ± 459b
75	15,336 ± 882b	15,775 ± 497b
100	14,646 ± 452b	15,502 ± 374b
125	13,914 ± 91.8b	15,312 ±344b
150	13,801 ± 658b	14,769 ±356b
F value	6.49	8.68

Within each column, means with different letters are significantly different at $p < 0.05$; SE, Standard Error

When the soil test value is below the critical value additional information is needed on the quantity of P required to raise the soil P to the required level. Havlin et al. (2005) suggested that when the soil test is below the critical level it may be desirable to apply P at rates that increase soil test above the critical level. This is known as buildup or sufficiency program. Generally, Havlin et al. (2005) suggested applications of 5 to 15 kg P ha^{-1} are required to increase soil test P level to 1 mg kg^{-1}, depending on soil properties influencing P-fixation capacity. When soil test is at or slightly above the critical level, it can be maintained by P fertilizer rates that replace P removal and loss by crop removal, erosion, and fixation. In this regard Dahnke et al. (1990) suggested that knowledge of the soils ability to supply nutrients, the amount of nutrients required for crop growth, and the influences of applied nutrients on crop growth is all needed to improve fertilizer recommendations. Over all this research clearly indicated that the positive significance influence of P fertilizer application on potato tuber yield on Andisol of study area. In addition, soil test P calibration trial can provide information about the soil P status in order to improve P fertilizer efficiency.

Soil test p after three weeks of planting. Extractable P concentration extracted after three weeks of planting by using Olsen extraction method were also significantly differed ($P < 0.05$) among P fertilizer amount applied (Fig. 3 and 4). The main effect of P fertilizer resulted in mean soil test P values of 23.8 to 113 mg kg^{-1} and 118 to 229 mg kg^{-1} for low and high P soils respectively. The highest mean soil P concentration 113 mg kg^{-1} (Fig. 3) and 229 mg kg^{-1} (Fig. 4) was recorded from 150 kg P fertilizer ha^{-1} for low P and high P soils respectively. Soil test P responded to P fertilizer rate analyzed after three weeks of planting higher at low P soil (Fig. 3) than high P soil (Fig. 4). This is because the initial P status of low P soil lower than high P soil. Thus, yield response to P fertilizer was also higher on low P soil than high P soil.

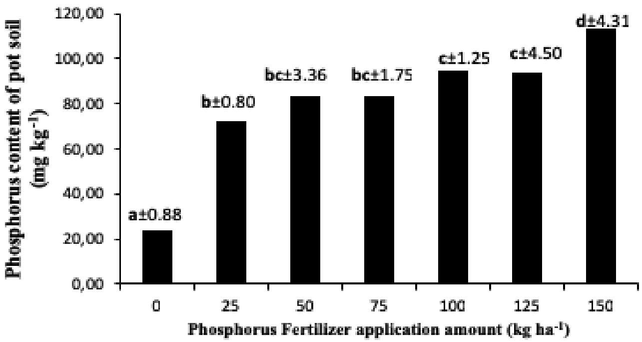

Fig. 3. Low P soil three weeks after P fertilizer application mean soil test P using Olsen extraction methods with response to P fertilizer rates. Graphs represented by different letters are significantly different at $P < 0.05$; bars with standard error.

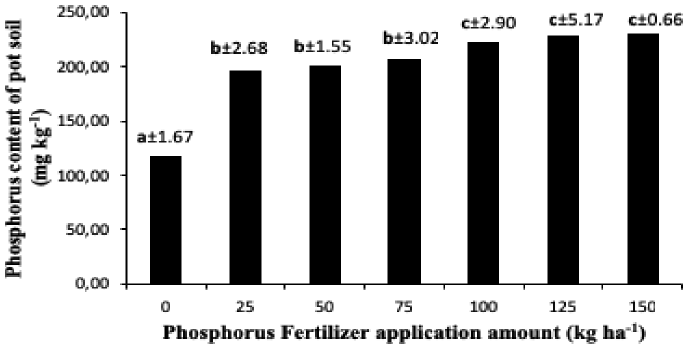

Fig. 4. High P soil three weeks after P fertilizer application mean soil test P using Olsen extraction method with response to P fertilizer rates. Graphs represented by different letters are significantly different at $P < 0.05$; bars with standard error.

CONCLUSION

According to the results it was concluded that potato tuber yield responded to P fertilizer rate significantly different as compared with yield obtained without P fertilizer on Andisol of the study area. The results of this experiment clearly revealed the importance of soil test-based P fertilizer application for improving yield of potato and P fertilizer efficiency on Andisol of Lembang in turn it can help to increase farmer's agricultural profitability. Using the Cate and Nelson graphical method the critical level of soil extractable P concentration for potato production was 68.8 mg kg^{-1} and 191 mg kg^{-1} by Olsen extraction method for low and high P soils respectively. There was strong relationship between soil test and response to P fertilizer. Extractable P concentration extracted after three weeks of planting by using Olsen extraction method was also significantly differed among P fertilizer rates. This result will provide important information for soil fertility specialists and farmers in the study area on the practical use of soil test-based for P fertilizer recommendation program. Researchers can use this study for future intensification in other areas as a basis for developing soil test system for fertilizer recommendation.

Soil test crop response fertilizer recommendation could be economically and environmentally promising in Lembang. Furthermore, further soil test calibration field trial should conduct to determine how well this greenhouse test can be perform in the field to get more accurate information about final calibration and interpretation data in order to determine fertilizer requirement. In addition similar experiments on potato to determine critical limit for other nutrients also needed to improve productivity on Andisol of study area.

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FRUIT GROWTH, ENDOCARP LIGNIFICATION, AND BORON AND CALCIUM CONCENTRATIONS IN NAM HOM (AROMATIC) COCONUT DURING FRUIT DEVELOPMENT

Kanyanat Nikhontha, Krisana Krisanapook, Wachiraya Imsabai*
Department of Horticulture, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand
*Corresponding author: agrwyi@ku.ac.th

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ABSTRACT

Fruit growth, endocarp lignification, and boron and calcium concentrations in ‘Nam Hom’ coconut during fruit development were studied. This study was conducted at Ban Paew district, Samut Sakhon province between January 2014 -September 2015. Whole fruit shape during the first 4 months (mo) after flowering was oval and turned to semi-oval at 8 mo. The shell was a round shape from 5 mo onwards. The endocarp (shell) started to accumulate lignin 2 mo after flowering but accumulation was highest and constant over the 4-8 mo period. Lignin accumulation started from the stylar end and progressed to the stem end. It was completed in the shell by 6 mo. This stage was accompanied by a decrease in water content. The concentrations of cellulose and hemicelluloses in the coconut shell increased rapidly from 2 to 6 mo then remained constant. The amount of fiber in the coconut husk increased with fruit age and was highest at the final harvest. Coconut husk had greater concentrations of both calcium and boron than occurred in the shell. Calcium concentration in the coconut husk decreased only slightly throughout fruit development while calcium concentration in the coconut shell decreased markedly with age. Boron concentration in the coconut husk decreased with fruit age whereas the highest concentration in the shell occurred at 4 mo and then subsequently decreased. These data indicated that the possible role of boron and calcium are likely to be necessary for shell formation and endocarp lignifications of coconut.

Key words: growth, shell, husk, lignin, cellulose, hemicelluloses

INTRODUCTION

‘Nam Hom’ coconut, or aromatic coconut, is a dwarf type of coconut which assimilates the liquid and solid endosperm at an immature stage (young coconut or tender coconut). Consequently, the coconut bunch can be harvested 6.5-7 mo from flowering. ‘Nam Hom’ coconut was ranked fourth of all fruit exported from Thailand in 2016. The main export markets for ‘Nam Hom’ coconut are the USA and China and the quantity and value of these exports have increased continuously over recent years (Office of Agricultural Economic, 2016).

The fruit of coconut, which is a fibrous drupe, consists of the husk (exocarp + fibrous mesocarp), a shell (endocarp) and the endosperm (which is eaten). Fruit development of coconut var. Nana, in terms of dry weight accumulation, was shown to have a sigmoidal pattern (Jayasuriya and Perera, 1985). Jaroonchon et al. (2017) reported that fruit development of ‘Nam Hom’ coconut followed a double-sigmoid growth curve being characterized by three stages like other drupe fruit such as peach (Chalmers and Ende, 1975; Dardick et al. 2010), Japanese plum (Kritzinger et al. 2017), apricot (Gulsen et al. 1995) and olive (Rapoport et al. 2013). In the first phase, development was characterized during the first 5 mo by rapid growth of the whole fruit and endocarp; in stage II, the growth rate slowed between 5 to 6 mo of growth; and in the final stage, stage III, which was from 6 mo onwards, the fruit grew steadily until full maturity (Jaroonchon et al. 2017).

During stage II, the endocarp is lignified and its thickness is increased, turning brown and becoming hard (Siriphanich et al. 2011; Jaroonchon et al. 2017). This endocarp hardening of 'Nam Hom' coconut followed the same pattern as that in peach and Japanese plum. In peach fruit during stage II, the mesocarp is relatively quiescent and the endocarp lignifies and hardens, which is the characteristic growth pattern in stone fruit. Fruit hardening is an easy stage to identify in fruit development and endocarp (shell or pit) hardening has become a widely used marker for both biological studies and orchard management (Rapoport et al. 2013). In peach and plum, pit splitting or pit-splitting during development can affect fruit quality. Similarly, with 'Nam Hom' coconut, cracking or splitting during development can affect the quality of the coconut fruit. However, there is very little information on endocarp lignification during fruit development in coconut. Improved knowledge about endocarp hardening would provide options for managing this development disorder.

Moreover, endocarp hardening in peach is considered to be the result of secondary cell wall thickening and liginification (Ryugo, 1964). Hayama et al. (2006) reported that the cellulose content of the peach endocarp increased rapidly from 48 to 83 days after full bloom (DAFB), then increased slightly thereafter. In *Zinnia elegans*, lignification proceeded after the formation of cellulose microfibrils in the secondary cell wall (Nakashima et al. 1997). In additional, hemicellulose is one of the primary plant cell wall which has cellulose-hemicellulose network (Geitmann 2011), meanwhile secondary cell wall (natural liginocellulose) mainly consist of cellulose, hemicellulose, and lignin in a 4:3:3 ratio and contain a small amount of pectin (Chen 2014). It was considered important, therefore, to understand cellulose and hemicellulose accumulation in endocarp during coconut fruit development.

A number of plant nutrients are important during seed and fruit development of coconut. Boron and calcium have been reported as being necessary for coconut fruit growth. Boron plays very significant role in nitrogen metabolism, protein biosynthesis, cell division and cell wall formation (Chamak and Romheld, 1997). In coconut, boron deficiency causes various malformations and fruit from boron deficient coconut palms are often cracked, have a blackened husk, or lack a shell (Jayasekara and Loganathan, 1988; Kamalakshiamma et al. 2000; Kamalakshiamma and Shanavas, 2002). Calcium is an important nutrient for fruit quality. It is involved in cross-linkages in the middle lamella, which binds cells together, and plays an important role in the stabilization of cell membranes (Stebbins et al. 1972). Determination of boron and calcium concentrations in the husk and the shell during coconut fruit development would help to determine the importance of these particular nutrients for coconut fruit growth.

The research sought to investigate the lignification of the endocarp during shell hardening, including cellulose and hemicelluloses content, and to determine the concentration of boron and calcium in the husk and shell of 'Nam-Hom' coconut fruit during the first 8 mo of development.

MATERIALS AND METHODS

Twenty-four 'Nam Hom' coconut trees of the same size and age (7-years-old) were selected from an orchard in Samut Sakhon province, Thailand. Within each coconut tree, all inflorescences were tagged at flowering to investigate subsequent fruit growth and shell hardening from 1 to 8 mo of age. Coconut bunches were harvested randomly from the selected trees every month, with three bunches at each sampling time.

Fruit weight, fruit size and shell size, husk thickness and shell thickness. Each whole fruit was weighed (g) (Ohaus Adventurer, USA), and height (cm) and diameter (cm) were measured (vernier caliper, Matui, Japan). Fruit were then cut longitudinally and shell size was measured (height and diameter, cm). Husk thickness and shell thickness were measured at four positions: stem-end position, two positions on each side and at the stylar-end position.

Water content in husk and shell. The coconut husk and shell were separated and chopped into small pieces and their fresh weight (FW) was recorded before drying at 70C in a hot air oven for 72 h or until constant weight. The water content was calculated as follows:

$$\text{Water content (\%)} = \frac{\text{FW-DW}}{\text{FW}} \times 100$$

FW: the initial fresh weight before drying
DW: final dry weight after drying

Fiber in coconut husk. Fiber content of the husk was determined on a 5 g sample using the method of Gould (1977).

Lignin, cellulose and hemicellulose concentrations in the coconut shell. Endocarp tissues were collected monthly. The endocarps were chopped into small pieces and then dried in a hot air oven at 70C before analysis. A 1 g sample of dried endocarp was analyzed for neutral-detergent fiber (NDF), acid-detergent fiber (ADF) and acid-detergent lignin (ADL) concentrations using the detergent method (van Soest et al. 1991). The concentration of lignin is presented as the percentage of ADL. The contents of cellulose and hemicellulose were calculated as follows:

% cellulose = % ADF - % ADL
% hemicellulose = % NDF - % ADF

Lignin staining (lignin accumulation). Longitudinally cut fruit (three fruit per bunch per sampling date) were stained for lignin formation using phloroglucinol-HCl (pink-red color). The lignin staining was modified using the method of Callahan *et al.* (2009) to determine when and where in the endocarp lignification started and where it spread throughout the endocarp. Cut fruit were placed in a phloroglucinol solution [2% (w/v) dissolved in 85% ethanol and mixed with concentrated HCl in the ratio 2:1] for 10 min to indicate the presence of cinnamaldehyde groups in lignin, and then photographed.

Boron and Calcium concentrations. A 1 g sample of either dried coconut husk or shell was placed in a porcelain crucible and heated in a muffle furnace from room temperature to 750C for 3 h. The porcelain crucible was then placed at room temperature for cooling. The ash was dissolved in 5 mL of concentrated HCl and 5 mL of concentrated nitric acid, and then adjusted to a volume of 100 mL using distilled water. Boron and calcium were analyzed using an inductively coupled plasma-optical emission spectrometer (ICP-OES) (700-ES series ICP-OES, Agilent Technologies, Australia) at 208 nm for boron and at 393 nm for calcium. The concentrations of boron and calcium in mg/kg were determined using standard curves.

Statistical analysis. The means between fruit age were compared using analysis of variance (ANOVA) and Tukey tests at a significance level of $P \leq 0.05$. Principal component analysis (PCA) was used as a statistical method to evaluate the relationships between fruit age and lignin, cellulose, hemicelluloses, boron and calcium content in coconut shell using PAST version 3.0.

RESULTS AND DISCUSSION

Fruit and shell growth. Fruit fresh weight increased from the 3rd mo until the 6th mo by the similar growth rate. However, the growth rate increased exponentially from 1-5 mo after flowering and then declined with actual fruit weight declining in the final month of assessment (Fig. 1A). The water content in the coconut husk also declined during the last month of development as the fruit matured (Fig. 3). The decrease of fruit weight after 7 mo was caused by a reduction in the volume of coconut water (Jaroonchon et al. 2017) and also decrease in water content in coconut husk.

Fruit and endocarp (shell) size had similar growth characteristics (Figs 1B and 1C). In first 5 mo, the size of the fruit and the shell rapidly increased, almost linearly. The growth rate then declined. Fruit shape during the first 4 mo was oval and changed to semi-round in the final stages of development (Fig.5). In contrast, the shape of the coconut shell in first 4 mo was oval and then the shell shape changed to round due to the diameter having a higher growth rate (Figs 1C and 5).

A previous study reported that the growth (size) pattern of ‘Nam Hom’ coconut fruit followed a double sigmoidal curve (Jaroonchon et al. 2017). However, in this research, the results showed a similar pattern of fruit growth in the first and in the second phases, but growth was different in the third phase. Jaroochon et al. (2017) found that the size of both the fruit and the shell slightly increased in phase III but at a slower rate than in the first phase. In our study, although overall fruit size did not increase over the final month of development, both husk thickness and mesocarp thickness at the stem end did increase (Fig. 2A), while shell thickness remained constant (Fig. 2B).

The husk of coconut fruit is morphologically fibrous mesocarp. Fiber content in the coconut husk slightly increased during fruit development from 1 to 7 mo after flowering, and then sharply increased at 8 mo to about 12%, concomitant with the decrease in the water content of the coconut husk (Fig. 3). The fiber and water in coconut husk made the coconut husk flexible which supporting high pressure inside the fruit. Thereafter, a decrease in water content of coconut husk made their flexibility change, when coconut fruit had more mature.

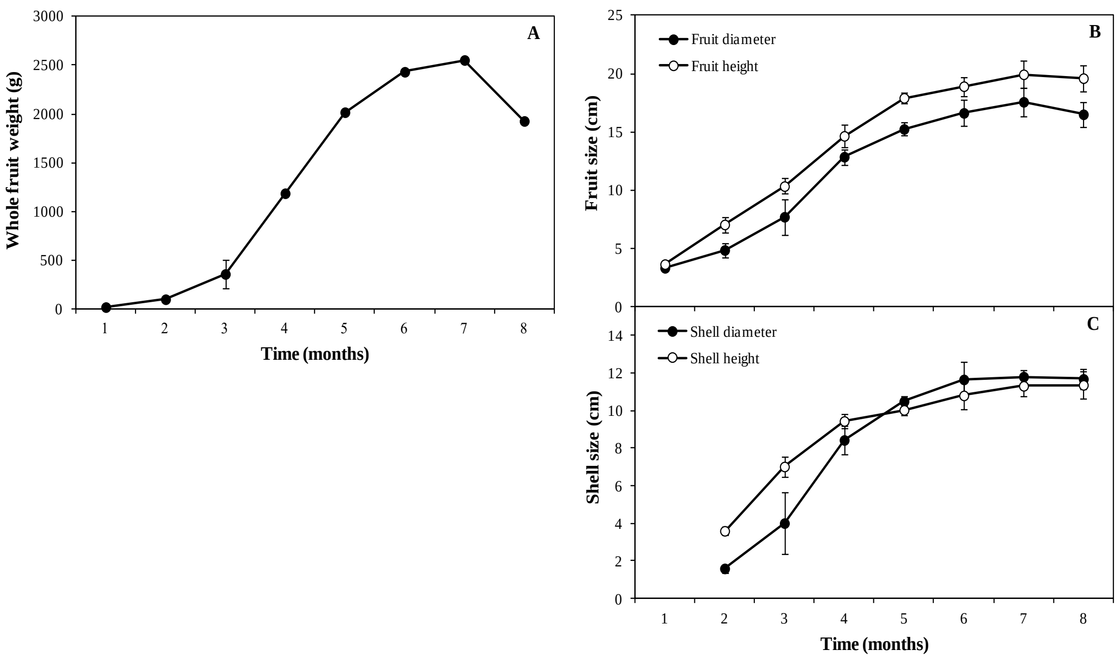

Fig. 1. Change of fresh weight (A), fruit size (B) and shell (endocarp) size (C) of coconut fruit during development. Vertical bars indicate ± SD (n = 5-15 fruit). Some SD values were smaller than the size of the symbols used.

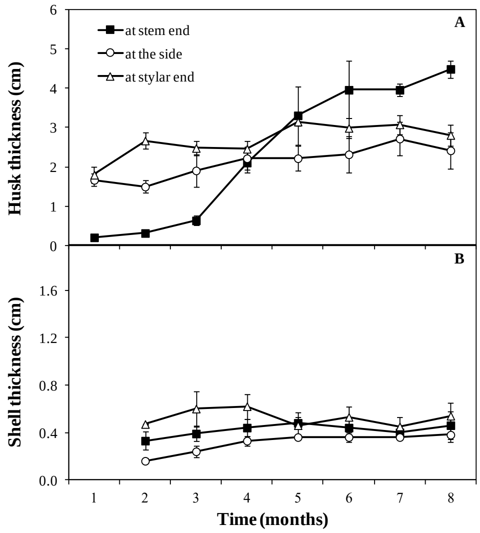

Fig. 2. Change of husk thickness (A) and shell thickness (B) of coconut fruit during development. The thickness was measured in 3 positions; at stem end, at the side and at stylar end. Vertical bars indicate ±SD (n=5-15 fruit). Some SD values were smaller than the size of the symbols used.

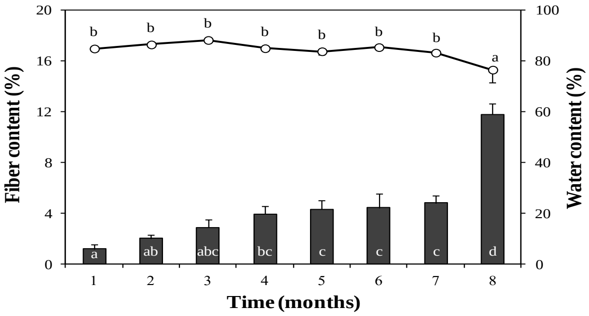

Fig. 3. Fiber content (column graph) and water content (line graph) in coconut husk during fruit development. Vertical bars indicate ±SD (n=3 fruit). Some SD values were smaller than the size of the symbols used. Significant differences (*P < 0.05*) are indicated in lower case letter.

Endocarp lignification and shell hardening. Stage II, defined as being the fruit development phase when fruit growth rate slows down, was defined as being 5 to 6 mo from flowering. The shell also attained maximum size at approximately 5 mo, and then remained the same size until harvest (Figs. 1A and 5). The phloroglucinol-HCl test first revealed lignin in the endocarp at 5 mo with accumulation starting at the stylar end. Lignin accumulation then progressed to the stem end and was completed around the entire shell by the 6 mo development stage (Fig. 5). The accumulation of lignin has been shown to be affected by temperature (Kritzinger et al. 2017) so the timing of lignin accumulation may differ from year to year. In this study, chemical determination of the lignin content showed that accumulation started at 4 mo but, in contrast, the lignin staining did not reveal the presence of lignin until 5 mo of development. The possible reason for this difference in timing is that the water content at 4 mo was still high and started to decrease at 5 mo (Figs 4 and 5). Therefore, the concentration of lignin is diluted by water at the 4 mo stage and the concentration of lignin at 4 mo may not be sufficient for staining to occur as the phloroglucinol-HCl test for lignin is not very sensitive. The lignin content in the shell of 'Nam Hom' coconut was about 26% which is considerably less than that previously reported in the shell of tall type coconut (27-50%) (Cagnon et al. 2009).

The concentrations of cellulose and hemicelluloses in the coconut shell were measured during fruit development. The concentration of cellulose was approximately twice that of the hemicelluloses throughout fruit development. Both increased exponentially until 6 mo after flowering and then remained constant until harvest (Fig. 6). This indicates that the endocarp accumulated a large amount of cellulose and hemicelluloses during endocarp hardening, and that the accumulation progresses continuously during stage III, similarly to that in peach (Ryugo, 1962; Hayama et al. 2006). The concentration of cellulose in the shell of the 'Nam Hom' coconut was about 40-43% and, therefore, similar the cellulose content in the shell of tall coconut (van Dama et al. 2004). This indicted that cellulose content is likely to be related to the mechanical strength of the shell during hardening in the 'Nam Hom' coconut (Hayama et al. 2006).

Endocarp lignification proceeded rapidly concomitant with the decrease in water content in the shell and with the increases in the concentrations of cellulose and hemicelluloses (Figs 4, 5 and 6). The coconut shell became a dark color and it was very difficult to cut the shell with a sharp knife by 6 mo after flowering. As the result, the coconut shell lost flexibility and became rigid. In Japanese plum, the creation of more rigid stones (endocarp), made them more prone to breakage (Kritzinger et al. 2017). Consequently, a loss of flexibility in the shell during lignification might enhance the chance of shell cracking or shell splitting in 'Nam Hom' coconut.

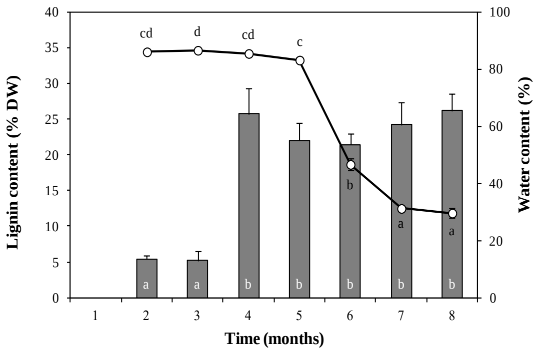

Fig. 4. Lignin content (column graph) and water content (line graph) in coconut shell during fruit development. Vertical bars indicate ±SD (n=3 fruit). Some SD values were smaller than the size of the symbols used. Significant differences ($P < 0.05$) are indicated in lower case letter.

Fig. 5. Time-course of shell hardening as shown by the degree of lignifications using phloroglucinol-HCl stain. Transverse sections of the whole fruit were stained with phloroglucinol-HCl reagent. Bright red coloration is indicative of lignins. Lignin was detected from 5 mo in endocarp tissue (shell) through the period of development tested in this study. Vertical bar indicate scale. The inflorescences of coconut were tagged in January 2014 and January 2015.

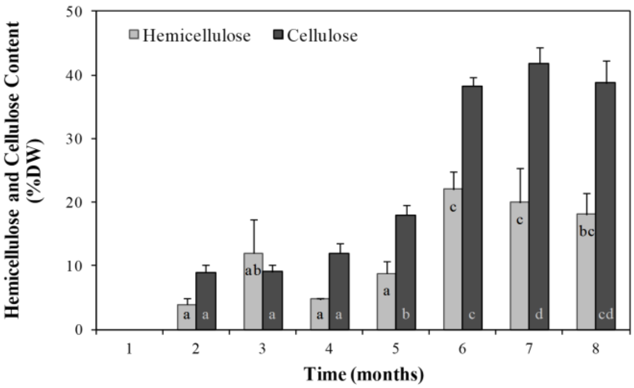

Fig. 6. The content of hemicelluloses and cellulose in coconut shell during fruit development. Vertical bars indicate +SD (n=3 fruit). Significant differences ($P < 0.05$) are indicated in lower case letter. Black lower case letter for hemicellulose and white lower case letter for cellulose.

Boron and calcium concentrations in the husk and shell. Boron and calcium concentrations in the husk and in the shell were studied during fruit development. The coconut husk had greater concentrations of both boron and calcium than those determined in the coconut shell. Boron concentration in the coconut husk decreased with fruit age whereas the highest concentration in the coconut shell occurred at 4 - 5 mo and then subsequently decreased (Fig. 7A). It is noted that boron is necessary for shell formation in peach (Evert et al. 1988). Calcium concentration in the coconut husk declined by only a small amount throughout fruit development, while calcium concentration in the coconut shell decreased with fruit age (Fig. 7B). There was a sharp decrease in calcium concentration in the coconut shell at 5 to 6 mo during the shell hardening phase.

Principle component analysis (PCA) base on a correlation matrix showed that the first component (PC1) with an eigenvalue greater than 1.0 contributed about to 76.26% of the total variation (data not shown). The highest loadings in PC1 (component 1) indicated the importance of this component, with cell wall component, boron and calcium representing the largest portion of those associated with the shell formation in 'Nam Hom' coconut (Fig. 8). PCA analysis revealed that lignin, cellulose and hemicellulose concentrations were strongly associated with lignification of endocarp (Figure 4-6, 8). While, the calcium and boron concentrations were well correlated with the early stage of endocarp development (2-5 mo) (Fig. 7-8).

According to these data indicated that the high calcium and boron concentration in coconut shell of 2-5 mo after flowering play a role in the primary cell wall synthesis. Calcium plays a key function of the cell wall structure (Helper 2005) while boron plays a role in cell wall ultrastructure, which is critical to cell-wall expansion (Hu and Brown 1994). Thus, boron and calcium seem to play important role in the shell formation at early stage. However, coconut fruit at 4-5 mo after flowering revealed the highest boron concentration in coconut shell (Fig. 7A) and was well correlation with this stage (Figure 8) during lignin accumulation and water content decreased (Fig. 4). These indicated that boron might be used as a precursor for the lignin biosynthesis (Lewis 1980). The rapid deposition of lignin coincided with increase in cellulose and hemicellulose (Fig. 6 and 8) and, the growth rate of shell started decrease and the size of shell was constant at the later stage (Fig. 1C). The excess boron limits the growth of tobacco cells, it enhances the strength of the wall (Ghanati et al. 2002). Therefore, the deposition of lignin with in cellulose-hemicellulose net work leads to the secondary cell wall as a natural lignocelluloses (Chen 2014).

The results showed that both boron and calcium were necessary for shell formation and endocarp lignifications in ‘Nam Hom’ coconut. Therefore, application of both boron and calcium during fruit development should be recommended for reducing some physiological disorders and for improving fruit quality. Boron deficiency causes fruit cracking, a blackening of the husk, or the lack of a shell (Kamalakshiamma et al. 2000; Kamalakshiamma and Shanavas, 2002) and calcium is an important nutrient for fruit quality (Stebbins et al. 1972).

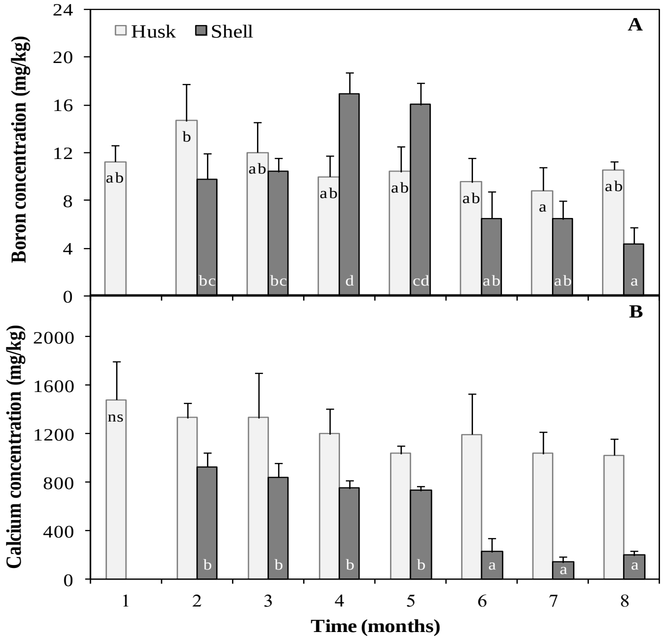

Fig. 7. The concentrations of boron (A) and calcium (B) in the coconut husk and coconut shell during fruit development. Vertical bars indicate +SD (n=3 fruit). Significant differences (*P < 0.05*) are indicated in lower case letter. Black lower case letter for coconut husk and white lower case letter for coconut shell.

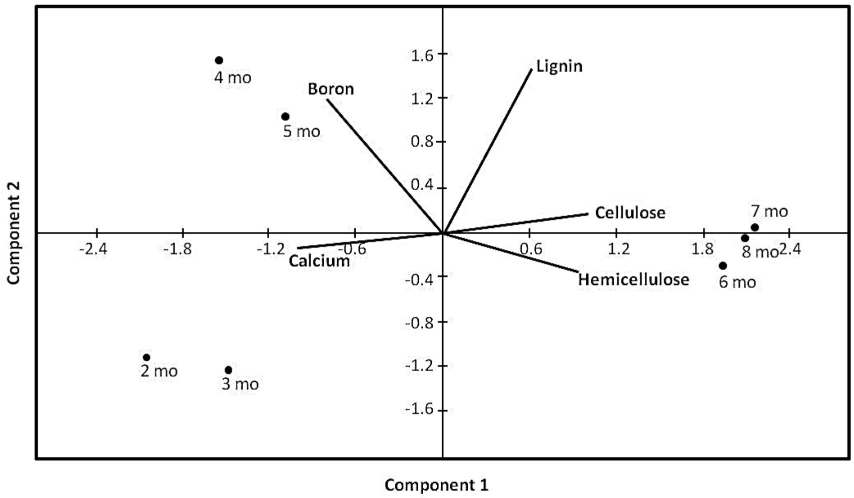

Fig. 8. Principal component analysis (PCA) of the analysis of lignin, cellulose, hemicelluloses, boron and calcium in the coconut shell (indicated by the green lines) and the coconut fruit age: 2 mo, 3 mo, 4 mo, 5 mo, 6 mo, 7 mo and 8 mo (mo = months after flowering).

CONCLUSIONS

The husk and shell of ‘Nam Hom’ coconut fruit grew rapidly in size during the first 5 mo after flowering and slowed down thereafter. Whole fruit shape during the first 4 mo after flowering was oval and turned to semi-oval at 8 mo. The shell was a round in shape from 5 mo onwards. Lignin accumulation started from the stylar end and progressed to the stem end of the endocarp (shell), and was completed by 6 mo. This stage was accompanied by a decrease in water content. The concentrations of cellulose and hemicelluloses in the coconut shell increased rapidly from 2 to 6 mo and then remained constant. The amount of fiber in the coconut husk increased with fruit age, being highest at harvest. Both boron and calcium concentrations were high in the shell when the fruit was young but decreased with development. Both elements are likely to be important for shell formation.

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IMPACT OF CLIMATE CHANGE AND ECONOMIC FACTORS ON MALAYSIAN FOOD PRICE

Kelly Kai Seng Wong [1 *], Chin Lee [2] and Wang Li Wong [3]
[1] Department of Agribusiness and Bioresource Economics, Faculty of Agriculture,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[2] Department of Economics, Faculty of Economics and Management,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[3] Department of Finance, Faculty of Accountancy, Finance and Business,
Tunku Abdul Rahman University College,
Jalan Genting Kelang, 50932 Kuala Lumpur, Malaysia
* Corresponding author: kellywong@upm.edu.my

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ABSTRACT

This paper is motivated by the increasing food price over the recent years (2010 – 2017) in Malaysia. Food is a necessity for mankind and everyone has equal rights to enjoy adequate food protecting from hunger and malnutrition. In general, we understand that food and agriculture production are highly related. Crop production is affected biophysically by climatic variables, *i.e.* suitable rainfall and temperature for photosynthesis process to take place. If these climatic variables alter extremely in a long-term period, crop production will be affected and crop damage can occur due to the climate change effect such as extreme flood and drought. Hence, if climate change effect is defined as a linear relationship, it will result in a misleading explanation whereby as long as rainfall and temperature increase (or decrease) it will cause the crop production to decrease (or increase). Given the problem associated with food price, this paper investigated the food price determinants by looking at both economic factors and climate change. Non-linear time series analysis namely Engle-Granger (EG) cointegration test and Error Correction Mechanism (ECM) were performed by including the determinants such as Carbon Dioxide (CO_2), crude oil price, exchange rate and real gross domestic product (RGDP). The results showed that both economic Real Gross Domestic Product and climate factors jointly affect food price significantly and climate factor (CO_2) exhibits a strong non-linear U-shaped impact on food price in the long run. In addition, the Error Correction Term (ECT) showed that food market will have a slower self-recovery mechanism to adjust and return the temporary food market demand-supply shock to the equilibrium.

Key words: food price, nonlinear cointegration

INTRODUCTION

From 2010 to 2017, the Malaysian food price exhibited a steep growth which surpassed the consumer price index (CPI) (Fig. 1). In 2017, the Malaysian food price index soared to a high record of 128.6 which indicates that the general level of food price has increased by about 28.6% compared to the year 2010. However, the CPI for 2017 was 119.4 which means that the national inflation had increased by 19.4% compared to the year 2010. This implies that food inflation is serious in Malaysia and CPI may no longer be an appropriate measurement for the cost of living in the country. The higher food price inflation will affect the social welfare especially by putting more burden on the lower income group. In general, the lower income group has to spend a greater proportion of income on food (Ibrahim, 2015). When the food price increases more than the consumers' food purchasing power, then the food may become a luxury good and consumers may be at risk of being on the food insecurity path. This could have an alarming effect among the low income group who may not have access to food and eventually suffer from chronic undernourishment situation. On the other hand, this posed danger to the nation's food price stability and food sustainability, which major concerns of the policy makers.

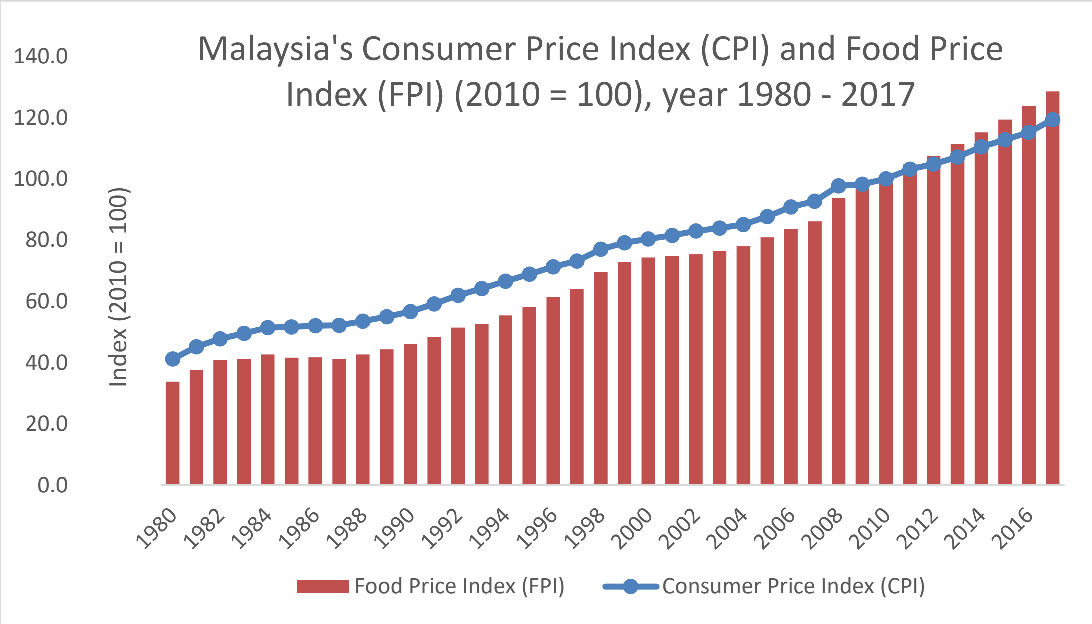

Fig. 1. Malaysia's Consumer Price Index and Food Price Index (2010 = 100), 1980 – 2017
Source: Bank Negara Malaysia's Monthly Statistical Bulletin, January 2018

In the recent decades, studies have showed that the crude oil price is the main factor that influences the increase in food price (*e.g.* Kwon and Koo, 2009; Nazlioglu and Soytas, 2011; Reberedo, 2012; Ibrahim, 2015; and Abdlaziz et al. 2016). Crude oil price is a direct factor influencing the producers' cost of production, such as transportation cost, product processing cost, etc. Hence, the impact of increase in crude oil price will drive food price to hike, and ultimately will generate the cost-push inflation in the food market. Due to Malaysian economy transformation from agriculture- and commodity-based to industrial-based economy, this increases the possibilities for the country to be exposed to global food and oil crisis (Ibrahim 2015). For instance, the global and Malaysia's food price crisis which occurred in 2008 and 2011 were impacted by the international crude oil price shock. Besides that, the other economic factors also will elevate food inflation. When Malaysian currency depreciated, a higher price will be paid for the imported food. Therefore, it will lead to the increase in food import bills and cause a higher increase in the food price.

However, food production and food price are also affected by the non-economic factors such as climate change. In general, we understand that the production of crops is affected biophysically by climatic variables. Without rainfall or temperature, crops will not grow. Increased rainfall and temperature at a lower level will enhance crop production. However, if these climatic variables rise extremely or over the optimum level, flooding or drought may occur which will damage crop production. According to Cai, Bandara, and Newth (2016), climate change has posed a major threat to agriculture which could be highly vulnerable to it. Some international non-government organizations (NGOs) and experts found that the climate change will cause a negative impact on food production. This explains that the extreme increase in temperature will reduce agriculture production (food availability decreases) (Sivakumar and Stefanski, 2011). Consequently, the yield loss will push the food inflation up. In a nutshell, if only linear analysis is applied, the effect of climate change on crop production will give a misleading explanation whereby as long as rainfall and temperature increase it will cause to the crop production to decrease.

In the recent decades, food price in Malaysia has increased and fluctuated with the changes in economic factors and also as a result from climate change. In order to address the food price movement, it is important to confirm the most pertinent variables to be controlled in order to tackle the fluctuation of food price in Malaysia. Therefore, this study aimed to determine the impact of economic factors (economic growth, exchange rate, and crude oil price) and climate change on the Malaysia's food price fluctuations.

The study on oil price pass-through effect into the food price fluctuation has captured much interest of many researchers (e.g. Nazlioglu and Soytas, 2011; Ibrahim and Said, 2012; Reberedo, 2012; Ibrahim, 2015; Abdlaziz et al., 2016). Besides that, Harri et al. (2009), Kwon and Koo (2009) and Baek and Koo (2010) found that the exchange rate movements and petroleum price played a significant role in determining the food price inflation. This indicates that the exchange rate itself is playing an important role in determining the food price fluctuation (Roache and Rossim, 2010). According to Abdlaziz, et al. (2016), the depreciation of US dollar was one of the important factors that influences global food prices and this was supported by Nazlioglu and Soytas (2012)'s findings. Hence, exchange rate is expected to show a positive causal impact on food price in Malaysia. Ibrahim (2015) has posited that the depreciation of Malaysian Ringgit will lead to the increase in Malaysia's food import bill and subsequently drive the domestic food price upwards. Futhermore, most of the studies also included real GDP to determine the food price changes (Ibrahim and Said, 2012; Ibrahim, 2015; Abdlaziz et al. 2016; and Tadasse et al. 2016). The real GDP was found to have a significant positive impact on agriculture commodity and food price in many literatures. This indicates that the rise of economic productivity will increase the national income which would result in the upward shift of the aggregate demand curve and consequently drive the food price hike.

The likely negative impact of climate change on agriculture has important implications for the developing countries and temperature increases will led to the decrease in agriculture productivity (Cervantes-Godoy and Dewbre, 2010). According to Bandara and Cai (2014), climate change will cause agriculture yield losses and drive the food price to increase. This implies that climate change will give some negative impacts on the food production through the decrease of agriculture production and then increase in market food price. According to Parry et al. (2004), biophysical effects explain the linkages between climate change and agricultural responses. Accordingly, the production of crop is affected biophysically by climatic variables, such as the rise in temperatures, changes in precipitation regimes, and increase in atmospheric carbon dioxide levels. However, the direct effects of CO_2 on crops' yield are widely used as a proxy for the temperature raise in climate change impact studies[1] (Kimball et al. 2002; Derner et al. 2003; Tubiello and Ewert, 2003; Parry et al. 2004). For instance, Ekpenyong and Ogbuagu (2015) employed the sum of the three popular greenhouse gas emission (CO_2, methane and nitrous oxide emissions) as a proxy for climate change and found that the climate change has a negative impact on the agricultural productivity.

However, Huong, Bo, and Fahad (2018), using quadratic Ricardian model, found that the climate change or meteorological variables have an inverted U-shaped relationships with agriculture revenue. This indicates that the agriculture productivity will increase up to a certain level of CO_2 but will decrease when the temperature or CO_2 greenhouse gas emission increases over the threshold value. Hence, climate change is also believed to have a nonlinear U-shaped relationship with the food price.

[1] Most of the researchers have agreed that the greenhouse gas emission (CO_2) could serve as a proxy to capture the temperature and climate change effect (Nelson et al. 2009; Sivakumar and Stefanski, 2011; and Bandara and Cai, 2014).

In terms of the normal biophysical effects, increased temperatures below the threshold level will increase the agricultural productivity and subsequently it will drive the food price to decrease. In this situation, temperature and food price have a negative relationship. In contrast, excessive temperatures are amplifying drought effects and consequently cause a loss of crops and agricultural production (Bates et al. 2008; Brown and Funk 2008; Adhikari et al. 2015). Consequently, the decrease in food supply will drive the soaring food price when the temperature rises higher than the threshold value.

In the past, most of the researchers only focused either the impact of economic factors (Aker and Lemtouni, 1999; Arshad, 2012; Applanaidu et al. 2013, Ibrahim 2015) or climate change effects on the food price movement (Ericksen, 2008; Gregory and Ingram, 2008; Ericksen et al. 2009). However, there are limited food price studies that covered both climate change and economic factors on their research works. The impact of temperature on the food price is not yet analyzed in literature especially in the case of Malaysia. In order to fill in this research gap, this study examined the impacts of both economic factors and climate change on the Malaysia's food price movement in a non-linear analytical approach.

METHOD OF ANALYSIS

Cointegration test is one of the basic approaches to confirm that estimated time series regression does not produce a spurious regression. In this study, the Engle-Granger cointegration test (hereafter EG) and Error Correction Mechanism (ECM) regression were adopted. The first step to test the cointegration in EG test was to estimate the long-run equation with Ordinary Least Square (OLS) method, which is:

$$Y_t = c + \beta_1 X_t + \varepsilon_t \tag{1}$$

where Y_t denotes the endogenous variable and X_t denotes the exogenous variable(s).

In this study, the food price was estimated based on the supply-demand theory. The food demand (Qd) was determined by the food price index (FPI), currency exchange (MYR) which captured the food trade effect whereas the RGDP captured the aggregate demand for food:

$$Qd_t = \alpha_1 - \lambda_1 \, FPI_t + \lambda_2 \, MYR_t + \lambda_3 \, RGDP_t + \varepsilon_{1t} \tag{2}$$

In supply theory, quantity supplied (Qs) is determined by the market food price (FPI), and crude oil price (COP) which captures the cost of production. However, according to the Ricardian quadratic model, agriculture production is affected by the climate change in a non-linear inverted U-shape (see Huong, Bo, and Fahad, 2018). As mentioned before, the normal increase in temperature will increase crop production due to the biophysical effects. However, the decrease in agriculture production due to the excessive temperatures such as CO_2 gas emission (Parry et al., 2004) will drive the market food supply shock and then food price hike (Edoja et. al. 2016). Hence, the climate change variable should be included into the food supply model which is as follows: [2]

$$Qs_t = \alpha_2 + \lambda_4 \, FPI_t - \lambda_5 \, COP_t + \lambda_6 \, CO_{2\,t} - \lambda_7 \, CO_2{}^2{}_t + \varepsilon_{2t} \tag{3}$$

Under the market equilibrium situation, the Qs is equal to the Qd or the equation (2) is equal to the equation (3). Hence, the market food price can be estimated as:

$$\alpha_1 - \lambda_1 \, FPI_t + \lambda_2 \, MYR_t + \lambda_3 \, RGDP_t + \varepsilon_{1t} = \alpha_2 + \lambda_4 \, FPI_t - \lambda_5 \, COP_t + \lambda_6 \, CO_{2\,t} + \lambda_7 \, CO_2{}^2{}_t + \varepsilon_{2t}$$

[2] The CO_2-squared represents the nonlinear U-shaped effects of climate change on the food price as mentioned before.

λ_1 FPI $_t$ + λ_4 FPI $_t$ = α_1 + λ_2 MYR $_t$ + λ_3 RGDP $_t$ + $\varepsilon_{1\,t}$ – α_2 + λ_5 COP $_t$ – λ_6 $CO_{2\,t}$ + λ_7 $CO_2^2{}_t$ – ε_{2t}

$$FPI_t = \alpha_1 - \alpha_2 + \lambda_2\, MYR_t + \beta_3\, RGDP_t + \beta_5\, COP_t - \beta_6\, CO_{2\,t} + \beta_7\, CO_2^2{}_t + \varepsilon_{1t} - \varepsilon_{2t} \quad (4)$$

To simplify equation (4), we re-write the food price function as:

$$FPI_t = c + \beta_1\, COP_t + \beta_2\, MYR_t + \beta_3\, RGDP_t - \beta_4\, CO_{2\,t} + \beta_5\, CO_2^2{}_t + \varepsilon_t \quad (5)$$

where the $c = \frac{\alpha_1 - \alpha_2}{\lambda_1 + \lambda_4}$, $\beta_1 = \frac{\lambda_5}{\lambda_1 + \lambda_4}$, $\beta_2 = \frac{\lambda_2}{\lambda_1 + \lambda_4}$, $\beta_3 = \frac{\lambda_3}{\lambda_1 + \lambda_4}$, $\beta_4 = \frac{\lambda_5}{\lambda_1 + \lambda_4}$, $\beta_5 = \frac{\lambda_7}{\lambda_1 + \lambda_4}$, and $\varepsilon_t = \frac{\varepsilon_1 - \varepsilon_2}{\lambda_1 + \lambda_4}$.

Oil price hike, depreciation of domestic currency and economic expansion will lead to increase in food price. Following this, COP, MYR, and RGDP were expected to have positive sign. However, the climate change should have U-shaped relationship, indicating that the CO_2 and CO_2-squared were expected to have negative and positive sign, respectively.

Therefore, we can estimate the Equation (5) using simple OLS and then obtain and use the residual series from this estimated regression to estimate a *k* lag augmented regression which can be expressed as:

$$\Delta\hat{\varepsilon}_t = (\rho - 1)\hat{\varepsilon}_{t-1} + \sum_{j=1}^{k} \delta_j \Delta\hat{\varepsilon}_{t-j} + u_t \quad (6)$$

where the $\Delta\hat{\varepsilon}_t$ indicates the first difference of estimated error term which is obtained from the Equation (5). If the null hypothesis of ρ-1=0 is rejected in the Augmented Dickey Fuller (ADF) test, it indicates that the estimated variables (COP, MYR, RGDP, CO_2, CO_2^2 and FPI) have a long-run cointegrated relationship and the long-run estimated regression or Equation (5) do not produce a spurious regression. After the cointegration test, we proceeded to the ECM estimation in order to confirm the short-run equilibrium among the estimated variables. In ECM, we considered the error term ($\hat{\varepsilon}_t$) in the Equation (5) as the long-run equilibrium error or the disequilibrium magnitude. Hence, we can use the error term to tie the short-run behaviour of food price (FPI) to its long-run value. In general, the ECM is written as:

$$\Delta y_t = \Omega_0 + \alpha\hat{\varepsilon}_{t-1} + \sum_{i=1}^{k} \Phi_i\, \Delta y_{t-i} + \sum_{h=0}^{r} \theta_h\, \Delta x_{jt-h} + u_t \quad (7)$$

where the u_t is the stochastic term and $\hat{\varepsilon}_{t-1}$ is the lagged value of the error term in Equation (5). Besides that, the y_t represents the FPI_t and the x_j represents the exogenous, including COP, MYR, RGDP, and CO_2. The *k* and *r* are the optimum lag length selected based on the general to specific approach and in order to avoid the auto-serial correlation on u_t. In addition, α is the long-run speed of adjustment, also known as error correction coefficient, while Φ_i and θ_h illustrate that short-run elasticities.

In this study, ECM Equation (7) can be re-written as:

$$\Delta lnFPI_t = \Omega_0 + \alpha\ ECT_{t-1} + \sum_{i=1}^{k} \Phi_i\, \Delta lnFPI_{t-i} + \sum_{h=0}^{r} \theta_h\, \Delta lnCOP_{t-h} + \sum_{h1=0}^{p} \theta_{h1}\, \Delta lnMYR_{t-h1} + \sum_{h2=0}^{q} \theta_{h2}\, \Delta lnRGDP_{t-h2} + \sum_{h3=0}^{r} \theta_{h3}\, \Delta lnCO_{2\,t-h3} + \sum_{h4=0}^{s} \theta_{h4}\, \Delta lnCO_{2\,t-h4}^2 + u_t \quad (8)$$

where: the ECT_{t-1} = ln FPIt – c – $\beta_1$ln COP_t – β_2 ln MYR_t – β_3 ln $RGDP_t$ – β_4 ln CO_{2t} – β_5 ln $CO_2^2{}_t$ and α in Equation (8) is the magnitude of self-adjustment which expected to be negative if the variables are cointegrated.

Data collection. In this study, time series data from 1980 to 2017 were used to estimate the factors determining the food price in Malaysia. The Food Price Index (FPI) was adopted to represent Malaysian food price. Furthermore, the crude oil price (COP) was proxied by the West Texas Intermediate crude oil price in US dollar per barrel and the Malaysian exchange rate (MYR) measured in ringgit per US dollar. All of these variables were adopted from the Monthly Statistical Bulletin published by the central bank of Malaysia *(www.bnm.gov.my)*. However, the CO_2 gas emission is a proxy for the climate changed effects and the real income was represented by the real gross domestic product (RGDP) and measured in millions ringgit as adopted from *https://data.worldbank.org/indicator*.

RESULTS AND DISCUSSION

In this study, secondary data was used to determine the food price fluctuation. Hence, the basic requirement of time series data was to examine the data stationary level. It is necessary to check the unit roots whether the data are stationary at order zero or $I(0)$ or stationary at order one or $I(1)$. Table 1 shows the summarized results of the unit root test using the Augmented Dickey-Fuller (ADF) and Philip-Perron (PP) test. The ADF and PP tests showed that all variables had failed to reject the null hypothesis of unit roots in level form, indicating that all the variables were not stationary at order zero. Hence, the data was transformed into first difference form to re-test the stationarity of the data. Consequently, the ADF and PP tests confirmed that all data rejected the null hypothesis of unit roots at 1% significance level. This indicated that these data were stationary at order one or $I(1)$.

Table 1. Augmented Dickey Fuller (ADF) and Philip-Peron (PP) Unit root tests

	Level		**First Difference**	
Variables	**ADF**	**PP**	**ADF**	**PP**
FPI	-0.396	-0.414	-4.659***	-4.664***
	(0)	(2)	(0)	(2)
COP	-1.206	-1.261	-5.567***	-5.567***
	(0)	(2)	(0)	(0)
RGDP	-1.147	-1.094	-4.824***	-4.838***
	(0)	(1)	(0)	(1)
MYR	-1.131	-1.157	-6.032***	-6.031***
	(0)	(2)	(0)	(2)
CO_2	-1.355	-1.417	-6.554***	-6.517***
	(0)	(1)	(0)	(3)
CO_2^2	-1.133	-1.173	-6.570***	-6.540***
	(0)	(1)	(0)	(2)

Note: All variables are converted into the form of logarithm, *** represents as significant at 1% significance level. The number in the parenthesis (…) represents the optimum lag selected for the test. To select optimum lag order in ADF test, the Schwarz Info Criterion (SIC) is adopted and to select the best lag order in PP test, Newey-West Bandwith (NWB) is used.

Engle-Granger Cointegration Test. The result for the Engle- Granger cointegration test showed that the model's stochastic term (u_t) is stationary at order zero or $I(0)$ and rejects the null hypothesis of no cointegration relationship at 1% significant level (Table 2). Therefore, all the exogenous variables (COP, MYR, RGDP, CO_2, and CO_2^2) showed that a long-run cointegration relationships with the food price movement.

The long-run regression showed that all the explanatory variables followed the expected sign but only RGDP and CO_2 were highly significant at 1% significance level while CO_2^2 were statistically significant at 5% significance level. The estimated elasticity of RGDP is 0.7806 which defines that 1%

increase in RGDP will lead to food price rise about 0.7806%, holding other factors constant. Similar with the finding of other researchers, climate change was found to have a nonlinear impact on the food price. The long-run regression showed that the gas emission (CO_2) had a U-shaped relationship on the food price movement.[3] The elasticity of CO_2 showed that 1% increase of CO_2 will reduce the food price by 1.867%. The threshold value of the CO_2 is 286,244.04 kiloton (kt) which indicates that if the gas emission CO_2 raise more than this level, agriculture production will decrease and drive the food price to increase.[4] In 2017, the total greenhouse gas CO_2 emission in Malaysia was recorded at 280,908.09 kt which is close to the threshold level.[5]

Table 2. Summary of Engle – Granger Cointegration Test

FPI	C	COP	MYR	RGDP	CO_2	CO_2^2
	α	**β₁**	**β₂**	**β₃**	**β₄**	**β₅**
	-5.2288	0.0046	0.0830	0.7806***	-1.8671***	0.0743**
	(-0.929)	(0.205)	(1.189)	(5.291)	(-2.814)	(2.358)
Engle-Granger Cointegration Test: (Δu_t= -ρu_{t-1} + $\sum_{i=1}^{k} \beta_i$ Δu_{t-1})					-4.0772*** [0]	
Critical Values:				**1%**	**5%**	**10%**
				-4.07	-3.37	-3.03

Notes: ***, ** and * denotes significant at 1%, 5% and 10% respectively. The figure in the parenthesis (…) represents the t-statistic for the coefficient. The figure in the bracket […] denotes the optimum lagged selected based on the SIC.

Error Correction Mechanism (ECM). In order to show the unbiased estimation of ECM model, some crucial diagnostic tests were applied *i.e* R-squared, auto-serial correlation test, Jarque-Bera normality test, and ARCH test. In this ECM model, the R-squared was 0.564 which indicates 56.4% of the variation of ΔFPI is explained by ΔCOP, ΔMYR, ΔRGDP, ΔCO_2 and ΔCO_2^2, while the remaining 43.6% were not explained by other factors that are not included in the estimated regression. In addition, the F-statistic was statistically significant at 1% significance level which indicates that the model was fitted and explained by the all independent variables. In order to confirm that the estimated regression was free from the auto-serial correlation problem, the auto-serial correlation test was applied and result was not significance to reject the null hypothesis that the residuals are serial correlated. On the other hand, the estimated regression's residual was not correlated and the ECM model was confirmed unbiased. In addition, the regression's residual was found normally distributed and the variance of the residual was homoscedasticity and constant. This was confirmed by the Jarque-Bera test and ARCH test, both of which failed to reject the null hypothesis. In addition, the CUSUM and CUSUM square (Figure 3) showed that the coefficients in this estimated ECM were stable and the model was Best Linear Unbiased Estimator (BLUE).

[3] The F-statistic for the null hypothesis $\beta_4 = \beta_5$ is 19.22 and the p-value is 0.0001, which reject the null hypothesis and this infer that the quadratic relationship exist in this model.

[4] The threshold value is calculated based on the first derivative on the long-run regression, which is $\frac{\partial FPI}{\partial CO2} = -1.8671 + 0.1486\, lnCO_2 = 0$. After the mathematic solution on this derivative function, the $\exp(CO_2)$ is equal to exp(12.5646) = 286,244.04.

[5] The Malaysia's CO_2 is based on the World Bank Indicator and retrieved from *https://data.worldbank.org/indicator.*

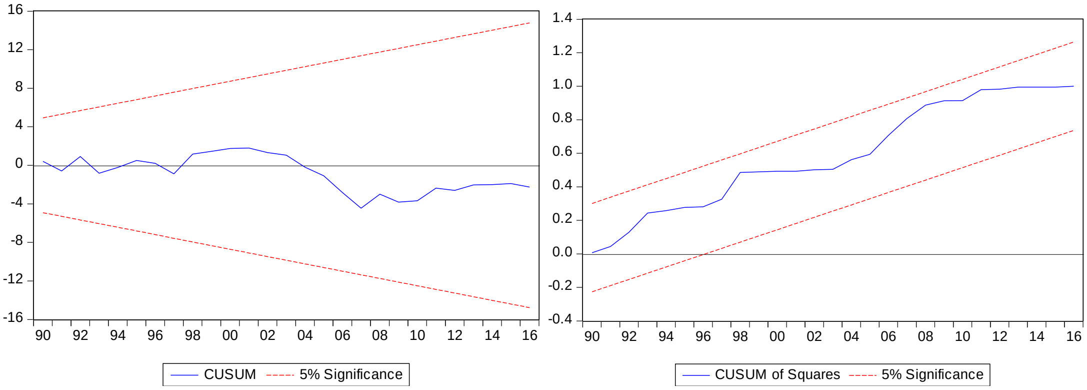

Fig. 3. CUSUM and CUSUM square for the ECM model

In this study, the findings of ECM showed that all short-run variables bore the expected signs (Table 3). The negative coefficient for the error correction term (ECT) lagged one was estimated in value of -0.3975 and it was statistically significant at 1% significance level. This indicates that the food market adjustment is playing a significant impact on auto-convergence which is the short-run disequilibrium and will automatically return to the initial equilibrium point. Moreover, the magnitude of the speed of adjustment (-0.3975) showed that the market itself has a moderate speed to converge into the long-run.

Based on the estimated ECM, the short-run elasticity for FPI lagged one was statistically significant at 1% level. However, the exogenous variables were not significant in affecting the short-run changes of FPI. This indicates that the changes of food price in short-run was based on the food market itself but not on the external factors. Furthermore, the estimated F-statistic 2.933 (p-value = 0.0978) showed a non-significant relationship to reject the null hypotheses that the short-run elasticities of CO_2 is equal to the elasticities of CO_2^2. This indicates that the CO_2 still has a quadratic relationship with the changes of food price but it was at a lower confidence level.

Based on the findings, there are some policy implications that can be suggested. Firstly, this study showed that the food market has self-recovery mechanism to adjust to the temporary food market demand-supply shock back to the equilibrium. Hence, policy-maker should focus on the long-run food price hike than short-run price shock since the short-run market self-adjustment (ECT) was significant. Secondly, the economic growth will increase the household purchasing power and increase the market food price in long-run. This suggests that the food market should have a well-planned strategy on their agriculture or food supply and government has to ensure food self-sufficiency or not to decrease food production. Otherwise, the food crisis such as that of the 2007/2008 international food crisis can happen again. Finally, the non-linear climate change effect suggests that the importance of water supply facilities and good irrigation system to address the problem of drought when the temperature increases over the threshold value. Hence, the threshold level of the temperature provided a significant warning information for the farmers. In 2017, the greenhouse gas CO_2 emission in Malaysia was recorded close to the threshold level, hence, policy maker should strengthen the existing rules and regulations to restrict the manufacturing sector from producing more greenhouse gases in order to slow down the CO_2 emission and prolong the time to reach the threshold level. For example, government can sell permits to address the greenhouse gas issues or implement a pollution tax for such as gas emission. In addition, government also can provide research grant and subsidies to expand the sustainable energy source (solar energy) in order to reduce the coal and fossil fuel use.

Table 3. Summary findings of error correction mechanism

Variable	Coefficient	Standard Error	P- Value
C	0.0194**	0.0071	0.011
ECT_{t-1}	-0.3975***	0.0885	0.0001
ΔFPI_{t-1}	0.3885***	0.1148	0.0022
ΔCOP_t	0.0069	0.0127	0.5901
ΔMYR_t	0.0029	0.0350	0.9352
$\Delta RGDP_t$	0.1289	0.1005	0.2101
ΔCO_{2t}	-1.0353*	0.5997	0.0957
$\Delta CO_2{}^2{}_t$	0.0414	0.0267	0.1325
Diagnostic Checking:			
R square		0.564	
Adjusted R square		0.452	
F- statistics		4.999*** [0.001]	
Serial Correlation		4.4842 [0.1062]	
Normality Jarque-Bera		1.6572 [0.4366]	
ARCH		0.4867 [0.4854]	

Notes: ***, ** and * denotes significant at 1%, 5% and 10% respectively. The figure in the parenthesis (…) represents the standard error for the result. The figure in the bracket […] denotes the p-value.

CONCLUSION

In the recent decades, the food price in Malaysia has increased rapidly. Therefore, this study aimed to investigate the impact of economic factors (economic growth, exchange rate, and crude oil price) and climate changed towards Malaysia's food price fluctuation. This study had employed the cointegration method on data over 38 years from 1980 to 2017. As for the overall findings, for the ADF and PP tests, all the variables were stationary after transformed into first difference or $I(1)$. The test for cointegration showed that there is long run cointegration between the food price and the underlying variables (i.e. COP, MYR, RGDP and CO_2). This means that all the independent variables jointly and significantly affect the food price in the long-run. The result showed that in the long run, increase in RGDP, MYR, and COP will lead to increase in food price. However, in a short period, the crude oil price, currency exchange, and real GDP have insignificant impact towards food price fluctuations. The changes in food price in a short period were solely caused by its own lag and the ECT. As claimed by classical economists, market price always acts like an "invisible hand" to adjust the market shock back to the equilibrium situation in all free market. Furthermore, climate change is found to have a strong non-linear U-shaped impact on the food price change in the long-run but it was a weak quadratic impact in a shorter period which clarified the critics made in this study.

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TECHNICAL EFFICIENCY OF WOMEN IN INDIGENOUS RICE PRODUCTION IN SAGADA, MOUNTAIN PROVINCE, PHILIPPINES

Emmanuel C. Flores and Julieta A. Delos Reyes
Department of Agricultural and Applied Economics
College of Economics and Management
University of the Philippines Los Baños
Corresponding author: jadelosreyes@up.edu.ph

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ABSTRACT

This study assessed the technical efficiency (TE) of *Kankanaey* women in rice production in Sagada, Mountain Province, Philippines. Primary data were collected in February 2016 for cropping period December 2014 to May 2015. From 120 respondents interviewed, 139 male-headed and 139 female-headed rice parcels were studied. The factors of production and TE were determined using stochastic production frontier analysis while mean differences between genders were t-tested. Small rice parcels had lower production because they were more difficult to cultivate, used lesser seeds, high-yielding variety (HYV) and rodenticide. These constraints, along with problems of *saktoto* worm infestation and lack of water were more often experienced in women-managed parcels. These parcels had lower TE and production due to: non-participation of women in *dap-ay*; inadequacy of man-labor; smaller size of parcels; inadequate logistical and infrastructure support for dilapidated terraces and pathways; lack of irrigation water; and lack of organic inputs for rice production. Women inclusion in the *dap-ay* especially in determining the agricultural calendar and declaration of ubaya; reviving the *lampisa* system for irrigation management; expansion of rice parcel area; practicing *ub-ubbo*; provision of logistical and infrastructure support for indigenous rice farming; and provision of rice technical support for organic rice farming were recommended.

Key words: stochastic production frontier analysis, Indigenous Peoples, women empowerment

INTRODUCTION

In the Mountain Province of the Philippines, where historically rice self-sufficiency had been attained, rice is grown in mountainous areas with slopes varying from 0° to 30° and have more complex irrigation systems. One of the rice farming communities in the province is the *Kankanaeys* of Sagada, traditionally referred to as indigenous peoples (IP) belonging to the *Igorots* or the "people of the mountains" (ILO, 2007). They are known for their stone-walled rice terraces with areas ranging from few square meters to half a hectare. The use of advanced agricultural machineries and high yielding varieties (HYVs) are usually prohibited by their environment and culture. They follow an agricultural calendar determined by biophysical, meteorological and hydrological factors. Community rituals like *ubaya* (observance of holiday or no workday) are observed during occurrences of human sickness or death or crop pest infestation and prohibit villagers to work on their farms. The traditional practices of both men and women have made their rice production sustainable for centuries (Corpuz, 2002).

The decline in *Kankanaeys*' rice production is partially attributed to their integration into the cash economy leading them to favor production of cash crops, and the men's entry into the labor market. Specifically, starting the 1980s, small-scale gold mining became popular, shifting man-labor from farming to mining. Thus, gender division of labor and source of management in their rice farming were affected. Currently, women are the common source of management and labor in their rice production. They take the roles of men in rice farming which include heavy works in sloping and high stone-walled rice fields. Although land preparation is still usually done by men, increasingly, their rice fields are becoming female-headed, worked by women and their children (Corpuz, 2002).

Several studies claimed that despite the increasing role of women in agriculture, still there are gender gaps when it comes to access to land, extension, technology, finance, time, mobility and information which affect technical efficiency (TE). Women have smaller and more dispersed parcels and are less likely to secure tenure. They have less access to extension services usually provided for male farmers on the invalid hypothesis that information will drip across to women. They use lower levels of technology due to limited access or cultural restrictions. They have less access to formal financial services due to high transaction costs, limited education, socio-cultural constraints and collateral requirements. They have greater time constraint and are less mobile due to childcare and household works. Lastly, they are less educated which hampers access to and ability to understand technical information and they also have less access to agriculture-related trainings and seminars (Fong and Bhushan, 1996 as cited by Lamug, 2004). Meanwhile, according to FAO (2010), while productivity is affected by various factors such as climate, temperature, quality of seeds, fertilizers, among others, the technical knowledge of farmers is the most important factor to increase productivity. Also, even with the availability of new agricultural machineries and seed varieties, some farmers chose to continue their traditional practices which are commonly less productive, such that many have not yet achieved full potential yield, giving rise to technical inefficiency.

In the context of *Kankanaey* women who are increasingly assuming major roles in rice farming, the question of whether such claims of some authors are true or not needs hard evidences. It is essential therefore that gender studies in agricultural productivity, particularly in rice, which is the major crop of the *Kankanaeys* be done, for empirical support. With these, the question of whether or not *Kankanaey* women are able to efficiently manage their indigenous rice production and increase rice productivity, given their existing resources and technology can be answered. The current study attempted to answer this question and to find out other issues related to TE of women rice farmer-managed parcels, as well as how they can be addressed. Specifically, it: described the indigenous rice production practices of *Kankanaeys*; assessed the TE of their managed rice parcels; determined the factors affecting their TE; and identified the problems in their indigenous rice production.

This study was anchored on the hypotheses that female-headed parcels are more technically inefficient than male-headed, and that certain socio-economic characteristics and adherence to cultural practices of rice parcel head and characteristics of rice parcels affect TE of indigenous rice production.

CONCEPTUAL FRAMEWORK

Figure 1 shows that there can be differences in TE between rice parcels being managed by males and females because of socio-economic diversities among the farmers themselves. Foremost of these is the shifting of male labor into mining thus increasing women management of farms. This is very important because there are inherent disparities between what women and men can physically do in the farm and this can impose some limitations on the efficiency of farm management. The characteristics of rice parcels can also be critical in farm management, particularly the size and distance from irrigation facility, seedbed, input supplies, and place of residence of rice parcel head. Difference in location between own parcel and co-managed parcels and their bio-physical characteristics may likewise affect TE due mainly to the terrain and the sloping nature of the terraces. Furthermore, observance of agricultural calendar and rituals such as *ubaya* can be diverse between men and women, since there is gender division in the management of their ancestral domain and its resources. *Ubaya* refers to the unifying community holiday similar with Sabbath. The traditional leadership institution for men (*dap-ay*) is responsible for the observance of their farming calendar while women are commonly tasked to oversee activities of villagers during *ubaya*. Farm management practices (input utilization) are affected by differences between genders and directly affect TE which affects output.

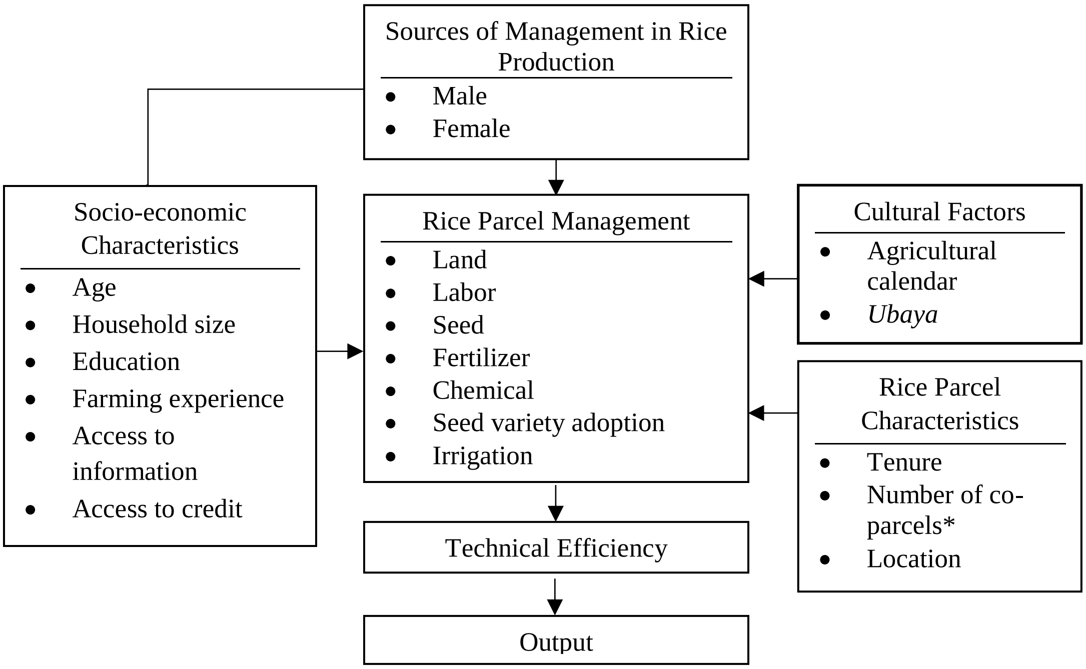

Fig. 1. Conceptual framework used in analyzing the effects of gender on TE of indigenous rice production in Sagada, Mountain Province, Philippines

*Co-parcel is defined in this study as other rice parcels simultaneously managed by the same farmer.

RESEARCH METHODOLOGY

The study was conducted in Pidlisan, Sagada, Mountain Province, consisting of barangays Aguid, Bangaan, Fidelisan and Pide. Personal interviews of 120 rice parcel heads (60 males and 60 females) selected through stratified random sampling were performed using pre-tested interview schedule for detailed rice production data for single cropping year December 2014 to May 2015.

Rice parcels of different locations were treated as separate units of the parcel head due to differences in bio-physical characteristics such as soil fertility, temperature, slope, source of irrigation, and distances from seedbed, input supplies and residence of the parcel head which could affect input utilization. In total, 278 rice parcels (139 male-headed and 139 female-headed) were studied.

Descriptive analysis (using frequency, percentage, and means) and test of two means were employed. The study also utilized the TE effects frontier model (using Frontier 4.1) to obtain the maximum likelihood estimates (MLE) of the production function and TE parameters of the stochastic production frontier. The significant factors affecting production and TE, as well as the TE levels were determined using Equations 1 and 2 (Battesse and Coelli, 1993), respectively.

$$\ln\left(\widehat{Q}_j\right) = \beta + \sum_{i=1}^{14} \beta_i \; \ln(X_{ij}) + (v_j - u_j) \qquad \text{Equation 1}$$

where:

$\widehat{Q}_j$ = predicted aggregate quantity of harvested rice (kg) of the j^{th} rice parcel
X_1 = land (per 100 sqm)
X_2 = seed (kg per 100 sqm)
X_3 = Nitrogen (kg per 100 sqm)
X_4 = Phosphorous (kg per 100 sqm)

X_5 = rodenticide (L per 100 sqm)
X_6 = pesticide (kg per 100 sqm)
X_7 = adult male labor (man-hour labor per 100 sqm)
X_8 = adult female labor (man-hour labor per 100 sqm)
X_9 = middle-aged male labor (man-hour labor per 100 sqm)
X_{10} = middle-aged female labor (man-hour labor per 100 sqm)
X_{11} = young labor (man-hour labor per 100 sqm)
X_{12} = animal-labor (man-animal-hour labor per 100 sqm)
X_{13} = machine-labor (man-machine-hour labor per 100 sqm)
X_{14} = seed variety adoption (1=introduced HYVs; 0=traditional)
ln = natural logarithm
β = parameters to be estimated
E = composite error term, defined as $(v_j - u_j)$ in Equation (1)

$$U_j = \delta_0 + \sum_{i=1}^{13} \delta_i Z_{ij} + e_j \qquad \text{Equation 2}$$

where:
U_j = technical inefficiency of the j[th] rice parcel
Z_1 = age of farmer (year)
Z_2 = household size (number)
Z_3 = education (year)
Z_4 = rice parcel management experience (year)
Z_5 = source of management (1: male; 0: female)
Z_6 = access to information such as trainings and seminars (1: access; 0: no access)
Z_7 = access to credit (1: access; 0: no access)
Z_8 = deviation from agricultural calendar (day)
Z_9 = *ubaya* violations (number)
Z_{10} = tenure (1: owned; 0: borrowed)
Z_{11} = number of co-managed parcels (number)
Z_{12} = distance of the rice parcel from seedbed (hours travelled)
Z_{13} = distance of the rice parcel from irrigation outlet (hour travelled)
δ = parameters to be estimated
e = error term

RESULTS AND DISCUSSION

Study area. Sagada has a total land area of 9,969 hectares with 2,223.8 hectares devoted to agriculture, 431.5 hectares of which are planted with rice. The town has a mountainous terrain of gentle to very steep slopes. It is a tributary of the Chico River, where two major river systems in Pidlisan are connected, one running through the Bumod-ok Falls in Fidelisan and the other located in Bangaan. The Mabileng Irrigation, the largest irrigation system in Northern Sagada is sourced from the Bomayeng Falls in Aguid and irrigates the rice fields in Pidlisan (Sagada MAO, 2015). Sagada has Type 1 climate, with the wet season running from May to October and dry season from November to April. It has a mean precipitation of 204.97 mm and temperature of 20.71˚C. The soil is acidic with a pH range of 4.55 to 5.0 and is deficient in Phosphorus and Nitrogen. Potassium, however, is adequate and organic matter is medium. The soil has shallow depth, low water-retention capacity and prone to erosion (CSC-UPB, 1999 as cited by NCIP, 2004). The common sources of income are farming, mining, tour guiding, backyard animal raising, logging and carpentry. Most are Christians, but elders considered themselves as pagan, performing rituals for farming and other community activities (PITO, 2014).

Rice production practices. In Sagada, the single cropping agricultural calendar is based on the appearances of different kinds of birds such as *kiling*. Community rituals are observed by the farmers such as *begnas*, *pakde*, and *ubaya*. The calendar synchronizes activities to facilitate labor exchange and pest management. The "new year" is celebrated in August with the first sowing of seeds. However, with the introduction of HYVs, sowing of seeds is done starting December until January. Clearing of weeds in the stone walls is done in November, followed by plowing and harrowing. The removed weeds and wild sunflower plants are mixed into the soil during plowing to serve as fertilizer. The fields are flooded before plowing to ease the work. These are done with hand tools made of wood and metal such as hand trowel and plough, while others ease their work with the aid of carabao. Putting of mud around paddies is done to prevent seepage.

Originally, transplanting is done in November to December; however, with HYVs, transplanting is performed in January to March. The fields are flooded before pulling the seedlings from seedbed and transplanting. When dry season starts, people usually go to irrigation outlet to divert water to their rice fields. In the previous years, there were water distributors or *lampisa* who disperse water from Mabileng irrigation to the rice fields. Come harvest time, the *lampisa* were given a small portion of the harvest of the rice fields assigned to them. However, since 2014, there were no *lampisa* volunteers anymore. Weeding is done during late March to April when grasses have already grown. At the same time, damaged rice plants are replaced. Weeds, stems and leaves of pine trees are used to cover rat tunnels in the stone walls. Rats eat up the palay grains, so they need to be prevented from entry or driven them away as early as possible. Driving away birds is known as *buwew*. A small hut equipped with boiled resin of a shrub and constructed in an area where birds stay most is used to catch birds. Those who helped in the construction of the hut, usually young males, were given palay during harvesting. Harvesting is done in May. In the past, farmers used to cut palay at about 7 to 8 inches from the panicle using a hand reaper known as *lakem*, then bundled them with the use of *bika* or rattan strips. Palay bundles were transported using bamboo stick or *assiw*. After threshing palay with the use of *saplitan*, an improvised thresher made of wood, grains were transported with the use of woven basket known as *gimata*. However, with HYVs, people are now using hand sickle known as *kompay* in harvesting. The use of manual thresher is commonly done, and grains are transported in sacks using a tram line.

The grains are dried under the sun for at least 2 to 3 days after which they are winnowed by women with the use of woven rattan or *i-gao*. Before, people used to hand pound palay using *lusong* and *pat-o* or mortar and pestle made of stone and wood, respectively. At present, rice mills are being used, but hand pounding is still done to red and black rice and *dikit* or glutinous rice. The exchange of free labor among members of a group or *ub-ubbo* is commonly adopted. It involves completion of farm works for each of the member in rotation until all members shall have been served. This is commonly practiced during transplanting and harvesting.

Rice parcel heads. Results shown in Table 1 reveal that women-farmers (51 years) are younger than men who had an average age of 56 years. Similarly, women had lower mean household size (5) than men-farmers (6). Women had higher average formal schooling (8.05 years) than men (7.64 years). Men did not continue education after elementary and worked in mining and logging instead. Since women were younger than men, they had lesser experience in rice parcel management (23 years) than men (26 years). Before, children are required to help in rice farming to learn their culture and tradition. However, fewer children are participating in rice farming nowadays due in part to the growing issue of child labor. In addition, more women (89) had access to information such as trainings and seminars than men (74). Most are members of the Pidlisan Tribe Organization (PITO) which promotes the use of indigenous micro-organisms to produce organic fertilizer. There are members of cultural leadership institutions, *dap-ay* for men who are responsible for their farming calendar and *balikatan* for women for the collection of fines for *ubaya* violations. There were seminars attended on organic fertilizers and integrated pest management (IPM) organized by PITO, DA and Cordillera Highland Agricultural Resource Management Program (CHARMP). Also, more women (23) had acquired credit for rice farming than males (10) particularly because they had to pay for hired labor, fertilizers and pesticides. More women had higher paid hired laborers since they had fewer source of family labor.

Table 1. Means and mean differences in the socio-economic and rice parcel characteristics, by sex, 278 rice parcels, Sagada, Mountain Province, 2015.

Variable	Mean		Mean Difference		Standard Error
	Male	Female			
Socio-economic Characteristics					
Age (year)	55.92	50.5	-5.42	***	1.65
Household size (number)	6.06	5.16	-0.79	***	0.33
Education (year)	7.64	8.05	0.40		0.41
Parcel management experience (year)	26.24	22.82	-3.41	**	1.67
Access to information[a]	74	89			
Access to credit[a]	10	23			
Rice Parcel Characteristics					
Tenure[a]	111	104			
No. of co-managed parcels (number)	2.04	2.04	0.00		0.18
Distance from seedbed (walking hour)	0.14	0.32	0.19		0.03
Distance from irrigation (walking hour)	0.25	0.28	0.04		0.03
Cultural Factors					
Deviation from agricultural calendar (day)	24.95	25.73	0.26		0.35
Ubaya violation (number)	0.97	0.93	-0.04		0.12

*, ** and ***significant at 10%, 5% and 1% level of probability, respectively; [a]dummy variable where 1=with access to information and credit and owned parcel; and 0 otherwise

Women managed lower number of owned rice parcels (104) than men (111). Borrowing of rice parcels is common, since there are many idle parcels due to lack of water and labor. These parcels are more prone to destruction of stone walls and erosion. Most of the rice farming households in Pidlisan have been managing more than one rice parcel, usually of different locations (mean of 2 rice parcels each). In reality, parcel heads found difficulty overseeing or managing parcels all at the same time, for every farming activity. This affected their observance of agricultural calendar and utilization of inputs.

Rice parcels. The rice fields are commonly terraced, supported by century age stone walls or *agabat*, with height ranging from less than a meter to greater than one meter. The rice paddies or *sinkong* have irregular shapes and different sizes ranging from few square meters to less than half a hectare. A rice parcel is a piece of land composed of one or more adjacent rice paddies. Rice parcels differ in bio-physical factors such as source of irrigation water, soil fertility, temperature, and distance from seedbed. The average walking distances between rice parcels and seedbed (0.3 hours or 18 minutes) and irrigation facility (0.28 hours or 16.8 minutes) were higher among female-headed parcels than those male-headed (0.14 hours or 8.4 min, 0.25 hours or 15 minutes, respectively). Seedbeds are commonly put up directly on the rice parcels to be planted, on rice parcels with good fertility and lesser pests, or on rice parcels near their houses. However, more women had seedbeds on rice parcels near their houses to enable them to maintain the seedlings while doing household chores. The Mabileng irrigation is the common source of irrigation water for the rice parcels. Other sources of irrigation are the Balikwey irrigation, Bumod-ok Falls, Bellang and Lenang Lakes. The distance of the rice parcels from irrigation negatively affected the schedule of farming activities.

Cultural practices/traditions. Women (26) had slightly higher average number of days of deviation from the agricultural calendar than males (25). Deviations were observed mostly during land and seedbed preparation. Rice field should be flooded before land preparation, but female-headed parcels were irrigated later due to farther distance from the irrigation facility. On the other hand, *ubaya*, a community ritual, was more frequently violated by men (0.97) than females (0.93). This runs counter to the higher deviation from agricultural calendar by women. The main reason is the fact that *ubaya* is not limited to farming but include also rituals for sickness and death of villagers. Moreover, women had higher awareness of these declarations because they are responsible for the collection of fees for the violation of the *ubaya*, unlike the agricultural calendar which is male determined.

The results of t-tests of two means show that age, household size and management experience had significant mean differences between genders (Table 1). Hence, women are significantly younger, had significantly lower household size and had lesser management experience than men.

Factors affecting production. Table 2 shows the different factors that could possibly affect rice production between genders. The t-test of two means revealed that rice parcel area, seed, adult and middle-aged male labor and machine labor had significant mean difference between genders (Table 2). That is, women had significantly lower rice parcel area, use less seed, and employ fewer adult and middle-aged male and machine labor. This is because women had lower average rice parcel area (410 sqm) than men (460 sqm). The size of rice parcel influenced the use of seeds, fertilizers, pesticides and labor. Consequently, the average amount of seed used was lower among women (2.43 kg/100 sqm) than men (3.15 kg/100 sqm). More women (97) had also the higher tendency to adopt HYVs than men (95). Elder respondents who are mostly males strictly follow their agricultural calendar, which is usually adopted when traditional varieties are used. On the other hand, land preparation of most women started late, hence, more females adopted HYVs to cope up with the observance of the agricultural calendar. HYVs used were *Bordagol*, *C-1*, *Daswan* and *Taiwan* which are planted in February to March. Meanwhile, traditional varieties used were *Apolog*, *Pokpoklo*, *Senyor*, red and black rice which are planted in January to February.

Table 2. Means and mean differences in factors that could possibly affect production by sex, 278 rice parcels, Sagada, Mountain Province, 2015.

Variable	Mean		Mean Difference		Standard Error
	Male	Female			
Area of parcel (100 sqm)	4.6	4.10	0.50	**	0.43
Seed (kg)	3.15	2.43	0.72	**	0.36
HYV Adoption[a]	95	97			
Nitrogen (kg)	0.47	0.73	-0.26		0.13
Phosphorous (kg)	0.25	0.34	-0.09		0.08
Rodenticide (L)	0.09	0.15	-0.06		0.04
Pesticide (kg)	0.03	0.07	-0.04		0.02
Adult male labor (man-hour)	185.35	88.55	96.80	***	11.96
Adult female labor (man-hour)	130.29	199.51	-69.22		11.28
Middle-aged male labor (man-hour)	104.48	56.54	47.94	***	10.39
Middle-aged female labor (man-hour)	76.22	131.22	-55.00		10.73
Young labor (man-hour)	11.78	26.91	-15.13		6.24
Animal-labor (man-animal-hour)	3.51	2.71	0.80		0.69
Machine-labor (man-machine-hour)	3.81	3.15	0.66	**	0.36

*, ** and ***significant at 10%, 5% and 1% level of probability, respectively

[a]dummy variable where 1=male; those with access to information and credit; owned parcel; and 0 otherwise

Man-labor is vital in rice farming in Pidlisan since activities are mostly done manually. Middle-aged laborers are aged between 18 to 59 years. Males at these ages are active in mining and logging. The mean middle-aged male and female labor employed among male-headed parcels constituted 104.48 and 76.22 man-hours/100 sqm, respectively. Meanwhile, the mean middle-aged male and female labor employed among female-headed constituted 56.54 and 131.22 man-hours/100 sqm, respectively. Adult labor classification was for those who are at least 60 years, majority of whom are working primarily in the farms. The average adult male and female labor employed among male-headed parcels were 185.35 and 130.29 man-hours/100 sqm, respectively. Meanwhile, the average adult male and female labor employed among female-headed were found to be 88.55 and 199.51 man-hours/100 sqm, respectively. Moreover, machine-labor was also employed but it was more frequent during milling of majority of harvest. On the average, females employed lower (3.15 man-machine-hour labor/100 sqm) than males (3.81 man-machine-hour labor/100 sqm). Black, red, brown and glutinous rice were hand-pounded since the grains would be broken if milled using their available rice mills.

Production and technical efficiency analysis. TE is the deviation of the average production function from the frontier production function, suggesting the need to estimate these two production functions. The Ordinary Least Squares (OLS) was used in the parameter estimation for the average production function, while the Maximum Likelihood Estimation (MLE) was employed for the frontier production function. The presence of technical inefficiency was determined using the t-test of gamma and the generalized likelihood ratio (GLR) test.

Table 3 reveals that the t-test of gamma (0.06953) was not significant but the sigma squared was found to be significant at 10 percent level of probability, implying the correctness of the specified assumption for the distribution of the error term. It had a coefficient of 0.006 indicating that the values in the distribution were dispersed from the mean by 0.60 percent. On the other hand, GLR statistic (96.98) was greater than the chi-square value (24.38) with degrees of freedom of 15 at 5 percent level of probability. Furthermore, the log likelihood value for the MLE model was higher than the OLS model. Thus, technical inefficiency existed and the MLE model better fitted the data.

Table 3. Ordinary least squares and maximum likelihood estimates of the stochastic production frontier, production function, 278 rice parcels, Sagada, Mountain Province, 2015.

Variable	OLS Coefficient		T-Ratio	MLE Coefficient		T-Ratio
Constant	1.39034	***	38.25761	1.47247	***	36.54923
Land	0.84099	***	37.20774	0.80274	***	36.08609
Seed	0.11193	***	4.85553	0.05931	***	2.75611
Seed Variety Adoption	0.02338	*	1.78031	0.03350	**	2.59002
Nitrogen	0.00001		0.55887	-0.00002		-1.11645
Phosphorous	0.00001		0.30345	0.00000		0.25212
Rodenticide	0.00001		0.39044	0.00004	**	2.54778
Pesticide	-0.00001		-0.58711	-0.00002		-0.85632
Adult male labor	0.00004	**	2.06051	-0.00002		-1.16446
Adult female labor	-0.00001		-0.47023	0.00002		1.40260
Middle-aged male labor	-0.00003	*	-1.71490	-0.00005	***	-2.93065
Middle-aged female labor	0.00000		-0.06323	0.00002		1.16580
Young labor	0.00000		-0.15183	-0.00002		-1.46147
Animal-labor	-0.00001		-0.45573	0.00001		0.84856
Machine-labor	0.00000		0.08080	0.00000		-0.22965
Sigma-squared	0.00823			0.00593	***	7.38587
Gamma	0.05000			0.06953		1.00392
Log-likelihood value			277.16381			325.65176
GLR test statistic						96.97592***

*, ** and *** significant at 10%, 5% and 1% level of probability, respectively

Coefficients implied that land, at 1 percent level of probability significantly and positively affected production, suggesting that every 1 percent increase in land area, holding other things constant, would result to 1.47 percent increase in production. As expected, increasing land utilization would increase production. Moreover, rodenticide, at 5 percent level of probability significantly and positively affected production, suggesting that every 1 percent increase in the amount of rodenticide used, *ceteris paribus*, would result in 0.00004 percent increase in output. Furthermore, seed at 1 percent level of probability significantly and positively affected production, indicating that every 1 percent increase in seed used, other things held constant, would result to 0.06 percent increase in production. Also, seed variety adoption, at 5 percent level of probability significantly and positively affected production, signifying that the use of HYVs, ceteris paribus, would result in 0.03 percent increase in output.

Meanwhile, middle-aged male labor was significantly but negatively related to production at 1 percent level of probability, which implies that every 1 percent increase in employment of middle-aged male labor, *ceteris paribus,* would decrease output by 0.00005 percent. One possible reason for this is that middle-aged males used to juggle their time and effort between mining or logging and rice farming, both of which require strength, and this could have negatively affected the quality of labor devoted to rice farming.

Women had significantly smaller parcel area and seed utilization, which were significantly and positively related to production. Moreover. They had significantly lower utilization of middle-aged male labor, which was significantly but negatively related to production. However, its MLE coefficient was nearly close to zero (0.00004), hence, the effect can be considered negligible. Results revealed that men (98.16%) were significantly more technically efficient than women (89.72%) at 5 percent level of probability (Table 4). This means that production of male-headed parcels could only be improved by 2.12 percent, but the female-headed ones could improve production by 10.67 percent.

Table 4. Means and mean differences in technical efficiency and production by sex, 278 rice parcels, Sagada, Mountain Province, 2015

Measure	Male		Female
Technical Efficiency			
Mean (%)	98.16		89.72
Mean difference (%)		8.44***	
Standard error		0.47	
Production			
Mean (kg)	104.04		83.96
Mean difference (kg)		20.08**	
Standard error		8.76	

***significant at 1% level of probability; ** significant at 5% level of probability

Also, it can be seen in Table 5 that household size positively influenced TE, that is, as household size increases, TE also increases. This is to be expected since family labor is vital in laborious and manual activities of rice farming. Likewise, access to information directly affected TE at one percent level of probability, suggesting that as more information and skills are acquired, TE improves. Skills may be about composting, organic farming, and integrated pest management (IPM). However, in the case of women, this could have been negated by the fact that they have significantly lower rice parcel area, seeding rate, adult and middle-aged male and machine labor. On the other hand, level of formal education negatively affected TE, at five percent level of probability, implying that farmers with higher educational attainment were more technically inefficient. Those with higher level of education have the higher tendency to have employment other than rice farming such that not enough attention is being given to rice farming. This is bolstered by the finding that deviation from agricultural calendar negatively affected TE at one percent level of probability. This is because the agricultural calendar helps in pest management and labor exchange, hence, as farmer deviates from this calendar, pest infestation becomes more likely. Those farmers with regular employment tended to have more deviations from the agricultural calendar. Similarly, the number of co-parcels (other parcels simultaneously managed by the same farmer) negatively affected TE at one percent level of probability since parcels are located far apart and have different bio-physical characteristics, making simultaneous management more difficult.

Table 5. Maximum Likelihood Estimates of the stochastic production frontier, technical inefficiency function, 278 rice parcels, Sagada, Mountain Province, 2015

Variable	MLE Coefficient		T-Ratio
Constant	-0.15882		-0.89706
Age	0.10726		0.88248
Household size	-0.11062	***	-3.06715
Education	0.00008	*	1.91816
Parcel management experience	0.00377		0.09650
Sex	-0.14014	***	-7.71583
Access to information	-0.04455	***	-2.89693
Access to credit	-0.03112		-1.19789
Tenure	-0.00507		-0.25947
No. of co-managed parcels	0.11162	***	2.97838
Distance from seedbed	-0.00002		-1.01962
Distance from irrigation	0.02564		1.45010
Deviation from agricultural calendar	0.17075	***	3.54180
Ubaya violation	-0.00002		-1.35961

*, ** and *** significant at 10%, 5% and 1% level of probability, respectively

Problems encountered in indigenous rice production. There had been rivalry in irrigation water due to lack of *lampisa* to manage the Mabileng irrigation facility and which was made even more difficult with the occurrence of El Niño. Also, loggers use irrigation canals to transport timber from the mountains. As a practice they block irrigation outlets for greater volume of water to carry the timber along the stream. In addition, some irrigation canals had been damaged due to landslides caused by typhoons. More women had problems on lack of water for their rice fields partly due to longer distance of their rice parcels from the irrigation facility and their greater time constraint (due to household chores) that prohibits them to oversee the channeling of water to their irrigation outlet. This results to them having more problem on *saktoto* (worms associated with lack of water) and them applying more pesticide to control the spread of these worms. Problems on rats, rice birds, and golden snails were also more frequently encountered.

Also, more women had problems on soil fertility as this is associated with their use of inorganic fertilizers. Application of inorganic fertilizers had also been inevitable in fields which were irrigated with water that contain chemical wastes from the mines. Similarly, more females faced physical constraints such as small area of rice paddies and high stonewalls which were more laborious to work on. More of them had difficulty in transporting seedlings (from near their households) and harvest due to lack of stone pathways, long distance and difficult terrain going to fields. Stone pathways going to some fields were dilapidated by landslides. Miners had also added damages to these pathways due to heavy loads they transport. Other problems faced were typhoons which caused damages to palay and irrigation canals; and limited and immobile rice mills, hence, palay had to be transported and the cost of milling was relatively high. Some traditional varieties are hand-pounded since the available rice mills are not suitable for milling these varieties.

CONCLUSION AND RECOMMENDATIONS

Based on the results of the study it can therefore be concluded that female-headed parcels were more technically inefficient (89.72%) than male-headed ones (98.16%) and this has been the result of the disadvantages the women are faced with, both bio-physical and cultural which negated their technical advantage. These disadvantages include: non-participation of women in the dap-ay; inadequacy of man-labor; small size of rice parcels; inadequate logistical and infrastructure support to address their dilapidated state of the terraces and pathways; lack of irrigation water; and lack of organic inputs for rice production. The following are therefore recommended:

Inclusion of women in the dap-ay especially in determining the agricultural calendar and declaration of ubaya. The *dap-ay* system promotes cultural traditions and customary laws which encourage sustainable management of resources by determining the agricultural calendar and declaring *ubaya*. While the agricultural calendar is generally based on bird sightings and other natural occurrences, still this may be based on subjective perceptions of those included in the *dap-ay,* all of whom are male. It is being argued that, at present, in their decision-making, the *dap-ay* is not considering the situation of women who more often cannot follow the agricultural calendar simply because of their other responsibilities in the household. It is hoped that with the inclusion of women in the *dap-ay*, these may likewise be considered so that they will not be frequently violating the agricultural calendar. This is particularly important for female farmers because they are the ones who encountered pest infestation more often due to their frequent deviation from agricultural calendar.

Encourage the continued practice of the ub-ubbo. *Ub-ubbo* is the practice of exchange of labor among the different farms, generally in rotation until all who are engaged in this have been served. This is favorable for smaller households with limited family labor. It can be recalled that women-farmers had significantly lower household size. Household size positively related to TE.

Expansion of rice parcel area should be fostered for adjacent ones. Borrowing of rice parcels is very common among *Kankanaeys* as this is an important practice for them to prevent rodent infestation in untended plots. Meanwhile, increasing parcel area can be beneficial to women who have difficulties manually doing land and seedbed preparation because animal-labor is inappropriate in small parcels. It would therefore be ideal if borrowing of adjacent rice paddies can be promoted or more permanently, exchange of parcels can be encouraged.

Provision of logistical and infrastructure support for indigenous rice farming. Results revealed that more women had difficulty transporting seedlings (from near their households) and harvest due to lack of stone pathways, long distance and difficult terrain going to fields. Furthermore, existing stone pathways were dilapidated by landslides and frequent use of miners. It is therefore suggested that pathways going to rice fields be improved using part of the community income from the Sagada tourism industry. Irrigation systems should be rehabilitated and maintained through collective participation in community maintenance to establish a sense of ownership.

Revival of the lampisa system. The *lampisa* (irrigation water distributors) should be revived and maintained by institutionalizing their compensation instead of them doing volunteer work and given only a small portion of the harvest of the rice fields assigned to them. Efficient water distribution is critical also because leaving the land without irrigation and idle increases the occurrence of rat infestation, soil degradation, stone wall destruction and erosion. The lack of *lampisa* also disenfranchises the female-headed parcels because women have less time ensuring that enough water is diverted into their parcels. A regular *lampisa*, may also deter the loggers from blocking the water gates and pathways to effect better streamflow.

Provision of institutional support to organic rice farming. Traditionally, *Kankanaey* rice farmers are used to practicing organic rice farming. However, the low soil fertility in rice fields close to the mining sites and irrigated by the river in Fidelisan, where processing of gold ore is being done caused many farmers to resort to greater use of inorganic fertilizer that through time further degrades the soil. According to them, producing organic fertilizers such as composted wild sunflower plants normally found within the communities take a long time, as well as being more laborious. A welcome development, however, is that the Tebtebba (Indigenous Peoples International Center for Policy Research and Education, Inc) and PITO are currently working on the use of indigenous microorganisms (IMO) and manual shredder to decrease the period of decomposition of organic matter. The use of this technology should be promoted among the rice farmers through a series of technical training. It is also highly possible that production of organic fertilizer and pesticides can be institutionalized by assigning certain farmer groups to take charge of their production for sale to or exchange with other farmers. The use of traditional soil management practices such as planting of nitrogen-fixing plants like beans and peanuts on the fields should also be employed.

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ANTIFUNGAL ACTIVITY OF SOIL YEAST (*LACHANCEA KLUYVERI* SP132) AGAINST RICE PATHOGENIC FUNGI AND ITS PLANT GROWTH PROMOTING ACTIVITY

Chonthicha Sripodok[1], Anon Thammasittirong[1,2], and Sutticha Na-Ranong Thammasittirong[1,2*]
[1]Department of Microbiology, Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand
[2]Microbial Biotechnology Unit, Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand
*Corresponding author: sutticha.n@ku.ac.th

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ABSTRACT

A soil yeast, *Lachancea kluyveri* SP132, was isolated from rice paddy field soil in Nakhon Pathom province, Thailand, and was evaluated for its antifungal activity and plant growth promoting activity at Kasetsart University, Kamphaeng Saen Campus, Thailand, from 2016-2017. SP132 displayed potent *in vitro* inhibitory activity on mycelial growth against *Rhizoctonia solani,* a rice sheath blight fungal pathogen, using the dual culture method. The potent yeast also exhibited antifungal activity against *Curvularia lunata*, a rice dirty panicle fungal pathogen. Cell-free culture of SP132 displayed an effect on hyphal morphology and mycelial growth of pathogenic fungi. Based on the inhibition activity values, cell-free culture of SP132 showed the best effect on *R. solani* growth. The highest inhibition activity against *R. solani* (87.67%, compared with the control) was achieved using 30% cell-free culture. The ability of SP132 to produce extracellular antifungal enzymes (chitinase, cellulase and amylase) suggested that these enzymes may be partly correlated with the antagonistic activity against rice pathogenic fungi. Study on plant growth promoting activities revealed that this effective yeast antagonist produces indole-3-acetic acid (IAA) and ammonia and can generate phosphate solubilization. The treated rice seed with SP132 had improved seed germination and seedling growth. These results suggested that the *L. kluyveri* SP132 isolated in this work may be further used as a biocontrol agent and plant growth promoting agent.

Key words: rice sheath blight, rice dirty panicle, biocontrol, seed germination, seedling growth

INTRODUCTION

Sheath blight caused by *Rhizoctonia solani* is one of the most common and destructive diseases of rice, which occurs throughout temperate and tropical rice production countries, including Thailand. Rice sheath blight disease causes 10% and 20% annually yield loss in India and Thailand, respectively (Boukaew and Prasetsan, 2014). Under outbreak and favorable environmental conditions, the yield loss can reach over 50% (Qingzhong et al., 2001; Richa et al., 2016). *R. solani,* a sclerotium-forming plant pathogenic fungus, is a universal soil saprotrophic and facultative plant parasite. Apart from rice, this pathogen also infects several important plant species, for example, sugar beet, cucumber and potato (El-Tarabily, 2004; Huang et al., 2012; Ben Khedher et al., 2015). Dirty panicle is also a serious disease of rice, causing great losses in grain and seed production. The Southern part of Thailand had 92.2% of disease occurrence (Bubpha et al., 2016). Balgude and Gaikwad (2016) reported that this disease was found to be very severe all over Maharahtra, India, causing 20-40% yield loss. *Curvularia lunata* is one of the primary causal fungal pathogens of dirty panicle disease. This fungus is also a pathogen on various plant species, such as lotus, sweet sorghum and mulberry (Cui and Sun, 2012; Tong et al., 2015; Bussaban et al., 2017).

Fungicides are widely used for controlling these fungal plant pathogens. However, chemical control has a significant impact on human health and environment. Biological control has been described as an attractive alternative and environmentally friendly strategy for controlling plant diseases. Yeasts are one of the promising antagonistic microorganisms, since they are effective against a wide range of pathogens, are easily produced in large scale production using inexpensive substrates and do not produce toxins or metabolites harmful to human health (Qing and Shiping, 2000; Nally et al., 2015). Several yeast species have been shown to be effective biological control agents in protecting plants against fungal diseases. For example, yeasts isolated from the sour and grey rots, *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe*, showed biocontrol activity against *Botrytis cinerea* which causes grey rot disease (Nally et al., 2013). *Pichia guilliermondii* and *Metschnikowia pulcherrima* showed potential antagonistic activity against *Fusarium fujiikuroi* which causes bakanae disease of rice (Matić et al., 2014).

In recent years, a large array of yeasts, including species of *Galactomyces*, *Barnettozyma*, *Aureobasidium* and *Rhodotorula*, have been shown to act as biocontrol agents and plant growth promoting agents (Ignatova et al., 2015; Fu et al., 2016). Plant growth-promoting microorganisms have a number of beneficial effects on plant growth, for example, nitrogen fixation, phytohormones production, solubilization of mineral phosphates and other nutrients and cyanide, siderophore and antibiotic production (de Souza et al., 2015).

In this study, we isolated yeast strains from rice leaves and rice field soil samples and screened the potent yeast against *R. solani*. The selected yeast antagonist, *Lachancea kluyveri* (Syn. *Saccharomyces kluyveri*) SP132, which showed the best activity to inhibit *R. solani*, was also evaluated for its inhibition activity against *C. lunata*. Cell-free culture was also investigated for its ability to inhibit fungal growth. To our knowledge, this is the first report of *L. kluyveri* acting as a biocontrol agent to inhibit the rice fungal pathogens, *R. solani* and *C. lunata*, and also as a plant growth promoting agent to improve seed germination and seedling growth of rice.

MATERIALS AND METHODS

Pathogenic fungi. The rice pathogenic fungi, *R. solani* KPK00289 and *C. lunata* KPK00290, were obtained from the Plant Health Clinic, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand. The pathogenic fungi were maintained at 4 °C on potato dextrose agar (PDA) medium.

Isolation and screening of antagonistic yeasts. The yeast antagonists were isolated from rice leaves, and rice field soils in Nakhon Pathom province and Suphanburi province, Thailand. Clay loam soil samples were collected at a dept below 10 cm. Leaf samples were collected from healthy rice plant. A 10 g of each samples was added to 100 ml of yeast extract peptone dextrose broth (YPD) supplemented with 100 µg/mL streptomycin and incubated at 30 °C for 24 h with shaking at 150 rpm/min. After serial dilution, the suspension was plated on YPD agar and incubated at 30 °C for 24 h. All yeast isolates were screened to select the antagonistic yeast displaying the strongest growth inhibitory activity against mycelial growth of *R. solani* using dual culture assay. Then, the selected yeast antagonist was also evaluated for its ability to inhibit mycelial growth of *C. lunata*. A 5 mm plug of 5 day-old pathogenic fungus was placed 2.5 cm away from the edge in a Petri dish containing PDA and incubated at 30 °C in an incubator without light for 24 h. The isolated yeast was streaked on the same Petri dish 4.5 cm away from the plug of pathogenic fungus (Saechow et al., 2018). After 3 days (*R. solani*) and 7 days (*C. lunata*) incubation at 30 °C, the percentage of inhibition of radial growth (PIRG) was calculated using the following formula: PIRG (%) = [(R1 – R2)/R1)] × 100, where, R1 is the radial diameter of the control colony and R2 is the radial diameter of the treatment colony (Rahman et al., 2009). Experiments were performed in triplicates.

Yeast identification. Identification of yeast antagonist was performed based on its genetic material using molecular biology technique. The amplification of the internal transcribed spacer (ITS) of the rDNA including the 5.8S gene was performed using PCR with the universal primers ITS1 and ITS4, according to White et al. (1990). The DNA sequence was compared to those previously published in GenBank using the BLASTN program.

Phylogenetic analysis. The sequences were multiple aligned using Clustal W and phylogenetic tree was generated with the neighbour joining method using MEGA X program (Kumar et al. 2018). Bootstrapping was performed for 1,000 replicates.

Effect of SP132 on hyphal morphology. Hyphal strands at the edge of the fungal colony nearest to the inhibition zone after incubation for 3 days (*R. solani*) and 5 days (*C. lunata*) were removed and examined under a light microscope (Olympus CX31, Japan).

Effect of SP132 cell-free culture on mycelial growth and spore germination. SP132 was grown in potato dextrose broth (PDB) with continuous shaking at 150 rpm and 30 °C for 84 h. Cell-free supernatants were collected by centrifugation at 15,000 rpm for 10 min at 4 °C, and then filtered through a 0.45 μm Millipore® membrane. The yeast cell-free culture was added to PDB containing spore suspension ($1x10^5$ spores/mL) of each fungal pathogen to yield a final concentration of 5%, 15% and 30% (Saechow et al., 2018). For the control, each fungal pathogen was grown in PDB medium without a yeast cell-free culture. After culture at 30 °C with shaking at 150 rpm for 7 days, the mycelia were filtered and dried at 55 °C until constant weight.

Extracellular hydrolytic enzyme productions. The qualitative assay for extracellular hydrolytic enzyme productions was carried out using the agar well diffusion method. The ability of SP132 to produce chitinase and cellulase was examined on colloidal chitin agar (colloidal chitin 10 g/L, yeast extract 0.5 g/L, $(NH_4)_2SO_4$ 0.1 g/L, $MgSO_4{\cdot}7H_2O$ 0.3 g/L, KH_2PO_4 1.36 g/L, agar 15 g/L) and carboxymethyl cellulose (CMC) agar (CMC 5 g/L, yeast extract 0.5 g/L, $(NH_4)_2SO_4$ 1 g/L, KCl 1 g/L, KH_2PO_4 1 g/L, agar 15 g/L), respectively. Protease, amylase and lipase productions were examined on skimmed milk agar (skimmed milk 10 g/L, glucose 1 g/L, $MgSO_4{\cdot}7H_2O$ 0.2 g/L, K_2HPO_4 0.2 g/L, agar 15 g/L), starch agar (soluble starch 2 g/L, yeast extract 5 g/L, beef extract 3 g/L, peptone 5 g/L, agar 15 g/L) and Tween 80 agar (Tween 80 10 mL/L, peptone 10 g/L, NaCl 5 g/L, $CaCl_2{\cdot}2H_2O$ 0.1 g/L, agar 15 g/L). A 200 µL sample of cell-free culture prepared as described above was added to the well. An equal volume of culture medium (PDB) served as the control. After incubation at 30 °C for 24 h, the colloidal chitin agar, CMC agar and starch agar were flooded with 1.5% iodine solution for 5 min (Kasana et al., 2008; Richa, 2016). Enzyme production on skimmed milk agar and Tween 80 agar were detected without staining. For chitinase, cellulase, protease and amylase enzyme detections, positive tests were indicated by a clear halo zone around wells. A precipitation around well indicated the positive reaction for lipase enzyme detection.

Indole-3-acetic acid (IAA) production. IAA production was determined using the method of Loper and Schroth (1986). SP132 was cultured in PDB broth containing 500 µg/mL of L-tryptophan at 30 °C with shaking at 150 rpm. After 48 h of incubation, a 2 mL sample of supernatant was mixed with 2 drops of orthophosphoric acid and 4 mL of the Salkowski reagent (35% of perchloric acid 50 mL, 0.5M $FeCl_3$ solution 1 mL) and incubated at room temperature for 30 min. Optical density of the developing pink color was measured spectrophotometrically at 530 nm.

Phosphate solubilization. Qualitative determination of phosphate solubilization was performed on a National Botanical Research Institute's phosphate (NBRIP) agar plate, containing 0.5% tricalcium phosphate, by observing the clear halo zone around the bacterial colony. The quantitative bioassay was performed by growing SP132 in NBRIP broth for 7 days at 30 °C on a shaker at 150 rpm. The amount of soluble phosphate was measured following the ascorbic acid method (Ruangsanka, 2014).

Ammonia production. SP132 was cultured in 10 mL peptone water and incubated at 30 °C for 48-72 h. The ammonia production was detected by adding 0.5 mL/tube of Nessler's reagent. The appearance of brown to yellow was a positive test for ammonia production (Cappuccino and Sherman, 1992).

Effect of SP132 on rice seed germination and seedling growth. Effect of SP132 on rice seed germination and seedling growth was investigated using a slightly modified method reported by Saechow et al. (2018). Rice seeds (cultivar Pathumthani 1, soft texture cultivar having a distinctive aroma and high cooking quality) were soaked in distilled water for 15 h, sterilized in 10% Clorox for 10 min and washed five times with sterilized distilled water. The surface sterilized seeds were soaked for 1 h in a cell-suspension of SP132 (1×10^8 CFU/mL) and then blotted dry. The seeds soaked in sterilized distilled water were used as the control. The treated seeds (100 seeds) were incubated in a tray with moist filter paper and incubated at 30 °C in a growth chamber. The percentage of seed germination and length of shoot and root were measured after 36 h and 7 days of incubation, respectively.

RESULTS AND DISCUSSION

Screening and identification of antagonistic yeast. Several previous reports demonstrated the potential value of yeast antagonists for controlling plant diseases, for example, bakanae disease of rice (Matić et al., 2014), grey rot disease and sour rot disease (Nally et al., 2013; Nally et al., 2015). Among the 86 yeast isolates obtained in this study, SP132 showed the highest inhibitory activity against colonies growth of *R. solani* (PIRG; 59%) using the dual culture method (Fig. 1A and B). This isolate was then selected to test its antifungal activity against the dirty panicle fungal pathogen of rice, *C. lunata*. The results revealed that SP132 could also inhibit colonies growth of *C. lunata* (PIRG; 29%) (Fig. 2A and B). SP132 was identified based on 5.8S-ITS region sequence analysis as *Lachancea kluyveri*, and its sequence was deposited in the GenBank database under the accession number MH333067. The result of phylogenetic analysis based on 5.8S-ITS sequence data is shown in Fig. 2.

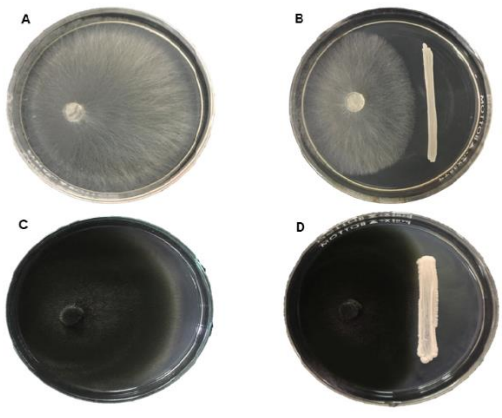

Fig. 1. Antifungal activity of SP132 against rice pathogenic fungi, *R. solani* (A); *R. solani* co-inoculated with SP132 (B); *C. lunata* (C); and *C. lunata* co-inoculated with SP132 (D).

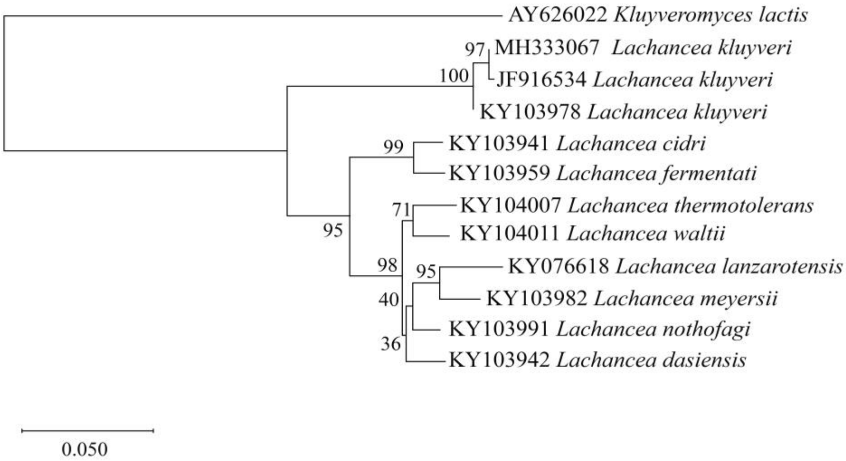

Fig. 2. Neighbour-joining tree based on 5.8S-ITS region showing the relationship between *L. kluyveri* SP132 (MH333067) and members of genus *Lachancea*.

Effect of SP132 on hyphal morphology of pathogenic fungi. The pathogenic fungi hyphae from the edge of the inhibitory halo were observed under a light microscope as shown in Fig. 3. SP132 caused cytoplasmic coagulation of *R. solani* hyphae (Fig. 3A) and enlargement of the cytoplasmic vacuoles of *C. lunata* hyphae (Fig. 3C), whereas the fungal hyphae from the untreated control samples showed normal and intact morphology (Fig. 3B and D).

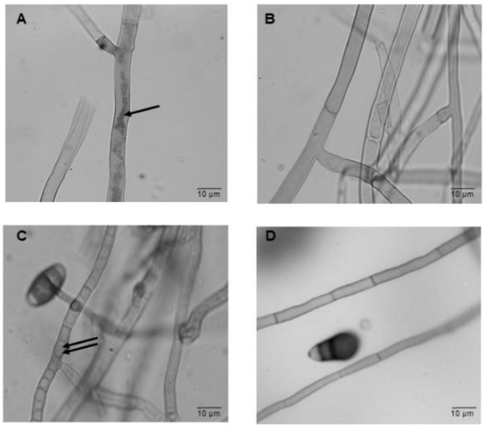

Fig. 3. Morphological changes of rice pathogenic fungi. Hyphae of *R. solani* from co-inoculation with SP132 (A); and normal hyphae of *R. solani* (B); hyphae of *C. lunata* from co-inoculation with SP132 (C); and normal hyphae of *C. lunata* (D). Arrow indicates cytoplasmic coaglulation and double arrows indicate vacuolization hyphae.

Effect of SP132 cell-free culture on fungal growth. The effect of SP132 cell-free culture on fungal growth was studied using the dry weight determination method. The pathogenic fungi were treated with different concentrations (5%, 15% and 30%) of SP132 cell free-culture. As shown in Table 1, the mycelial growth of *R. solani* and *C. lunata* were inhibited by cell free-culture. The highest dry weight reduction values of *R. solani* and *C. lunata* were 87.67% and 37.00%, respectively, after treating with 30% cell-free culture. Therefore, this concentration was selected to examine its effect on the spore germination and germ tube elongation of the rice fungal pathogen. Regarding to the sclerotium-forming fungal pathogen of *R. solani*, spore germination and germ tube elongation were only examined in *C. lunata* using a light microscope. In the presence of SP132 cell-free culture, spore germination and germ tube elongation occurred but the hyphae showed abnormal vacuolization (Fig. 4A). In contrast to the untreated control, spores of *C. lunata* germinated normally and the germ tubes developed into normal hyphae (Fig. 4B).

Table 1. Effect of SP132 cell-free culture on dry weight of *R. solani* and *C. lunata.*

Concentration of cell-free culture (%)	Dry weight reduction (%)	
	R. solani	***C. lunata***
5	37.33 ± 2.88^{c}	10.67 ± 0.58^{c}
15	50.00 ± 2.00^{b}	24.67 ± 1.53^{b}
30	87.67 ± 2.52^{a}	37.00 ± 1.73^{a}

Data represented as mean±standard deviation. Means in each column with the same lowercase superscript letter are not significantly (p<0.05) different.

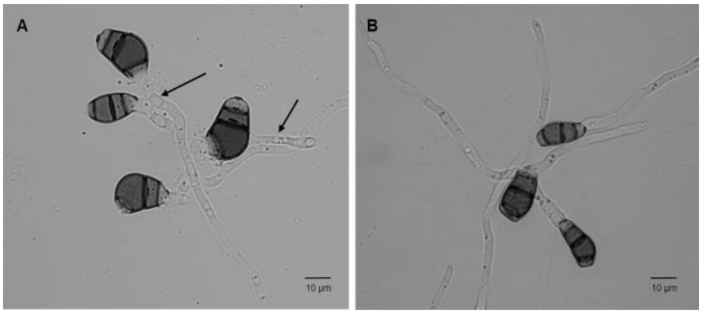

Fig. 4. Effect of SP132 cell-free culture (30%) on spore germination and germ tube elongation of *C. lunata* (A); and untreated spores of *C. lunata* (B). Arrows indicate abnormal vacuolization hyphae.

These results indicated that cell-free culture of SP132 showed an inhibitory effect on the growth and cellular changes of rice pathogenic fungi. Study on the extracellular enzyme production revealed that SP132 was able to produce chitinase, cellulase and amylase (Table 2). Khedher et al. (2015) suggested that protease and chitinase activities in cell-free culture of *Bacillus subtilis* V26 can act on *R. solani* growth by antibiosis. Melent'ev et al. (2001) reported that crude chitinase from *Bacillus* sp. 739 and pure chitinase caused cellular change, hyphal swelling and vacuolization, which affected the growth and caused dry weight reduction of *Fusarium* and *Helminthosporium*. Calistru et al. (1997) reported that extracellular enzymes (amylase, cellulase, pectinase, lipase and protease) from *Trichoderma* spp. may play an important role in antibiosis against *Aspergillus flavus* and *Fusarium moniliforme*. Fan et al. (2002) reported that *Pichia membranifaciens* and *Candida guilliermondii*, producing chitinase and β-1,3-glucanase, exhibited some effects on controlling *Rhizopus stolonifer*. The ability of yeast antagonists to produce and secrete lytic enzymes is suggested to be associated with the attachment of yeast cells to fungal hyphae and the partial degradation of fungal mycelia (Bar-Shimon et al., 2004; Fu et al., 2016). The hydrolytic enzymes from SP132 are suggested to be involved in the antagonist activity of biological control agents against fungal pathogens as described above. With an increase in the concentration of the cell-free culture of SP132, the inhibition value increased. These results may relate to the increased extracellular enzyme concentrations in cell-free culture.

Table 2. Extracellular enzymes production by SP132.

Extracellular hydrolytic enzyme				
Chitinase	**Cellulase**	**Protease**	**Amylase**	**Lipase**
+	+	-	+	-

+ corresponds to enzymatic activity detected.
- corresponds to no detectable enzymatic activity.

There are few reports demonstrating the ability of *L. kluyveri* as a biocontrol agent. Souza et al. (2017) reported that *L. kluyveri* CCMA0151 showed the ability to inhibit *Aspergillus ochraceus* and *Aspergillus caebonarius* growth. Nally et al. (2013) demonstrated that *L. kluyveri* BSk11 significantly reduced *Fusarium oxysporum* and *Rhi. stolonifer* growth. However, no biocontrol mechanism of this yeast antagonist has been reported. Here, we first report on the inhibitory effects of *L. kluyveri* on the rice fungal pathogens, *R. solani* (sheath blight disease) and *C. lunata* (dirty panicle disease). Based on the results in this investigation, the antifungal activity against rice pathogens may be partly explained by the production of extracellular hydrolytic enzymes.

Effective suppression of plant diseases by microbial biocontrol agents may also be influenced by the specific pathogen, host commodity and particularly by environmental conditions (Zahavi et al., 2000; Tian et al., 2002). Survival and antagonistic activity of yeast antagonists in the environmental conditions depend on yeast species. The yeast suspensions of *Trichosporon pullulans*, *Cryptococcus laurentii* and *Rhodotorula glutinis* were sprayed at concentration of 1×10^8 CFU/mL onto sweet cherry fruit in two orchards located in Beijing and Jinzhou district of Liaoning Province, China. The results revealed that only *Cryp. laurentii* and *Rho. glutinis* remained at high and stable population levels on the surface of sweet cherry fruit under field conditions which the temperature ranged from 10.8-32.2 °C (Shi-Ping et al., 2004). Calvo-Garrido et al. (2014) reported that under Mediterranean climate in vineyard located in Spain (relative humidity 61.8-61.9%, temperature 22.1-22.8 °C and rainfall 21.7-25.0 mm), yeast suspension of *Candida sake* at 1×10^7 - 5×10^7 CFU/ml was effective at reducing *Bacillus cinerea* secondary inoculum on necrotic grapevine tissues. Therefore, future work is needed to evaluate the effectiveness of SP132 in reducing rice disease under greenhouse and field conditions.

Plant growth promoting analysis and effect of SP132 on rice seed germination and seedling growth. In the past few decades, the plant growth-promoting characteristics of various microorganisms, including yeast, have been reported (Amprayn et al., 2012; Ait Kaki et al., 2013; Ignatova et al., 2015; Fu et al., 2016). In the present investigation, SP132 was able to solubilize phosphate (13.80 mg/L) at 30 °C after 7 days in the NBRIP liquid medium (Table 3). The production of IAA and ammonia was also positive in SP132.

As shown in Table 4 and Fig. 5, the treated rice seeds with a cell-suspension of SP132 had improved seed germination, with the germination values enhanced from 73.33% to 92.66%. Shoot and root lengths were significantly higher when the seeds were treated with the cell-suspension of SP132. At 7 days of rice seeding incubation, the shoot and root lengths of rice treated with the cell-suspension were enhanced by 56.93% and 25.00%, respectively, compared to the untreated seeds. These results indicated that the cell-suspension of SP132 was able to enhance rice seed germination and seedling growth compared with the untreated control. IAA is a phytohormone that has a positive effect on plant growth by stimulating plant cell elongation (Vessey, 2003). The low level of IAA produced by SP132 suggested that IAA production is not the main mechanism for enhancing rice seedling growth. Similar results were obtained by Amprayn et al. (2012), who reported that IAA production was not the main mechanism for increasing rice seedling growth using a cell-suspension of *Candida tropicalis* as a result of the low level of IAA production. The current results indicated that SP132 can potentially be used as an alternative agent to improve seed germination and plant growth. The improved rice seedling growth caused by SP132 may be due to the involvement of IAA production and other plant growth promoting agents acting synergistically to promote plant growth.

Table 3. *In vitro* production of plant growth-promoting metabolites.

Phosphate solubilization (mg/L)	IAA at 500 μg/mL of tryptophan (μg/mL)	NH_3
13.80±0.11	0.70±0.07	+

\+ corresponds to positive test.

Table 4. Effect of SP132 cell-suspension on rice seed germination and seedling growth.

Treatment	Germination (%)*	Shoot length (cm) **	Root length (cm) **
Untreated control	73.33±6.24^{b}	3.97±0.05^{b}	2.40±0.08 ^{b}
SP132	92.66±2.05^{a}	6.23±0.17^{a}	3.00±0.01^{a}

* Germination values were measured at 36 h of incubation.
** Shoot and root lengths were measured at 7 days of incubation.
Data represented as mean±standard deviation. Means in each column with the same lowercase superscript letter are not significantly (p<0.05) different.

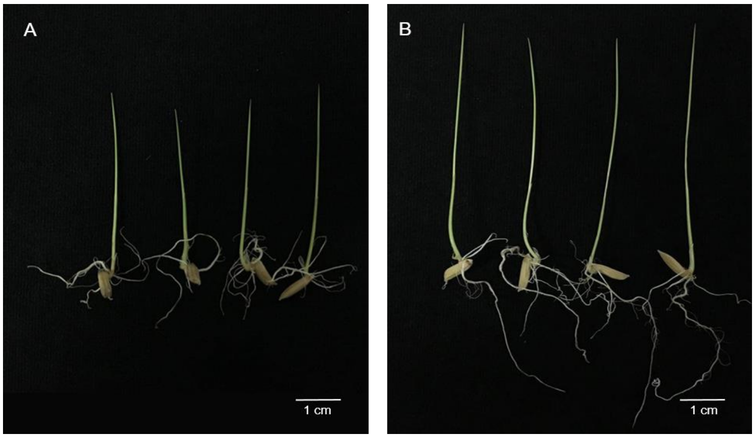

Fig. 5. Growth of rice seedlings (7 days of inoculation) from untreated control (A); and treated with SP132 (B)

CONCLUSION

L. kluyveri SP132, isolated from rice paddy field soil, exhibited potent *in vitro* inhibitory activity against rice fungal pathogens, especially, *R. solani*. Additionally, SP132 displayed multiple plant growth-promoting traits. This yeast antagonist can potentially be used as an alternative plant growth promoting agent to improve rice seed germination and seedling growth. Future work is needed to evaluate the effectiveness of SP132 in reducing rice disease and enhancing rice growth under greenhouse and field conditions.

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ANALYSIS OF INCOME AND FACTORS DETERMINING THE ADOPTION OF INTEGRATED RICE-FISH FARMING SYSTEM IN SEYEGAN DISTRICT, SLEMAN REGENCY, YOGYAKARTA, INDONESIA

Yusman Syaukat[1] and Dwi Rizki Julistia[2]
[1, 2] Departement of Resource and Environmental Economics
Faculty of Economics and Management, Institut Pertanian Bogor (IPB University)
Jl Agathis, Kampus IPB Darmaga, Bogor, Indonesia 16680
Corresponding author: ysyaukat@apps.ipb.ac.id

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ABSTRACT

Integrated rice-fish farming is a potential alternative farming to increase farmers' income in overcoming increasingly competitive land use. Rice-fish farming has been applied in Margoluwih Village, Seyegan District, Sleman Regency, Yogyakarta Province for a few years. This study aims to analyze the use of inputs and production costs in rice-fish (*minapadi*) farming compared to monoculture rice farming, to estimate the income of rice-fish farming and monoculture rice farming, and to identify factors that influence farmers' decision in adopting the integrated rice-fish farming. The study was conducted at Margoluwih Village, Sayegan District, Sleman Regency, Yogyakarta in March 2017. A total of 50 farmers were surveyed, comprising of 25 rice-fish farmers and 25 monoculture rice farmers. The methods used to achieve these objectives are descriptive analysis, income analysis, and logistic regression analysis. The results show that rice-fish farming requires inputs such as fish seeds, fish feed, prebiotics, and molasses of sugarcane while monoculture farming does not require such inputs, but monoculture farming uses pesticides and herbicides to overcome pest attacks and applies more chemical fertilizers than rice-fish farming. The labor time devoted to rice-fish farming is also higher than in monoculture farming. The total cost of rice-fish farming per hectare in one production season is Rp 63.47 million, while the total cost of monoculture rice farming amounted to Rp 17.55 million. However, rice-fish farming significantly earn more income compared to monoculture farming with an average value of Rp 28.45 and Rp 3.19 million per hectare in one growing season, respectively. Income is believed to be the main factor in determining the adoption, while social factors that influence farmer's decision to adopt rice-fish farming are age of farmer and experience of rice cultivation.

Key words: monoculture rice farming, *minapadi, jajar legowo*, farm income, logistic regression

INTRODUCTION

Demand for rice and fish is increasing overtime due to high population growth, economic development and urbanization. On the other hand, the supply is threatened because of the conversion of agricultural land, climate change and the environmental impact of overuse of fertilizer and pesticides during the green revolution period (Islam, 2016). Thus, there is an urgent need for a sustainable option which can produce rice and fish in a sustainable manner. Integrated rice-fish farming system (IRFFS) seems to be such an option, producing more rice and fish with less use of land and water in a sustainable way. IRFFS has been practiced in many countries, particularly in Asia. In China, rice-fish culture has been practiced for at least 1,700 years (Cai et al. 1995) and is listed by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) as one of the Globally Important

Ingenious Agricultural Heritage Systems (GIAHS) in 2005, owing to its long history and diversified patterns and techniques (Halwart and Gupta, 2004).

Saikia and Das (2008) and Halwart (1998) reported that presently, the rice-fish system is being practiced in Bangladesh, Cambodia, China, Egypt, Indonesia, Republic of Korea, Madagascar, Thailand and Vietnam. The practice supports a large share of the rural population in South, Southeast and East Asia and in parts of West Africa. In these places, rain-fed rice fields are designed to store water for extended periods, creating aquatic ecosystems with many similarities to natural floodplains (Heckman, 1979). These floodplain habitats of rice are later stocked by fish and grown throughout the wet season. Fishing from these rice-based farming systems is often carried out on regular, occasional or part-time basis, making a significant contribution to livelihoods of poor farmers. Rice-fish farming is a low-cost sustainable practice to obtain high value protein food and minerals (Saikia and Das, 2008). At the farm level rice-fish integration reduces use of fertilizer, pesticides and herbicides in the field. Such reduction of costs lowers farmer's economic load and increases their additional income from fish sale. With such savings and additional income, the net productivity from rice-fish farming are reported to be higher than monoculture rice farming (hereinafter referred to as monocrop). Halwart (1998) reported that from the practice of fish culture in rice-field with a total gain from savings of pesticides and earning from fish sales, the net income that a farmer obtains up to 65% higher than monocrop. On the contrary, the rice-fish culture increases the yield of rice (up to 25-30%) besides providing extra income to farmers. In addition, Newton (2002) argued that rice-fish integration is an important area for farmers who are marginalized, cultivate under difficult conditions and find the cost of pesticides and fertilizer financially burdensome.

Halwart and Gupta (2004) reported that IRFFS has been recognized globally in helping combat malnutrition and poverty. However, IRFFS has not been fully explored in many countries. Islam (2016) reported that though the potentiality of this technology has been widely documented, rice-fish farming systems are still not widespread in Bangladesh. The same condition also occurs in Indonesia. IRFSS in Indonesia is known as *minapadi* farming system (*mina* means fish and *padi* means rice). The prospect of developing *minapadi* in Indonesia is actually very large, since the *minapadi* system is currently only 142,122 hectares or about 1 percent of the total area of paddy fields in Indonesia. The *minapadi* system is believed to be an effective way to improve welfare and realize food sovereignty. The rice plant production is more qualified because it allows the creation of environmentally friendly organic farming and healthier products for consumption. The *minapadi* system will also increase fish production which in 2016 is targeted to reach 19.5 million tons[1].

Special Territory (Province) of Yogyakarta is one of the provinces that has developed the *minapadi* farming, with Sleman Regency as one of its development centers. At present, around 17 districts in Sleman Regency have developed this *minapadi* farming. Until 2018, it is estimated that the *minapadi* farming area has reached 128 hectares, while the potential land area suitable for the development of *minapadi* reaches 2,000 hectares[2.] The areas targeted for development were *dusun* (hamlet) Cibluk Kidul, Margoluwih Village, Seyegan District at the Sleman Regency. The paddy-field pilot rice yields an increase in rice harvest from an average of 6.5 tons/ha to 9.3 tons/ha with better quality rice, so farmers can sell it as 'healthy rice'. In addition, the sale of fish can also reach around

1 M Fajar Marta, "Sistem Mina Padi Indonesia Ditiru Negara lain", https://ekonomi.kompas.com/read/2016/09/28/150259426/sistem.mina.padi.indonesia.ditiru.negara.lain. (accessed at Febryary 5, 2019).

2 Gaya Lufityanti. Tribunjogja 11 Januari 2018. "Tahun 2018 Ini, Luas Minapadi di Sleman Ditargetkan Bertambah 20 Hektare", http://jogja.tribunnews.com/2018/01/11/tahun-2018-ini-luas-minapadi-di-sleman-ditargetkan-bertambah-20-hektare.

Rp 42 million/hectare/season[3]. The innovation of *minapadi* uses an 'ecosystem approach' through zero pesticides, and significantly reduces the level of use of chemical fertilizers. Besides that, *minapadi's* farming benefits rural life through passionate economic activities, and improves access to nutritious food. Lantarsih (2016) and Fausayana and Rosmarlinasiah (2008) argued that farming with the *minapadi* system as a form of intercropping of fish in rice fields together with rice cultivation is a cultivation technology capable of contributing positive for rice farmers, namely in increasing land productivity and rice production, also can increase farmers' income. Margoluwih Village is one of the areas in Sleman Regency that applies the *minapadi* farming system. According to the Department of Agriculture, Fisheries and Forestry of Sleman Regency (2016) the development of deep pond *minapadi* cultivation in Margoluwih Village is aimed at increasing land productivity, optimizing land use, increasing farmers' income, improving the quality of community nutrition, and achieving rice and fish production that can meet community's food needs.

Minapadi farming uses different inputs than monocrop, because in addition to inputs in the rice production process, *minapadi* farming also requires inputs in the fish production process. Farmers who implement *minapadi* farming will obtain greater revenues compared to the ones of farmers who do monocrop. However, *minapadi* farmers have to spend more production expenses (Rabbani *et al*., 2004; Dwiyana and Mendoza, 2006). The development of *minapadi* farming is a technological innovation of rice farming in a monoculture system to increase farmers' income in using paddy fields, not only because the amount of income received by farmers is even greater, but farming is also more beneficial for farmers when faced with conditions of rice harvest failure, because farmers still get profits from the production of fish in his rice fields (Frei and Becker, 2005; Nnaji et al. 2013; Siregar, 2015). Bosma et al. (2012) in their study showed that the factors that influence farmers' decisions to adopt *minapadi* farming are conditions of irrigated land, access to capital assistance, and knowledge and experience of rice and fish cultivation. Bambang (2003) says that income is the main factor that influences farmers' decisions to do *minapadi* farming.

The above issues give major motivation to properly assessing the potential socio-economic benefit of this *minapadi* system compared to monocrop, as well to identifying the factors which facilitate and hinder rice-fish technology adoption. The specific objectives of this paper are as follows: (1) to identify and estimate the use of inputs and production costs of *minapadi* farming compared to monocrop; (2) to estimate and compare the incomes from the two farming systems; and (3) to identify the factors that affecting the farmers in adopting *minapadi* farming.

RESEARCH METHODOLOGY

Location and time of research. This research was conducted in Margoluwih Village, Seyegan District, Sleman Regency, Yogyakarta. The location of this study was purposively chosen by considering that Seyegan District was a region that had the potential to develop *minapadi* farming in Sleman Regency, and Margoluwih Village was one of the villages that pioneered the commencement of *minapadi* farming in Seyegan District. The survey was conducted in March 2017.

Types and data sources. This study uses both types of data, primary data and secondary data. Primary data is obtained through observation and interviews using questionnaires to respondents who are the object of research, namely farmers who do *minapadi* farming and farmers who carry out monoculture rice (monocrop) farming in Margoluwih Village. Secondary data is supporting data obtained from the Central Statistic Agency, the Agriculture, Fisheries and Forestry Service of Sleman

3 Republika Online, Selasa 24 Jan 2017, "Menengok Mina Padi di Sleman yang Jadi Percontohan Asia Pasifik",https://www.republika.co.id/berita/ekonomi/makro/17/01/24/ok9qzu368-menengok-mina-padi-di-sleman-yang-jadi-percontohan-asia-pasifik

Regency, other agencies related to this research, and using information from various literature reviews. Respondents in this study were farmers who run *minapadi* and monocrop farmings in Margoluwih Village. The number of respondent sampled in this study were 50 farmers, consisting of 25 *minapadi* farmers and 25 monocrop farmers. The method of collecting respondents' data in this study was carried out by the method of total sampling (census) for *minapadi* farmer respondents, because the availability of *minapadi* farmers in the village is only 25 farmers (and they are members of a farmer group who sought the *minapadi* business), while monocrop farmers were carried out by simple random sampling method with a comparable number from about 400 farmers in the village.

Descriptive analysis. Descriptive method is a method used to obtain an overview in analyzing the use of inputs and costs on *minapadi* and monocrop farmings. The results of this analysis are presented based on existing information regarding the use of inputs and the results of cost calculations on *minapadi* farming as well as on monocrop farming.

Farm income analysis. Analysis of farm income is done to compare the income of the *minapadi* and monocrop farmings. Farm income consists of income on cash costs (cash income) and income on total costs (net income). Cash cost is a cost that must be spent directly by the farmer to pay the inputs used. Cash income is the difference between total revenue and total cash costs, while net income is the difference between total revenues and total production costs, including the costs of farmers' inputs used in the production process whose value is used with imputed costs. The components of cash costs in this study consisted of the costs of rice seed, fish seedling, fish feed, prebiotic, sugarcane molases, urea fertilizer, NPK fertilizer, SP-36 fertilizer, phonska fertilizer, organic fertilizer, manure, pesticides, herbicides, irrigation costs, tractor rental fees, land rental fees, land taxes, membership fees, compulsory savings for cooperative members, and costs of non-family labors. The calculated (imputed) costs consist of costs of using family labor and depreciation of farm equipments. The paired samples *t* test is used to determine whether the incomes from the two farming systems (*minapadi* and monocrop) are significantly different from zero.

Logistic regression analysis. Logistic regression model is used in estimating the factors that influence farmers in making decisions to adopt *minapadi* farming. The model was analyzed using *Stata 15.1* software. The selection of variables for logistic function estimation is based on previous research. The analytical model used to identify the factors that influence farmers in adopting *minapadi* farming is as follows (Pindyck and Rubinfeld 1991, Agresti 2002):

$$ln\left(\frac{P_i}{1-P_i}\right) = Z_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon_i$$

where: P_i = individual farmer's opportunity to adopt *minapadi* farming system; ($1-P_i$) = individual farmer's opportunity to make a decision on non-adopting of *minapadi* farming (i.e., implementing monocrop); Z_i = individual farmer's decision to adopt *minapadi* farming, α = intersept, β_i = regression coefficient parameter for X_i; X_1 = formal education level (year); X_2 = area of farm land (m^2); X_3 = farmer's age (year); X_4 = number of family dependents (person); X_5 = farmer's experience in doing rice cultivation (year); X_6 = distance of paddy fields from water sources (meter); and ε_i = error term.

RESULTS AND DISCUSSION

Input and output of *minapadi* and monocrop farmings.

This section explains the differences in the average input used between *minapadi* farming and monoculture rice farming, as well as comparisons of costs incurred by farmers to implement both types of farming. The total cost is summation of cash costs and imputed costs. *Minapadi* farming uses a different input variable from monoculture rice farming, because in addition to the inputs for rice production process, *minapadi* farming requires other kind of inputs, particularly fish seeds and fish feed, and requires more labor than the monocrop. The difference in the average use of inputs and production costs for *minapadi* and monocrop farming is shown in Table 1.

Table 1. Average input use and cost of production for *minapadi* and monoculture rice farming

Input use	*Minapadi*		Monocrop		Average Price (Rp/unit)
	Input	Cost	Input	Cost	
Cash cost					
Rice seed (kg/ha)	54.4	553,600	41.6	427,600	10,220
Fish seedling (kg/ha)	706.0	19,688,000	0.0	-	27,840
Fish feed (kg/ha)	2190.0	20,373,600	0.0	-	9,307
Prebiotic (liter/ha)	7.6	509,200	0.0	-	67,120
Cane molasses (liter/ha)	10.0	68,800	0.0	-	4,960
Urea fertilizer (kg/ha)	84.0	186,000	282.0	727,000	1,910
NPK fertilizer (kg/ha)	74.0	246,000	198.0	710,000	2,120
SP-36 fertilizer (kg/ha)	0.0	-	48.4	151,000	1,570
Phonska fertilizer (kg/ha)	68.0	187,000	0.0	-	980
Organic fertilizer (kg/ha)	912.0	684,000	658.0	493,500	540
Manure (kg/ha)	0.0	-	102.0	129,000	460
Pesticide (liter/ha)	0.0	-	4,2	345,200	69,040
Herbicide (liter/ha)	0.0	-	3.0	286,000	57,200
Irrigation fee (Rp/ha/season)		420,000		264,000	342,000
Tractor rent (Rp/ha/season)		708,000		644,000	676,000
Land rent (Rp/ha/season)		3,360,000		2,333,333	2,846,667
Land tax (Rp/ha/season)		186,667		198,667	192,667
Farmer group fee (Rp/season)		20,000		12,000	16,000
Co-operative saving (Rp/season)		-		20,000	20,000
Non-family labor (man-days)	24	9,520,760	18	6,411,350	376,442
Sub Total Cash Cost		**56,711,627**		**13,152,650**	
Imputed cost					
Family labor (man-days)	62.8	4,972,000	23	4,108,000	128,890
Tool depreciation (Rp/season)		1,785,467		293,600	1,039,533
Sub Total Imputed Cost		**6,757,467**		**4,401,600**	
Total Cost (Rp/ha/season)		**63,469,094**		**17,554,250**	

Minapadi farming uses more rice seed compared to rice-monoculture farming, which is 54.4 kg/ha compared to 41.6 kg/ha. This happened because of differences in rice planting patterns between *minapadi* and monocrop farming. In monocrop farming, tiled or rectangular patterns (such as tiles) are used in paddy farming, while in *minapadi* farming, a total of 80% of the total area is used to grow rice and the remaining 20% is used as deep ponds for fish. The rice cropping pattern generally uses "*jajar legowo*" 2:1. *Jajar Legowo* is one of the rice planting systems in Indonesia which is basically done by adjusting the distance between seeds during planting. This system has been proven to improve rice yield compared to the use of traditional systems. *Jajar legowo* 2:1 is a planting method that has 2 rows then interspersed by 1 empty row. *Jajar legowo* 2:1 cropping pattern applied by *minapadi* farmers aims to maximize land use, and the *jajar legowo* 2:1 cropping pattern requires more rice seeds than the tile planting pattern. In *minapadi* farming in Margoluwih Village, red tilapia fish (*Oreochromis niloticus*) is one of the farming products that usually grown by the farmers. Filling of water and stocking of tilapia seeds in *minapadi* farming was carried out after 14 days of rice planting. The average tilapia seed grown by *minapadi* farmers is as much as 706 kg/ha or spread 2 to 3 seeds per m^2 and the weight of fish seeds is around 25 gr/head. The average price of rice seeds is Rp 10,220 per kg, while the average price of red tilapia seeds is Rp 27,840 per kg (note: the exchange rate is USD 1 = Rp 14,000).

The type of fertilizer used in *minapadi* farming is not much different from the type of monocrop farming fertilizer. Urea, NPK and organic fertilizer were used as fertilizers by both *minapadi* and monocrop farming, but on *minapadi* farming phonska fertilizers were also used, while in monocrop farming SP-36 fertilizers and manure were used. The are different types and amount of fertilizers on *minapadi* and monocrop farmings. These occur because in monocrop farming there are three fertilization phases, whereas in *minapadi* farming there is only one fertilization phase, since the next fertilization is done naturally from feces and fish food. Monocrop farms still use pesticides and herbicides to overcome pests and weeds, but these inputs are not used in *minapadi* farming. However, *minapadi* farming uses more labor workdays compared to monocrop farming. This is because *minapadi* requires more labor time in land preparation to make deep ponds and canals, the installation of mulch and pool nets, and feeding of fish. Fish feeding is twice a day, morning and evening, starting from the time the fish seeds are stocked (14 days after rice is planted) until the fish is harvested (up to 14 days before rice is harvested). In total, *minapadi* and monocrop farmings require about 86.8 and 41.0 working days. The average time spent by worker in one working day (*hari orang kerja* or HOK) is about five hours. The output of *minapadi* farming consists of rice and fish, while the output of monocrop farming is only rice. Rice in *minapadi* farming yields a higher output of 7,612 kg/ha compared to monocrop farming which only produces 5,652 kg/ha, both in the forms of paddy (husked rice) (Table 2). Based on the research results, this happened because the *jajar legowo* 2:1 cropping pattern on *minapadi* farming produced more paddy than the monocrop farming which used tiled cropping patterns. In addition, with the cultivation of fish in the paddy fields, fish feed and fish feces can help grow rice and produce more rice tillers. *Minapadi* farming also produces red tilapia as much as 2,548 kg/ha.

Table 2. Productivity and revenue of *minapadi* and monoculture rice farming

Commodity	*Minapadi* farming	Monocrop farming
Productivity (kg/ha):		
- Rice	7,612	5,652
- Fish	2,548	0
Revenue (Rp/ha/season):		
- Rice	29,635,200	20,750,800
- Fish	62,284,000	0
Total revenue	**91,919,200**	**20,750,800**

Income of *minapadi* and monoculture rice farming

***Minapadi* and monocrop production costs**. The cost of *minapadi* and monocrop farming in this study is divided into cash costs and calculated (imputed) costs. Based on Table 1, the total costs incurred by the *minapadi* farmers are Rp 63,469,093, while the total costs for monocrop are Rp 17,554,250 per hectare per planting season. The cost for paddy seeds in *minapadi* farming is Rp 553,600 while monocrop farming is Rp 427,600. This is because there are different planting patterns on *minapadi* and monocrop farming, where the use of rice seeds for *minapadi* farming is more than the alternative. Other costs incurre by *minapadi* farmers but not issue by monocrop farmers are fish seed costs of Rp 19,688,000 and fish feed costs of Rp 20,373,600, including costs for prebiotics and sugarcane molasses. Monocrop farming uses more types and amounts of fertilizers, which results in greater costs of fertilizers. The costs of pesticides and herbicides to overcome pests and weeds on monocrop farming are also high. The total costs of labor in *minapadi* farming is greater than in monocrop farming, because more workdays is spent on the labor for land preparation in making deep ponds and canals, the installation of mulch and pool nets, and feeding fish (twice a day). This cost of labor includes both family and non-family labor. The agricultural tools used in the farming of *minapadi* and monocrop are also different. In general, monocrop farming uses only hoes, sickles and hand sprayers. *Minapadi* farming uses more equipment, including hoes and sickles, also drains, pool nets, mulch, and feed buckets. The more variety of equipment used in *minapadi* farming caused larger farm depreciation costs, Rp 1,785,467 compared to Rp 293,600 for monocrop farm.

Farm revenues. Farm revenue is the amount of farm output multiplied by the selling price of the product. Comparison between the average revenue of *minapadi* farming and monocrop farming is shown in Table 2 which shows that the average farmer revenue from *minapadi* farming is higher than the average farmer revenue from monoculture rice farming. The average farmer revenue per hectare per planting season on *minapadi* farming is Rp 91,919,200 while the total farmer revenue from monocrop farming is Rp 20,750,800. This is because there are differences in the output produced on *minapadi* and monocrop farmings. *Minapadi* farming produces rice and fish with an average price of paddy (husked rice) at Rp 3,896 per kg and the average price of red tilapia is Rp 24,480 per kg, while monocrop farming produces only rice with a slightly lower average price, which is Rp 3,668 per kg. The average price of *minapadi* rice is more expensive than monoculture rice because based on the results of research in the village, rice from *minapadi* farming has been considered to be more qualified by the society, since there is no pesticides and herbicide, and more flaky than monoculture rice.

Farm income. The incomes of *minapadi* and monocrop farmings in this study are analyzed based on income on cash costs (referred as cash income) and income on total costs (referred as net income). The net income will be lower than the cash income because in the analysis of total income has calculated all costs, including the cost of using family labor and depreciation of tools, while in the analysis of cash income both cost components are not taken into account. Farming incomes [both (5) and (6)] obtained by both *minapadi* farmers and monoculture rice farmers are positive, which means that the two farming systems are profitable, but the net income from *minapadi* farming is higher, Rp 28,270,106 compared to Rp 2,914,150 per hectare per season (Table 3). Profitability of *minapadi* and monocrop farmings can also be seen from the Revenue/Cost (R/C) ratio. Based on this criteria, the average value of R/C for the total cost perspective for *minapadi* farming per hectare per planting season is 1.45 while for monocrop farming is 1.18; meaning that the level of profit of the two types of farming systems are 45% and 18% from the total farming (production) costs, respectively. In general, the value of R/C for the cash costs and total cost perspective for *minapadi* farming is greater than monocrop farming, so it can be said that *minapadi* farming is economically more profitable than the alternative.

Table 3. Income of *minapadi* and monoculture rice farmings

Component	*Minapadi* farming	Monocrop farming	Difference
Revenue (1)	91,919,200	20,750,800	71,168,400
Cash cost (2)	56,891,626	13,435,050	43,456,576
Imputed cost (3)	6,757,467	4,401,600	2,355,867
Total cost (4)=(2)+(3)	63,469,094	17,554,250	45,914,844
Cash Income (5)=(1)-(2)	35,027,573	7,315,150	27,711,823
Net Income (6)=(1)-(4)	28,270,106	2,914,150	25,355,956
Cash R/C (7)=(1)/(2)	1.60	1.56	0.04
Net R/C (8)=(1)/(4)	1.43	1.15	0.28

Significance test of the mean outcomes. Significance test of the outcome values is conducted to determine whether there is statistical evidence that the mean difference between paired observations (*minapadi* and monocrop) on a particular outcome is significantly different from zero. The paired samples *t* test uses a parametric test. It compares two means that are from the same individual, object, or related units. In this case, the samples are 25 paired-farmers of *minapadi* and monocrop farmings.

The results can be divided into two groups, inputs and outcomes. In term of inputs, the components also can be divided into two: physical inputs and costs. In term of physical inputs, land area and use of organic fertilizer are not significantly different beween *minapadi* and monocrop farmings. However, the use of rice seed, and urea, NPK and organic fertilizers are different significantly between the two. In term of costs, the total imputed cost, total cash cost, and total cost of production are also siginificantly different between the two farmings (Table 4). In term of outcomes, all of the outcomes between *minapadi* and monocrop farmings are significantly different, except for cash R/C. Means of rice production, for example, are statistically difference at 5% significant level, while the other outcomes are statistically difference at 1% significant level. The test results, in general, show that the differences between the mean outcomes of *minapadi* and monocrop farmings are significantly different than zero, indicating that the mean outcomes of *minapadi* farming are significantly higher than those of monocrop farming.

Table 4. Mean input and outcome differences between *minapadi* and monocrop farmings

Variable	Value of variable		Pearson	t Stat	P value
	Minapadi	Monocrop	Correlation		(2 tails)
Inputs:					
Land area	1,400.00	1,304.00	0.15445	0.76094	0.45410
Rice seed	54.40	41.60	-0.04216	2.46305	0.02133
Urea fertilizer	84.00	282.00	0.18394	-9.65375	0.00000
NPK fertilizer	74.00	198.00	-0.03852	-3.66827	0.00121
Organic fertilizer	912.00	658.00	0.30014	1.19582	0.24344
Total imputed cost	6,757,466	4,401,600	0.26684	4.15513	0.00036
Total cash cost	56,891,626	13,435,050	-0.11654	10.43927	0.00000
Total cost of production	63,469,094	17,554,250	-0.03157	9.92439	0.00000
Outcomes:					
Rice production	7,612	5,652	-0.05721	2.30556	0.03009
Total revenue	91,919,200	20,750,800	-0.00130	9.89666	0.00000
Cash income	35,027,573	7,315,750	0.13562	8.27787	0.00000
Net income	28,270,106	2,914,150	0.09752	8.81891	0.00000
Cash R/C	1.60	1.57	0.0332	0.3730	0.7124
Net R/C	1.43	1.15	0.0437	4.0649	0.0004

Paired samples correlation shows the bivariate Pearson correlation coefficient for each pair of variables entered (with a two-tailed test of significance). Pearson coefficient measures the statistical relationship and the direction of the relationship between two continuous variables. It can take a range of values from -1 to +1. Based on the results on Table 4, in term of inputs, the use of rice seed, urea and NPK fertilizers, total imputed cost, total cash cost and total cost of production are significantly different, while land area and organic fertilizer use are not significantly different between the two farmings. In term of outcomes, all farming outcomes (rice production, total revenue, cash income, net income, and net R/C) are significantly different between the two farming systems, except for the cash R/C. Cash income and net income of the *minapadi* and monocrop farmings are positively related, implying that as the value of *minapadi* income increases, so does the value of the monocrop income. However, total revenue of the *minapadi* and monocrop farmings have negative values.

Factors affecting the farmers'decision in adopting *minapadi* farming.

Factors that are considered to affect farmers' decision in adopting *minapadi* farming system are analyzed using a logistic regression model, which is processed using the Stata 15.1 program. The independent variables are: formal education level (X_1); farm area (X_2); farmer's age (X_3); number of family dependents (X_4); farmers' experience in doing rice cultivation (X_5); and distance of paddy fields from water sources (X_6). Income variable is not included in the analysis. When the income variable of *minapadi* and monocrop farming is included in the model, there is convergence failure because the maximum profit for monoculture rice farmers does not reach the minimum income of the *minapadi* farmers, so complete separate occurs in the logistic regression model. As an alternative, variable cost is also tested. However, it results in the same problem. The full results of data analysis to estimate the factors that influence farmers' decisions in adopting *minapadi* farming is presented in Table 5. The dependent variable in this model is the farmer's decision to implement (adopt) *minapadi* farming (value "one") and the farmer's decision not to adopt *minapadi* farming or implementing monoculture rice farming (value "zero"). The Log-Likelihood value was -23.759, the G value was 21.80 and the P value was 0.0013. The resulting P value is below the 5% real level (α = 5%), it can be concluded that the overall logistic regression model can explain the farmers' decision in adopting *minapadi* farming. Detailed outputs of the regression analysis are presented in the Appendix 1.

Table 5. Factors affecting the farmers' decision in adopting *minapadi* farming

Predictor	Coef	P	Odds Ratio	Marginal Effect
Constant	8.48079	0.0660	4821.29	
Education level (X_1)	0.21169	0.3610	1.2357	0.05292
Paddy-field area (X_2)	-0.00011	0.8960	0.9998	-0.00003
Farmer age (X_3)	-0.21106	0.0030*	0.8097	-0.05276
Number of family member (X_4)	-0.22380	0.5590	0.7994	-0.05595
Experience in rice farming (X_5)	0.10296	0.0290*	1.1084	0.02574
Distance of rice field to water source (X_6)	-0.00097	0.3220	0.9990	-0.00024

The regression results indicate that there are two significant variables in the logistic regression model, namely the age of the farmers (X_3) and farmers' experience in doing rice cultivation (X_5). The age of the farmer variable is statistically significant. The older the farmer, the probability of adopting the *minapadi* farm declines. The odd ratio is 0.81, which means that every increase in the age of farmers by one year, the opportunity to implement (adopt) *minapadi* farming is 0.81 times less than the opportunity not to farm *minapadi*, cateris paribus. Likewise, marginal effect of the farmer age variable is -0.052, implying that when the farmer is one year older, the probability of the farmer in adopting *minapadi* farming reduced by 0.052 (5.2%), ceteris paribus. The age of *minapadi* farmers who less than 35 years was 16% and those with ages 35 to 44 years were 32%; whereas in monocrop farming there were no farmers who were under 44 years old, most monocrop farmers were in the age range of 45 to 54 years (48%) and ages 55 to 64 years (48%). Thus, *minapadi* farmers tends to be younger than the monoculture rice farmers, indicating that younger farmers have the desire and ability to implement the *minapadi* farm. Farmers' experience in doing rice cultivation (X_5) variable has a statistically significant value. The coefficient value is positive, indicating that the longer the experience of the farmer in cultivating rice will increase the probability to adopt *minapadi* farming. An odd ratio of 1.11 means that for every one year longer of rice cultivation experience, the probability of farmers to practice *minapadi* farming is 1.11 times greater than the probability of practicing the alternative, cateris paribus. Similarly, the marginal effect coefficient is 0.0257, indicating that as the farmer's experience in cultivating rice increases by one year, it will increase his probability in adopting the *minapadi* farming by 0.0257 (2.57%). These conditions indicate that when farmers' experience in doing rice cultivation is increasing, there is a tendency that the farmer will adopt *minapadi* farming.

The results of the regression analysis show that there are four non-significant variables, namely the farmer education (X_1), paddy field area (X_2), number of family dependents (X_4), and distance of paddy fields from water sources (X_6). Educational variable (X_1) is statistically not significant with a P value of 0.361 which is greater than the real level of 5% (α = 5%). Based on the field conditions, the education level of most *minapadi* farmers and monocrop farmers tends to be the same, namely graduating from junior high and high school, so there is no significant difference in the level of education between the two groups of farmers. Thus, the level of education does not have a tendency in determining farmers' decisions to adopting *minapadi* farming. Variable paddy field area (X_2) is also not significant because it has a P value of 0.896 which is greater than the real level of 5% (α = 5%). Field conditions indicate that most of respondents (both *minapadi* and monocrop farmers) manage a land of no more than 0.2 hectares, so that the rice field area managed by the *minapadi* farmers is statistically not different from those of monocrop farmers. Therefore, paddy field area is also not a factor in farmers' decision making to adopt *minapadi* farming.

Number of family dependents (X_4) variable is statistically not significant with the value of P equal to 0.559. Conditions in the field indicate that *minapadi* farmers and monocrop farmers have an average of 3 dependents in their families, 52% of *minapadi* farmers and 36% of monoculture farmers have 3 family dependents and no farmers have more than 5 family members, thus the number of family dependents does not have a tendency in making farmers' decisions to practice *minapadi* farming. Another variable that is not significant is variable of the distance of paddy fields from water sources (X_6) with a P value of 0.322. The distance from paddy fields to water sources represents the availability of irrigation water to the farmers in implementing *minapadi* farming, because water availability is the most important factor in the success of *minapadi* farming. Based on the results of the study, the Mataram irrigation channel that passes through Margoluwih Village is the source of water that irrigates all paddy fields in the village. Both rice fields for *minapadi* and monocrop farming can be irrigated well with a technical irrigation system from Mataram channel. **T**he distance between *minapadi* and monocrop lands from the water sources is not significantly different because the distance is not more than 2000 meters from paddy fields. Thus, it can be concluded that the distance between paddy fields and water sources that represent water availability does not influence farmers' decisions adopt *minapadi* farming.

CONCLUSIONS

There are differences in the type and amount of input use in *minapadi* farming and monoculture rice farming in Margoluwih Village. On the *minapadi* farm, fish seed, fish feed, prebiotics, and sugar cane molasses are needed; whereas monoculture rice farming (monocrop) does not require these inputs, but uses pesticides and herbicides that are not used in *minapadi* farming. Monocrop farming uses more fertilizers than *minapadi* farming, whereas *minapadi* farming uses more quantity of labor compared to the monocrop farming. The biggest costs incurred by the *minapadi* farmers are the costs of fish and fish feed each valued at Rp 19.68 million and Rp 20.37 million per hectare per planting season, so the total costs incurred by the farmers are Rp 63.47 million per hectare per planting season; while for monocrop farmers the total costs are only Rp 17.55 million. Comparison of income between *minapadi* and monocrop farming in Margoluwih Village shows that *minapadi* farming that carries out rice and fish cultivation jointly in paddy fields is statistically significantly more profitable than monocrop farming which only grows rice. The net income earned by the farmer per hectare during one planting season is Rp 28.45 million, while that of monoculture rice farming is only Rp 3.19 million. The profitability of *minapadi* farming reaches 45%, while monoculture rice farming is only 18% of the total cost of production of each type of farm. Both the cash income and net income of *minapadi* farming are significantly different than those of monocrop farming. Socio-economic factors are important in influencing farmers' decisions in adopting *minapadi* farming in Margoluwih Village. Income of *minapadi* farming is significantly higher than the monocrop farming and irrigation water is not limited factor to the farmers in adopting *minapadi* farming. However, adoption of *minapadi* farming is still limited. The results indicate that the farmers' age and experience in doing rice cultivation are the two significant social factors in adopting the minapadi farming. There should be other important factors that determining the adoption process, but not included in this analysis, for example availability of funding, since adoption of *minapadi* farming requires a high amount of funding.

RECOMMENDATION

Farmers pay a large amount of money in conducting *minapadi* farming to purchase fish seed and feed. To take advantage of the potential major expenditure, the role of farmer groups can be increased by making it as an institution capable of organizing farmers' capacity to produce fish seed and feed. The Sleman Regency of Agriculture, Fisheries and Forestry Service together with the field extension workers should provide technical and financial support, so that farmer groups can conduct business in making fish feed and fish hatcheries independently, thereby reducing the cost of purchasing both types of inputs and maintain their availability. *Minapadi* farming will be more profitable if farmers can increase the sale value of their farming products by increasing the role of *minapadi* farmer groups in promoting *minapadi* rice. *Minapadi* rice also has the potential to become a new icon for Sleman Regency. The Sleman Regency Government and its stakeholders are expected to conduct a laboratory research for *minapadi* rice content in order to ensure that *minapadi* rice has better quality compared to conventional (monoculture) rice, because it is pesticide free. In addition, improvement in marketing of *minapadi* rice and fish is also needed. The local government should motivate and facilitate the current adopters, who are mostly relatively young farmers, in developing *minapadi* farming intensively, since it generates more income, food and nutrition, and sustainability. Government should also extensively attract other potential farmers to practice *minapadi* farming, since the required irrigation water is still available in the locality. Government facilitation could be in term of socialization and training programs, provision of working capital, and improvement of marketing system and facilities.

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Attachment 1. Outputs of Regression Analysis

```
  ___  ____  ____  ____  ____ (R)
 /__    /   ____/   /   ____/
___/   /   /___/   /   /___/                    15.1   Copyright 1985-2017 StataCorp LLC
  Statistics/Data Analysis            StataCorp
    4905 Lakeway Drive
    College Station, Texas 77845  USA
    800-STATA-PC        http://www.stata.com
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      979-696-4601 (fax)

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Notes:
      1.  Unicode is supported; see help unicode_advice.
. *(7 variables, 50 observations pasted into data editor)
```

1. Output of Logit Regression

```
. logit y x1 x2 x3 x4 x5 x6

Iteration 0:   log likelihood = -34.657359
Iteration 1:   log likelihood = -23.848181
Iteration 2:   log likelihood = -23.759413
Iteration 3:   log likelihood = -23.759028
Iteration 4:   log likelihood = -23.759028

Logistic regression                     Number of obs   =         50
                                        LR chi2(6)      =      21.80
                                        Prob > chi2     =     0.0013
Log likelihood = -23.759028             Pseudo R2       =     0.3145

------------------------------------------------------------------------------
           y |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          x1 |   .2116947   .2318503     0.91   0.361    -.2427236     .666113
          x2 |  -.0001182      .0009    -0.13   0.896    -.0018821    .0016458
          x3 |  -.2110643   .0698243    -3.02   0.003    -.3479175   -.0742112
          x4 |  -.2238019   .3829721    -0.58   0.559    -.9744134    .5268095
          x5 |   .1029556   .0470943     2.19   0.029     .0106524    .1952588
          x6 |  -.0009743   .0009834    -0.99   0.322    -.0029018    .0009532
       _cons |   8.480797   4.618126     1.84   0.066    -.5705638    17.53216
------------------------------------------------------------------------------

. logistic y x1 x2 x3 x4 x5 x6

Logistic regression                     Number of obs   = 50
                                        LR chi2(6)      = 21.80
                                        Prob > chi2     = 0.0013
```

Log likelihood = -23.759028 Pseudo R2 = 0.3145

y	Odds Ratio	Std. Err.	z	P>|z|	[95% Conf. Interval]	
x1	1.235771	.2865138	0.91	0.361	.7844883	1.946656
x2	.9998819	.0008999	-0.13	0.896	.9981197	1.001647
x3	.809722	.0565383	-3.02	0.003	.7061572	.9284756
x4	.7994735	.306176	-0.58	0.559	.3774137	1.693521
x5	1.108442	.0522014	2.19	0.029	1.010709	1.215626
x6	.9990262	.0009825	-0.99	0.322	.9971025	1.000954
_cons	4821.291	22265.33	1.84	0.066	.5652067	4.11e+07

2. Output of Marginal Effect

. margins, dydx(*) atmeans
Conditional marginal effects Number of obs = 50
Model VCE : OIM

Expression : Pr(y), predict()
dy/dx w.r.t. : x1 x2 x3 x4 x5 x6
at : x1 = 11.18 (mean)
x2 = 1352 (mean)
x3 = 50.68 (mean)
x4 = 2.9 (mean)
x5 = 20.34 (mean)
x6 = 1470 (mean)

	Delta-method					
	dy/dx	Std. Err.	z	P>|z|	[95% Conf. Interval]	
x1	.0529235	.0579635	0.91	0.361	-.0606828	.1665298
x2	-.0000295	.000225	-0.13	0.896	-.0004705	.0004114
x3	**-.0527659**	**.0174585**	**-3.02**	**0.003***	**-.0869838**	**-.0185479**
x4	-.0559503	.0957382	-0.58	0.559	-.2435937	.1316932
x5	**.0257388**	**.0117774**	**2.19**	**0.029***	**.0026556**	**.048822**
x6	-.0002436	.0002459	-0.99	0.322	-.0007254	.0002383

*** signifikan pada tingkat kepercayaan 5%**

Notes:
X1 = Education level
X2 = Paddy-field area
X3 = Farmer age
X4 = Number of family member
X5 = Experience in rice farming
X6 = Distance of rice field to water source

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STORAGE DECISIONS OF JASMINE RICE FARMERS IN THAILAND

Orawan Srisompun[1*]**, Sakunkarn Simla**[1] **and Surasak Boontang**[1]
[1] Department of Agricultural Technology, Faculty of Technology,
Mahasarakham University ,44150 Thailand
Corresponding author: orawan.s@msu.ac.th

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ABSTRACT

The effects of economic and other factors on the jasmine rice storage decisions of farmers were analyzed using a binomial logistic regression model. The farm survey data from nine major productive provinces in the Northeastern region, and 330 rice farmers sampled during the 2017/18 crop year were examined. The data collection was done in January to April, 2018. The probability of storing jasmine rice was 43.6%, and the physical factors of the farms exhibited the highest effect on the storage decisions of the farmers. Factors such as having a barn, the jasmine rice yield, the region, the cultivation pattern, the female labor proportion, and participation in the rice-pledging scheme positively affected the storage decisions of the farmers. In contrast, household income negatively affected the storage decision. The study results suggest that the implementation of a policy for reducing the paddy supply during the harvest season requires economic and other incentives. Rice barn development is crucial for and correlated with the storage decision. Therefore, providing support for constructing or repairing barns increased the storage decision probability. Primarily, the large-scale farmers benefitted from the rice-pledging scheme. Public schemes should be thoroughly implemented. The need for sophisticated equipment, regulation procedures, and the high cost associated with rice storage reduced farmer participation, but the scheme did not affect the rice farm gate price.

Key words: rice storage, logistic regression, rice supply, pledging scheme, farm price

INTRODUCTION

Jasmine rice is a high-quality rice with long, tapering grains that become soft and scented when cooked. The demand for this rice by both domestic and international consumers is high. Because consumers value the properties of jasmine rice, farmers can sell it at a higher price than other types of rice (Isvilanonda, 2016). However, although jasmine rice has a high value, it has a key limitation. Because of the photosensitivity of jasmine rice, it grows only once a year (in the wet season) and should be harvested during the same year (November-December). Because large amounts of harvested jasmine rice enter the market at the same time, the farmers are forced to sell their rice at a low price during the harvest period (Thongngam, 1999). After harvesting their crops, the farmers have two choices: sell their crops immediately during the low-price season or store their harvested crops for sale later (Tomek and Robinson, 2014). Although the farmers can sell their crops either immediately after harvest or after the humidity decreases, crop storage is more advantageous than immediately selling it because the price of jasmine rice is generally low during the harvest season and high during the off-season (Office of Agricultural Economics, 2018). Therefore, the farmers who store their crops can sell them later at a relatively high price. Moreover, crop storage is necessary for maintaining the supply of rice and other agricultural crops in the market throughout the year because the demand for rice exists throughout the year (FAO, 1994). Agricultural crop storage for sale after the harvest season is a significant marketing mechanism that solves the problem of low crop prices during the harvest season. Furthermore, storage practices also reduce variations in the yield price and enable the sale of harvested crops in the market throughout the year, including the off-season, thus increasing farmers' incomes. However, without proper storage facilities and storage methods, the crop yield may be damaged by pests or plant diseases. Destruction during storage may cause crop damage or reduce crop quality, thereby reducing the yield value. Hence, farmers require effective and suitable storage methods that enable them to sell their crops for appropriate prices (Nwet et al., 2017). Crop storage not only ameliorates food shortages during the off-season but also helps farmers increase their incomes by selling their crops at a higher price in the off-season, when the crop supply is low (Hofstrand and Wisner, 2006).

Because the demand for rice persists throughout the year in Thailand, the price of rice increases after the harvest season and peaks between April and July (Office of Agricultural Economics, 2018). Accordingly, if the farmers store their rice and sell it between April and July, they can earn higher incomes than those earned from selling their rice during the harvest season; consequently, they can achieve maximum profits (Thongnit, 2008). However, most jasmine rice farmers choose to sell their rice immediately after harvest, preferring to sell freshly harvested rice instead of storing the rice for later sales. One of the causes of this preference is the shortage of agricultural labor, which causes farmers to use machines instead of human labor in rice cultivation. In particular, the harvesting process requires combine harvesters instead of manual labor. The moisture content of freshly harvested rice is approximately 20–27%. Farmers must dry the harvested rice before storage. Consequently, if the farmers do not have an adequate number of workers or a rice drying facility, they are compelled to sell their rice immediately after harvest (Srisompun et al., 2014). Another cause for immediate sale is that rice cultivation is not a major source of household income; the farmers' non-agricultural occupations may encourage them to minimize the time spent on rice production (Srisompun and Jarernrat, 2013) and reduce their household reliance on the income earned from the sale of stored rice. (Giles and Yoo, 2017).

Moreover, the adoption of modern technology and machines that increase farmers' rice yields has increased the costs of rice production (Chowdhury *et al.*, 2010). Most farmers borrow money to pay these increased costs; moreover, they may incur debts for other purposes. Hence, the need to pay off their debts may be a crucial factor in the farmers' decisions to sell their rice immediately (Stephens and Barrett, 2011). Thus, the marginal price of storage or storage costs may not be the key factor in the decision to store rice to obtain a higher price, which was observed previously. Instead, the following three key factors may affect the storage decision: physical factors related to the farm and farmer, economic factors, and social factors (Nwet *et al*., 2017). In this study, the effect of economic and other factors on the Thai farmers' decisions to store jasmine rice was analyzed. The results of this study were used to propose a policy for effectively managing the demand for rice during the harvest season to provide guidelines for creating a policy that supports rice storage for sale at an appropriate time.

MATERIALS AND METHODS

Conceptual framework and econometric model. In economics, the term "storage" indicates a production activity that bridges the time gap between production and consumption. Rice can be stored at farms and in markets. Storage at the nonfarm level involves selling the harvested rice to middlemen. Normally, the price falls for a short time during the harvest season, but farmers are able to sell their crops throughout the year (Tomek and Robinson, 2014). By storing the grain at harvest and waiting for the prices to increase sufficiently during the storage season, farmers can sometimes obtain higher total returns even after accounting for storage costs. However, this strategy is associated with risks because the prices sometimes fall during the storage season or do not increase sufficiently to cover the storage costs (Lai *et al*., 2003). If farmers can correctly anticipate the future supply and demand, they can store an appropriate amount of their crop for sale when the price increases from a low point during the harvest season and becomes sufficiently high to compensate for the cost of crop storage that the farmers incur (Saha and Stanford, 1994). The difference in price must be sufficient to motivate some farmers to sell their crops and others to hold back their crops until the price increases; consequently, seasonal crops will be allocated for sale in the market throughout the year depending on the relationship between the current yield price and the expected price, excluding the cost of storage. Farmers generally want to achieve the maximum profit or the minimum loss, and they need as much income that can be generated from selling their crops; hence, farmers will store their crops if they expect the profits from crop storage to be equal to or higher than the storage cost equation (1) (Enwet *et al*., 2017).

$$Pf - Pc \geq M \tag{1}$$

where Pf is the estimated income, Pc is the current price, and M is storage cost to crop sale.

In a study on the factors affecting the farmers' decisions to store their crops, although the storage decision was related to many variables, most of the farmers made their decision based on marginal profits (Wright and Williams, 1982). However, storing crops requires a large budget for obtaining a suitable storage system and equipment; hence, the storage decision is not easy for farmers (Strahan and Page, 2003). Moreover, each farmer's decision is related to his or her individual experiences, farm management concepts, socio-demographic background (e.g., educational level, social category, and income), and landholding size; all the aforementioned factors play significant roles in the decision-making ability (Ali and Kumar, 2011). A study that analyzed the factors affecting the decision to store jasmine rice reported a relationship between the physical factors related to the farm and farmers, economic factors, and social factors (Nwet *et al*., 2017) by using a binomial logistic regression model analysis. The decision to store rice was analyzed in two groups of farmers. One group sold their rice immediately, while the other group stored their rice for sale later. Hence, the dependent variable was the decision to store the rice for sale, which was a discrete variable with a value of either 0 or 1. The value 0 represented the farmers who sold their rice immediately without waiting for a price increase, while the value 1 represented the farmers who stored their rice for sale after the harvest season. The binomial logistic model was suitable for this type of data analysis. The hypothesis of the model was used to determine the probability of the farmers' decisions depending on the vector of the independent variable, X_{ij},, which was related to farmer *i,* the variable *j,* and the vector of an unknown parameter (β), as shown in equation (2) (Xiong *et al.*, 2016).

$$P_i = F(Z_i) = F(\beta X_{ij}) = 1/[1 + epc(Z_i)] \tag{2}$$

where Zi ranges from -∞ to ∞ and Pi ranges between 0 and 1;
Pi is nonlinearly related to Zi;
F is the cumulative distribution function (CDF); and
β is the unknown parameter.

The model value was estimated using the maximum likelihood method so that the logistic model could be used to estimate the value of the probability of the farmers' decisions to store rice, which can be described as shown in equation (3):

$$P_i = P[y_i = 1] = \frac{e^{x_i\beta}}{1+e^{x_i\beta}} \tag{3}$$

After the model value estimation was performed using the maximum likelihood method, the probability of the farmers' decisions to store rice according to the production type and region was performed, including the marginal model value estimation, which was the probability evaluation of the decision to store rice caused by each of X variables (X_i) by defining the other factors as constant values, as shown in equation (4):

$$\frac{\Delta P_i}{\Delta X_i} \parallel all\ other\ x\ constant = \frac{\partial P_i}{\partial X_i} \quad (4)$$

The dependent variable was the decision to store rice, and the independent variables were divided into the following four groups: the farmers' economic and social characteristics; the farms' physical characteristics; economic factors; and social and communication factors (Mencher and Saradamoni, 1982; Unnevehr and Stanford, 1983; Sthapit *et al*., 1996, Lyon, 2003; Srisompun *et al*., 2014; Hofstrand and Wisner, 2006; Giles and Yoo. 2007; Ali and Kumar, 2011; Tomek and Robinson, 2014). The variable meanings and descriptions are shown in Table 1.

Table 1. Variables affecting the farmers' decisions to store rice using a logistic regression model

Variable	**Variable name**	**Variable description/unit**
<u>Dependent variable</u>		
STORAGE	Decision to store rice for sale	1 = storage for sale 0 = no storage for sale
<u>Independent variables</u>		
Economic and social characteristics of the farmers		
SEX	Sex of key laborer	1 = male, 0 = female
AGE	Age of key laborer	Years
EDU	Education level of key laborer	1 = uneducated, 2 = primary school, 3 = secondary school, 4 = high school, and 5 = diploma or higher
AGLABOR	Agricultural labor amount	Person
FEMALESHARE	Female labor proportion	%
MOCCUPA	Major occupation is farming	1 = yes, 0 = no
INCOME	Household income	TH baht/year
DEPT	Have any household debt	1 = yes, 0 = no
Physical characteristics of the farms		
CREGION	Central northeastern region	1= Central northeastern region 0 = Other
SREGION	Lower northeastern region	1= Lower northeastern region 0 = Other
OGROUP	Rainfed area-organic rice	1 = Rainfed area-organic rice 0 = Other
CGROUP	Rainfed area-conventional rice	1 = Rainfed area-conventional rice 0 = Other
MSIZE[1/]	Jasmine rice plantation area	1 = medium size, 0 = other
LSIZE[2/]	Jasmine rice plantation area	1 = large size, 0 = other
BARN	Have a granary/barn	1 = yes, 0 = no
BARNCAP	Storage capacity	Sq. m.
Economic factors		
CASHCOST	Cash cost of jasmine rice	TH baht/year
DRYCOST	Rice drying cost	TH baht/ton
JASYIELD	Jasmine rice yield	Metric ton
JASPRICE	Jasmine rice price in the harvest season	TH baht/kilogram
Social and communication factors		
MEMORG	Member of a financial institution	1 = yes, 0 = no
MEMGROUP	Member of a farmer group	1 = yes, 0 = no
PLEDJOIN	Participated in the BAAC rice -pledging scheme	1 = yes, 0 = no

Note: [1/] Medium (jasmine rice cultivated area 1.6-4.8 ha); [2/]large (jasmine rice cultivated area >4.8 ha)

Study area and data collection. The present study was an empirical study that used data from farmer interviews in the major jasmine rice plantation areas in the following nine provinces: Nakhon Phanom, Maha Sarakham, Roi Et, Yasothon, Nakhon Ratchasima, Buri Ram, Surin, Si Sa Ket, and Ubon Ratchathani. The farmers who grew conventional jasmine rice and the farmers who grew organic jasmine rice in 12 villages were purposively sampled for this study. Overall, 330 farmer households were sampled. The sampling process was as follows:

1) A database of the farmers in each village in the study area was created to determine the number of farmers who had (or did not have) barns in the village, the average size of the farmers' barns, and the purpose of rice storage. This process was used to create the sampling framework.

2) The farmers in each group were distributed according to a list that provided the sampling framework for the purposive sampling. The data were collected from the groups of farmers who grew organic and conventional jasmine rice according to the proportions of each type of production in each group of the sampling frame. The sampled farmers in each group had the following three purposes for storing rice: storage for consumption or use as seeds only (173 households), storage for sale (78 households), and storage for sale by participating in the rice-pledging scheme of the Bank for Agriculture and Agricultural Cooperatives (BAAC) (80 households). The sample size of each group with a particular purpose for rice storage depended on the sampling framework in each village. For the farmers who grew jasmine rice in irrigated areas, the sampling was conducted according to a proportion of the purpose of rice storage, which was identical to the sampling of the farmers in the rainfed areas.

RESULTS AND DISCUSSION

Farmers' socioeconomic characteristics. From the study results, the average age of the farmers was 54-55 years old; 63.75% of the main labor force was male. Compared to plowing or crop tending during the planting process, the rice drying process is not difficult; therefore, the paddy storage decision may not be much different between the male and female farmers. The key factor should be the number of household laborers, as most rice drying processes use household labor more than hired labor; thus, household labor shortage should be a significant factor affecting the farmers' yield stockpiling decisions. From the observation, the average number of household laborers was 2.50-2.98 people per household, and the main occupation for most of them was farming on their own farm. Organic rice farmers have higher incomes than other population groups partly because of the income from the nonagricultural sector. The farmers who stored their rice had higher incomes than the farmers who keep their rice for household consumption.

Moreover, debt is another factor affecting the decision to store rice, and it was expected that the households with higher debts would tend to sell their rice immediately after harvest more often than the households without debt because they needed to sell their rice to pay their debts, and most of their creditor are BAAC (Bank for Agriculture and Agricultural Cooperatives). The annual scheduled payment period is after the harvest season or until March every year. From the data observation, it was found that more than 70% of the farmers in the study area had debts, and the farmers who stored their rice had average debts of 208,675 baht per household, which is more than the debt of the farmers who kept their rice stored for seeds or consumption; the farmers who grew jasmine rice in the rainfed areas had the lowest debts, while the irrigation area farmers had the highest household debts, approximately 215,357 baht per household.

Regarding the plantation size, the farmers had an average plantation area of 4.60 hectares, of which an average of 3.81 hectares were used for jasmine rice paddies. The farmers who kept their rice stored had 5.06 hectares of jasmine rice paddies, which was more than that of the farmers who did not store their crops by approximately 2 times; the farmers in the rainfed areas had more jasmine rice paddy areas than the farmers in the other areas. The farmers' yield was approximately 7.63 tons per household. The farmers who stored their crops yielded 10.48 tons on average, which is higher than the amount yielded by the farmers who sold their crops immediately, only 5.07 tons annually. When considering the production environment, the farmers in the rainfed areas had greater jasmine rice yields than the farmers in the other areas. .

Farmers' decisions to store rice. Regarding the storage pattern, we found that most of the farmers (78.85%) sold their rice immediately after harvest, whereas 21.15% dried their rice and stored it in barns. The farmers who stored their rice had the following three main purposes: household consumption, planting seeds, and later sale. Some of the farmers in the storage group may have participated in the rice-pledging scheme of BAAC to wait for a price increase after the harvest season. The data survey showed that approximately 52.57% of the farmers stored their rice only for household consumption and for use as seeds for the next planting season. Furthermore, 23.26% and 24.17% of the farmers stored their rice crops to sell and to participate in the rice-pledging scheme of the BAAC, respectively (Table 2).

Table 2 The sampled farmers' decisions to store jasmine rice categorized by region, farm size, production environment, and storage facility in the 2017/18 crop year

Rice sale	Region			Farm size		
	Upper north-eastern	Central north-eastern	Lower north-eastern	Small	Medium	Large
	(%)					
· Store for consumption and seeds	96.00	56.36	37.43	75.45	45.45	33.33
· Store for sale	4.00	41.82	16.96	22.73	27.27	16.67
· Store for the rice-pledging scheme	0	1.82	45.61	1.82	27.27	50.00
	Production environment			**Have a barn**		**Total**
	Rainfed		**Irrigation**	**Yes**	**No**	
	Conventional	**Organic**	**Conventional**			
· Store for consumption and seeds	40.49	51.85	86.67	46.30	80.33	52.57
· Store for sale	25.77	25.00	13.33	25.19	14.75	23.26
· Store for the rice-pledging scheme	33.74	23.15	0.00	28.52	4.92	24.17

Note: [1/] Small (jasmine rice cultivated area <1.6 ha); medium (jasmine rice cultivated area 1.6-4.8 ha); and large (jasmine rice cultivated area >4.8 ha)

The project of postponing paddy selling via the BAAC (granary-pledging scheme) is the government's policy to support farmers in the harvesting season when the rice price drops and decreases the paddy supplies in that period, which provides options to farmers to postpone their sales without concerning their household expenses and debts. The farmers are able to get a loan with the BAAC for their jasmine and sticky paddy yield at 90% of the market price, which is limited up to 300,000 baht, without any interest. The farmers have to pay back the loan within 4 months after the loan is approved. The farmers who participated in the granary-pledging scheme tended to keep their paddy crops more than the farmers who had never participated in this project; this was because of their experience of storing their paddy crops with the scheme and the ability to evaluate the risks and revenue from stockpiling rice. From the observation, it was found that 76.43% of the farmers who kept their rice stored had participated in the granary-pledging scheme before, while 29.59% of the farmers had never participated in this project. From the overview of the production environment, 63.19% of the rainfed crop farmers had participated in the granary-pledging scheme, which was the highest proportion, while only 15% of the irrigation crop farmers had participated in the granary-pledging scheme; however, most of the farmers, more than 80%, knew about the granary-pledging scheme and that it is still operated.

Moreover, the survey data showed that most of the farmers who stored their rice for sale or who participated in the rice-pledging scheme of the BAAC were large-scale farmers with a jasmine rice planting area of >4.8 ha. These large-scale farmers (66.67%) stored their jasmine rice for sale and/or participation in the rice-pledging scheme of the BAAC, while most of the small farmers (33.33%) stored their rice for household consumption and use as seeds for the next planting season (Table 2). Therefore, the rice-pledging program, which was intended to benefit several small farmers, was mainly beneficial to the large-scale farmers. However, the farmers who participated in the rice-pledging program sold their rice at a relatively high price. The need for sophisticated equipment, regulation procedures, and the high cost and high risk associated with rice storage affected the storage decision, but the scheme did not affect the rice farm gate price because the number of farmers participating in the program was low (Paopongsakorn, 2010).

Considering the regional or geographical characteristics of the study area, a difference was observed in the storage decision by the farmers in the lower northeastern region, who stored their rice for sale (approximately 16.96%), and those who participated in the rice-pledging scheme of the BAAC (45.61%). In contrast, only 4% of the farmers in the upper northeastern region stored their rice for sale, and none of them participated in the rice-pledging scheme of the BAAC; 96% of the farmers stored their rice only for household consumption or use as seeds for the next season (Table 2). The storage proportion varied between the regions with the type of rice required for home consumption. The main type of rice consumed by most of the farmers in the lower northeastern region was jasmine rice. Consequently, the farmers only grew jasmine rice to ensure that they had sufficient jasmine rice for home consumption throughout the year. In the upper northeastern regions, the farmers mainly consumed glutinous rice, while jasmine rice was only grown for sale.

An analysis of the decision to store paddy rice in different production environments showed that 78.83% of the farmers in the irrigated areas sold their rice immediately after harvesting it, and 8.33% stored their rice for later sale. None of the farmers in the irrigated areas stored their rice to participate in the rice-pledging scheme of the BAAC because most of the farmers in the irrigated areas needed to invest in dry-season rice, and some had to prepare the plantation areas for dry-season rice cultivation. These farmers either lacked an adequate number of workers to dry the rice or did not have rice storage facilities. More than 93.44% of the farmers who did not have barns sold their rice immediately after harvest, while only a few farmers who had barns sold their rice immediately. The proportion of farmers who stored their rice for sale was higher in the rainfed areas than in the irrigated areas. In the rainfed areas, approximately 50% of the farmers stored their rice for sale, and approximately 33.74% of the farmers participated in the rice-pledging scheme of the BAAC (Table 2).

Factors affecting the farmers' decisions to store rice. In Table 3, which presents the estimation results of the logistic regression model, the value of the probability χ^2 indicated that the independent variable in the model could explain either the dependent variable or the decision to store jasmine rice with an explanatory power of 43.60%. The coefficient estimation result showed that the proportion of female labor ($p < 0.10$) and household income ($p < 0.05$) significantly influenced the decision to store jasmine rice for sale. This result indicates that a household with a high proportion of female laborers was more likely to decide to store their rice for sale than a household with a lower proportion of female laborers. This variable coefficient analysis result reflects the role of female members in the postharvest process of rice cultivation (Mencher and Saradamoni, 1982; Unnevehr and Stanford, 1983; Sthapit *et al*., 1996). The farmers who required fine and constant operation, which requires fewer workers than are needed for land preparation, weed and pest prevention, or activities that require large farming machines, tended to hire fewer female workers than male workers (Barker and

Cordova, 1978; Paris et al. 2005). The household income variable had a negative coefficient value, which indicated that the households with high incomes were less likely to store their rice than those with low incomes that sold their rice immediately after harvest. Currently, the proportion of the sampled farmers' household income from the non-agricultural sector was approximately 80%. Hence, the members of the high-income households also spent time on activities outside the agricultural sector, which caused a labor and time shortage in the rice drying process (Srisompun et al. 2014). Thus, the farmers in the high-income households chose to sell their rice immediately and did not store it.

Table 3. Estimated results of the factors affecting the decisions of farmers to store jasmine rice

Variable name	**Coefficient estimates**			**Marginal effect model**		
	Coeff.	**Std. Err.**	**P>z**	**Coeff.**	**Std. Err.**	**P>z**
Economic and social characteristics of the farmers						
Sex of key laborer	0.1455	0.3394	0.6680	0.0358	0.0834	0.6680
Age of key laborer	0.0147	0.0171	0.3880	0.0036	0.0042	0.3880
Education level of key laborer	0.0700	0.1369	0.6090	0.0172	0.0336	0.6090
Agricultural labor amount	-0.0259	0.1564	0.8680	-.0064	0.0385	0.8680
Female labor proportion	0.0107*	0.0065	0.0990	0.0026*	0.0016	0.0990
Major career is farming	0.2132	0.1522	0.1610	0.0524	0.0375	0.1620
Household income	0.0000***	0.0000	0.0490	-0.0000***	0.0000	0.0500
Household debt	-0.4426	0.3424	0.1960	-.1095	0.0847	0.1960
<u>Physical characteristics of the farms</u>						
Central northeastern region	2.5233**	0.8566	0.003	0.5560***	0.1456	0
Lower northeastern region	2.9652***	0.8858	0.001	0.6210***	0.1285	0
Rainfed area-organic rice	0.9082*	0.5475	0.097	0.2227*	0.1305	0.0880
Rainfed area-conventional rice	1.1330**	0.5104	0.026	0.2720**	0.1160	0.0190
Plantation area-medium size	-0.0376	0.3985	0.925	-.0092	0.0980	0.9250
Plantation area-large size	-0.8588	0.6663	0.197	-.2000	0.1446	0.1670
Have a granary/barn	1.2942***	0.4730	0.006	0.2833***	0.0858	0.0010
Storage capacity	0.0025	0.0232	0.916	0.0006	0.0057	0.9160
Economic factors						
Cash cost of rice production	0	0	0.675	-0.0000	0	0.6750
Rice drying cost	0.0003***	0.0001	0.003	0.0001***	0	0.0030
Jasmine yield	0.0001***	0	0.004	0.0000**	0	0.0040
Jasmine rice price in the harvest season	0.0740	0.1267	0.559	0.0182	0.0311	0.5590
Social and communication factors						
Member of a financial institution	-0.5781	0.3276	0.078	-.1423	0.0801	0.0760
Member of a farmer group	0.0879	0.3273	0.788	0.0216	0.0802	0.7880
Participated in the rice-pledging scheme	0.9992**	0.3272	0.002	0.2404**	0.0759	0.0020
Constant	-7.9721	2.3021	-3.460			
Log likelihood = -156.43	LR χ^2 = 156.4300			Power of prediction = 43.60%		
Pseudo R^2 = 0.3416	Prob. [χ^2>value] = 0.000					

Note: *, **, and *** indicate statistical significance at the 90%, 95%, and 99% levels

The environment and rice production type, which were considered the physical characteristics of the farms, were significantly related to the decision to store rice. In the irrigated areas, the farmers who grew conventional rice were less likely to store their rice for sale at a higher price than the other farmers, while the farmers who grew conventional rice in the rainfed areas exhibited a higher probability of storing their rice for sale than the farmers who grew organic rice in the rainfed areas. The relevant study results are presented in Table 4. The farmers in the rainfed areas exhibited the highest probability of storage, whereas the farmers in the irrigated areas exhibited the lowest probability of storage; this was because some of the farmers in the irrigated areas needed to sell their rice to invest in the next season's crop and used household labor to cultivate the dry-season rice. Thus, no labor was available for drying the rice, while the farmers who grew organic rice in the rainfed areas exhibited a lower likelihood of storing their rice than the farmers who grew conventional rice; this was because most of the organic rice farmers had marketing support and sold their rice to the organic farmer group immediately after harvest. The consumer demand for organic products is increasing in Thailand (Songkhumchailiang and Huang, 2012); consequently, this farmer group chose to sell its crops immediately instead of storing them for later sale. Other physical factors, such as the region or having barns, were positively associated with the storage decision. The households in the lower northeastern region were more likely to store their rice than those in the other regions. Furthermore, having a barn was another significant factor in the farmers' decisions. The farmers who had barns decided to store their rice more often than those who did not have barns. Other factors, such as the storage capacity and farm size, did not significantly affect the decision to store rice.

Previous economic theories and the results of previous studies have indicated that economic factors are the most crucial factors affecting the decision by farmers to store their crops (Hofstrand and Winer, 2006; Tomek and Robinson, 2014); however, the results of this study showed that economic factors, including the cash cost of growing rice and the price of jasmine rice during the harvest season, did not influence the farmers' rice storage decisions. This implies that the farmers were not concerned about the price obtained. Moreover, the study hypothesis indicated that the farmers who had higher production cash costs sold their rice immediately without any storage; however, the coefficient estimation result was nonsignificant, partly because the farmers with high production costs were large-scale farmers who decided to sell some of their rice immediately after harvesting and stored the remaining crop for sale when the price increased. In contrast, the drying cost and volume of the jasmine rice yield had statistically significant effects on the farmers' paddy storage decisions. This implies that the farmers who had higher drying costs were more likely to store their paddy rice for sale than the farmers who had lower costs and produced relatively low volumes of jasmine rice. The last factor was related to social and communication issues; Lyon (2003) indicated that the community groups in rural or remote areas strongly incentivized the farmers' storage decisions. Accordingly, the farmers who had participated in the rice-pledging scheme of the BAAC were more likely to store their crops than the farmers who had never participated in the scheme. Moreover, although most of the farmers knew about the rice-pledging scheme of the BAAC, neither project awareness nor a financial institution or farmers' group membership affected the storage decision. The positive value of the coefficient of estimation indicated that the group members may have selected rice storage, but the relationship between the knowledge and awareness of the scheme or membership and the storage decision was nonsignificant.

In the marginal effect model analysis, which defined the other factors as constant, the relationship between the independent variables and the dependent variable of each factor were analyzed. The results showed that the coefficient estimation of the dependent variable was in the same direction as the coefficient analysis result in the main model. The results showed that the sampled farmers exhibited a 43.6% probability of storing their jasmine rice when categorized by the production environment and production pattern (Table 4). This study result was consistent with the mentioned model; the farmers who grew conventional rice in the rainfed areas exhibited a higher probability of rice storage than the other farmers. When region was used for the categorization, the farmers in the lower northeastern region exhibited a higher probability of rice storage (64.4%), which was higher than that exhibited by the farmers in the central (39.8%) and upper northeastern (8.6%) regions.

Table 4. Probability of jasmine rice storage categorized by the production environment and decision to store rice

Production type/region	Probability of storage			
	Mean	**Std. Dev.**	**Min**	**Max**
<u>**Production type**</u>				
Conventional rice- rainfed area	0.611	0.276	0.027	0.990
Organic rice- rainfed area	0.441	0.280	0.011	0.951
Conventional rice- irrigation field	0.158	0.150	0.007	0.581
<u>**Region**</u>				
Upper northeastern	0.086	0.072	0.007	0.266
Central northeastern	0.395	0.235	0.036	0.873
Lower northeastern	0.644	0.263	0.066	0.990
Total	**0.474**	**0.307**	**0.007**	**0.990**

CONCLUSIONS

Most of the jasmine rice farmers sold their paddy immediately after harvest. The estimation result of the logistic regression model showed that the physical factors of the farm, namely, the production pattern, region, and having barns, were the most crucial factors affecting the farmers' paddy storage decisions. Moreover, the farmer households that participated in the rice-pledging scheme of the BAAC were more likely to store their paddy rice for sale than the farmer households that did not participate in the scheme. Regarding the socioeconomic factors, the study results indicated that households with high proportions of female laborers and low household incomes exhibited a higher tendency to store their paddy rice for sale than the other households. In contrast, the economic factors, namely, the price of a paddy and the production costs of jasmine rice, did not affect the farmers' paddy storage decisions. The results of the marginal effect model showed that the farmers in the lower northeastern region were more likely (64.4%) than those in the other regions to store their paddy rice for sale at a high price. Therefore, the result of this study is the following major policy proposal to enhance the effectiveness of the current policy for reducing the jasmine rice supply in the market during the harvest season and to encourage farmers to store their rice for maximum profit:

1. The purpose of the rice-pledging scheme is to provide subsidies to farmers and support the rice price during the harvest season. However, the number of farmers who currently benefit from the rice-pledging scheme is low, and most of them are large-scale farmers. Any public policy should ensure the thoroughness of policy implementation.
2. The reasons underlying the decisions of farmers to sell their rice immediately after harvest without participating in the rice-pledging scheme include not only the storage risk but also the need for sophisticated equipment, regulation procedures, and the high cost of storage. The rice-pledging scheme has not affected the rice farm gate price because the number of farmers participating is low.
3. Rice barn development is crucial for and correlated with the storage decision of farmers. Hence, providing adequate support for the construction and repair of barns will increase the probability of the farmers' decisions to store jasmine rice for sale.

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POTENTIAL DEVELOPMENT OF GLUTINOUS RICE COMMUNITY TOWARDS NEW AGRICULTURAL CULTURE TOURISMS IN UPPER NORTHEASTERN THAILAND

Patcha Sattaka*
Glutinous Rice Research Unit, Faculty of Natural Resources aand Agro-Industry
Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus,
Muang, Sakon Nakhon, 47000, Thailand
Corresponding author: patcha.sat@ku.th

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ABSTRACT

Glutinous rice growing is concentrated in Northeastern Thailand. It not only impacts people's livelihoods, culture and traditions, but is also unique in its taste, consumption and extensive utilization. Thus, those in the glutinous rice community should make use of their unique glutinous rice culture to promote agricultural/cultural tourism. The study locations were Ban Phu in Mukdahan province, the Khao Mao Wan Community Enterprise, Ban Prong in Nakhon Phanom, and the Noi Chomsi Community Enterprises in Sakon Nakhon in January-March 2017. The study showed that the communities in Upper Northeastern Thailand have the potential to develop as an agricultural/cultural attraction. Moreover, the study indicated that glutinous rice attraction has high potential based on 10 indicators: production, processing, culture and tradition, location, facility, natural resource management, community participation, community administration, services, and promotion of glutinous rice attractions. However, the glutinous rice community can improve attractions by focusing on food security issues. It is anticipated that by integrating rice cultivation and cultural activities into the overall community development program, glutinous rice attractions will increase awareness of the role of glutinous rice regarding food, jobs, and cultural security to ensure a sustainable quality of life for glutinous rice farmers and their associated communities.

Key words: agricultural tourism, cultural tourism, development

INTRODUCTION

In the Greater Mekong Subregion (an emerging economic subregion of Southeast Asia), rice is culturally preferred for production and consumption, especially in the Mekong River Basin, where the local variety is known as glutinous rice. It is believed that the glutinous rice is associated with the Tai ethnic people who migrated along the Mekong River to Southeast Asia in the past. People in Southeast Asia consume glutinous rice as the staple food, especially in Thailand and Lao PDR. The scientific name of glutinous rice is *Oryza sativa* var. *glutinosa*, and the common names are sticky rice, waxy rice and sweet rice (Nguyên, 2001). Glutinous grains have a brown or black or purple seed coat depending on the type of the variety; the color of milled grains is white or black or purple. Generally, the milled grains of glutinous rice are an opaque white color and become translucent after cooking. Normally, rice grains contain two types of starch (amylose and amylopectin), but glutinous rice grains are distinguished from ordinary rice by having negligible amounts of amylose and high amounts of amylopectin (Falvey, 2000; Nywikol, 2008). Moreover, glutinous rice is gluten-free, therefore, it is safe for people who have celiac disease and gluten sensitivity. The world distribution of glutinous rice varieties has resulted in glutinous rice varieties being found in 37 countries—Lao PDR, Thailand, Indonesia, China, the Philippines, India, Vietnam, Myanmar, Cambodia, Japan, Malaysia, South Korea, Taiwan, Nepal, Bangladesh, Srilanka, Brunei Darussalam, Brazil, the United States of America, Hungary, Senegal, Tanzania, Turkey, Burundi, Colombia, Ethiopia, Georgia, Guinea, Guinea Bissau, Guyana, Iran, North Korea, Pakistan, Russian Federation, Surinam, Uzbekistan, and Venezuela. The continent from where the majority of glutinous rice varietal samples were collected for conservation at IRRI was, as expected, Asia, with 6,484 varieties or over 99% of the collection. The largest collection was from Lao PDR (2,470 varieties), followed by Thailand (1,289 varieties) and Indonesia (529 varieties), respectively (Figure 2) (Sattaka et al. 2014).

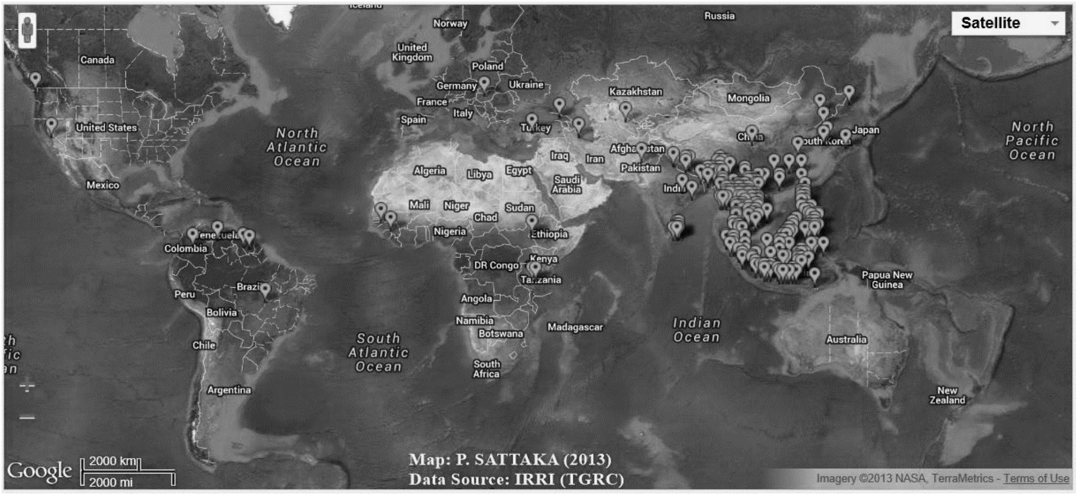

Fig. 1. Geographical distribution of glutinous rice globally (Source: Sattaka et al. 2014)

Geographically, glutinous rice growing is concentrated around an area in the northeastern part of Thailand. This glutinous rice 'zone' covers an area of approximately 2.49 million ha. For the people in this rice zone, glutinous rice is much more than an agricultural commodity as it is their livelihoods, their culture and traditions. It is, indeed, their food security as well as their jobs and cultural security. The small cultural differences between the different Tai speaking groups are overshadowed by their overwhelming cultural similarities which include language, rice cultivation system, glutinous rice consumption, and many traditional cultural practices. In most, if not all, glutinous rice farming communities or towns, people usually observe and carry out various rice-related traditional practices and celebrations, such as the Ploughing Ceremony at the beginning of the rice cultivation season, usually around May, and the Rice Harvest Celebration in December. Glutinous rice is also unique in its taste, consumption, and utilization—much of which is culturally related. As such, it can serve as a geographically specified 'trade mark' of the country. Many traditional local products are being developed to become OTOP products (One Tambon (Subdistrict) One Product) such as Hang rice. Other popular local products include Khao Mao which is made from green and young parboiled rice. Other more common products are Sweet Fermented Glutinous Rice and Local Glutinous-Rice Wines. Moreover, increasingly, tourists are appreciative of the natural environment, especially in developing regions. Local agricultural production and local markets are also increasingly popular, even in urban cities. Agricultural landscapes, including glutinous rice farms in traditional rural settings, can be and are amazingly beautiful and attractive sights, especially to urban tourists. Form the above point it has accorded with Choeichuenjit and Sapsanguanboon (2014) reported that one of the most interesting tourism sectors is cultural tourism that use culture and tradition of community as a product to differentiate from other types of tourism which adds value to tourist destinations. Furthermore, Richards (2018) explained that cultural tourism is a type of tourism activity in which the visitor's essential motivation is to learn, experience and consume cultural attractions in a tourism destination. Riddhagni (2018) indicated that cultural tourism is becoming popular in Thailand that increase number of tourists. It has taken the position as the importance segments of country's economic. Leopenwong (2014) and Ornrat (2018) reported that the culture tourism was the important policy to promote tourism in the upper northeastern provinces. But the cultural tourism has also just a festival-based tourism activity, there is no development of support activities for additional revenue. The major problems were insufficient budgets to develop the attraction, community's participation, and lack of public relations and good management about the tourism activities. The concept to promote glutinous rice community towards new agricultural culture tourisms is one of the strategy for sustainable community development by using by using capitalization on nature and cultural assets of places.

Moreover, the current study aimed to show that the communities in Upper Northeastern Thailand have the potential to develop to be cultural attractions based on the community or farmers' management. The more specific objectives of the study were i) socio-economic information of glutinous rice community; ii) facts on glutinous rice planting, production, security; iii) factors affecting the potential to develop new cultural tourism opportunities. Because Thailand is an emerging country for cultural tourism, the country should make use of its unique glutinous rice culture to promote eco-cultural tourism to selected glutinous rice producing communities. Research and development support to identify and promote such cultural traditions relating to glutinous rice would certainly help keep the young generation of rice farmers on the farm and ensure sustainable production of glutinous rice toward the sustainable development goals of the country.

RESEARCH METHODOLOGY

Study area. This project was undertaken in three provinces in the upper northeastern region of Thailand where farmers grow glutinous rice and are famous and unique in glutinous rice culture and products. The study locations were Ban Phu in Mukdahan province, the Khao Mao Wan Community Enterprise, Ban Prong in Nakhon Phanom, and the Noi Chomsi Community Enterprises in Sakon Nakhon,

1. Ban Phu village in Mukdahan province, Ban Phu is an old Phu Tai ethnic community located in Nong Sung district, Mukdahan province. There have a unique culture and traditions, especially regarding food as the people consume glutinous rice as staple food. Tourists can join and experience a homestay with the villagers and learn all the preserved cultures of this village via living locally. The village is surrounded by mountains and beautiful natural resources, especially glutinous rice fields that provide clean, fresh air.

2. The Khao Mao Wan Community Enterprise in Nakhon Phanom province, grows Khao Mao or young flattened rice which is made from young glutinous rice. The best Khao Mao has to be made from local glutinous rice varieties that are harvested in October. It is consumed as an indigenous snack by local communities in Thailand, Lao, and Vietnam. The processing method of Khao Mao has been transferred from ancestors to descendants so Khao Mao knowledge is well-known local wisdom of Thai people in the northeastern region. Thus, the Khao Mao Wan Community Enterprise use this local wisdom to produce Khao Mao as a famous glutinous rice product. The Khao Mao Wan Community Enterprise receives a high income from Khao Mao (about USD 31,250 per month) during October to January. There is a learning center for glutinous rice processing where tourists can study, test, and experience Isaan's warm hospitality. Moreover, the community is located in That Phanom District, which is also the site of the most important Buddhist temple in the region and tourists can visit the most cherished chedis in Southeast Asia.

3. The Noi Chomsi Community Enterprise in Sakon Nakhon is well known as a provider of Hang rice in Sakon Nakhon province. It has a learning center for farmers, students, and foreigners. Hang rice is geographical indicator (GI) of Sakon Nakhon province that is made from both non-glutinous rice and glutinous rice. Hang rice originated because the famers did not have enough glutinous rice to consume before the next harvest season. Therefore, they harvested grain at the immature stage (about 85% of grain maturity) to make Hang Rice for their own consumption. Hang rice is soft has a good flavor and aroma and is highly nutritious. Nowadays Hang Rice is used as a main food source in some

household in Thailand. Because of the fame of Hang rice, the Community Enterprises Noi-Chomsi has developed Hang rice quality by using the organic rice standard of the USDA and good manufacturing practices for value adding and market expansion. Tourists can study Hang rice processing and visit various organic glutinous rice and non-glutinous rice fields.

Data collection. Data were collected using a community survey and interviewing schedule according to the objective of the research namely to obtain socio-economic information, facts on glutinous rice planting, production, and security, and factors affecting the potential to develop new cultural tourism opportunities based on glutinous rice. The data were collected in January-March 2017. Simple random sampling method was used to select where farmers grow glutinous rice and are famous and unique in glutinous rice culture and products. Based on the total members of the group which are 250 members in Ban Phu village Mukdahan, 30 members in The Khao Mao Wan Community Enterprise Nakhon Phanom, and 30 members in The Noi Chomsi Community Enterprise Sakhon Nakhon. Thus the required sample size was determined to be 90 respondents in total with equal numbers from Mukdahan, Nakhon Phanom, and Sakhon Nakhon.

Data analysis. 1. The survey used *rai* for area measurement and the Thai currency (THB) for all monetary values to make it easier for the farmers to provide their data. All survey results were converted into hectares (6.25 rai=1 ha), and THB were converted to USD at a rate of USD 1=THB 32.50 (Bank of Thailand, 2016).

2. Glutinous rice production and measurement were divided into: growing area (ha), yield (kg.ha^{-1}), annual glutinous rice production (kg per household), and annual farmer income from glutinous rice (USD).

3. Monthly glutinous rice consumption sufficiency of the farmers was determined and the criteria for scoring and measurement were: 0 indicated "Insufficient" and 1 indicated "Sufficient". Therefore, the total annual maximum score for glutinous rice security was 12 being (modified from Jenson and Nord, 2012; Prachasan, 2012).

4. Glutinous rice production stability comprised six situations: farmers kept water in a well for use on farm; improving soil fertility every year; planning to produce glutinous rice for the whole year's consumption; keeping some glutinous rice for emergencies; having a plan to reduce chemical agents used in glutinous rice production; and have sources of glutinous rice knowledge in the community. The criteria for scoring and measurement were: 0 = "Unstable" and 1 = "Stable" and the maximum total score for glutinous rice security was 6 (modified from Jenson and Nord, 2012; Prachasan, 2012).

5. Glutinous rice utilization consisted of three items: farmers consume clean and safe glutinous rice; farmers consume other dishes instead of glutinous rice; and farmers are able to process glutinous rice to make edible dishes, with the criteria for scoring and measurement being: 0 = "No" and 1 = "Yes". Thus, the maximum total score of glutinous rice security was 3 (modified from Jenson and Nord, 2012; Prachasan, 2012).

6. Factors affecting potential of glutinous rice community to develop new cultural tourism aspects consisted of three mains section and a Likert Scale (1-5 score) was used for scoring and measurement:

6.1 The potential of glutinous rice community was evaluated using 10 components: production, processing, culture, location, facility, natural resource management, community participation, community administration, services, and promotion.

6.2 The components of glutinous rice attractions were: infrastructure, knowledge of attractions, culture and tradition, glutinous rice products, services, natural resource management, promotion, and community participation, community administration and supporting organization.

Likert Scale interpretation, the range was calculated ($5 - 1 = 4$) and then divided by five as this was the greatest possible value for the scale ($4 \div 5 = 0.80$). The score range for each evaluation criterion was: 1 to 1.80 (Very low); 1.81 to 2.60 (Low); 2.61 to 3.40 (Moderate); 3:41 to 4:20 (High); and 4:21 to 5:00 (Very high.)

7. After collecting the data and checking the data for errors, a computer program was used to determine percentages, arithmetic means and standard deviations for analysis. Regression analysis was used to determine how the important factors influenced the potential of the glutinous rice community toward new cultural tourism aspects in Upper Northeastern Thailand. The dependent variable was the score of potential of the glutinous rice community. The independent variable was the score of infrastructure, knowledge of attractions, culture and tradition, glutinous rice products, service, promotion, natural resources, community participation, community administration, supporting organization

RESULTS AND DISCUSSION

Socio-economic information of glutinous rice community

Glutinous rice farmers. Of the farmers, 56.3% were female and 43.8% were male. Approximately 66.3% of the farmers were 40-59 years old, with an average age of 52 years. Of the farmers, 76% had completed elementary school education and 10.8% had completed their senior high school education. Nearly 59.5% had more than 30 years of glutinous rice planting experience, with the overall average experience being 25 years. It was found that 68.8% of the farmers owned less than 2.00 ha, with the average area being nearly 1.22 ha.

The study indicated that most famers were elderly with an average age of more than 50 years, and most had elementary school education. Therefore, these facts indicated that the farmers had limited access to knowledge on glutinous rice production. However, the farmers had large amounts of experience over a long time in planting glutinous rice with the average being more than 28 years but some of them could not understand, accept, and apply the new technology on glutinous rice development from their friends and the agricultural extension workers. Moreover, the farmers operated at a small agricultural scale, each owning an area less than 1.90 ha (Ngee-on, 2001; Sarast and Wongsamun, 2008; Nithiyanan et al. 2012; Srisompun et al. 2013) because the growing area had been progressively subdivided through ancestral lineage or by liability, which had an effect on the available agricultural area and glutinous rice production. Thus, the farmers need to improve the production system by using knowledge and appropriate technology to increase both the quantity and quality of glutinous rice.

Glutinous rice planting methods. The study found that 70% of farmers grew glutinous rice using the transplanting method and 30% used the broadcasting method. Approximately 93.5% of respondents used the RD6 seed variety and only 3.3% used local seed varieties. Glutinous rice seed was produced mainly by farmers (62%) while 22% purchased their seed from a government organization. Approximately 33.5 and 60% of farmers applied chemical fertilizer once and twice, respectively. Most farmers harvested their glutinous rice by hand (78%) and kept their harvest in their barn (75.8%). The study indicated that most Thai farmers used the RD6 seed variety which is a photoperiod-sensitive rice variety. Moreover, the RD6 seed variety is also considered to be a good glutinous rice variety because the cooked rice is soft and aromatic and fetches a high price. Because it is photoperiod-sensitive, it can be grown only once a year in the wet season during June-November using the transplanting method (Bureau of Rice Research and Development, 2009). Thus, a non-photoperiod-sensitive variety of RD6 was developed by Maejo University and the Rice Department so that it could be grown in the dry season, whilst still having the same quality and quantity as the RD6 photoperiod-sensitive variety (Agriculture and Food Cluster, 2015). Even thought, most farmers used the RD6 seed variety for their consumption but local seed varieties was used for processing rice products such as the Khao Mao Wan Community Enterprise in Nakhon Phanom province. The best Khao Mao has to be made from local glutinous rice varieties with its natural, pandan-like aroma as well as soft and sticky texture (Fig. 2). During October to February the tourists - who visit Khao Mao Wan Community Enterprise - can study local wisdom to produce Khao Mao that to be made from various local glutinous rice.

Fig. 2. Khao Mao at Khao Mao Wan Community Enterprise in Nakhon Phanom province

For Hang rice in Noi Chomsi Community Enterprise could be produced from many varieties both non-glutinous rice and glutinous rice. Normally, RD6 glutinous rice were used to produce Hang rice, cooked hang rice is soft, aroma and has good flavor. One of the important of Hang rice in Sakon Nakhon province was registered geographical indication (GI) on July 26, 2006. The registration of GI provides protection for rice strains by certifying their origin and quality in relation to a farming community. Thus, Noi Chomsi Community Enterprise has a learning center for tourist (Fig. 3).

Fig. 3. Participants of international workshop on "Climate Smart, Innovative Food Preservation and Processing Technologies Applied by Women in Rural Environments" by Food and Agriculture Organization (FAO) visited Hang rice processing in Noi Chomsi Community Enterprise

Glutinous rice as food security. Sustainable production of glutinous rice is, undoubtedly essential for Upper Northeastern Thailand, considering its role as a staple food and in relation to the many cultural traditions and livelihoods of the people. The study showed that 100% of the respondents had glutinous rice consumption sufficiency for a year. To provide glutinous rice stability of availability, most farmers (93%) sourced water from a well for use on the farm, 94% improved soil fertility every year, and 98.8% had a plan to produce glutinous rice for the whole year's consumption. Furthermore, 96% of the Thai farmers kept glutinous rice for emergencies, 92% had a plan to reduce chemical agents for glutinous rice production, while only 83% sourced glutinous rice knowledge in the community. Considering glutinous rice utilization, 78% of farmers were able to consume clean and safe glutinous rice and 51% of farmers consumed other dishes instead of glutinous rice. Moreover, 95% of farmers were able to utilize glutinous rice in other edible dishes.

The study indicated that the community had food sufficiency in glutinous rice because of the importance of glutinous rice as an attraction and to show visitors the potential of glutinous rice production. Moreover, most of the glutinous rice areas were in rain-fed catchments and 71.3% of farmers had encountered increased drought during 2013-2016 and flooding in 2017 but they tried to maintain their level of glutinous rice planting. Glutinous rice is important not only for food security but also for nutritional security. One serving of glutinous rice can provide, in addition to approximately 169 calories and 7-8% of protein, significant amounts of essential vitamins and minerals (Gray 2010). Many local glutinous rice varieties are known to provide special quality tasting products, such as Black glutinous rice and Hang glutinous rice in Sakon Nakhon province and Ban Phu village in Mukdahan province (Fig. 4).

Fig. 4. Hang rice products

There are many traditional glutinous rice products which are locally consumed in all GMS countries and form part of their economies but with limited market. In addition, it should be noted that in each member country of the GMS, some of the potential glutinous rice community destinations are, in fact, already tourism sites, but without focusing on the rice and food security issues. It is anticipated that by integrating the rice cultivation and cultural activities into the overall community development program, the promotion of Glutinous Rice Corridor can be effectively carried out.

Factors affecting potential of glutinous rice community toward new cultural tourism in Upper Northeastern Thailand. Increasingly, people are appreciative of the natural environment, especially in more developed regions. Local agricultural production and local markets are also increasingly popular, even in urban cities. Agricultural landscapes, including glutinous rice farms in traditional rural settings, can be and are amazingly beautiful and attractive sights, especially to urban tourists. Moreover, in glutinous rice farming communities or towns people usually observe and carry out various rice-related traditional practices and celebrations, such as the Ploughing Ceremony at the beginning of the rice cultivation season (usually around May) and the Rice Harvest Celebration in December. In addition, it should be noted that in each glutinous rice area of the country, some of the potential glutinous rice community destinations are already popular tourism sites, but without a specific focus on rice and food security issues. It is anticipated that by integrating the rice cultivation and cultural activities into the overall community development program, the promotion of a Glutinous Rice Corridor can be effectively implemented. Thus, developing glutinous rice attractions will help to showcase the potential of the glutinous rice community toward agricultural cultural tourism. This concept supported the tourism policy 2018 in Thailand that would be sustainable tourism, focus on quality tourism, create higher economic value, and distribute tourism income to the regional areas and pride of local heritage (Wattanavrangkul, 2017). The study indicated that the glutinous rice attractions in the study area have high potential based on 10 indicators: production, processing, culture and tradition, location, facility, natural resource management, community participation, community administration, services, and promotion of glutinous rice attractions (Table 1). The potential of glutinous rice production had the highest score because the farming community has glutinous rice in excess of its domestic needs, and the surplus can be sold and processed. For glutinous rice production and natural management, glutinous rice production is grown using sustainable agriculture and agriculture standards such as the Good Agriculture Practice Standard and the Organic Rice Standard. It can build confidence with the consumer and the tourist to visit and learn, and also friendly with the environment. Moreover, these system lead farmers to self-sufficiency, a concept developed by His Majesty the King. As the report of Khamung (2015) indicated that local communities possess advantages of natural resources and culture heritage to attract tourist; its success will greatly increase if the communities observe and practice self-sufficiency farming and use sustainable agricultural production while preserving. For value added, the quality yields were used in processing based on integrated the local wisdom and appropriate technology to improve local products on glutinous rice to become One Tumbon One Prodcut (OTOP products) or One Sub-district One Product with five stars level such as Khao Mao at Ban Prong in Nakhon Phanom and Hang rice at Noi Chomsi. Even though, Ban Phu village do not have processing products from glutinous rice, but they have culture and tradition on food made from glutinous rice to serve for visitor such as Khao Tom Mat or Khao Tom Pat, grilled glutinous rice, and steamed glutinous rice in the meal. Moreover,

glutinous rice was used in traditional welcome ceremony for visitors that stayed in Bam Phu called the ceremony as "Bai Sri" or "Bai Sri Su Kwan".
(Fig. 5).

Fig. 5. Grilled glutinous rice, steamed glutinous rice in the meal and "Bai Sri" or "Bai Sri Su Kwan" in Bam Phu

For location of glutinous rice attractions, there are located on local road but do not far from main road and have guidepost for the guidance of travelers. Moreover, glutinous rice attractions have facilities to support travelers such as clean toilets, accommodations, free parking lot, and souvenir shop etc. The activities of glutinous rice attractions were managed by the members in community by using participation process. They have annual production plans and the activities; the member duty was assigned based on ability and proficiency by the community committees. For services, the attractions showed the process of glutinous rice production, products, culture and tradition by the community guides, that the tourists can try and learn. Besides, the tourists can test the glutinous rice products and purchase from the souvenir shop in the community. Although, the attractions have high level of promotion of glutinous rice attractions because of the famous products, but they have limited the channel communication to promote the attractions especially in Ban Prong in Nakhon Phanom and Hang rice at Noi Chomsi. Given rising interest in cultural tourism, local communities are developing more and more travel-related businesses, including homestays, shops, and restaurants. This has created jobs and generated income for communities. However, it has often also changed the local ways in a manner that erodes long-term tourism potential. Therefore communities and stakeholders should promote glutinous rice attraction by emphasize long-term benefits rather than short-term income, to ensure timely supply-side development (Amornvivat et al. 2016).

Table 1. Potential of glutinous rice community toward agricultural cultural tourism

Indicator	Mean	Std.Dev.	Interpretation
Glutinous rice production	3.88	0.75	High
Glutinous rice processing	3.57	0.56	High
Glutinous rice culture and tradition	3.60	0.85	High
Location of glutinous rice attractions	3.50	0.78	High
Attraction facility	3.60	0.83	High
Natural resource management	3.53	0.82	High
Community participation	3.73	0.88	High
Community administration	3.70	0.95	High
Services	3.61	0.81	High
Promotion of glutinous rice attractions	3.47	0.86	High
Total	**3.66**	**0.58**	**High**

As mentioned earlier, glutinous rice is unique in its origin and distribution. It is also unique in its taste, consumption, and utilization—much of which is culturally related. As such, it can serve as a geographically specified trademark of the upper northeastern region of Thailand. Many traditional local products are being developed to become OTOP products. In fact, GI glutinous rice has been identified and certified (for example, Hang rice from Sakon Nakhon province in Thailand). Other popular local products include Young Glutinous Rice Cereal or Khao Mao which is made from green and young parboiled rice. It is also used to produce many rice snacks and desserts. Other more common products are Sweet Fermented Glutinous Rice and local Glutinous-Rice Wines in Nakhon Panom province. Thus, upper northeastern tourism is one of the programs in regional development in recognition of its important contribution toward socio-economic development and the conservation of natural and cultural heritage resources. Thus, the upper northeastern tourism strategy was defined to develop and promote eco-tourism as a single destination and offering a diversity of good quality and high yielding sub regional products-by fostering a sustainable tourism development approach. In the case of glutinous rice attraction development, the study indicated that infrastructure (p =.021), knowledge of attractions (p =.001), promotion (p =.042), and supporting organizations (p =.013) affected the potential of glutinous rice attractions (Table 2)

Table 2. Factors affecting the potential of glutinous rice community toward new agricultural cultural tourism in Upper Northeastern Thailand

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.181	.329		-.549	.585
Infrastructure	.243	.104	.253	2.347	.021*
Knowledge of attractions	.308	.088	.322	3.498	.001*
Culture and tradition	.035	.022	.104	1.597	.114
Glutinous rice products	.045	.110	.044	.407	.685
Service	.037	.027	.117	1.336	.185
Promotion	-.060	.029	-.163	-2.063	.042*
Natural Resources	.007	.014	.049	.527	.599
Community participation	.031	.028	.098	1.114	.269
Community administration	.010	.115	.009	.083	.934
Supporting organization	.256	.101	.215	2.542	.013*

Dependent Variable: Potential of glutinous rice community
*p < .05, F=17.78, p-value=.000, and R-square = 0.692 (69.2%)

Infrastructure plays a major role in the development of attractions. The study found that the development infrastructure associated with glutinous rice attractions should improve accommodation (clean and safe, good food), accessibility (transportation, signpost, location, road, etc.) and amenities (internet, toilet, shopping facilities, etc.). Moreover, the tourist would like to do different things including gaining knowledge from experiencing attractions (Haneef, 2017). Thus, glutinous rice attractions should provide new knowledge about glutinous rice that shows its importance, uniqueness, and culture and tradition, while also creating activities involving glutinous rice such as planting, cooking, and eating. The farms attractions would then allow tourists to have the opportunity to see culturally constructed landscape, local culture, and local agricultural practice. While competition among tourism sites and number of new developments are increasing, it is very important to identify market niches. Therefore, promoting glutinous rice tourism is a challenge and it is important to increase the potential of glutinous rice tourism by making it better known and ensuring cleanliness highlighting the magic and spirit of each destination, and using Social Media to promote tourism. To develop the potential of the glutinous rice community toward new cultural tourism there needs to be support to improve attractions to be better, more beautiful, and convenient. Moreover, the knowledge for improving the glutinous rice community toward new agricultural cultural tourism opportunities needs to be applied based on the appreciated technology and what the community wants.

The study showed that culture and tradition and glutinous rice products is not an essential factor affecting in the development by the reason of the unique of glutinous rice production and culture in the community, that take well-known attractions. For example, glutinous rice products-Khao Mao and Hang rice, received five stars level of OTOP and Ban Phu homestay is one of attractions that recommended by the Mukdahan Provincial office of Tourism and Sports. Moreover, culture and tradition tourism should preserve their local culture and wisdom. The same as the study of Khamung (2015) indicated that local communities need to employ sustainable agriculture practices and at the same time preserve their local cultural heritage. The same as natural resources is not essential factor because glutinous rice attraction used GAP and organic production standards. These standards are friendly with environment. Moreover, the farmers also preserved local glutinous rice varieties for utilization and learning.

CONCLUSIONS AND RECOMMENDATION

Glutinous rice tourism was one of the programs of the GMS Economic Cooperation Program in recognition of its important contribution to socio-economic development and the conservation of natural and cultural heritage resources. Thus, the upper northeastern region tourism strategy was defined to develop and promote agricultural cultural tourism as a single destination, offering a diversity of good quality and high yielding sub regional products-by fostering a sustainable tourism development approach. The study results indicated that glutinous rice community development toward new agricultural cultural tourism opportunities should have a socio-economic basis as most farmers have small scale production of less than 2 ha, based on rainfed irrigation, and low glutinous rice yields, so the productivity per area of glutinous rice production should develop not only for food security but also for the job security of the farmers. Moreover, glutinous rice communities considering change to increase attractions need to consider food security and the identity of each community. The promotion of a Glutinous Rice Corridor can be effectively carried out by integrating rice cultivation and cultural activities into the overall community development program. The potential development of glutinous rice communities toward new agricultural cultural tourism ventures will require considerable infrastructure, knowledge of the attractions, and their promotion, as well as the need to support improvements to develop better, more beautiful, and convenient attractions based on appreciated technology and the community’s needs. It is hoped that glutinous rice attractions will increase awareness on the role of glutinous rice for food, jobs, and cultural security, especially for the low-income population, and that this will lead to greater research and development effort to ensure the sustainable quality of life for glutinous rice farmers and communities. Quality tourism to these communities throughout Upper Northeastern Thailand to the East-West Economic Corridor (the Glutinous Rice Corridor) will, hopefully, help contribute to the same development goals for all.

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EVALUATION OF DIVERSITY OF PLANT GENETIC RESOURCES GROWN IN MYANMAR HOME GARDEN: DISTRIBUTION AND UTILIZATION OF *HIBISCUS* GENUS PLANT "CHINBAO"

Mami NAGASHIMA[1]・Kenji IRIE[1]・Saki YOSHIDA[1]・Hidehiko KIKUNO[1]・Ohm Mar Saw[2]・Than Than Soe[3] and Kazuo WATANABE[4]

[1] International Agricultural Development, Graduate School of Agriculture,
Tokyo University of Agriculture, Sakuragaoka 1-1-1, Setagaya, Tokyo 156-8502, Japan
[2] Department of Agricultural Research, Ministry of Agriculture,
Livestock and Irrigation, Yezin, Nay Pyi Taw, Myanmar
[3]Yezin Agricultural University, Yezin, Nay Pyi Taw, Myanmar
[4] Gene Research Center, University of Tsukuba,
Tennodai 1-1-1, Tsukuba, Ibaraki 305-8572, Japan
Corresponding author: nagashima@makino.or.jp

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ABSTRACT

The main objective of the survey was to collect accessions of Chinbao (Generic name of five species in the genus *Hibiscus* that used as vegetables in Myanmar) (Nagashima et al., 2016) and clarified current status of those in Myanmar. From 2014 to 2018, a total of 342 samples were collected in Myanmar, including 244 *Hibiscus sabdariffa* samples, 58 samples of *Hibiscus cannabinus*, 30 samples of *Hibiscus radiatus*, 8 samples of *Hibiscus acetosella* and 2 samples of *Hibiscus surattensis*. In Myanmar, *H. sabdariffa* is the most dominant among the five species. Next, the frequency of appearance was higher in order of *H. cannabinus, H. radiatus, H. acetosella, H. surattensis*. The frequency of appearance of *H. cannabinus* was distinctly different between the peninsula and the central dry area. Clear differences in utilization of *H. radiatus* and *H. acetosella* between the northern west mountainous area (Chin state) to other area were noted.

Key words: accession collection, ethnobotany, nomenclature

INTRODUCTION

Myanmar has a great diversity of climates, ranging from Am (Tropical monsoon) in the peninsula to Aw (Savanna) in the center, and to Cw (Temperate: dry in winter) in the north. The topography varies, with mountains in the north and west area, a high plateau in the east side, and flat land in center, in the delta and river basin in the south. The country has borders with Bangladesh, India, China, Laos, and Thailand, and diverse tribe minorities live in their own food cultures (Cummings, 1996). The agro-climatic diversity in Myanmar is favorable for growing a variety of crops, and the country possesses a great diversity of crop genetic resources that remain to be explored (Nakagawa et al, 2002, Wakui et al, 2016).

According to previous studies of Nagashima et al. (2016), there found 5 kinds of *Hibiscus* plants called Chinbao, cultivated in large quantities throughout whole Myanmar (Fig.1). As in the African countries, it was observed that even in Myanmar young leaves are used as daily vegetables (Wilson and Menzel, 1964; Wilson, 1999). The leaves and shoots of 5 kinds of *Hibiscus* plants were eaten raw or cooked as a sour-flavored vegetable or condiment. The seeds were ground into oil and the fleshy fruiting calyces were used like cranberries in jellies. The crop is a good choice for low-rainfall areas because of high drought tolerance (Mohamed et al. 2015). Future improvement in functionality and cultivation properties of these *Hibiscus* species is highly anticipated, but the information on the diversity and utilization of *Hibiscus* genetic resources in Myanmar is still insufficient. This study sought to fill this gap and special focus on areas with different geographical features to clarify the differences in utilization and distribution of five *Hibiscus* plants there.

MATERIALS AND METHODS

The survey was conducted 7 times from August 2014 to September 2018 with the permission of Department of Agricultural Research (DAR) of the Ministry of Agriculture, Livestock and Irrigation, Myanmar (MOALI). We visited 75 townships in 12 states and regions as shown in Table 1. We collected fruit, seed and cutting samples of local or wild landraces from farmers and roadside. In addition, we gathered samples with interviewing farmers to collect information, including local plant name, sowing place, usage, cultivation methods, cropping pattern and additional information.

RESULTS AND DISCUSSION

Collection samples. In this survey, the *Hibiscus* genus observed in this survey could be categorized into five species; *H. sabdariffa*, *H. cannabinus*, *H. radiatus*, *H. acetosella* and wild relative *H. surattensis* (Fig.1). About 71% of the total 342 collected seeds were identified with *H. sabdariffa*. The method of collecting seeds samples were done by dividing it from farmers, sampling in the field and buying at the seed shop. *H. sabdariffa* and *H. cannabinus* were able to buy seeds at the seed store. But, other Chinbao were limited to very small cultivation in the home garden or wild condition on roadside, and seeds were not sold at the seed store. Therefore, some samples were collected in rooted cutting instead of seed. Regional differences in frequency distribution of 5 *Hibiscus species* is shown in Table 1. The samples that we collected in this survey were divided into two subsets. One was conserved for further research and crop improvement at the Seed Bank in DAR, MOARI, which is located in Yezin, Nay Pyi Taw, Myanmar. The other was transferred to and conserved at Tokyo University of Agriculture (TUA) at Tokyo, Japan, under a Standard Material Transfer Agreement (SMTA) for the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) of the United Nations (UN), Food and Agriculture Organization (FAO) and a phytosanitary certificate that was issued by the Plant Quarantine Office of Department of Agriculture, MOALI, Yangon, Myanmar to introduce to Japan.

Utilization and distribution of 5 *Hibiscus* species

***H. sabdariffa* (roselle).** in this survey, *H. sabdariffa* was found to be cultivated in all the investigated administrative areas with market-oriented purpose. Of the 342 seeds collected, 244 seeds were *H. sabdariffa* (Table 1). Among the five species, *H. sabdariffa* was the most frequently grown one, especially cultivated in large-scale field in Sagaing and Mandalay region located in central dry zone. Most Myanmar farmers depend on rainfall, and crop cultivation is greatly affected by the weather. Because *H. sabdariffa* is excellent in drought tolerance, cultivation is possible in a vast arid region spreading along the Ayeyarwady River (Mohamed et al., 2015). In particular, farmers in the Saganing area cultivate *H. sabdariffa* after the second stage of rice. *H. sabdariffa* appears most frequently in markets among Chinbao, to be used as vegetables for stir-fry and soup.

The farmers' eaves price of leaf is about 300 to 500 MMK (1 MMK = about 0.08 JPY) in one cup, but the price rises in winter season to about 500 to 1000 MMK. Although this vegetable is inexpensive, it is a stable revenue source for farmers due to high demand throughout a year. *H. sabdariffa* is called Chinbao, Birra (foreign)-Chinbao or Chinbao-Ni (red) in all over Myanmar. In addition, *H. sabdariffa*, which has no branches and reaching 4 m in height, was called Show (fiver) -Chinbao, and long stem fibers were used as rope. In some areas, there were local names by tribe-specific language. For example, the Chin tribe called "Anthol", the Gurka tribe called Bell chyanlee, and the Mon tribe called Baey. In addition to tribe-specific languages, there were also names that could be attributed to the cultivation time and history (Table 2). Thus, as there are many local names, we have found that *H. sabdariffa* is being used on a daily used by many tribe groups throughout Myanmar.

Table 1. Regional differences in frequency distribution of 5 *Hibiscus* species

State or Region	*H. sabdariffa*			*H.cannabinus*			*H.radiatus*			*H.acetosella*			*H.surattensis*			Subtotal	$\chi 2$ value & Significance	Classes with relatively high frequency
	No. of seeds	in %	*Deviation	No. of seeds	in %	*Deviation	No. of seeds	in %	*Deviation	No. of seeds	in %	*Deviation	No. of seeds	in %	*Deviation			
Delta area																		
Ayeyarwady	11	78.6	58.7	0	0.0	-1.8	3	21.4	17.6	0	0.0	-2.0	0	0.0	0.0	14	5.44	
Bago	15	60.0	40.1	6	24.0	22.2	3	12.0	8.2	0	0.0	-2.0	1	4.0	4.0	25	7.05	
Yangon	14	87.5	67.6	2	12.5	10.7	0	0.0	-3.8	0	0.0	-2.0	0	0.0	0.0	16	2.64	
Coastal areas of the peninsula																		
Mon	17	100.0	80.1	0	0.0	-1.8	0	0.0	-3.8	0	0.0	-2.0	0	0.0	0.0	17	6.83	
Tanintharyi	8	100.0	80.1	0	0.0	-1.8	0	0.0	-3.8	0	0.0	-2.0	0	0.0	0.0	8	3.21	
Central dry area																		
Sagaing	37	75.5	55.6	8	16.3	14.6	2	4.1	0.3	1	2.0	0.0	1	2.0	2.0	49	3.15	
Magway	38	73.1	53.2	11	21.2	19.4	3	5.8	2.0	0	0.0	-2.0	0	0.0	0.0	52	2.62	
Mandalay	36	53.7	33.8	25	**37.3**	**35.6**	6	9.0	5.2	0	0.0	-2.0	0	0.0	0.0	67	21.24 **	*H.cannabinus*
Mountainous area																		
Kachin (north)	16	94.1	74.2	1	5.9	4.1	0	0.0	-3.8	0	0.0	-2.0	0	0.0	0.0	17	4.45	
Chin (west)	11	37.9	18.0	2	6.9	5.1	11	**37.9**	**34.1**	5	**17.2**	**15.2**	0	0.0	0.0	29	62.08 **	*H.radiatus* & *H.acetosella*
Shan (east)	39	84.8	64.9	3	6.5	4.8	2	4.3	0.5	2	4.3	2.3	0	0.0	0.0	46	6.21	
Kayah (east)	2	100.0	80.1	0	0.0	-1.8	0	0.0	-3.8	0	0.0	-2.0	0	0.0	0.0	2	0.80	
Subtotal	244	71.3	-	58	17.0	-	30	8.8	-	8	2.3	-	2	0.6	0	342	125.74 **	

Notes) * : Deviation in % from the expected value.

Table 2. List of local names of five Hibiscus genus plants in Myanmar

District	*H. sabdariffa*	*H. cannabinus*	*H.radiatus*	*H.acetosella*	*H.surattensis*
Kachin	bell chyanlee*1(CHINBAO/ Gurkha) BIRRA-CHINBAO*2(Foreign) CHINBAO-NI(Red) SHOW-CHINBAO(Fiver)	CHINBAO-KA (Bitter) SHOW-CHINBAO(Fiber) CHINBAO-PYU(White)	CHINBAO-KA(Bitter) RECHA-CHINBAO(Split into five)	CHINBAO-NI(Red)	-
Sagaing	BIRRA-CHINBAO(Foreign) CHINBAO -NI(Red) KATHE-CHINBAO(Kathe tribe)	CHINBAO-KA (Bitter) SHOW-CHINBAO(Fiber) CHINBAO-PYU(White) RECHA-CHINBAO(Split into five)	CHINBAO-KA (Bitter) RECHA -CHINBAO(Split into five)	-	CHINBAO-WIN(Wild)
Chin	antol (CHINBAO/ Chin) CHINBAO-NI(Red)	antol ka(Bitter CHINBAO/ Chin) CHINBAO-KA(Bitter)	antol ka(Bitter CHINBAO/ Chin)	antol ni(Red CHINBAO/ Chin)	-
Shan	BIRRA-CHINBAO(Foreign) CHINBAO-NI (Red) CHINBAO-PYU(White)	CHINBAO-KA (Bitter) SHOW-CHINBAO(Fiber)	CHINBAO-KA (Bitter) RECHA -CHINBAO(Split into five)	CHINBAO-NI(Red) BAN-CHINBAO(Flower)	-
Mandalay	BIRRA-CHINBAO(Foreign) CHINBAO-NI (Red) CHINBAO-PYU(White)	CHINBAO-KA(Bitter) SHOW-CHINBAO (Fiber) CHINBAO-PYU(White)	CHINBAO-KA(Bitter) CHINBAO-YOWPYU(White stem)	-	-
Magway	BIRRA-CHINBAO(Foreign) CHINBAO-NI (Red)	CHINBAO-KA(Bitter)	CHINBAO-KA(Bitter) CHINBAO-RECHA(Split into five)	-	-
Kayah	CHINBAO-NI(Red)	CHINBAO-KA (Bitter)	-	-	-
Bago	BIRRA-CHINBAO(Foreign) CHINBAO-NI(Red) RECHA-CHINBAO(Split into five)	CHINBAO-KA (Bitter) CHINBAO-PYU (White) CHINBAO-RECHA(Split into five)	CHINBAO-RECHA(Split into five) CHINBAO-KA(Bitter)	-	CHINBAO-WIN(Wild)
Yangon	BIRRA-CHINBAO(Foreign) CHINBAO-NI (Red) CHINBAO-YOWNI (Red stem)	CHINBAO-KA (Bitter) CHINBAO-YOWPYU (White stem) CHINBAO-RECHA(Split into five)	CHINBAO-RECHA(Split into five)	-	-
Mon	baey(Duck leg/ Mon) TAWNY-CHINBAO(Field・Mon) WOW-CHINBAO（Rrain season） CHINBAO-GYI(Tall)	NIIN-CHINBAO (Winter)	BAN-CHINBAO (Flower) SHWE-CHINBAO(Gold)	-	CHINBAO-WIN(Wild)
Ayeyarwady	CHINBAO-NI (Red)	CHINBAO-KA(Bitter)	CHINBAO-KA(Bitter)	CHINBAO-NI(Red)	-
Tanintharyi	WOW-CHINBAO（Rain season） CHINBAO-GYI(Tall)	CHINBAO-PYU(Whitea) CHINBAO-KA(Bitter)	-	-	CHAW-CHINBAO(Stone)

Upper case: Burma language name, Lower case: Local Language name, (/): Meaning of the word/ Tribe name

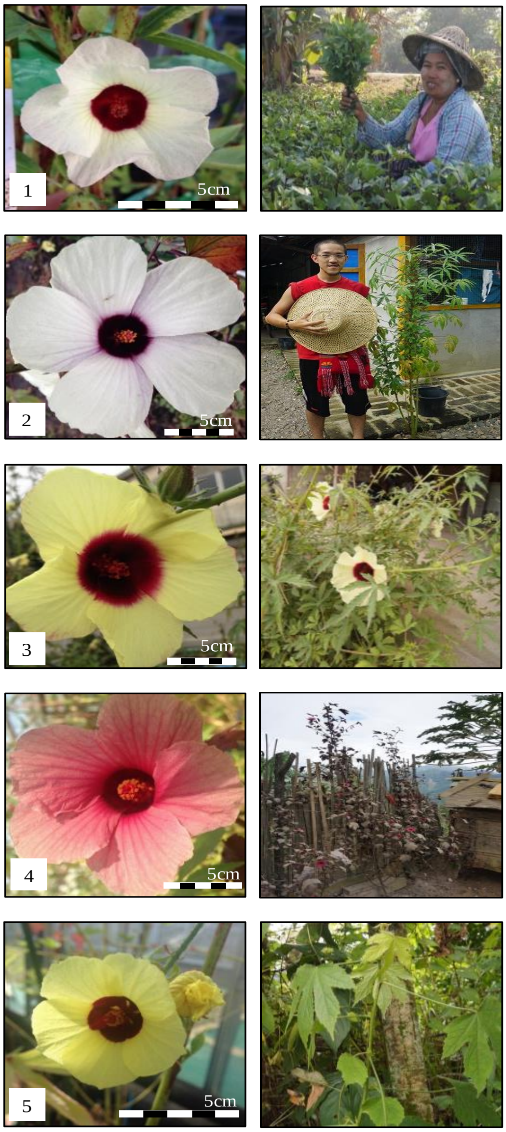
***H. cannabinus* (kenaf).** Among the 342 seeds collected, 58 seeds were found to be *H. cannabinus* and grown frequently next to *H. sabdariffa.* However, the cultivation was small and limited in home gardens or the outer circumference of the field. The frequency of appearance of *H. cannabinus* was distinctly different between the peninsula and the central dry area. Cultivation and utilization of *H. cannabinus* were confirmed mainly in the central arid area, especially Mandalay, also in the western mountainous areas and the east highland areas. However, cultivation was hardly confirmed in the coastal areas of the peninsula, and seeds could not be collected either (Table 1). (As an exception, a Shan woman who married to a peninsular house brought Shan State seeds and cultivated in the garden). Like *H. sabdariffa,* it was used for fry or soup, but harder and bitter in comparison with *H. sabdariffa*. Leaf or young stem of *H. cannabinus* was sometimes sold on the market (500-800MMK/bunch), which was a bit higher price than *H. sabdariffa.*

H. cannabinus is called Chinbao-Ka (bitter), Chinbao-Pyu (white/green) or Show (fiber)-Chinbao in Myanmar (Table 2). However, in the Mon state of the peninsula, the name NIIN (winter/snow)-Chinbao was discovered. This is the meaning of "Chinbao growing in the winter season". In contrast, *H. sabdariffa* had a unique name in the peninsular part of Tawny (field)-Chinbao and Wow (rainy season)-Chinbao. They mean "Chinbao cultivated in the field”, and "Chinbao cultivated in rainy season. From this terminology, it was indicated that in the peninsula part, *H. sabdariffa* was cultivated in rainy season and *H. cannabinus* was grown in winter. *H. cannabinus* has been reported to grow under various soil and water conditions (Dempsey, 1975; Amaduccia et al., 2000). However, it was not cultivated during the rainy season in case of the peninsula. On the Peninsula, moisture in the soil is usually saturated due to rainfall due to heavy precipitation and gray sol soil (Ground water level is high and drainage is no good) (Fig.1). Seeds of *H. cannabinus* may sometimes germinate on stem under high temperature and high humidity conditions (Crane and Acuna, 1945). In addition, *H. cannabinus* seeds are susceptible to high relative humidity and temperature. In other words, improper seed production environment and seed preservation method greatly reduce seed quality and survival rate. It was speculated that this is the reason why *H. cannabinus* is not cultivated in the peninsula during the rainy season.

H. radiates. The country of origin of *H. radiatus* is India, Myanmar or Pakistan (Hooker, 1872; Bailey, 1899). Like *H. sabdariffa, H. radiatu*s is widely adopted in a wide range of environments, and it is shown that cultivation is possible throughout Myanmar. However, compared with *H. sabdariffa,* the leaves do not grow well, the stem has many thorns, the texture is bad and the taste is bitter, so it seems that usage frequency is low. There is little to be cultivated in the field, in many cases a small amount was grown for self-consumption in the home garden. When there is surplus for in self consumption, it may be sold in the market. *H. radiatus* seeds was not sold at market. There was a clear difference in the appearance of *H. radiatus* between the mountainous region (Chin state) in the northwest and other regions. *H. radiatus* frequently occurred in relatively high-altitude areas. Especially, the frequency of appearance in Chin State was higher than other area significantly (Table 1). One of the reasons for this was inferred that *H. radiatus* is more adaptable to low temperatures in winter than other Chinbao. The other was inferred to be due to the taste of people living in highlands. The elderly of the Shan tribe calls this Chinbao-Ka and likes to eat it. This is familiar to the people living in Takayama eating wild plants on a daily basis. Therefore, it was presumed that there is a tendency to like bitter taste as compared with tribe groups of other regions.

H. acetosella. In case of *H. acetosella*, the whole plant is red, and the flowers are bright red. It might be the reason that they call it Chinbao-Ni (red). It is vegetable in Africa, but decorative use is mainly done in tropical and subtropical countries (Morton and Ledin, 1952; Exell, 1961). In Myanmar, usage frequency was low, and it seemed rare. Cultivation was limited to home gardens and it tended to prefer humid environment. The leaves and seeds of *H. acetosella* were never observed in markets in Myanmar. According to Kachin tribe, they eat it as a medicine, but the medicinal efficacy could not identified in this survery. In addition, Shan tribe call it Ban-Chinbao (flower), using it as a vegetable and ornamental plant in garden. Like *H. radiatus*, there was a clear difference in the appearance of *H. acetosella* between the mountainous region (Chin State) in the northwest and other states and regions (Table 1). *H. acetosella* occurred only in relatively high-altitude areas in Sagaing, Shan and Chin. Especially, the frequency of appearance in Chin State was higher than other states and regions significantly. One of the reasons for this was inferred that *H. acetosella*, like *H. radiatus*, is more adaptable to low temperatures in winter than other Chinbao.

H. surattensis. *H. surattensis* has stiff and sharp thorns on the stem and its leaves are hard. *H. surattensis* grows naturally in very dry areas, rocky area and coastlines. In the Tanintharyi region, many habitats were confirmed on rocky field along coastline. Therefore, Mon tribe call it Chwau (stone)-Chinbao (Table 2).



H. sabdariffa (roselle)
Among the five species, H. sabdariffa was the most frequently grown one, especially cultivated in large-scale field in Sagaing and Mandalay region located in central dry zone.

H. cannabinus (kenaf)
The cultivation was small and limited in home gardens or the outer circumference of the field.

H. radiatus
There is little to be cultivated in the field, in many cases a small amount was grown for self-consumption in the home garden.

H. acetosella
The usage frequency was low, and it seemed rare. Cultivation was limited to home gardens and it tended to prefer humid environment.

H. surattensis
It grows naturally in very dry areas, rocky area and coastlines. In the Tanintharyi region, many habitats were confirmed on rocky field along coastline.

Fig.1 CHINBAO(five *Hibiscus* plants) in Myanmar

It is a complete wild species, not cultivated, it is not sold in the market either. In Tanintharyi, Sagaing and Chin, only people living near this habitat collect and eat extremely young leaves. The taste is inferior to the other four *Hibiscus* plants. However, because it grows along the coast, high temperature dry area and dry mountainous area it is presumed that it is excellent in drought and salt tolerance.

The investigation from 2014 to 2018 revealed substance of identification of *Hibiscus* genus vegetable called Chinbao in Myanmar, cultivation situation, use, distribution and so forth. each tribe group classifies the name of each Chinbao according to its appearance, usage and cultivation period nomenclature is often determined by the application, the cultivation time and the characteristics of the plant itself (Table 2). in addition, it is clear from interview that there are differences in the introduction process and the cultivation scale of Chinbao for each region. Factors that cause the difference can be roughly divided into two, natural factors and human factors.

In natural factors, the difference in the elevation of the cultivated land will result in the difference in ecological environment, the production work will be stipulated. As for human factors, the preference difference for acidity and bitterness of each tribe group had a great influence on the selection of Chinbao to cultivate. However, in Myanmar located at low latitude, flowering started in November (daytime: less than 13 hours) (Tukamoto et al., 1963), leaf yield is greatly decrease. Therefore, breeding targets in the future are required to produce varieties that are hardly affected by short days. As a result, H. sabdariffa is cultivated throughout the year, and production is expected to increase.

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CHEMICAL COMPOSITION AND *IN VITRO* ANTIOXIDANT AND ANTIBACTERIAL ACTIVITIES OF *SARGASSUM VULGARE* C. AGARDH FROM LOBO, BATANGAS, PHILIPPINES

Eldrin DLR. Arguelles[1]*, Rosario G. Monsalud[1] and Arsenia B. Sapin[2]
[1]Philippine National Collection of Microorganisms, National Institute of Molecular Biology and Biotechnology (BIOTECH), University of the Philippines Los Baños, 4031
[2]Food Laboratory, National Institute of Molecular Biology and Biotechnology (BIOTECH), University of the Philippines Los Baños, 4031
*Corresponding author: edarguelles@up.edu.ph

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ABSTRACT

Seaweeds are notable in producing diverse kinds of bioactive compounds with promising pharmacological properties. A study was conducted at the National Institute of Molecular Biology and Biotechnology (BIOTECH), University of the Philippines Los Baños from July to November 2018 to evaluate the proximate composition and potential antioxidant and antibacterial properties of a brown macroalga, *Sargassum vulgare* C. Agardh. Determination of the total phenolic compounds using Folin-Ciocalteu reagent showed that the dried algal biomass have a total phenolic content of 10.13 ± 0.166 mg GAE/g. Relative antioxidant efficiency showed that *S. vulgare* exerted potent radical scavenging activity in a concentration dependent manner with EC_{50} value of 37.2 ± 0.015 μg GAE. The tested algal extract exhibited radical scavenging activity that is dose-dependent and positively correlated to its phenolic content. On the other hand, proximate composition of the dried macroalga showed that *S. vulgare* contains high carbohydrate, ash and crude fiber content of 34.18±0.32%, 27.09±0.00%, and 22.59±0.21 respectively. Methanolic extract of the macroalgal strain was subjected to microtiter plate dilution assay against a wide spectrum of pathogenic bacteria. *S. vulgare* showed pronounced activity against *Staphylococcus aureus* having MIC of 250 μg/ml. *Aeromonas hydrophila*, *Bacillus cereus* and Methicillin-resistant *S. aureus* were also moderately inhibited each having MIC of 500 μg/mL, 500 μg/mL, and 1000 μg/mL, respectively. Minimum bactericidal activity against *S. aureus* is higher than that of *Bacillus cereus* and *Aeromonas hydrophila*, having 500 μg/mL and 1000 μg/mL, respectively. On the other hand, Methicillin-resistant *S. aureus* exhibited MBC value of >1000μg/ml. This study showed the potential antioxidant and antibacterial activity of *S. vulgare*, which make it a suitable candidate for production of new bioactive compounds important for pharmacological and food industries.

Key words: brown macroalgae, phenolic content, proximate composition, radical scavenging activity, seaweed

INTRODUCTION

Macroalgae are noted as promising sources of biologically active metabolites as they are capable of synthesizing diverse types of secondary metabolic compounds marked by a broad extent of biological activities. They produce substances namely terpenoids, sterols, phenols, halogenated ketones, polysaccharides, water-soluble (B-complex and C) as well as fat-soluble (provitamin A and vitamins D, E and K), peptides, proteins, dietary fibers, minerals (such as magnesium, phosphorus, calcium, iodine, potassium, iron, and sodium), and polyunsaturated fatty acids and are described to possess antioxidant, antifungal, antiviral, and antibacterial activities (Arguelles et al. 2018; Cox et al. 2010; Chew et al. 2008). Recently, the occurrence of antibiotic resistant bacteria is a worldwide problem in health and medicine. To replace safer use of antibiotics, studies on the use of secondary metabolites from natural sources, including seaweeds have been increasing. Brown seaweeds such as

Sargassum spp. have been reported to have bioactive property antagonistic to a number of medically important bacteria Gram-negative and Gram- positive bacteria such *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pnemoniae*, *Clostridium perfringens*, *Staphylococcus aureus*, and the like (Oumaskour et al. 2012; Osman et al. 2010; Yoon et al. 2010). Thus, *Sargassum* has been regarded as candidate sustainable natural reserve resources with promising antibacterial biological activities associated to its secondary and primary metabolites (Yende et al. 2014).

The fact that the harsh environments in which seaweeds are exposed to in combination with exposure to high light intensity and elevated concentrations of oxygen can induce development of free radicals and several potent oxidizing agents. However, seaweeds are scarcely affected from any significant photodynamic impairment during metabolism because of the development of protective adaptive mechanisms and synthesis of compounds (Cox et al. 2010). Many research studies have showed that seaweeds contain various phytochemicals (such as polyphenols vitamins C, E and carotenoids) with antioxidant activity, which are accountable for their valuable health effects. *Sargassum* spp. contains fucoxanthin, fucoidan, as well as phlorotannin compounds that play a role as oxidizing agent. Phlorotannin is a polyphenolic compound that is only found in brown algae known to have other biological activities such as antioxidant and anti-proliferative, angiotensin-I-converting enzyme inhibition, inhibitors of matrix metalloproteinases, and UV radiation absorption ability (Soleimani et al. 2018). Fucoidan is reported to have pharmacological properties including anticoagulant, antithrombotic, anti-inflammatory, anticancer, and antioxidative properties (Soleimani, et al. 2018; Morya et al. 2012). These biological activities of fucoidan is linked with its chemical structure particularly the sulfate groups that is dependent to the fucose monomer of fucoidan (Soleimani et al. 2018). Fucoxanthin is considered as one of the main carotenoid in *Sargassum*. This pigment is responsible for the transfer of light energy to photosynthetic reaction centers (particularly the chlorophyll *a*) for photosynthesis. It has been reported that this bioactive pigment are characterized to have effective anti-obesity, anti-inflammatory, antidiabetic and antioxidant activities (Xia et al. 2013). Due to its natural origin, seaweed-derived antioxidants pose a greater potential in collation to other synthetic sources such as butylatedhydroxy toluene (BHT) and butylatedhydroxy anisole (BHA).

The Philippine coast has an extensive coastline with great biodiversity of marine macroalgae yet to be explored. Despite their diversity in forms and types, relatively few studies are known about the antioxidant and antibacterial potential of these algae and to date, scientific investigations of their biological activities is still limited in the country. This study is the first report in the Philippines exploring the biological activities of a brown macroalga, *Sargassum vulgare* C. Agardh. The present investigation sought to do proximate composition analysis, screen for antibacterial activity and determine the amount of total phenolic compounds in *Sargassum vulgare* (using gallic acid as the standard). The antioxidative activity was evaluated and the correlation among antioxidant activity and total phenolic content was established.

MATERIAL AND METHODS

Seaweed collection and preparation. Fresh marine brown macroalga *Sargassum vulgare* C. Agardh was collected on 20 July 2018 from Lobo (Lat. 13° 35’ 54.1’ N; Long. 121° 15” 33.2’ E), Batangas, Philippines. The macroalaga was characterized and identified based on morphotaxonomic features according to Algae Base (web site: www.algaebase.org) and Trono (1992). The collected seaweed sample was thoroughly cleaned with filtered seawater to remove associated sand debris, planktons and loosely attached microorganisms and was immediately transferred to the laboratory using sterilized polythene bags. The seaweed sample was then washed rigorously with sterile tap water to take away excess salt on the external surface of the alga. The water was drained off, and the seaweed laid out on a clean blotting paper. The seaweed was again thoroughly washed with sterilized distilled water to eliminate the remaining surface salt and to avoid pumping out the solvent during the extraction process. The algal sample was air-dried (for six days), chopped into short pieces and pulverized into fine-grained powder in a mixer grinder.

Preparation of seaweed extract for antibacterial screening. The powdered seaweed biomass was soaked in methanol (1g seaweed powder: 30 mL methanol) and extracted in an ultrasonic bath for 30 minutes and stirred for 1 hour. The algal extract was centrifuged at 12,000 rpm at 20°C for 20 minutes. The algal extract was concentrated using a rotary evaporator at 40 °C until a crude extract was obtained, and kept at 4 °C (Arguelles 2018).

Total phenolic content. The total phenolic compound present in the macroalgal extract was calculated using Folin-Ciocalteu method based on the process done by Nuñez Selles et al. (2002). Briefly, macroalgal extract was diluted with sterile distilled water and to 0.5 ml of the diluted sample extract, 0.5 ml of Folin-Ciocalteu's reagent and 0.5 ml of 10% Na_2CO_3 solution were mixed in a test tube. The reaction mixture was then set aside to stand for 5 minutes and 5 mL of distilled water were mixed to the solutions. The spectrophotometric readings were determined at 720 nm using a Shimadzu UV-1601 spectrophotometer with reagent plus water as blank sample (Arguelles 2018). Calibration curve was constructed using gallic acid as the standard; the total phenol was expressed as gallic acid equivalents (GAE).

DPPH radical scavenging assay. The radical scavenging activity of the macroalgal extract on 2,2-diphenyl-1-picrylhydrazyl (DPPH) was determined following the protocol of Ribeiro et al. (2008) with some modifications. Briefly, 100 µl of aliquot of algal extract was mixed to 5.0 ml of 0.1 mM DPPH methanolic solution. The reaction mixture was completely homogenized using a vortex mixer and then cast aside for 20 minutes at ambient temperature. The spectrophotometric readings of the sample solution were determined utilizing a UV-VIS spectrophotometer at 517 nm. The percent inhibition (%) was estimated by using the mathematical formulae specified by Ribeiro et al. (2008).

$$\text{Inhibition (\%)} = [(A_{\text{control}} - A_{\text{sample}}) / A_{\text{control}}] \times 100$$

where: A_{sample} = absorbance reading of the test sample (DPPH solution plus test sample) and $A_{control}$ = absorbance reading of the control (DPPH solution without sample). In this study, gallic acid (a synthetic antioxidant) was utilized as the positive control. The percentage scavenging activity of the macroalgal extract was analyzed and the concluding result was expressed as an EC_{50} value (the amount of the macroalgal extract exhibiting 50% scavenging of the DPPH radical expressed in µg/ml).

Proximate composition analysis. The procedure for the proximate chemical composition analysis of *S. vulgare* was determined by following the standard AOAC (2011) methods. Crude lipid of *S. vulgare* was obtained from the powderized macroalga using petroleum ether as the solvent in a Soxhlet extractor (Bhuiyan et al. 2016; Siddique et al. 2011). After the extraction process, the solvent was evaporated to dryness and the residue was further dried until an unvarying weight is obtained at 105°C. Carbohydrates or nitrogen free extract was obtained by deducting the sum of moisture, ash, crude fiber, crude protein, and crude fat from 100. On the other hand, protein content of *S. vulgare* was analyzed by Kjeldahl method. A conversion factor of 6.25 was used to estimate the total amount of nitrogen in the crude protein (g per 100 g edible portion). To measure the crude fiber, 2 g of powderized seaweed sample was boiled together with a 0.3 N H_2SO_4. The solution was then filtered and thoroughly washed using 200 ml of boiling water and NaOH (0.5 N), respectively, following the procedure done by Siddique et al. 2013 and Bhuiyan et al. 2016. The collected residue of the reaction mixture was further extracted and rinsed using acetone and boiling water. Lastly, the leftover material was further dried up at 105℃ for 3 h until unvarying weight is achieved. The moisture content of *S. vulgare* was analyzed by subjecting the macroalgal sample to dryness at 105℃ until unvarying weight is observed. Moisture content was calculated by getting the difference of the final mass of the algal sample from the initial mass of the sample. Ash content of the seaweed sample was determined by calcinations in a muffle furnace at a temperature of 550℃ for 4 h.

Tests microorganisms. Type cultures of five pathogenic Gram-negative bacteria (*Pseudomonas aeruginosa* BIOTECH 1824, *Aeromonas hydrophila* BIOTECH 10089, *Salmonella typhimurium* BIOTECH 1826, *Escherichia coli* BIOTECH 1825, and *Enterobacter aerogenes* BIOTECH 1145) and four Gram-positive bacteria (Methicillin-Resistant *Staphylococcus aureus* BIOTECH 10378, *Listeria monocytogenes* BIOTECH 1958, *Staphylococcus aureus* BIOTECH 1823, and *Bacillus cereus* BIOTECH 1509) were acquired from the Philippine National Collection of Microorganisms, National Institute of Molecular Biology and Biotechnology (BIOTECH), University of the Philippines Los Baños (UPLB), Philippines. The test organisms were pre-cultured using Luria Bertani (LB) medium overnight with shaking at 37 ºC. The morphological and biochemical tests were checked continuously to ensure purity (Arguelles 2018).

Micro-dilution antibacterial assay. Minimum inhibitory concentration (MIC) of the macroalgal extract was determined by employing two-fold serial dilution technique following the procedures done by Arguelles 2018. Using a 96-well microtiter plate, 100 µl of bacterial cultures (approximately 1x 10^5 cells/ml) were added to 100 µl of macroalgal extract test samples prepared in different dilutions starting from 1000 µg/ml down to 7.8125 µg/ml. Methanol was also included as the negative control. The seeded plate was incubated overnight at 35°C in an ambient air incubator, after which the minimum inhibitory concentration was recorded. MIC is described as the lowest amount of the test algal extract that totally inhibited bacterial growth after a 12-h incubation period. After the incubation time, microtiter plates were checked for the absence or presence of bacterial growth. The minimum concentration of the algal extract at which there is no observable growth of bacteria was considered as the MIC for the extract–microbe combination under consideration. As for the controls, the MIC of tetracycline against each bacterial species was similarly determined. The experiments done in this study were conducted in triplicate and the microdilution trays were incubated at 35ºC for 12 h (Arguelles et al. 2017).

The minimum bactericidal activity (MBC) was determined by plating a loopful of bacterial sample from each MIC assay wells that showed growth inhibition into freshly prepared tryptic soy agar plates (Arguelles 2018). The petri plates were stored at 35°C for 24 hours and were checked for visible colony growth or lack of growth for each dilution subculturing. No growth indicated that the algal extract was bactericidal at that dilution. On the other hand, colony growth indicated that the macroalgal extract was bacteriostatic at that dilution. The lowest concentration that did not exhibit visible growth on agar subculture after the incubation period was regarded as MBC value (Arguelles 2018).

Statistical analyses. The experimental data are showed as means ± standard deviations (mean ± SD) of three parallel experimental measurements. The statistical test for the correlation analysis and linear correlation coefficient were evaluated using MS Office Excel 2007.

RESULTS AND DISCUSSION

Proximate composition analysis. The nutritional value of seaweeds is usually evaluated using its biochemical composition like carbohydrates, protein, ash content, lipids as well as crude fiber. The proximate composition based on dry weight of *Sargassum vulgare* C. Agardh was shown in Table 1. It was found that carbohydrate (34.18%) is the major component in dried seaweed. Carbohydrates constitute 30 – 60% of the total dry weight of brown seaweed, which is mainly composed of cellulose, fucoidan, alginates and laminaran (Vijay et al. 2017). The result of this study showed higher carbohydrate content as compared to other reported *Sargassum* species such as *Sargassum tennerimum* and *Sargassum wightii* with maximum carbohydrate content of 23.54% and 23.50%, respectively (Manivannan et al. 2009; Vijay et al., 2017).

Table 1. Proximate composition of *Sargassum vulgare* C. Agardh.

Proximate composition	Percent composition (%)
Moisture Content	7.89±0.15
Ash Content	27.09±0.00
Crude Protein	7.69±0.23
Crude Fat	0.56±0.10
Crude Fiber	22.59±0.21
Carbohydrate	34.18±0.32

Dietary fibers from seaweeds contained some vital nutrients and substances that gained significant interests for nutraceuticals and functional foods for human utilization and consumption such as polysaccharides showing anticoagulant, antitumor, anti-herpetitic and antiviral biological activity (Ahmad et al. 2012). In this study, dried *S. vulgare* showed a relatively high crude fiber content of 22.59%. This result falls within the range of earlier published studies, which reported that dried seaweed is comprised of about 10% to 62% total fibers (Serrano et al. 2015; Ahmad et al. 2012). The protein content of the dried seaweed sample is 7.69%, which is within the range of those reported for Sargassaceae (Casas-Valdez et al. 2006). Variation in protein content of species within the genus *Sargassum* can be due to difference in seasonal period and geographic area (Ahmad et al. 2012). A study made by Manoonphatyaporn et al. (2014) showed difference in the chemical composition of brown macroalga *S. aquifolium* and *S. oligocystum* in three seasonal periods. *S. oligocystum* have significant ($p \leq 0.05$) high protein and vitamin C contents as compared to *S. aquifolium* in all seasons with observed highest protein content in rainy monsoon season while highest vitamin C content in hot dry season. On the other hand, other biochemical components such lipid, ash, carbohydrate, and crude fiber contents were not significantly different in each of the *Sargassum* species during seasons (Manoonphatyaporn et al. 2014). A single preliminary collection of brown seaweed *S. vulgare* was done in the current study during the dry season. Variations in the chemical composition of *S. vulgare* are possible if collected and analyzed at different season and geographical area. The present study provides baseline information to take into account the most suitable seasonal period for harvest of *S. vulgare* for sustainable use and management.

Ash content of the powdered macroalga is 27.09%, which is considerably high. High amount of ash is linked with appreciable level of diverse mineral amount of mineral elements in the sample (Serrano et al. 2015; Matanjun et al. 2008). The total lipid content (0.56%) in the algal biomass was found relatively low and is considered as a minor proximate component. The result of this investigation fell within the ranges described previously by other studies (Gómez-Ordóñez et al. 2010; Casas-Valdez et al. 2006). Results of the total nutritional profile of *S. vulgare* recommends that the macroalga is a suitable candidate as alternative source of mineral and nutrition supplements as well as of food with high carbohydrate and crude fiber content. This study could also be considered as baseline information for further advanced study on nutritional value and as prospective resources for the development of seaweed-based products for enhanced animal and human nutrition. However, biological evaluation making use of animal and human feeding research is prescribed to prove the nutritional significance and benefits of *S. vulgare*.

Total phenolics and antioxidant activity. The total phenolic content present in the macroalgal extract was evaluated and is expressed as mg of GAE/g of the dried algal biomass (Table 2). The total phenolic content in the analyzed macroalgal biomass is 10.13 ± 0.166 mg GAE/g. Similar phenolic concentration was observed by Somanah et al (2012) from shallow water seaweeds such as the phaeophyceae (*Sargassum binderi, S. latifollium, S. duplicatum, Padina gymnospora, P. tetrastromatica,* and *Turbinaria ornata*), the rhodophyceae (*Gracilaria millardetti, Jania adhaerens,* *Haliptilon subulata*) and the chlorophyceae (*Codium lucasii, C. intricatum, Ulva reticulata, U. lactuca* and *Chaetomorpha crassa* of Mauritius with total phenolic contents ranging from 4.00 to 264.38 mg gallic acid equivalent (GAE) 100 g^{-1} as well as Ganesan et al. (2008) likewise reported methanol extracts of Indian seaweeds which vary from 1.5 mg GAE/g to 4.1 mg GAE/g.

Table 2. Phenolic content and DPPH free radical scavenging activity of methanolic extract of *Sargassum vulgare.*

Seaweed	Total Phenolic Content* (mg GAE/g)	EC_{50} (µg GAE)
Sargassum vulgare C. Agardh	10.13 ±0.166	37.2 ±0.015

*Average of triplicate sample

DPPH radical scavenging activity. DPPH free radical scavenging activity assay is a preliminary test to assess the capacity of the algal extract to give hydrogen or to scavenge free radicals. The assay has been used extensively because of its susceptibility for the detection and screening of bioactive metabolites even at small amounts as well as high throughput screening. Antioxidant activity of marine algae is associated to the existence of bioactive substances which may come from vitamins and vitamin precursors (ascorbic acid, α-tocopherol, thiamine, niacin, and β-carotene), pigments (carotenoids and chlorophylls), phenolics (such as hydroquinones and polyphenolics), phospholipids (such as phosphatidylcholine), peptides, terpenoids, and other antioxidative substances, which are capable of scavenging free radicals produced during scavenging of oxygen-containing compounds, metal-chelating ability, or peroxidation (Cox et al. 2010; Yende et al. 2014). Anthocyanins and polyphenols are capable of donating hydrogen to scavenge DPPH reducing it to diphenylpicrylhydrazine. The present study showed that *S. vulgare* extract act as antioxidant since it possesses hydrogen-donating properties. Also, antioxidative activity of the seaweed extract intensifies in a concentration-dependent manner (Figure 1) with EC_{50} value of 37.2 ± 0.015 µg GAE (Table 2).

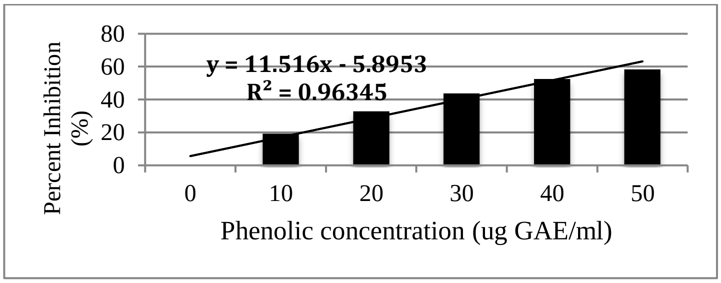

Fig. 1. Correlation between total phenolic content and total antioxidant activity (DPPH radical scavenging assay) of *S. vulgare*.

The antioxidative potential of several brown macroalgal species (such as *Fucus* spp. and *Sargassum* spp.) from Danish coast were reported to possess scavenging ability on DPPH with EC_{50} ranging from 85.7-1466.7 µg/ml (Farvin and Jacobsen 2013). This result is considerably less effective as compared to that of *S. vulgare* in the current study (EC_{50} = 37.2 ±0.015 µg GAE), which demonstrates the great potential of the alga assayed in this study as alternative source of naturally-derived antioxidants. The reported antioxidative potential of *S. vulgare* could be used as a replacement for commercially available artificial antioxidants (such as butylated hydroxyanisole (BHA), propyl gallate, butylated hydrotoluene (BHT) and tert-butylhydroquinone), which have been studied to have tumorigenic and carcinogenic effects at high doses (Chia et al. 2015). The capability of *S. vulgare* extracts to scavenge free radicals may have potential food industry application for lengthening the shelf life of processed food products during storage and distribution (Cox et al. 2010).

Correlation study between total phenolic content and antioxidant activity. In this study, strong correlation between DPPH assay and total phenolic content (R^2=0.963) indicated that bioactive compounds such as polyphenols present in *S. vulgare* extract are involved in antioxidant activity by scavenging DPPH (Figure 1). Previous studies reported that a positive correlation exists among phenolic compounds and antioxidant activity in seaweeds (Wang et al. 2009; Matanjun et al. 2008). Many brown macroalgae species contain polyphenolics and in this investigation the antioxidative activity of *S. vulgare* extracts could be ascribed to these important bioactive compounds. Further identification of phenolic components is necessary to get more appropriate understanding regarding correlation between phenolics and antioxidant activity (Arguelles et al. 2017).

Screening for antibacterial activity. *Sargassum* produces various bioactive metabolites such as polysaccharides, polyphenols, terpenoids, steroids, glycerides, plastoquinones and the like (Soleimani et al. 2018; Yende et al. 2014). Thus, *Sargassum* has been regarded as a promising natural resource with captivating bioactivities coupled to its synthesized biochemical metabolites (Soleimani et al. 2018; Yende et al. 2014). The results of the inhibitory activity of the methanolic extract of the macroalga *S. vulgare* against pathogenic bacteria are summarized in Table 3.

Table 3. Antibacterial activity of *Sargassum vulgare* extract.

Test organism	Minimum inhibitory concentration (µg/ml)	Minimum bactericidal concentration (µg/ml)
Gram-positive bacteria		
Staphylococcus aureus BIOTECH 1823	250.00	500.00
Bacillus cereus BIOTECH 1509	500.00	1000.00
Methicillin-Resistant *Staphylococcus aureus* BIOTECH 10378	1000.00	>1000.00
Listeria monocytogenes BIOTECH 1958	>1000.00	ND
Gram-negative bacteria		
Aeromonas hydrophila BIOTECH 10089	500.00	1000.00
Pseudomonas aeruginosa BIOTECH 1824	>1000.00	ND
Escherichia coli BIOTECH 1825	>1000.00	ND
Enterobacter aerogenes BIOTECH 1145	>1000.00	ND
Salmonella typhimurium BIOTECH 1826	>1000.00	ND

*ND = Not Determined

S. vulgare showed pronounced activity against *Staphylococcus aureus* having MIC of 250 µg/ml. *Aeromonas hydrophila*, *Bacillus cereus* and Methicillin-resistant *S. aureus* were also moderately inhibited each having MIC of 500 µg/mL, 500 µg/mL, and 1000 µg/mL, respectively. No activity was observed against *Listeria monocytogenes*, *Eschrichia coli, Salmonella typhimurium* and *Pseudomonas aeruginosa*. Minimum bactericidal activity against *S. aureus* (500 µg/mL) is higher than that of *Bacillus cereus* and *Aeromonas hydrophila* having 1000 μg/mL. On the other hand, MBC value against Methicillin-resistant *S. aureus* is >1000 μg/ml. These experimental findings are similar with previous studies (Osman et al. 2010; Oumaskour et al. 2012; Ali et al. 2016). However, other studies such as Ibtissam et al. (2009) and El Shayaf et al. (2016) reported that methanolic extract of *S. vulgare* did not exhibit antibacterial activity against *S. aureus*. Notable variations in the results of the current study and the findings of other investigations can be attributed to several factors such as intraspecific differences in the kind of secondary metabolites produced by the macroalga, often associated to seasonality variations (Osman et al. 2010; Omar et al. 2012). Also, differences in capability of the method of extraction to recuperate the bioactive substances as well as variations in the method of antimicrobial assay would cause differences in sensitivities of the tested bacterial strains (Gonzalez et al. 2001; Osman et al., 2010). Lastly, differences in the stage of active metabolic growth and sexual maturity of the macroalgae can also cause variations in its biological activity (Al-Judaibi 2014). This study also reports that the methanolic extract of the alga is more potent for its activity towards Gram-positive bacteria, especially *S. aureus* and *B. cereus* than Gram-negative bacteria. Differences in terms of antibacterial activity of the extract may be due to the considerably intricate structure of the Gram-negative bacterial cell wall. Generally, Gram-negative bacteria are characterized by a complex, multilayered cell wall structure affecting the penetration of active compounds within the bacterial cells causing added protection for the organism against antibiotics (Arguelles 2018). The cell membrane of Gram-negative bacteria is associated with degradative enzymes in the periplasmic space, which has the capability of degrading unfamiliar molecules introduced from the external environment of the cell (Kim and Lee 2008). Bioactive compounds from seaweeds acts against bacterial pathogen by altering the permeability of bacterial cell and loss of important internal macromolecules or by the intrusion with the membrane structure and function resulting to cellular instability and loss of integrity that leads to cell death (Arguelles 2018).

To the best of our knowledge, this paper is the first report in the Philippines about antibacterial activity of *S. vulgare* strain against Methicillin-resistant *Staphylococcus aureus*, *Bacillus cereus*, *Staphylococcus aureus,* and *Aeromonas hydrophila*. The general antibacterial activity assessed from the present study demonstrates the existence of biologically active compounds in the seaweed extract of which displayed promising antimicrobial activity effective against medically important Gram-positive and Gram-negative bacteria. Thus, further study should be conducted to purify and identify these bioactive substances. *Sargassum* is a rich resource of the Philippine archipelago, hence the availability of this alga for industrial use.

CONCLUSION

Sargassum vulgare C. Agardh represents a potential source of polyphenols and other bioactive compounds for the production of natural antibiotics and antioxidants. Further studies are needed to know the chemical structure and determine the nature of bioactive compounds responsible of the activity of the algal extract that showed promising antibacterial activity. Not only the existence of useful compound which cause this macroalga engrossing but also its diversity and the feasibility of not only collecting them but also of optimizing its growth at varying environmental conditions, resulting to enhanced production of important bioactive compounds for food and pharmaceutical industry.

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COMPARATIVE LIFE HISTORY OF COCONUT SCALE INSECT, *Aspidiotus rigidus* Reyne (HEMIPTERA: DIASPIDIDAE), ON COCONUT AND MANGOSTEEN

Cris Q. Cortaga, Maria Luz J. Sison, Joseph P. Lagman,
Edward Cedrick J. Fernandez and Hayde F. Galvez
Institute of Plant Breeding, College of Agriculture and Food Science,
University of the Philippines Los Baños, College, Laguna, Philippines 4031
Corresponding author: mjsison@up.edu.ph

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ABSTRACT

The devastation of millions of coconut palms caused by outbreak infestation of the invasive Coconut Scale Insect (CSI) *Aspidiotus rigidus* Reyne, has posed a serious threat to the industry in the Philippines. The life history of *A. rigidus* on coconut and mangosteen was comparatively studied to understand the effects of host-plant species on its development, to investigate potential host-suitability factors that contributed to its outbreak infestation, and to gather baseline information on the development and characteristics of this pest. The study was conducted at the Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños. Insect size (body and scale) was not significantly different on both hosts during egg, crawler, white cap, pre-second and second instar stages, as well as during male pre-pupal, pupal and adult stages. The female third instars and adults, however, were bigger on mangosteen than on coconut. At the end of second instar, sexual differentiation was very visible wherein parthenogenic females further undergone two developmental stages: third instar and adults that feed permanently on the leaves. Males undergone three stages: pre-pupa, pupa and winged adults. Males normally have shorter life cycle and smaller bodies than the females. Developmental rate of *A. rigidus* before second instar was not significantly different on both hosts. However, stages approaching to insect maturity of both males and females developed faster on coconut. As a result, *A. rigidus* life cycle was shorter on coconut than on mangosteen. Moreover, insect fecundity was higher on coconut due to longer female longevity. More females than males were observed on mangosteen while the sex ratio was almost equal on coconut. These results suggest that coconut provides better nourishment and living conditions that support shorter life cycle and augment insect development, longevity and reproduction which are potential host-suitability factors that contributed to the outbreak. Mangosteen is an effective host-plant to rear *A. rigidus* pure culture as validated also by DNA sequence analysis. Information generated can be used for monitoring and timely management of the pest, in studying host-insect interaction, and in mass rearing for future studies.

Key words: CSI, *Cocos nucifera*, *Garcinia mangostana*, morphometry, developmental rate

INTRODUCTION

So called as the ‘Tree of Life’, the coconut (*Cocos nucifera* L.) is an important economic crop largely grown in tropical and subtropical countries. The Philippines considerably has the world’s largest agricultural area devoted to coconut farming and next only to Indonesia in terms of production. The country has about 12 million hectares of agricultural land and 3.25 million hectares of which is planted with coconut. From these coconut farms, about 330 million fruiting trees producing 15,207 billion nuts per year was reported (PSA, 2016). From 1997 to 2014, the highest copra production was recorded in 2010 with an average of 3.03 million metric tons. The Philippine Coconut Authority (PCA) also reported that 26 million Filipinos rely on the coconut industry. However, the devastation of millions of palms caused by outbreak infestation of Coconut Scale Insect (CSI) species *Aspidiotus rigidus* has posed a serious threat to the coconut industry in the Philippines. This invasive species of CSI voraciously sucks the leaf sap resulting to yellowing and drying of leaves and eventually, plant death. The insect species was initially observed in 2009 in Tanauan, Batangas (Adalla and Sison, 2014) and was initially misidentified as *Aspidiotus destructor* (Molet, 2015) since it was the only previously known CSI species in the country. This species, however, is not considered detrimental to crops due to the presence of natural enemies (Watsons et al. 2015). Further investigations in the outbreak areas especially in the south of Luzon island (CALABARZON) and Basilan province in Mindanao revealed that *A. rigidus*, an introduced CSI species, was the cause of severe damage on coconut palms (Adalla and Sison, 2014; Watsons et al. 2015). This insect is not preferred by the natural enemies of *A. destructor* due to its tough scale covering that is difficult to pierce with their mandibles (Reyne, 1948). *A. destructor* and *A. rigidus* are closely related CSI species and only differ on few traits. *A. rigidus* was originally classified as a subspecies of *A. destructor* and was elevated later on as a new species (Reyne, 1947; Molet, 2015). *A. rigidus* had also caused severe outbreak in the Sangi Island (North Celebes) in Indonesia when it was still a subspecies (Reyne, 1948). Monocotyledonous plants such as palms and *Musa* sp. are generally the host plants of this sucking insect and so far, mangosteen (*Garcinia mangostana*) is the only known dicotyledonous alternate host plant (Watsons et al. 2015).

Coconut is a favored host of both *A. rigidus* and *A. destructor* but on mangosteen, only *A. rigidus* thrives (Cayabyab et al. 2016; Reyne, 1948; Watsons et al. 2015). The *A. rigidus* outbreak has also imposed a serious threat on mangosteen farms in the Philippines. It was even surmised that *A. rigidus* was first observed on this plant before on coconut. Mangosteen is an industrial crop regarded for its delicious fruit and principally, for its important pharmaceutical uses e.g., as food supplements, giving it the popular moniker ‘Queen of fruit’. Majority of growing areas and vast plantations of this crop in the Philippines are found in the Mindanao island, the southern part of the archipelago. Due to its vital economic and nutritional value, this crop is now being planted in Luzon, the northern Philippines. On coconut palms and mangosteen trees, the coconut scale insect is commonly found on the lower surface or underside (abaxial) of the leaves. The presence of stomata in this area create a humid environment which favors insect growth and development (Reyne, 1948). In coconut, the insects target first the lower fronds keeping the upper fronds green, but in extremely heavy attacks (20-30 scales per cm^2 or 40-60 million insects per coconut palm; Reyne, 1948), all parts of the coconut shoot including sometimes the seednuts are encrusted by *A. rigidus*. Despite the severity of the issue, there is still scarce knowledge about the scale insect and its host preference which can be of help in understanding the irregularity on host range (e.g., mangosteen) (Watsons et al. 2015).

As an essential approach towards full understanding of this invasive species, life history of *A. rigidus* on coconut and mangosteen was comparatively studied in this paper, to understand the effects of two different host-plant species on the development, morphometry and other traits of *A. rigidus*; to investigate potential host-suitability factors that contributed to its outbreak infestation; and to gather baseline information on the development and characteristics of this pest. These are the information that can be used for effective pest monitoring and in adopting timely management strategies to mitigate the infestation, especially on these two important industrial crops.

MATERIALS AND METHODS

Collection and identity validation of *Aspidiotus rigidus*. *A. rigidus*-infested coconut leaves were collected from the IPB Coconut experimental field at Brgy. Tranca, Bay, Laguna which was characterized with high *A. rigidus* infestation (Fig. 1a). To further assure that *A. rigidus* was the predominant species, if not the only CSI species present, the infested leaves were first examined for the distinct morpho-characteristic of female *A. rigidus* before using it as source of insect crawlers (1st instar). The identity of the insects was validated through the presence of egg casings that arrange in white crescent shape/formation near the pygidium under one-half of the scale cover of typical healthy adult female insects (Watsons et al., 2015) (Fig. 2g). This is one unique characteristic that differentiates *A. rigidus* from other species of CSI such as *A. destructor*.

Fig. 1. Infestation of *A. rigidus* on host plants. (a) Crawler source palms in IPB Coconut experimental field, Brgy. Tranca, Bay, Laguna, (b) *A. rigidus*-infested coconut leaves clipped on the underside leaves of mangosteen host, and (c) *A. rigidus*-infested mangosteen leaves clipped on the underside leaves of coconut host to introduce crawlers inside a glasshouse.

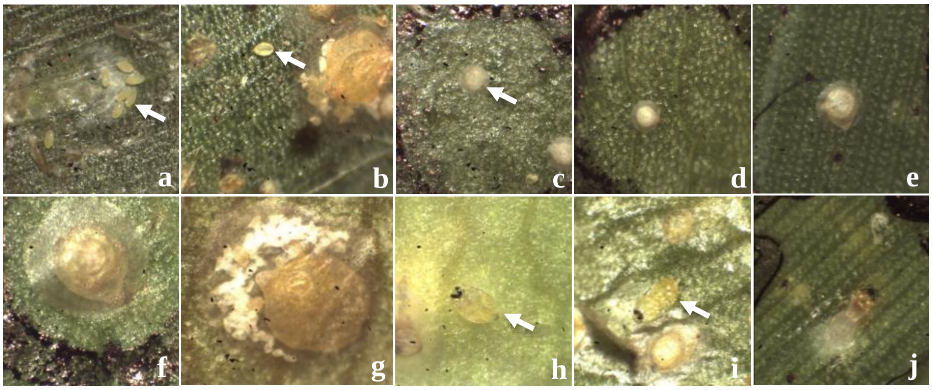

Fig. 2. Life cycle of *A. rigidus*. (a) Eggs, (b) crawler, (c) white cap stage, (d) pre-second instar, (e) second instar; Female: (f) third instar, (g) egg-laying adult; Male: (h) pre-pupa*, (i) pupa*, (j) winged adult (45x magnification). *scales removed.

Rearing of *A. rigidus* on mangosteen and introduction to host plants. Clean and uninfested coconut (Laguna Tall variety) and mangosteen (unknown farmer's variety) seedlings of one year of age were used as host plants in this study. Since *A. rigidus* may live in complex with other CSI species in the collected coconut leaves, pure culture of *A. rigidus* was first conducted through differential rearing using separate mangosteen seedlings. Through this, contamination of *A. destructor* was avoided during crawler introduction to coconut host. Pure culture is possible since only *A. rigidus* thrives on mangosteen (Reyne, 1948; Watsons et al., 2015). Inside the glasshouse, *A. rigidus* rearing was established by clipping (using paper clips) the infested coconut leaves (cut in approximately 7 inches long) on the abaxial or underside leaves of mangosteen seedlings, where the insect could favorably grow and reproduce (Fig. 1b). Mangosteen seedlings were placed on top of grill benches wherein nets were installed as cover/roofing to provide slight shading from sunlight. Boxes filled with water were placed underneath the benches to maintain a high relative humidity (RH) which is preferred by the insect (Reyne, 1948). The second generation *A. rigidus* crawlers from mangosteen rearing was introduced to coconut seedlings following the same clipping method previously described (Fig. 1c). Alongside, infestation on mangosteen seedlings was also done following the same procedures except that the infested leaves from the IPB coconut field (Fig. 1a) were the source of crawlers. After 48 hours, the clipped leaves were removed to obtain crawlers with uniform age that have transferred on both hosts. At this period, insects were permanently attached in the underside of the host's leaves. Seedlings with good infestation of healthy *A. rigidus* were selected and brought inside the rearing laboratory for observation, data gathering, and documentation at the Entomology Section, Institute of Plant Breeding, College of Agriculture and Food Science, University of the Philippines Los Baños, College, Laguna. The infested seedlings used were returned to the glasshouse every after data gathering/documentation to allow insect development.

Life history monitoring and documentation. Thirty (30) live insects, well-spaced on the leaves, were selected and encircled using a fine marker pen for the ease of observation. The insects were regularly monitored and documented throughout their life cycle by viewing them directly under a digital dissecting microscope (Optika microscope model SZM-LED1, Italy) while still attached on the host's leaves. Images were taken and measurements were performed using the microscope's software (OptikaISview v.3.6.6). Morphometry (length and breadth/width in millimeter, mm) of the various instars or stages of *A. rigidus* were measured and their corresponding developmental rates (in days) were counted. In addition, data regarding the number of eggs laid (fecundity), male to female ratio, female longevity, as well as other notable observations or changes on the insect's characteristics at different life stages were recorded throughout the experiment. Data gathered were statistically analyzed using RStudio v.1.0.136. The estimated insect and scale size/area (computed by multiplying the length and width) and the developmental rate were graphed using GraphPad Prism v.8.1.1.

RESULTS AND DISCUSSION

Life cycle

Eggs and crawler emergence. Inside the scale, eggs were laid one at a time by the adult female at a regular interval through a single large opening at the pygidium. Freshly laid eggs were light yellow and as they mature, black eye spots can be observed under the microscope (Fig. 2a). Mean length and width of eggs observed on coconut was 0.20mm and 0.10mm, respectively which were slightly bigger than on mangosteen with 0.18mm and 0.10mm, respectively (Table 1). Hence, crawlers that emerged were also slightly bigger on coconut (0.21mm and 0.13mm, respectively) than on mangosteen (0.20mm and 0.13mm, respectively) (Table 1). However, statistical analysis implicates that egg and crawler sizes were not significantly different on both hosts (Fig. 3). The crawlers (Fig. 2b) emerged by breaking the anterior of the egg casing and gradually pushed themselves out, sometimes with in-between breaks. They stayed inside the mother's scale for up to 24 hours before exiting through the scale cover. When expelled forcefully through removal of the mother's scale, some of them crawled to the nearest adult females and attempted to enter their scales. Though not significantly different on both hosts, eggs produced by female insects reared on mangosteen hatched slightly faster (2 days average) while on coconut, eggs usually hatch after 3 days (2.5 days average) (Table 2). Compared to *A. destructor*, eggs of *A. rigidus* hatch generally faster since they are laid at an advanced developmental stage (Watsons et al., 2015). When the crawlers were out of the scale covering, they crawled over the leaves quite actively to search for a suitable place to attach themselves and often made circular movements. During crawler development, the egg size increased and after hatching, white, semi-transparent and thin empty egg casings were collected near the pygidium and formed a crescent shape (Fig. 2g). This is one characteristic that distinguishes *A. rigidus* from other CSI species and is widely used to morphologically validate its identity. In contrast, the empty egg casings of *A. destructor* are scattered in the surrounding of mother's body. Crawlers are characterized with well-developed appendages, antennae and eyes; oblong shaped and yellowish in color. Crawler or 1st instar stage is the major dispersal phase of CSI since they are very lightweight and can freely move. They are easily carried or transported by wind which facilitates widespread infestation of this insect pest. Some crawlers that failed to exit from the mother's scale died inside, probably, due to the strong attachment of the scale unto the leaves and the crowding of eggs, crawlers, and egg casings. In severe infestation, overlapping of scales can be observed wherein some insects are buried under many scales.

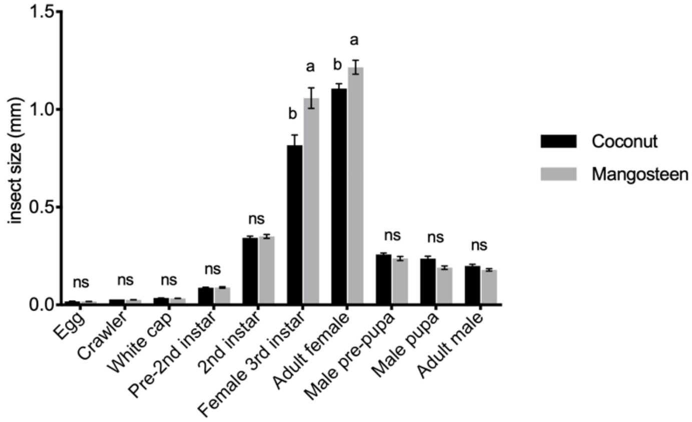

Fig. 3. Insect size/area (mean±SEM) of different developmental stages of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at α=5%; ns=not significant.

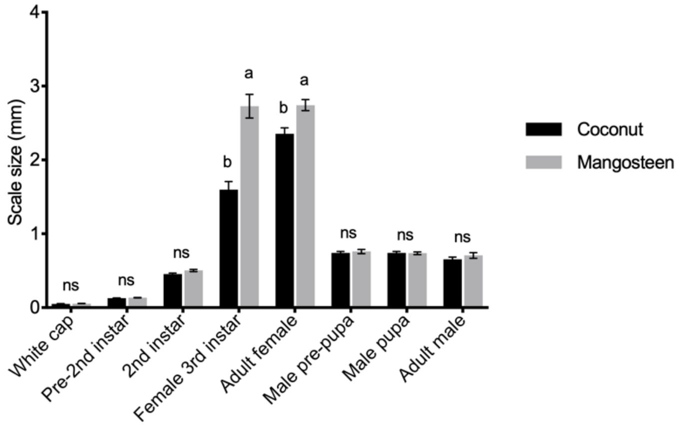

Fig. 4. Scale size/area (mean±SEM) of different developmental stages of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at α=5%; ns=not significant.

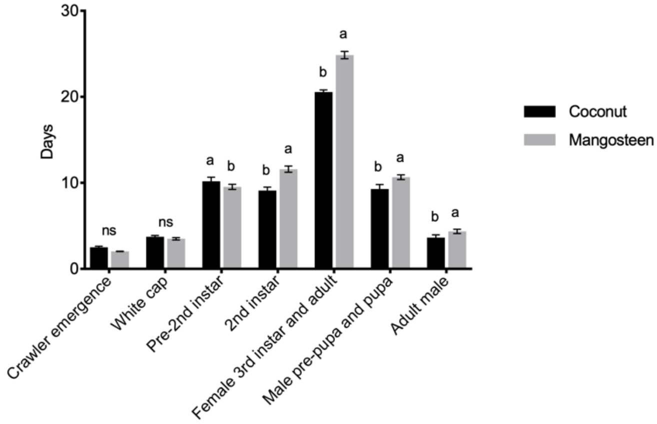

Fig. 5. Developmental rate (mean±SEM) of *A. rigidus* reared on coconut and mangosteen host plants. Means with different letters for each developmental stage differ significantly at α=5%; ns=not significant.

Table 1. Morphometry (mm) of *A. rigidus* on mangosteen and coconut hosts (*n*=30).

Developmental stages	**Mangosteen**				**Coconut**			
	Scale (mm)		**Body (mm)**		**Scale (mm)**		**Body (mm)**	
	L±SD	**W±SD**	**L±SD**	**W±SD**	**L±SD**	**W±SD**	**L±SD**	**W±SD**
Egg	-	-	0.18±0.01	0.10± 0.01	-	-	0.20±0.01	0.10±0.01
Crawler (1st instar)	-	-	0.20±0.01	0.13± 0.01	-	-	0.21±0.01	0.13±0.01
White cap	0.24±0.03	0.23±0.03	0.21±0.02	0.16± 0.02	0.23±0.02	0.22±0.03	0.21±0.02	0.16±0.01
Pre-2nd instar	0.38±0.04	0.36±0.03	0.33±0.04	0.27± 0.03	0.37±0.03	0.35±0.03	0.33±0.02	0.27±0.02
2nd instar	0.74±0.07	0.68±0.07	0.64±0.06	0.54± 0.05	0.71±0.03	0.64±0.04	0.64±0.03	0.54±0.03
♀3rd instar	1.71±0.33	1.55±0.31	1.13±0.18	0.92± 0.14	1.37±0.31	1.13±0.22	1.00±0.19	0.80±0.15
♀Adult	1.80±0.15	1.52±0.15	1.21±0.14	1.00± 0.07	1.70±0.14	1.38±0.16	1.17±0.07	0.95±0.07
♂Pre-pupa	0.96±0.08	0.79±0.07	0.65±0.06	0.37± 0.03	1.01±0.04	0.74±0.06	0.66±0.04	0.39±0.02
♂Pupa	0.96±0.08	0.77±0.06	0.63±0.08	0.30± 0.04	1.02±0.04	0.73±0.06	0.70±0.06	0.34±0.04
♂Adult (inside scale)	0.94±0.06	0.75±0.09	0.81±0.05	0.22± 0.02	1.01±0.07	0.65±0.09	0.85±0.05	0.23±0.03

SD=standard deviation; L=length; W=width

Table 2. Developmental rate (days) of *A. rigidus* on mangosteen and coconut hosts (*n*=30).

Developmental stages	Mangosteen Days±SD	Coconut Days±SD
Crawler emergence	2.03±0.18^{ns}	2.50±0.72^{ns}
White cap	3.50±0.81^{ns}	3.73±0.85^{ns}
Pre-2nd instar	9.53±1.61^{b}	10.20±2.5^{a}
2nd instar	11.60±1.91^{a}	9.11±2.08^{b}
♀3rd instar and adult	24.87±2.32^{a}	20.57±1.33^{b}
♀Total life cycle	52	46
♂Pre-pupa and pupa	10.67±1.01^{a}	9.29±1.87^{b}
♂Adult (inside scale)	4.36±0.77^{a}	3.64±1.07^{b}
♂Total life cycle	42	38

SD=standard deviation; ns=not significant; mean values followed by different letters differ significantly at α=5%

White cap stage and pre-second instar. Crawlers were allowed to establish for 48 hours in the abaxial side of the leaves of both hosts. After they found suitable areas in the leaf for fixation and insertion of rostrum, the white cap stage started wherein they produced whitish thread of wax intertwined together through body movements especially in the pygidium. This turned into a thin waxy scale covering upon incorporation of some fluid secreted by the insect (Reyne, 1948) (Fig. 2c). At this stage, they became immobile and their body sizes increased. Though not significantly different on both hosts, this stage lasted for an average of 3.5 days on mangosteen which was slightly faster than on coconut with 3.7 days average (Table 2; Fig. 5). Hereafter, the insect undergone pre-second instar period (also referred as 'nipple stage') wherein concentric circles on the scale became discernible, scale and body sizes increased, body appeared greenish and somewhat swollen, and the insect prepared for its first molt to develop into second instar (Fig. 2d). Pre-second instar on mangosteen completed in 9.53 days average which was significantly faster than on coconut with 10.2 days average (Table 2, Fig. 5). In terms of body size (mean length and width), it was quite equal on both hosts during white cap stage (0.21mm and 0.16mm, respectively) and pre-second instar (0.33mm and 0.27mm, respectively) (Table 1; Fig. 3). Though not significantly different on both hosts, scale coverings were slightly bigger on mangosteen during white cap stage (0.24mm and 0.23 mm, respectively) and pre-second instar (0.38mm and 0.36mm, respectively) than on coconut (Table 1; Fig. 4) . During pre-second instar, yellow spots due to feeding can be seen already on the upper part of the leaves (adaxial). Generally, the insects preferred the folded areas of the leaves such as on coconut, most of them attached near the midrib or veins; while on mangosteen, the insects were found near the midrib and linings, and close to the petioles of the leaves. Under normal field conditions, they are typically observed on the underside of the leaves due to its preferable humid environment caused by the presence of stomates (Reyne, 1948). They attack first the lower fronds of coconut palm keeping the upper fronds green (Fig. 1a). However, in serious outbreaks, all parts of the coconut shoot (sometimes including the seednuts) are attacked.

Second instar. After the first molt, the insect entered second instar wherein they appeared yellowish (somewhat transparent in some insects), their appendages and antennae were lost, and a subcentral molt ring (exuviae; casted or shed skin from the 1st instar) was incorporated on the scale (Fig. 2e). During the molting process, the insect developed body ridges and the color changed to yellowish orange with reddish pygidium (Fig. 6a). After the molting process, a new body was seen inside the scale, under the exuviae (Fig. 2e). Body size of insect (mean length and width) at this stage was the same on both hosts (0.64mm and 0.54mm, respectively) (Table 1; Fig. 3). Though not significantly different on both hosts, scale coverings were slightly bigger again on mangosteen (0.74mm and 0.68mm, respectively) than on coconut (Table 1; Fig. 4). This trend was the same as in white cap and pre-second instar, however, development into second instar was significantly faster on coconut with 9.11 days average than on mangosteen with 11.6 days average (Table 2; Fig. 5).

Fig. 6. Molting of *A. rigidus* towards (a) second instar, (b) female third instar, and (c) male pupal stage showing expelled exuviae (45x magnification).

Male *A. rigidus*: Pre-pupal, pupal, and adult stages. At the later stage of second instar, male *A. rigidus* started to appear slender or tapered (v-shaped) towards the posterior end with scale covering looked elliptical, body turned light yellow with pygidial structure quite retained; but the most prominent feature was the presence of two developed black eye spots (pre-pupa) (Fig. 2h). Though not significantly different on both hosts, mean length and width of males during pre-pupal period were slightly bigger on coconut (0.66mm and 0.39mm, respectively) than on mangosteen (0.65mm and 0.37mm, respectively) (Table 1 & Fig. 3). After this stage, the males molted and entered pupal stage in which genitalia and appendages started to develop, body and scale further elongated, and pygidial structure was lost. Initial antennae were formed, and male body appeared already separated from the host leaf (Fig. 2i). During molting towards pupal stage, the exuviae or casted skin was deposited on the posterior end and expelled out of the scale cover (Fig. 6c). Thus, only the exuviae at first molt (from crawler) can be seen incorporated in the scale of males. Though not significantly different on both hosts, mean length and width of pupa were slightly bigger on coconut (0.7mm and 0.34mm, respectively) than on mangosteen (0.63mm and 0.3mm, respectively) (Table 1; Fig. 3). The average days of males to complete both pre-pupal and pupal stages were significantly shorter on coconut (9.29 days) than on mangosteen (10.67 days) (Table 2; Fig. 5). The pupa molted again and further transformed into yellow colored adult male, with fully developed antennae, eyes, appendages and wings (Fig. 2j). Females did not undergo these stages. Instead, females undergone third instar and then, as egg-laying adults that feed permanently on the leaves. Though not significantly different on both hosts, mean length and width of winged adult male (under scale cover) were slightly bigger on coconut (0.85mm and 0.23mm, respectively) than on mangosteen (0.81mm and 0.22mm, respectively) (Table 1; Fig. 3). Scale size of males at all developmental stages was not significantly different on both hosts (Table 1; Fig. 4). Adult males emerged by making a longitudinal cut on the posterior part of the scale wherein the wings were once situated. Some adult males emerged by moving backwards through the opening in the posterior end of the scale created during wing development. Some males, however, died with their wings trapped (or glued) in the scale or in the unexpelled exuviae, thus disabling them to fly as their wings were deformed or destroyed. Adult males crawl with their wings pointed upward and sometimes move by flying and jumping. The same as in pre-pupal and pupal stages, development to adult male was significantly faster on coconut (3.64 days) than on mangosteen (4.36 days) (Table 2; Fig. 5). In total, male *A. rigidus* completed its life cycle faster on coconut with 38 days average than on mangosteen with 42 days average (Table 2). *A. rigidus* males were thus generally healthier on coconut host supporting shorter life cycle and slightly bigger bodies.

Female *A. rigidus*: Third instar and adult stages. *Aspidiotus rigidus* is most destructive as females since they permanently attach and feed on the leaves and produce eggs. Females continued secreting waxy thread to produce bigger scale to accommodate the growing body. After the second instar and second molt (Fig. 6b), the females entered third instar or pre-oviposition stage wherein they prepare to develop and produce eggs (Fig. 2f). At this stage, both body and scale sizes increased rapidly and the pygidium was further developed. The second exuviae was incorporated in the scale just below the first exuviae. In some insects, the eye spots from the crawler stage (1st instar) were still visible (under the microscope) even up to this stage though these were initially seen on the dorsal part of the head, now seemed to have moved to the sides of the enlarged insect's head. It was observed that the insect generally changes position at various developmental stages as shown by different orientation of first and second exuviae, and the third instar body. The female body was very delicate containing largely yellowish fluid which gives its characteristic color. The 'up and down' movement of the pygidium at this stage seemed to be more distinguishable and continuous. This was probably because, aside from its preparing to develop and lay eggs, it continuously secreted waxy fluid while moving its body. At third instar, the abdominal tip was usually observed at or close to the periphery of the scale covering (Fig. 2f). Mean length and width of third instar females were significantly bigger on mangosteen (1.13mm and 0.92mm, respectively) than on coconut (1mm and 0.8mm, respectively) (Table 1; Fig. 3). After the third instar, the insect transformed into gravid female adults (Fig. 2g). This is the last developmental stage of female *A. rigidus* which is also referred to as oviposition stage. Unlike in third instar, the adult female produced more scale covering at the abdominal tip to make enough room for laying and incubation of eggs. After several ovipositions, the scale covering was usually crowded with eggs, newly emerged crawlers, and egg casings. The same goes in the adult females, they were significantly bigger (mean length and width) on mangosteen (1.21mm and 1mm, respectively) than on coconut (1.17mm and 0.95, respectively) (Table 1; Fig. 3). Likewise, significantly bigger scales (mean length and width) were observed on mangosteen during third instar (1.71mm and 1.55mm, respectively) and adult stage (1.8mm and 1.52mm, respectively) (Table 1; Fig. 4). The scale cover was opaque and largely oval or circular shaped on both hosts. When removed from the leaves, the rostrum (feeding tube) inserted by *A. rigidus* in the leaf tissues for sucking sap was located at the center of the upper half of the insect's ventral part. This hair-like structure appeared to grow longer as it explored the internal leaf tissues and consumed the sap resulting to leaf yellowing. The female body has many grooves, especially near the pygidium, which also facilitated body movement. Females molted twice (second and third instars) and no further molting was observed when approaching the adult stage. Also, they are parthenogenic and thus can develop and lay eggs even with the absence of males. Between the two hosts, female *A. rigidus* (body and scale) were therefore significantly bigger on mangosteen but contrastingly in males, though not significantly different on both hosts, they were slightly bigger on coconut. However, in spite of the seemingly healthy status of females on mangosteen, insect development under these two stages were significantly faster on coconut (20.57 days) than on mangosteen (24.87 days) (Table 2; Fig. 5). Thus, insect developmental stages before second instar may be slightly slower on coconut, however, stages approaching to female maturity developed faster. Hence, life cycle of female *A. rigidus* was significantly shorter on coconut (46 days average) suggestive to its outbreak characteristic in this host (Table 2). On mangosteen, the life cycle completed in the average period of 52 days long (Table 2). The duration of female life cycle on coconut confirmed the report of Reyne (1948) in which, if compared to *A. destructor* life cycle, is about 1.5 times longer (Watsons et al., 2015). Salahud and Arthurs (2015) also reported that *A. destructor* has a very short life cycle of 35 days on coconut. The shorter developmental stages of *A. rigidus* at second instar to adult females resulted to shorter life cycle on coconut which indicates adequate nutrition. Regardless of hosts, female insects were generally bigger than males but male insects matured earlier than the females (Table 1 and 2; Fig. 3 and 5).

Fecundity, longevity and sex ratio of *A. rigidus* on both hosts. As mentioned, female *A. rigidus* can reproduce through parthenogenesis. Reyne (1948) never observed copulation (or mating) in both *A. rigidus* and *A. destructor* though adult males are oftenly seen amongst female insects. In the present study, copulation in *A. rigidus* was also not observed but in the case of *A. destructor*, Tabibullah and Gabriel (1975) were able to observe copulation in this species. Insect fecundity recorded on coconut was higher (75 eggs average) than on mangosteen (48 eggs average) (n=30). One factor that might have contributed to this was the longevity of female *A. rigidus* which was longer on coconut (up to 3.5 months) compared to mangosteen (up to 2.5 months) leading also to much higher fecundity. In *A.*

destructor, eggs could range from 40-60, and in some cases 75-100 (Reyne, 1948) which means this species generally lays more eggs than *A. rigidus*. In this study, by counting 100 insects, more females were observed on mangosteen (1:3.11 male to female ratio) while the sex ratio was almost equal on coconut (1:1.14). The male and female ratio of *A. rigidus*, however, may be highly variable but most of the time, male insects comprise 25-50% of the colony (Reyne, 1948). The effect of sex ratio in terms of egg production of *A. rigidus* is not clearly understood. In *A. destructor,* there was no considerable difference when it comes to egg production between mated (by males) and unmated (parthenogenic) female scale insect as reported by Reyne (1948).

***A. rigidus* pure culture rearing and natural enemies.** Rearing pure culture of *A. rigidus* was successfully done using mangosteen seedlings kept inside the glasshouse as this species may live in complex with *A. destructor* in the collected coconut leaves. Pure culture was possible due to non-preference of *A. destructor* on mangosteen (Reyne, 1948; Watsons et al. 2015; Cayabyab et al. 2016) and avoided contamination of this species during introduction of *A. rigidus* to coconut host. *A. destructor* is a polyphagous pest attacking coconut and banana, including major tropical fruits and ornamental crops (Lal, 2004). Rearing was initially carried-out using squash fruits as it was conducted by Tabibullah and Gabriel (1975) on *A. destructor*. However, *A. rigidus* was not successfully reared on squash fruits. Crawlers infested the fruit and successfully established but insect development was delayed after reaching second instar. Instead, mangosteen seedlings were used to mass rear *A. rigidus* and in studying its life cycle. The average temperature of the rearing set-up in the glasshouse was 26ºC with an average RH of 76%. Source material (coconut leaves) infested with many gravid females, eggs and crawlers of *A. rigidus* was selected and used during rearing establishment to ensure good insect transfer on the mangosteen leaves. Samples of reared CSI were also submitted for molecular identification and confirmation. DNA sequence analysis confirmed the identity of the scale insect on mangosteen as *A. rigidus* only (Latina 2016; Galvez et al. 2018).

As the *A. rigidus* in the rearing set-up grew in number, natural enemies including predatory mites and the newly discovered *Comperiella calauanica* (Fig. 7a) (Barrion et al. 2016) were observed on newly infested plants. Natural enemies are naturally occurring biological control agents which regulate pest population at a level not causing serious economic loss on crops. The female *C. calauanica* oviposits on the body of the coconut scale insect and its egg develops into adult through consumption of the insect's tissues (Fig. 7b).

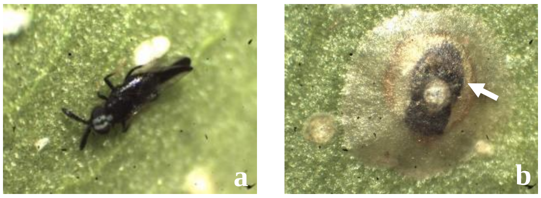

Fig. 7. (a) Adult female *Comperiella calauanica* Barrion, Almarinez, Amalin & Carandang and (b) its parasitism (45x magnification).

The mature *C. calauanica* emerged by making exit holes on or near the pygidium of the parasitized body of *A. rigidus*. This parasitoid posed the most significant parasitism which is a problem when rearing *A. rigidus*, but this also implies its effectiveness as a biological control agent for *A. rigidus* (Almarinez et al., 2015). In Oman, a coccinellid beetle, *Chlorocorus nigritus*, introduced from India was successfully used to control *A. destructor* (Kinawy, 1991). In the Philippines, *Scymnus* coccinellid species were effective predators of *A. destructor* (Palacio et al. 1984).

CONCLUSION

The various information generated in this study suggest that coconut as host of *A. rigidus*, compared to mangosteen, provides better nourishment and living conditions that support faster life cycle and development, longer female longevity, and higher insect fecundity which are potential host-suitability factors that contributed to the outbreak infestation. Mangosteen, on the other hand, supports bigger *A. rigidus* females and slightly faster developmental rate prior to second instar. This means that different host-plant species have effects on the growth, development, and reproduction of *A. rigidus* which may be augmented due to better host suitability. Such host suitability could be regarded as one of the determinants of the insect's outbreak potential. Mangosteen is an effective host-plant to mass rear pure culture of *A. rigidus* since *A. destructor* could not be reared on this crop. Successful mass rearing of *A. rigidus* is also necessary in the conduct of host resistance confirmatory tests for selected promising coconut varieties. The findings of this paper could also be used as baseline information for studying host-insect interaction and in conceptualizing timely management and effective monitoring strategies to mitigate pest infestation especially on these two valuable industrial crops.

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SCREENING FOR COLLUSION IN T HE PHILIPPINE CHICKEN MEAT, CHICKEN EGG AND PORK MARKETS

Charis Mae T. Neric, Prudenciano U. Gordoncillo, Cenon D. Elca, and Janine P. Curibot
Department of Agricultural and Applied Economics, College of Economics and Management, University of the Philippines Los Baños, College, Laguna 4031
Corresponding author email: catolentino2@up.edu.ph

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ABSTRACT

Since chicken meat, chicken egg and pork are regularly consumed by majority of the Filipino population, changes in the quantity supplied and retail prices significantly affect buyers. Protecting the welfare of the consumers and even producers by promoting free and fair competition is of utmost concern. Firms entering into anti-competitive agreements such as market collusion can hurt consumers because of the high prices they are being charged. The paper screened for possibility of market collusion in the Philippine markets of chicken meat, chicken egg and pork, by observing significant breaks in the prices of industry data. Piecewise regression analysis was performed on the nominal retail prices of chicken meat, chicken egg, and pork from 1990 to 2017. Findings revealed that the variations in the retail prices showed statistically significant shifts corresponding to critical events in the industry like entry, exit and mergers within the industry, as well as the acceleration of technical smuggling in the country. While the paper is limited only to the initial work of detecting market collusion, the paper recommends that further scrutiny by concerned agencies be done in order to verify and address the anti-competitive behavior of firms.

Key words: cartels; mergers and acquisition; technical smuggling; piecewise regression

INTRODUCTION

The livestock and poultry industry is one of the major contributors to Philippine agriculture. During the last 16 years, the industry accounted for approximately one-fourth of the country's output (i.e. gross value added) in agriculture and fishery. Pork has the highest output share (14.5%), followed by chicken (12.2%), chicken egg (3.3%), and beef (1.5%) (Philippine Statistics Authority [PSA], 2017). The industry also provides employment and acts as supplementary sources of income to thousands of Filipinos living in the rural areas for live animal production and urban centers as final market destination. Pork, chicken meat, and eggs are regularly consumed by majority of the population and are the main providers of protein to the Filipino diet. Consumers have a wide variety of choice in the purchase of meat products depending on taste, preference, access and income. Thus, from the viewpoint of consumers, domestically produced fresh meat not only competes with imported frozen meat, but also with secondary processed products (i.e. hotdog, pork sausage and cured pork) and canned goods (i.e. luncheon meat).

In order to promote free and fair competition in trade, industry, and all commercial activities in the Philippines, the Philippine Competition Act (PCA) or Republic Act 10667 was signed into law in 2014. This law provides for the establishment of the Philippine Competition Commission (PCC), a quasi-judicial body of the government enforcing the PCA. One of the concerns of the PCC is to penalize anti-competitive agreements such as market collusion or the formation of cartel among industry players.

Cartels are illegal arrangements between players of an industry to control for prices and therefore profit, thereby reducing the level of competition between them and other competitors.

When market players collude and, for instance, agree to set a common price instead of establishing competitive prices, social welfare is sub-optimal. Not only are consumers penalized for paying high prices but new firms can also be discouraged from entering the market since the collusive agreements act as a barrier to entry into the industry. Market collusions are therefore detrimental to the economic welfare of the society. Unfortunately, market collusions happen. Screening for market collusion is crucial in order to identify markets where collusion is suspected. Among developed economies like the US, EU and Japan, cartel detection is typically implemented using two approaches: reactive and proactive (Friederiszick, 2006; Nakazato, 2014; OECD, 2015). Competition agencies take their reaction when market participants file complaints against unfair competition of suspected cartels. Existing cartel members can also apply for clemency or pardon such as the case of whistleblowers. Competition agencies also have the option of granting leniency or reward programs to industries where a cartel has already been discovered.

A proactive approach, on the other hand, requires the active involvement of a competition agency in identifying particular market participants or specific markets associated with cartelization. There are two main economic-based detection tools, called cartel screens, used in the proactive discovery of cartels. These are structural methods using observable economic data and behavioral methods which focus on the behavior of cartel member firms (Abrantes-Metz, 2013). According to Grout and Sonderegger (2005), one of these cartel screens is structural method. A structural approach of cartel detection generally compares the structure and trend of markets with cartel and without cartel (i.e. perfectly competitive industry). For example, the absence of cartel or a competitive market is associated with many firms with low market share, low barriers to entry of new players, high volatility in response to crisis, and significant changes in market share due to many instances of entry and exit. In contrast, cartelization will most likely form in markets with few firms with substantial market share, markets that exhibit high barrier of competitor participation, markets that are stable even at times of economic and/or political crisis and markets that are, across long periods, monopolized by the same participants with constant market share. This approach also involves identifying market attributes generally viewed to be conducive to market collusions such as, an oligopolistic market structure, product homogeneity, and inelastic demand (Harrington, 2004).

The other detection tool is behavioral method, which usually involves the actual observation of communication or meetings of suspected cartel members. The behavioral approach can also take the form of outcomes of cartel behavior (Harrington, 2004). The focus will be on the end result of communication, meetings, illegal agreement, and coordination. This takes the form of market impacts like coordinated price increase and abnormally low production of firms (Harrington, 2004; Abrantes-Metz, 2013; Gomes, 2014). If there are structural breaks in firm behavior, then it follows that there will also be structural breaks in market outcome. However, it should be noted that these breaks are indicative only and does not guarantee that collusion occurred. The major reason is that these structural breaks may also be due to internal factors (e.g. firm efficiency) or external forces (e.g. occurrence of political and economic crisis) (Harrington, 2004). The behavioral approach also entails observations on the manner through which firms communicate or the outcomes of the firms' coordination. In rare occasions, market collusions are known through direct testimonials of individuals who are a party to the coordination or some stumble upon evidence of such collusive coordination. The other approach to detect market collusion is done through observations of firms' output and prices (Harrington, 2004).

The market condition and current policy setting of chicken meat, chicken egg and pork could significantly affect consumers. For instance, high prices offered by producers and market intermediaries would imply reduction of consumer welfare through lower consumption. Since prices are greatly influenced by the degree of competition in the market, increasing market competition through policy reforms could help lower prices and attract new customers. Thus, market competition aided by policy can help protect the welfare of both consumers and producers. The general objective of this paper was to screen for market collusion in the Philippine chicken meat, chicken egg and pork markets.

RESEARCH METHODOLOGY

In economics, welfare is optimal at the equilibrium point or at the point of intersection between the supply curve and the demand curve. The levels of output and prices beyond the equilibrium point are deemed inefficient and the result is a general economic welfare loss to the society. Addressing market collusion involves three distinct stages: screening, verification and prosecution. Screening identifies which firms exhibit suspicious behavior and may be candidates for further scrutiny by concerned agencies while verification involves singling out competition as an explanation for the observed behavior and provides evidence in support of collusion (Harrington, 2004). The final stage, prosecution, involves offering enough evidence to support the case that the anti-competition law was indeed abused. Due to time and logistical constraints, this study is limited to screening for market collusion or providing an analysis of the likelihood that market collusion is happening.[1]

Specifically, market collusion can be detected by observing significant breaks in the prices of industry data (Harrington, 2004; Abrantes-Metz, 2013; Gomes, 2014). For instance, a preceding downward price trend suddenly followed by significant and steady increases in prices could be a sign of market collusion. Changes in the average price, relationship between a firm's price and cost, relationship among firm's prices, as well as the variance of price and market share are some examples of patterns one ought to check for when screening for collusion (Harrington, 2004, Abrantes-Metz, 2013; Gomes, 2014). Moreover, the entry or exit of a significant player can also trigger a break in the price trend. A pattern can also be observed upon a breakdown of the collusive behavior of firms.

These breaks in the pattern of price behavior over time can be detected using segmented regression or piecewise regression models (Pindyck and Rubinfeld, 1981; Gujarati, 1988). Suppose for instance that an entry of a firm in the industry triggers a break in the price trend, then, this change can be captured by a piecewise regression model expressed as:

$$P_i = \beta_0 + \beta_1 T_i + \beta_2 (N_i - N^*) D_i + \varepsilon_i$$

where, P_i is price of the $_i$th observation;
β_0 are the parameter estimates;
T_i is the time trend;
N_i is the number of the $_i$th observation;
N^* is the number at break point; and
$D_i = 0$ if $(T_i - T^*) <= 0$
$= 1$ if $(T_i - T^*) > 0$
ε_i is the error term

If β_2 is significantly different from zero, then the break in the price trend is significant which implies that the entry or exit, or an event involving major players triggers possible collusive behavior or breaks the collusive behavior.

RESULTS AND DISCUSSION

Among the four commodities included in the study, only chicken egg, chicken meat, and pork were subjected to the piecewise regression analysis as these commodities have major players that

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[1] A recent study, for instance, on detecting market collusion was done by Wanhiphang in 2008 for the market of fresh milk in the United Kingdom which surveyed about 14,000 households for three years.

dominate the industry[2]. Monthly price data from January 1990 to December 2017 with a total of 336 data points was used. It was observed from the data that prices for chicken, chicken egg, and pork have been on the rise since 1990. Piecewise regression was used to obtain the difference between two or more different time periods; a method of finding that piecewise continuous function which best describes the data sample[3]. To do so, the independent variable was partitioned into intervals and a separate line segment was fitted to each interval. This was done in order to control for the unobserved heterogeneity and obtain a more robust estimate of the policy variable.

Since the increase in price may be attributed to several factors such as inflation, ARIMA errors were incorporated in the model to capture the unobserved heterogeneity inherent in time series regression. Based on the Likelihood Ratio (LR) test for no linear trend, the time series for chicken meat and pork retail prices have a linear trend, as it rejects the null hypothesis that no linear trend exists at 1% statistical significance. The LR Test results, Residual Plots, ACF and PACF graphs for chicken meat, chicken egg, and pork can be seen in Annex 3, 4, and 5, respectively. An Engle-Granger test for cointegration for chicken meat and pork was also conducted and, as expected, the price of chicken meat is not cointegrated with the price of pork (Annex 6).

Chicken Meat. The retail price of chicken meat per kilogram has increased from Php 53.07 in 1990, to as high as Php 148.73 in 2017 (Fig.1). While the entire series exhibited an upward trend, there is a distinctive shift in the line at the 156[th] observation. Scanning the events in the industry during the series, it was established that the 156[th] observation corresponds to the year 2002, around the time when Bounty Agro Ventures Incorporated (BAVI) operated in full swing its broiler chicken production nationwide.

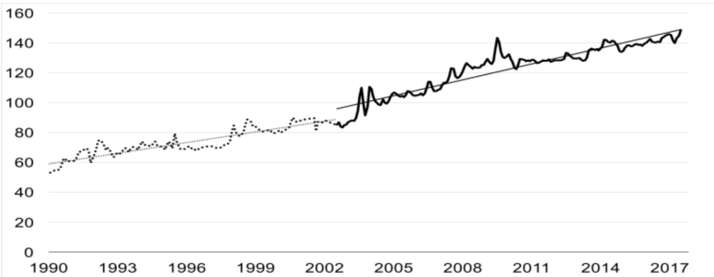

Fig. 1. Chicken meat retail prices from 1990 to 2017 highlighting the effect of the entry of BAVI in 2002

Conceptually, the entry of Bounty Agro Ventures Incorporated would have increased the supply of chicken meat in the country, which by principle would have caused downward pressure on the retail price of chicken meat. Instead, the retail prices of chicken meat, exhibited an exactly opposite pattern. This is an anomalous behavior, which merits further scrutiny in terms of whether or not the new player is in collusion with the other players in the industry. The parameter estimates of the piecewise regression (Table 1) for the trend line showed direct correlation between the retail price of chicken and time, that is from 1990 to 2017, the price has been consistently increasing. Further, the parameter estimate for the break dummy was also established to be positive and significant, which statistically confirms the pattern that the entry of Bounty Agro Ventures Incorporated in the chicken meat production industry shifted the trajectory of the increasing prices, which implies an acceleration of the rate of increase, that is not consistent with the fundamental principles in economics.

[2] Beef was not included in the analysis as the researchers considered that industry players are primarily backyard and small players. Moreover, the researchers was not able to correlate industry events that may have affected prices in the beef market.

[3] McGee, V. E., & Carleton, W. T. (1970). Piecewise Regression. Journal of the American Statistical Association, 65(331), 1109. doi:10.2307/2284278

Table 1. Results of the piecewise regression analysis for chicken meat retail prices to highlight the effect of the entry of BAVI and technical smuggling

Model	B	Standard Error	t	Significance
(Unstandardized Coefficients)				
Event 1: Entry of BAVI				
Constant	56.126	0.799	70.212	0.000
Time	0.232	0.008	30.757	0.000
Break_Dummy	0.088	0.012	7.332	0.000
Event 2: Effect of Technical Smuggling				
Constant	51.412	0.691	74.443	0.000
Time	0.29	0.004	65.431	0.000
Smuggling_Break_Dummy	-0.039	0.019	-2.058	0.040

A closer look at the trend of the retail price would reveal that there are actually three segments in the series (Fig. 2). The line showed an acceleration upon the entry of a new player, but in 2010, the rate of increase in the retail prices of chicken decelerated. Annex 1 shows the volume of chicken meat imports and technical smuggling from 1990 to 2016. According to Gordoncillo, et al. (2013), chicken meat is smuggled through misdeclaration of chicken meat into a different and cheaper product). It can be seen from the graph that during the early 1990s, technical smuggling was still minimal ranging from 20 to 350 metric tons but the volume of technically smuggled chicken meat considerably increased starting 1996. In early 2010, the rate of smuggling accelerated and has been increasing towards 2016.

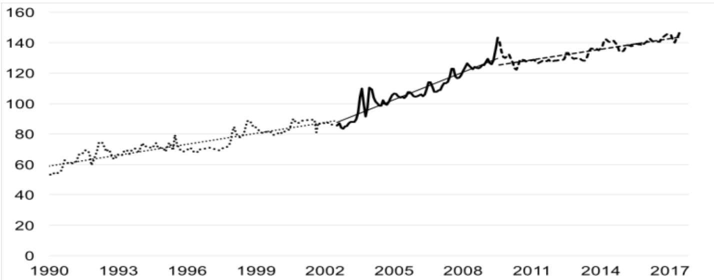

Fig. 2. Chicken meat retail prices from 1990 to 2017 highlighting the effect of the entry of BAVI in 2002, and the effect of smuggling in 2010

The effect of smuggling to the retail price of chicken was also estimated using piecewise regression and the parameter estimates are also shown in Table 1. The negative sign of the parameter estimate indicates that smuggling dampens the retail price of chicken in a statistically significant manner. Figure 2 shows graphically the dampening effect of smuggling to the domestic retail price of chicken.

Chicken Egg. The chicken egg industry is dominated by three major players: Bounty Farms, Universal Robina Corporation, and Venvi Agro-Industrial Ventures Corporation. The older companies like Bounty Farms were established as early as the mid-1950s. For the entire series from 1990 to 2017, the price of chicken egg has been increasing (Fig. 2). In particular, the price per piece of chicken egg has risen from as low as Php 1.77 in 1990 to as high as Php 5.73 in 2017. However, by about 2003, the rate of increase in the prices of chicken egg started to accelerate. This shift in the trend coincided with the entry of Venvi Agro-Industrial Ventures Corporation, which initially started producing about 125,000 eggs per day. Again, the price behavior defies economic logic, because the increase in supply would have exerted downward pressure on the price of chicken egg. Hence, there is reason to look deeper into the relationships of these major players in the chicken egg industry. Table 2 shows the estimated parameters for the piecewise regression intended to isolate the effect of the entry of Venvi Agro-

Industrial Ventures Corporation into the chicken egg industry in 2003. The estimated coefficients, statistically validated the pattern exhibited in the graph that the rate of increase in the prices of chicken egg accelerated after the entry of Venvi Agro-Industrial Ventures Corporation.

Table 2. Results of the piecewise regression analysis for chicken egg retail prices to highlight the effect of the entry of Venvi Agro-Industrial Ventures Corporation

Model	B	Standard Error	t	Significance
(Unstandardized Coefficients)				
Event 1: Entry of Venvi Agro-Industrial Ventures Corporation				
Constant	1.747	0.028	61.616	0.000
Time	0.011	0.000	46.598	0.000
Break_Dummy	0.004	0.000	8.538	0.000

Pork. The retail prices of pork per kilogram showed an increasing trend for the entire series; from as low as Php 52.27 in 1990 to Php 208.50 in 2017 (Fig. 3). However, in about 2001, the rate of increase in prices exhibited an accelerated rate of increase. This noticeable shift coincided with a significant change in the industry, that is, San Miguel Corporations acquired Pure Foods Corporation.

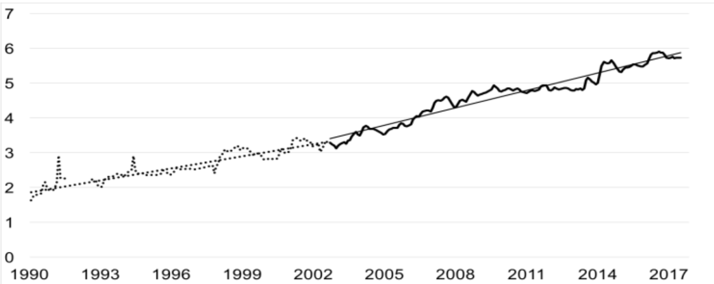

Fig. 3. Chicken egg retail prices from 1990 to 2017 highlighting the effect of the entry of Venvi Agro-Industrial Ventures Corporation

Table 3 shows that the acquisition of Pure Foods Corporation by San Miguel Corporation, shifted the slope of the regression line upwards, which means that the level of rate of increase in prices post acquisition has accelerated. While this significant change may not necessarily be considered collusion, the acquisition of Pure Foods Corporation by San Miguel Corporation increased the latter's market power. This is also a critical competition issue.

Table 3. Results of the piecewise regression analysis for pork retail prices to highlight the effect of San Miguel Corporation's acquisition of Pure Foods Corporation and technical smuggling

Model	B	Standard Error	t	Significance
(Unstandardized Coefficients)				
Event 1: San Miguel Corporation's Acquisition of Purefoods Corporation				
Constant	55.101	0.868	63.508	0.000
Time	0.392	0.008	46.355	0.000
Break_Dummy	0.110	0.013	8.497	0.000
Event 2: Effect of Technical Smuggling				
Constant	21.022	3.329	6.315	0.000
Time	0.595	0.015	38.746	0.000
Smuggling_Break_Dummy	-0.277	0.036	-7.782	0.000

While the long term trend for the prices of pork showed an increasing trend, the trend is actually divided into three segments (Fig. 4). The initial increasing trend accelerated around the end of 2001 and started to decelerate towards the early part of 2010.

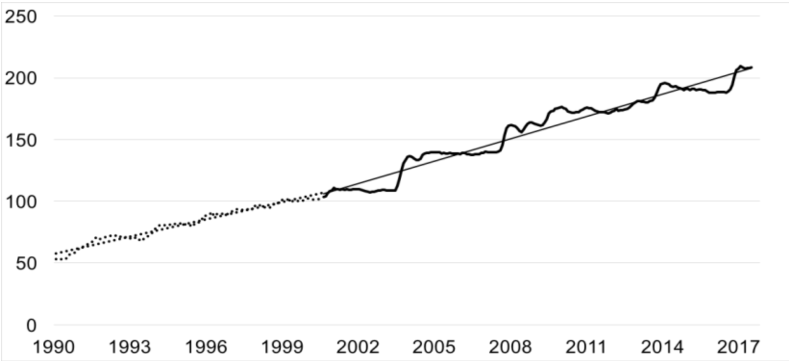

Fig. 4. Pork retail prices from 1990 to 2017 highlighting the effect of San Miguel Corporation's acquisition of the Pure Foods Corporation

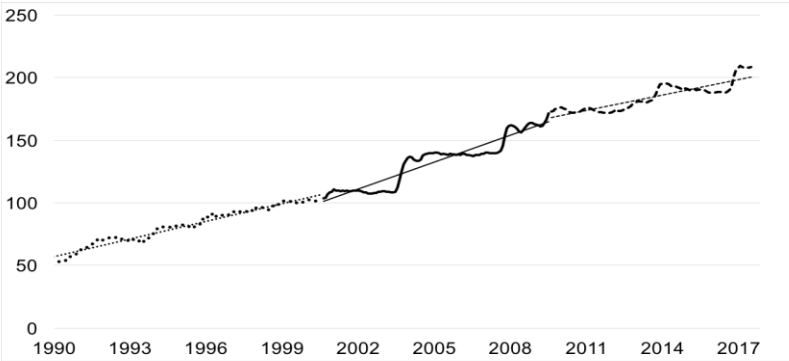

Fig. 5. Pork retail prices from 1990 to 2017 highlighting the effect of San Miguel Corporation's acquisition of the Pure Foods Corporation and the effect of smuggling

Like chicken meat, pork is also one of the commodities that are being smuggled into the country (Annex 2). Specifically, there was a considerable increase in the volume of pork being smuggled into the country since 2010. While there were fluctuations after 2010, the graph generally shows a rising trend. Moreover, Table 3 shows that the extent of technical smuggling has dampened the domestic prices of pork. This can be validated by the negative sign of the parameter estimate for the dummy differentiating the period when smuggling has become rampant.

CONCLUSIONS AND RECOMMENDATIONS

The variations in the firm and industry level prices showed discernable patterns of associated behavior. The analysis of the industry level prices showed statistically significant shifts corresponding to critical events like entry, exit and mergers within the industry, as well as the acceleration of technical smuggling in the country.

Based on the results of the analysis, the entry of a new player in the industry may have accelerated the rate of increase in prices. However, this behavior refutes economic logic since the increase in supply is expected to exert downward pressure on the prices. Hence, concerned agencies such as the PCC, the Department of Agriculture – Bureau of Animal Industry, and the Department of Trade Industry may have a reason to look deeper into the relationships of these major players in the chicken egg industry. Mergers are issues that affect competition. One of the results of the regression analysis showed that mergers may have caused an acceleration in the increasing trend of prices. Hence, mergers have to be critically assessed in terms of its potential impact on prices to prevent unnecessarily giving a firm increased monopoly power to control prices.

Smuggling dampens the domestic prices. While these may seem beneficial to consumers, this issue has to be looked at in terms of food safety. Moreover, on the production side, the effect on competition is at the small-scale and backyard producers' level. Prices depressed by smuggling will erode the competitive edge of small-scale and backyard producers. Therefore, the PCC should argue for the merit of anti-smuggling from a competition perspective.

ACKNOWLEDGMENT

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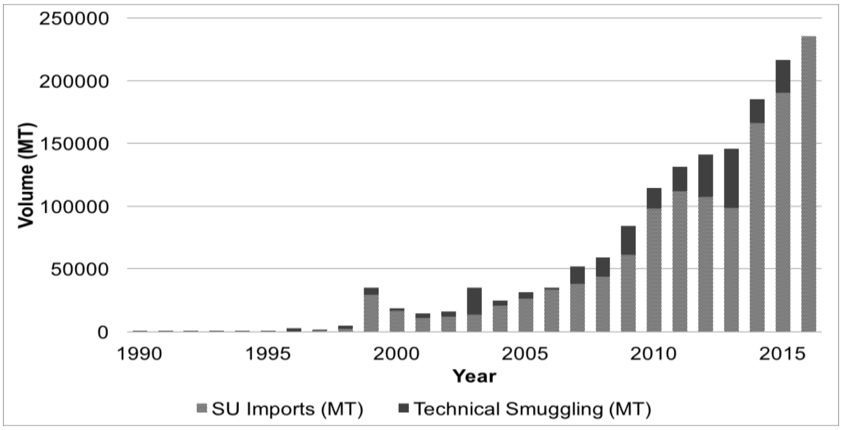
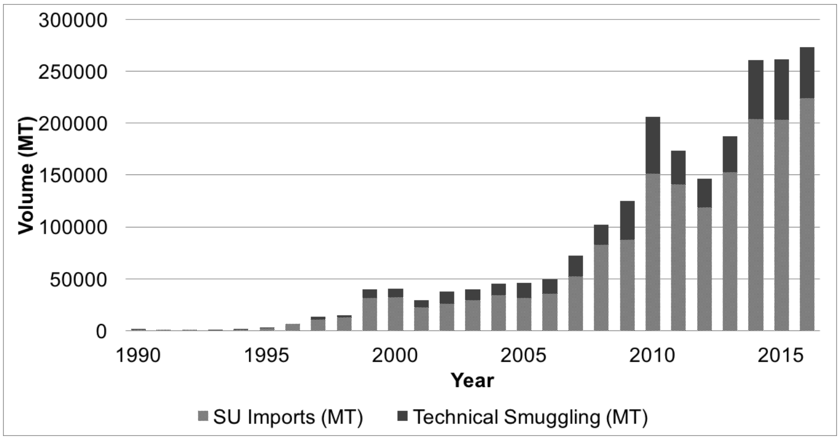
ANNEXES

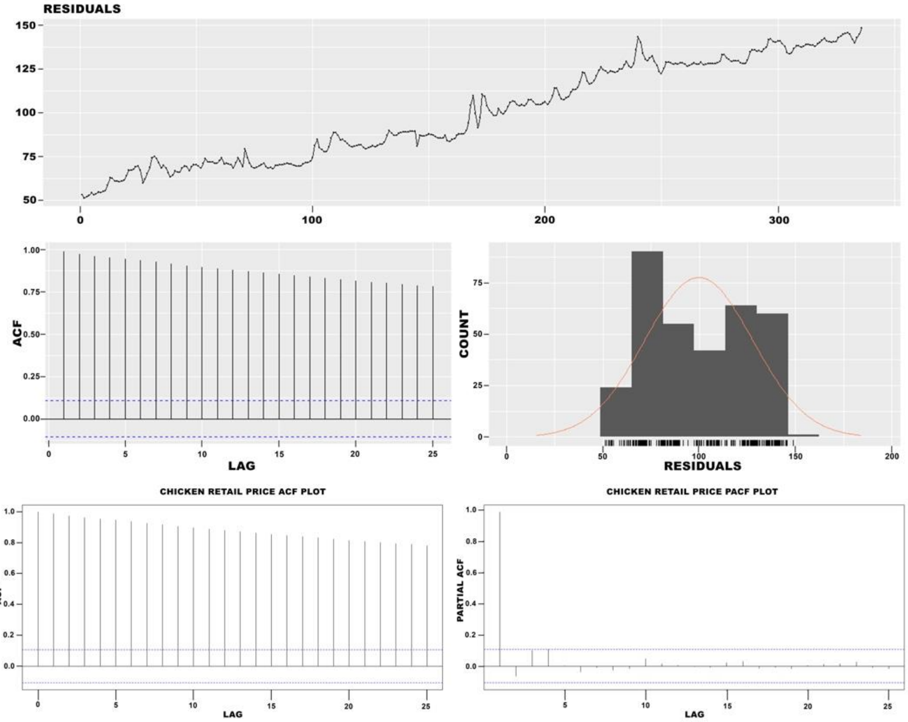
Annex 1. Volume of Chicken Meat Imports and Technical Smuggling from 1990-2016



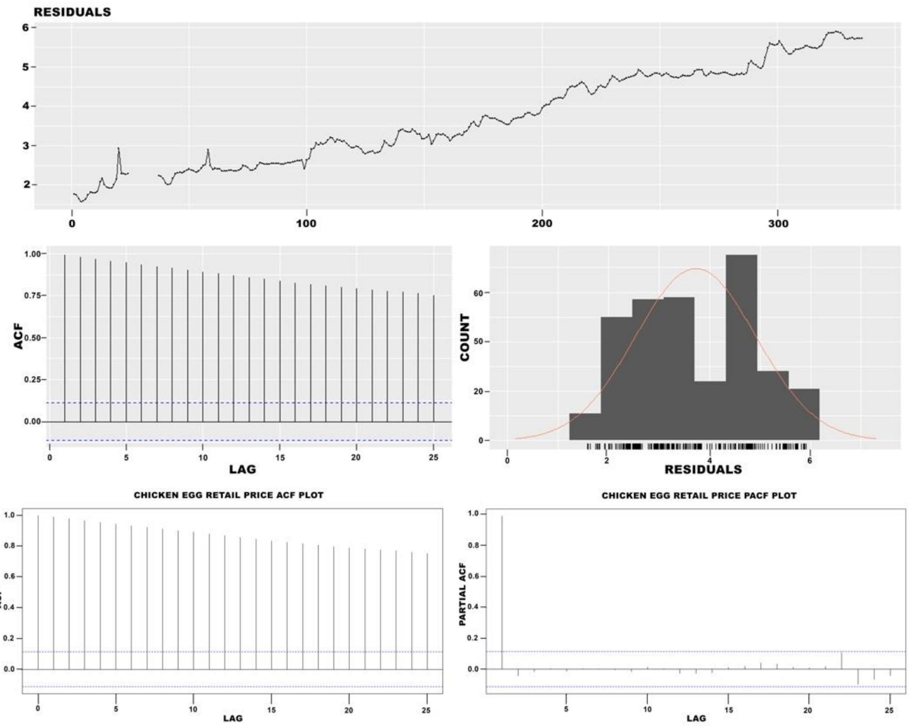
Annex 2. Volume of Pork Imports and Technical Smuggling from 1990-2016



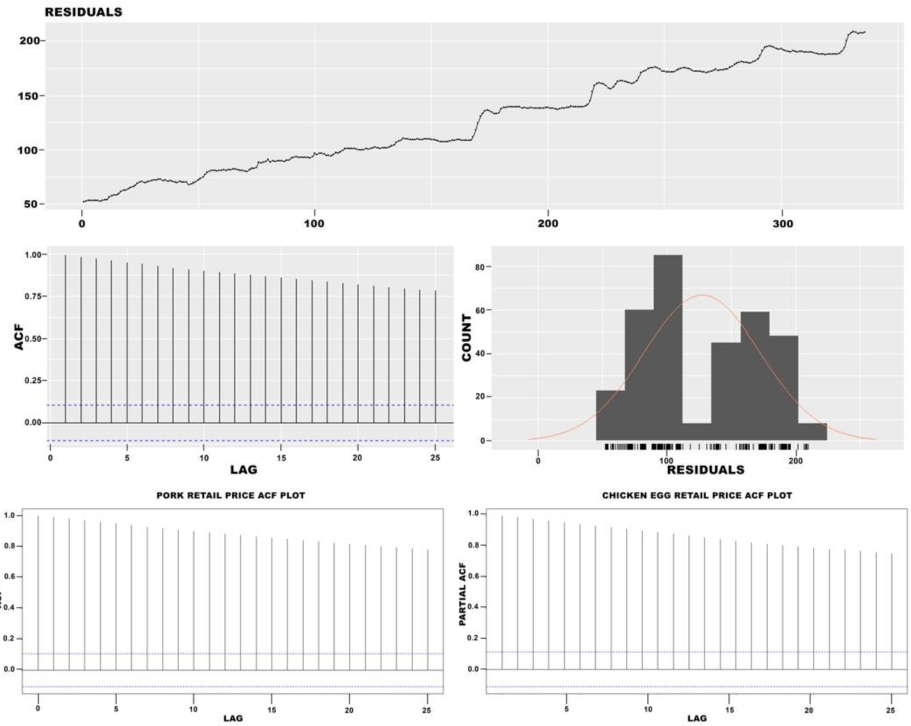
Annex 3. LR Test, Residual Plots, ACF and PACF Graphs for Chicken Meat



Annex 4. LR Test, Residual Plots, ACF and PACF Graphs for Chicken Egg

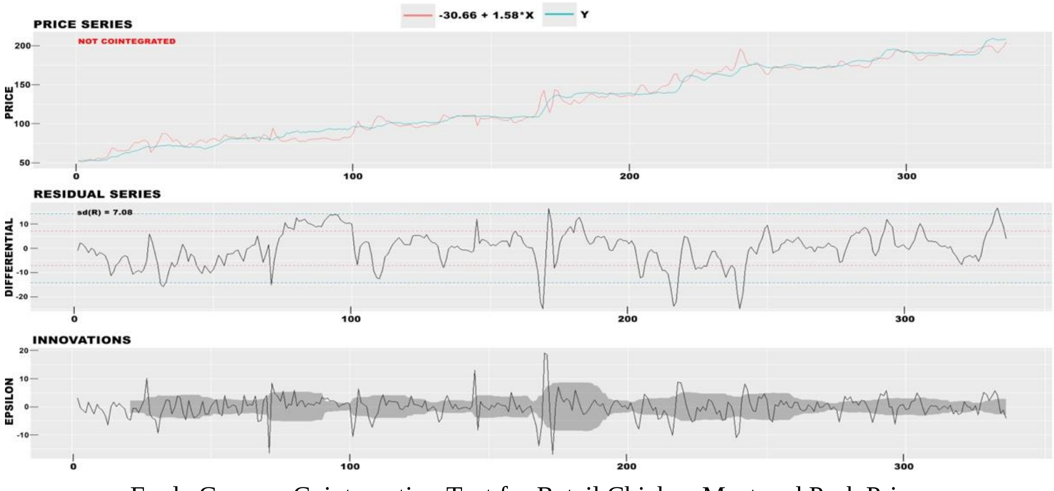


Annex 5. LR Test, Residual Plots, ACF and PACF Graphs for Pork

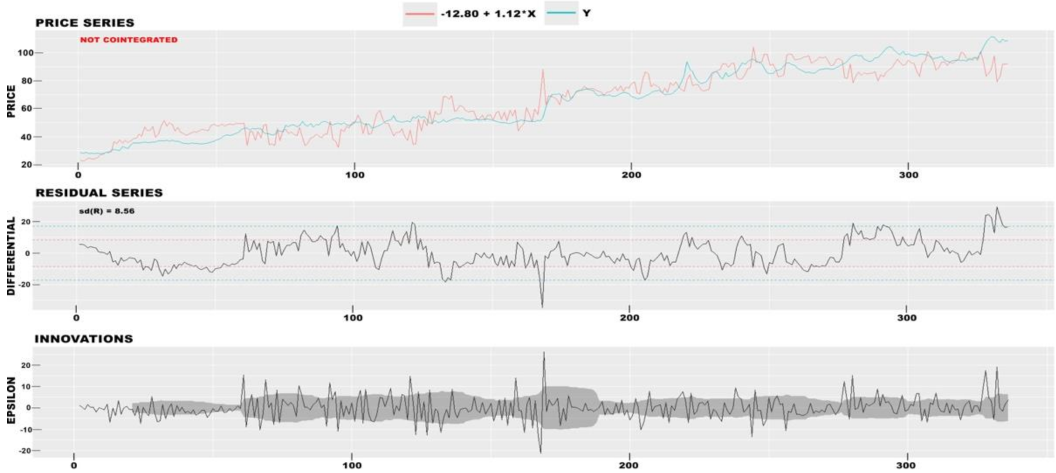


Annex 6. Testing for Cointegration between Chicken Meat and Pork Retail and Farmgate Prices

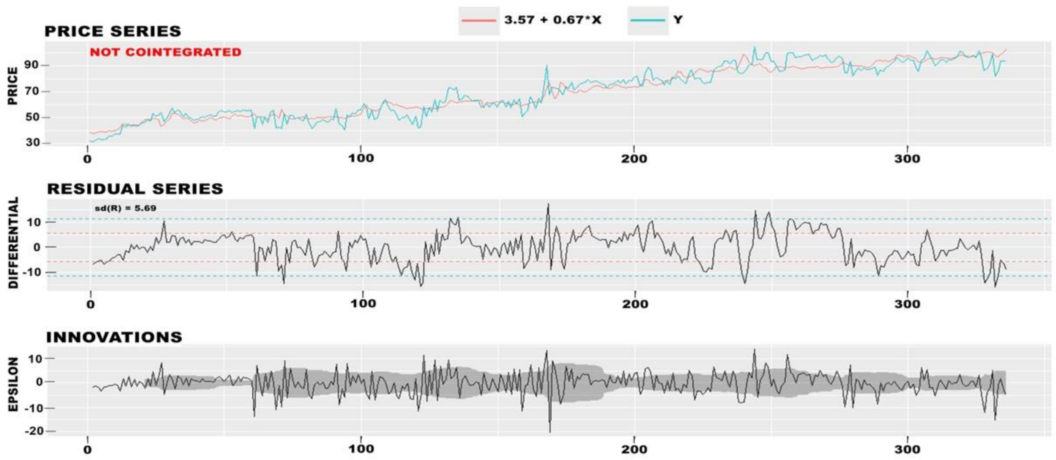
Engle Granger Cointegration test was used to determine whether two series are cointegrated with each other. The following graphs show that retail chicken meat and pork, wholesale chicken meat and pork, retail and wholesale chicken meat, as well as retail and wholesale pork, are not cointegrated. As expected, this could indicate that both products belong to different product markets altogether.



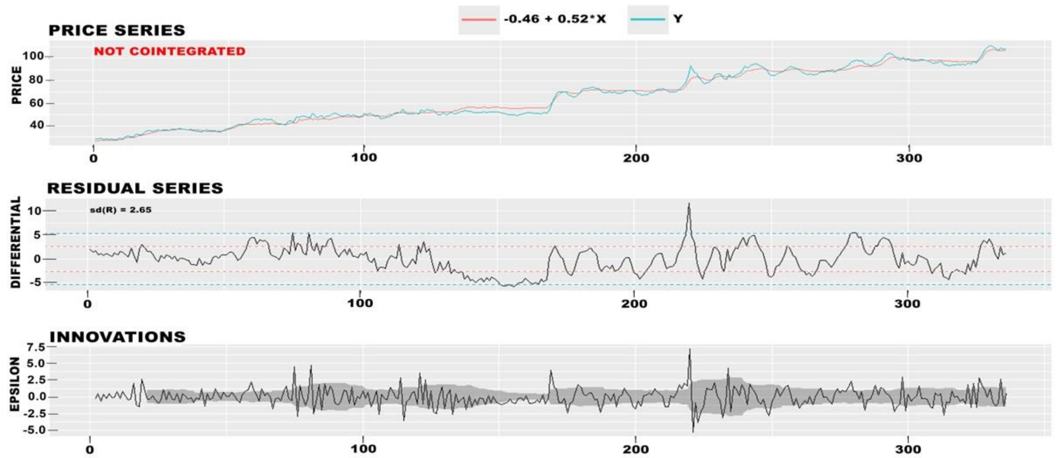
Engle Granger Cointegration Test for Retail Chicken Meat and Pork Prices



Engle Granger Cointegration Test for Wholesale Chicken Meat and Pork Prices



Engle Granger Cointegration Test for Retail and Wholesale Chicken Meat Prices



Engle Granger Cointegration Test for Retail and Wholesale Pork Prices

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APPLICATION OF ANALYTICAL HIERARCHY PROCESS (AHP) IN GENERATING LAND SUITABILITY INDEX (LSI) FOR SUGARCANE IN CENTRAL MINDANAO, PHILIPPINES

Jim Loui P. Alburo[1*], Jose Nestor M. Garcia[2], Pearl B. Sanchez[2] and Pompe C. Sta. Cruz[2]
[1]GeoMin Office, College of Forestry and Environmental Science,
Central Mindanao University, Musuan, Maramag, Bukidnon 8714
[2]College of Agriculture and Food Science, University of the Philippines-Los Baños,
College, Laguna, Philippines 4031
Corresponding author: jpalburo@up.edu.ph

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ABSTRACT

Sugarcane is one of the most promising industry in the Philippines and planted in any land in the country, particularly in Central Mindanao without prior assessment of the land to the crop. Application of an enormous amount of inputs to ensure better production is among common practice even in unsuitable areas. Generation of Land Suitability Index (LSI) in Central Mindanao as a major sugar cane district of Bukidnon province was made to identify the major factor that affects to sugarcane production, using Analytical Hierarchy Process (AHP) and GIS. The study was conducted last September 2015 to February 2016 on the 3rd district of Bukidnon. Weights of six performance factors in determining LSI to sugarcane production were established using AHP. Soil depth was the most important among the factors. Utilizing the LSI, land sugarcane suitability maps were generated for the Central Mindanao. The results matched the validation by comparing the results with the actual yields from sugarcane growers, correlation analysis and other relevant data from the Regional Sugar Regulatory Authority. Soil water holding capacity has a significant positive effect on the sugarcane yield while elevation and slope have significant negative effects. Don Carlos, Maramag and Quezon that are extensive sugarcane growing municipalities are highly suitable in the study and actual conditions.

Key words: land evaluation, GIS, Bukidnon, *Saccharum officinarum*, land assessment,

INTRODUCTION

Sugarcane, *Saccharum officinarum L.*, is a strongly growing grass and one of the most promising industry in the Philippines that generates 765 billion annually for the government in the form of tax (National Wages and Productivity Commission, 2014) and helping to not less than 62,000 farmers on their livelihood. The sugarcane production in all uses increased by 14.4 percent last quarter of year 2015 from its production level of 6.29 million metric tons during the same period last year to its current level of 7.19 million metric tons (PSA, 2017b). Sugarcane covers around 422,384 ha of the country's land area (SRA 2014) and about 17% is in Bukidnon (70, 863 ha) that mostly planted in Central part of the province and as one of the fast-growing area in Mindanao of the crop. In Bukidnon province, almost 200,000 ha of its land area is utilized for agricultural crops and 31 % is planted with sugarcane (PSA, 2017a). Central Mindanao has favorable environmental condition for growth in terms of temperature, radiation and precipitation or rainfed condition that match the sugarcane physiological requirements. It is classified as Type IV climate, characterized as no dry season (PAG-ASA/DOST, 2015). This high dependence on rainfed production highlights the importance of the weather on sugarcane production. Land productivity in areas suitable for rainfed sugarcane production is typically much higher than for cultivated land in cooler climates or arid sub-tropical and tropical agriculture (Fischer et al. 2007).

Principal climatic components that control sugar cane growth, yield and quality are temperature, light and moisture availability (Tu Khao, 2007). The study of Deressa et al., (2005) reveals that ripening stage requires low temperature levels to allow for sucrose accumulation. Sugar recovery is highest when the weather is dry with low humidity; bright sun shine hours, cooler nights with wide diurnal variations and very little rainfall during ripening period (Tu Khao, 2007). However, there is a diversity of cultural management practices without proper assessment of the land. Most of the sugarcane planters established and even expanded their farms regardless of the characteristics of the soil and land. Hence, some of the areas may not be suitable and farmers are compelled in applying high inputs to ensure good production. This will have implications on the competitiveness of the country's sugar. Moreover, farmers do not have desirable land indicators in sugarcane productions.

Generation of Land Suitability Index (LSI) of sugarcane locally and crop diversification is a way to address this problem. However, crop diversification is not usually practiced by the sugarcane farmers because they still consider sugarcane as the most profitable crop. Thus, local LSI is necessary to guide the most influential factors to obtain the optimum productivity. Considering the potential and suitability of these areas are necessary to avoid problems such as land misuse, environmental problems and increase indebtedness (Paiboonsak and Mongkolsawat, 2007). According to Perveen and Nagasawa (2006), land suitability evaluation provides general alternatives for local farmers in the area of agricultural land management of a particular crop. In most of the land suitability studies, the different factors are weighted of equal importance, but, some factors may be more important than the others. It is imperative that farmers could identify vital factors that affect the sugarcane production of their farms. This study attempts to determine the relative importance of the different factors of land suitability to sugarcane using the Analytical Hierarchy Process (AHP) and determine the influence of different factors to the yield of sugarcane growing areas.

MATERIALS AND METHODS

Study Area. The study was conducted in the 3rd District of Bukidnon Province, Philippines the most extensive sugarcane growing district of the province, covering an area of approximately 204,000 ha. The third district has a topography of flat, rolling and steep areas. It covers 8 municipalities: Damulog, Dangcagan, Don Carlos, Kadingilan, Kibawe, Kitaotao, Maramag and Quezon (Fig.1A) of which, 54 sampling locations (Fig.1B) were determined based on the soil series across the study site. The eastern part of the district is mostly very steep areas, particularly portions of the municipalities of Quezon and Kitaotao. The highest elevation is 1,660 m above sea level (masl) and the lowest point is 38 masl. The District has Type IV climate, characterized as having no dry season (PAG-ASA/DOST, 2015). The annual average monthly rainfall distribution from 2006-2011 was 241.68 mm. The rainy season lasts from March to October with rainfall generally more than 200 mm. The dry season has a mean monthly rainfall of generally 7.1 to 150.0 mm (www.buk.gov.ph, 2016).

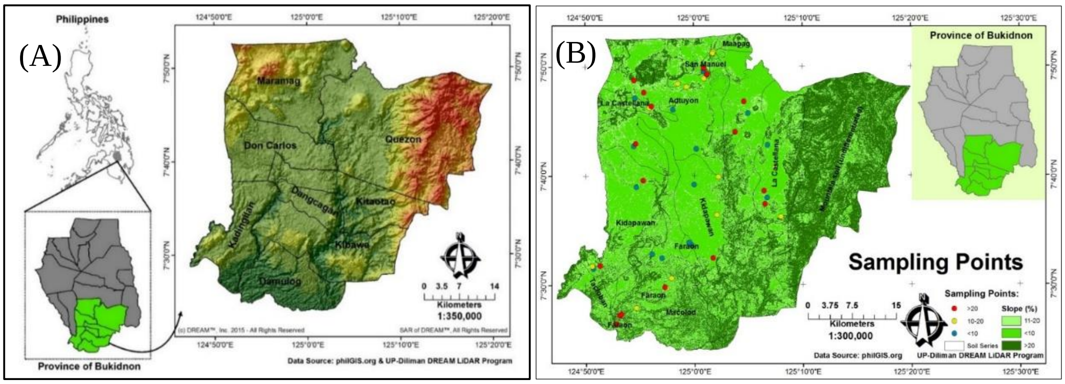

Fig. 1. (A) Administrative map and (B) sampling location of the study.

Implementation of analytical hierarchy process (AHP) in land suitability assessment. The AHP method enables users to determine the weights of the parameters in the solution of a multi-criteria problem (Akinci et al., 2013) and used as to determine consistent sets of estimates of relative weights and criteria from an expert (Saaty, 1980). AHP allows the participation of different groups or persons (considered as experts) but available literature does not recommend a specific number of respondents for AHP applications (Chavez et al, 2012). The foremost reason for using AHP was the collection of ideas from different stakeholders of sugarcane production in identifying the weights of different factors of production. Two groups of sugarcane suitability evaluators were organized, consisting of five experts from the sugarcane industry and academe and ten experienced sugarcane farmers. Each expert makes a judgement of relative weights (w_i) of all pairs of the n factors and these judgements are included in as a number (a_{ij}) in a square matrix A (*i.e.* the comparison matrix):

$$A = (a_{ij}),\ (i,j = 1,2,\ \ldots \qquad \text{(eq. 1)}$$

To ensure that the evaluators fully understand the factors considered, each factor was discussed with the participants prior to the assessment. As structured in Fig 2, the goal of the study was to generate Land Suitability of Sugarcane in six criteria. The criteria were the performance factors of sugarcane production with sub-criteria in each performance factor and the alternatives were the summation of criteria based on the value obtained from the sub-criteria. There were six criteria: soil depth (m), water holding capacity (WHC) (%), slope orientation, soil texture, slope (%) and elevation (m). These criteria were the factors that affect the main goal of the study and used as weights of different factors for sugarcane production.

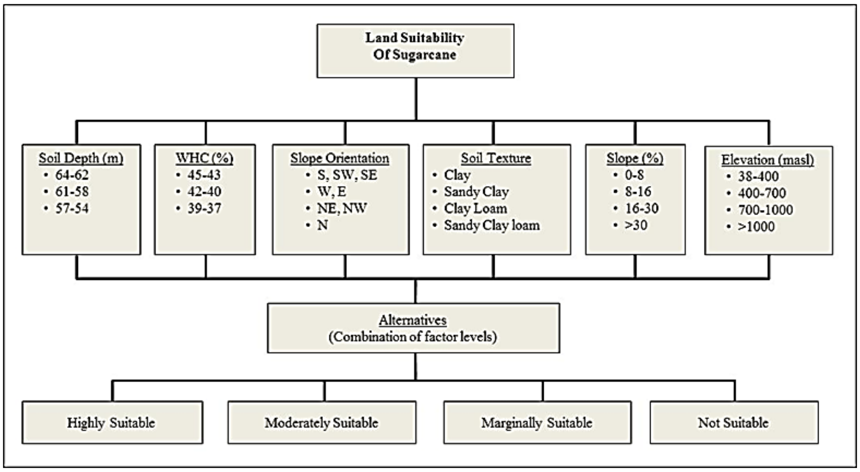

Fig. 2. Structure of elements, criteria, sub-criteria and alternatives in the application of AHP in determining land suitability to sugarcane.

Pairwise comparison of elements in each group was made, weighting and consistency ratios were calculated. To perform the pairwise comparisons, a scale of numbers was needed. Evaluators were asked to rate the different criteria affecting suitable land for sugarcane production. This scale indicates the dominance of one element among element with respect to the criteria on which they are compared (Saaty, 2008). The Saaty's scale, which was a scale from 1 (equally important) to 9 (extremely more important) was used for comparisons (Saaty, 2008). First level comparison has an associated eigenvector with the maximum eigenvalue. The normalized eigenvector gives the priority ordering and the maximum eigenvalue was a measure of the consistency of the judgment. The eigenvector was calculated using the following condition:

$$AW = \lambda_{\max} w \qquad (2)$$

where A was the comparison matrix, W was the eigenvector and λ_{max} was the maximum eigenvalue, which was used to estimate the consistency of the result. A positive reciprocal matrix like matrix A was fully consistent when λ_{max} was equal to n (Saaty, 1980). The closer λ_{max} was to n, the more consistent was the judgement. The deviation from consistency was called the consistency index (CI) and is represented by:

$$CI = \frac{\lambda \max - n}{n-1} \tag{3}$$

The estimated consistency was compared with the consistency value from a randomly generated reciprocal matrix, which was called the random index (RI). The Consistency Ratio (CR) relates the CI to the average RI for the same order matrix (fixed value):

$$CR = CI / RI \tag{4}$$

Alternatives were evaluated according to the weighting and ranking of the factors was made. After the analysis, the consolidated weight values were used for weighing the factors for sugarcane suitability. Consistency of giving weight values was guided by Consistency Ratio (CR), which measures the consistency of the judgements made. If the $CR \leq 0.10$ then the consistency was acceptable (Saaty, 1980). When a $CR > 0.10$ was detected, the respondent was asked to reconsider changing her/his more problematic judgments. The evaluators' responses were entered and calculated into an existing excel program developed by Goepel (2013). The results of the evaluation were grouped into three to determine which rating group was better. The three rating groups were: (1) the Experts, coming from the academic and research institutions involved in sugarcane; (2) the Farmers, who were experienced sugarcane farmers; and (3) the Combined Groups, which was the combination of the Experts and Farmer groups. The study opted to modify the inputs of decision maker, although the study of Franek & Kresta (2014) suggested that the inconsistency of the matrix inputs can be amended by checking relationships among the criteria and to find out the pairwise comparison that was not consistent with others in terms of chain of preferences. Revisions of several inputs was not practicable (Goepel, 2013). Moreover, according to the study of Goepel (2013), the distribution of CR values for all (80) participants in his projects, the median value is CR = 0.16, 80th percentile is at CR = 0.36. The ten-percent rule was obviously too strict for the practical applications and would have resulted in rejection and revision of most questionnaires.

Measurement of the Factors Affecting the Sugarcane Production

Soil depth determination. Determination of soil depth was done using post-hole soil auger (Fig. 3) for three weeks, the method was considered fast and easy. The soil depths were measured on identified sampling site. Sampling site was identified using slope map, sugarcane profile report of SRA and satellite image of google earth. The auger was marked every 15 cm from the end of the auger with a maximum of 100cm. For every 15 cm depth, soil samples were collected and driven further until the auger cannot penetrate anymore. The collected samples were laid continuously in a white broad sheet according to the depths that they were taken. For a more accurate measurement, a meter stick was used to measure the entire profile through the sampling hole. Soil samples were categorized in three (3) slope percentage (0- 10%, 11-20% and >20%) and replicated three (3) times. Though there were nine (9) soil series identified in the study site, only six (6) soil series planted with significant area of sugarcane. Fifty-four (54) soil samples were collected across the six (6) soil series. Among the soil series considered for sampling were Adtuyon, La Castellana, Macolod, Kidapawan, Faraon and San Manuel.

Water holding capacity and soil texture determination. Soil sampling was performed for the analysis of WHC and soil texture determination. Top soil samples were collected from the sampling sites, then air dried for one (1) week. Dried soil samples were pulverized using wooden mallet and sieved with 2mm sieve. Samples were then sent to Soil and Plant Analysis Laboratory (SPAL) in Central Mindanao University, Musuan, Bukidnon for the determination of soil texture and water holding capacity.

Fig. 3. Soil sampling for depth determination.

Geographic characterization. Geographic characteristics for optimum sugarcane production such as elevation, slope and slope orientation were extracted and determined using the Synthetic Aperture Radar-Digital Elevation Model (SAR-DEM) (UP-DREAM Project, 2015) with a pixel resolution of $10m^2$. Geographic characteristics were categorically classified based on sugarcane suitability level for certain geographic property.

Application of N, P_2O_5 and K_2O containing fertilizers. Essential nutrients such as N, P_2O_5 and K_2O containing fertilizers applied by farmers in synthetic form. Famers were interviewed regarding the amount of applied fertilizers, recorded and analyzed.

Land suitability evaluation. A database of the six factors in land suitability was created. These were: topography (slope), slope orientation, elevation, soil texture, water-holding capacity of soil and soil depth. The weights of each criteria were obtained using AHP and with the help of Multi Criteria Evaluation (MCE) procedure and with the weighted sum overlay within ArcGIS 10.2.2 to produce the land suitability map for sugarcane with spatial resolution of $10m^2$. The cultural practices of the farmers such as fertilizer application, weed management, land preparation and others were not considered since these factors largely vary between sugarcane farms and will make the suitability analysis complicated. Farmers' farm operations are not synchronized within the entire District. Since the area belongs to the same climate (Corona Classification), the study did not include the climate that could affect the sugarcane production. Each factor in the land suitability were standardized based on the results of AHP analysis and will form six thematic layers according to the groups of evaluators (Table 1). Each member of the group has weighted factors to the average of every criteria for land suitability. Hence, there were three groups that generates different map of land suitability.

Geographical characteristics categorically classified based on sugarcane suitability levels while mapping of the soil physical factors were interpolated based on the result of analysis. Interpolation is the process of obtaining a value for a variable of interest at a location where data has not been observed, using data from locations where data has been collected (Krivoruchko 2012). Interpolation of the data was made using Kriging model in ArcGIS 10.2.2. Kriging predictors have standard errors that quantify the uncertainty associated with the predicted values. Kriging uses a semi variogram – a function of the distance and direction separating two locations - to quantify the spatial dependence in the data (Krivoruchko 2012).

The author classified the factors for suitability of sugarcane production according to their characteristics as not easily alterable such as the identified six physical factors. The degree of suitability of each factor for each land unit studied was classified as Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3), and Not suitable (N) based on the classification of Sys et al (1993). Three suitability maps were generated based on different groups of suitability evaluators. The suitability maps were validated by comparing with the actual sugarcane yields, results of the correlation analysis and other relevant data. The suitability map that was consistent with the actual yields and correlation analysis was considered the most suitable.

Table 1. Classification of sub-factors based on their particular factors.

Factors	Sub-factors	Classification
Soil Depth, m	64-62	Highly Suitable
	61-58	Moderately Suitable
	57-54	Marginally Suitable
WHC	45-53	Highly Suitable
	42-40	Moderately Suitable
	39-37	Marginally Suitable
Slope Orientation	S, SW, E	Highly Suitable
	W, E	Moderately Suitable
	NE, NW	Marginally Suitable
	N	Not Suitable
Soil Texture	Clay	Highly Suitable
	Sandy Clay	Moderately Suitable
	Clay Loam	Marginally Suitable
	Sandy clay Loam	Not Suitable
Topography/slope, %	0-8	Highly Suitable
	8-16	Moderately Suitable
	16-30	Marginally Suitable
	>30	Not Suitable
Elevation	38-400	Highly Suitable
	400-700	Moderately Suitable
	700-1000	Marginally Suitable
	>1000	Not Suitable

Socio-economic survey of sugarcane farmers. A socioeconomic survey was conducted among sugarcane farmers to characterized and validate the degree of suitability of sugarcane growing areas by comparing with farmers' sugarcane yields. A stratified sampling of the farmers was made based on the extent of sugarcane growing area. From the eight (8) sugarcane growing municipalities of the third District, three (3) municipalities having extensive sugarcane area were selected, namely: Maramag, Don Carlos and Quezon. From the three municipalities, the barangays with large sugarcane areas were randomly selected from where the survey respondents were randomly selected. Sample size of the survey was determined using the Sloven's formula below. From the total population, 191 farmer respondents were selected, which is only 50% of the total sample size.

$$Sample\ Size = \frac{\frac{z^2 x\, p(1-p)}{e^2}}{1 + (\frac{z^2 x\, p(1-p)}{e^2 N})}$$

Where:
Z = sample size
p = the percentage picking a choice, expressed as decimal
c = confidence interval, expressed as decimal

The respondents were asked on their cultural practices and the yield performance of sugarcane. Farmer's farm geographic coordinates were also collected using the global positioning system (GPS) receiver device.

RESULTS AND DISCUSSIONS

Weighing of LSI performance factors using AHP. Among the 3 suitability evaluator groups, the Combined Groups has the least inconsistent value (1.6%) followed by the Farmers (2.5%) and the Experts (5.2%). Generally, the CR value decreases as the number of participant increases. Nevertheless, the CR values of three groups were still within the Saaty's rule of thumb on acceptable consistency ratio of <0.10 (Goepel, 2013). The ranking of the importance of the factors varied with the evaluator groups. However, soil depth (Rank 1) was consistently considered as the most important factor by all suitability evaluator groups. This may be related to sugarcane root penetration and ease in land preparation with the use of farm machineries in which approximately 75% of farmers used machineries. Generally, soil depth is one of the factors that most affected in heavy practice of machineries in sugarcane production (Foth, 1951) and reduced the soil permeability (Soane and Van Ouwerkerk, 2013). Meanwhile, the least important factor varied between the Expert and the Farmer but if Combined Groups to be considered, the least important factor was elevation. The least important factor in determining suitability of sugarcane production for Experts was elevation and slope orientation for farmers. According to farmers, using compass during planting was never their considerations. Nevertheless, the study of Bennie et al. (2008) showed the influence of slope orientation to the amount of solar radiation intercepted by the surface and vegetated surface while the study of Akinci et al. (2013) showed the importance of elevation as factor that influences due to the differences in temperature. The sun's energy is more concentrated on the Northern Hemisphere where its rays hit the Earth more directly and are thus more intense (Mclamb, 2011). Table 2 shows the percentage and ranking of factors of three groups.

Table 2. Percentage rank of LSI factors under different set of groups who evaluated the suitability to planting of sugarcane.

LSI FACTORS	Experts		Farmers		Combined Groups	
	%	**Rank**	**%**	**Rank**	**%**	**Rank**
Soil Depth	28.6	1	25.6	1	26.7	1
Water Holding Capacity	20.7	2	17.9	3	19.4	2
Slope Orientation	16.4	3	9.4	6	11.7	5
Soil Texture	16.0	4	12.6	5	14.1	4
Slope	10.2	5	20.6	2	16.5	3
Elevation	8.1	6	13.9	4	11.6	6

The system was based primarily on an integration of land qualities as related to crop requirements. The method was usually implemented using the pairwise comparison technique that simplifies preference ratings among decision criteria (Tienwong et al. 2009). After the land suitability map was generated, the best suited key factor for the suitability was used and become the basis for further discussions. Farmer's suitability assessment was the best among the three evaluators as this group were able to identify clearly the land classification of the studied areas.

Land suitability to sugarcane. Using the LSI evaluation results, three sugarcane suitability maps were generated from the Experts, Farmers and Combined Groups (Fig. 4) that generates three classification on the suitability. Relatively, result shown that none of the area in the district was not suitable for sugarcane production. The Experts' suitability map has the largest highly suitable areas with the least marginally suitable areas and the second highest moderately suitable areas. The farmers' suitability map has the second highest highly suitable areas with the least moderately suitable areas. The Combined Groups suitability map has the highest moderately suitable areas. In all the suitability maps generated, most of the highly suitable areas were in the western portion of the district covering almost all of Don Carlos, Dangcagan, northern portions of Kibawe and Kadingilan, southern portion of Maramag, and western portion of Kitaotao. Other highly suitable areas were dispersed in Quezon, Kitaotao, and Damulog. Most of the marginally suitable areas were in the eastern part of the district covering certain portions of Quezon and Kitaotao, of which were the areas with very steep slopes and are obviously not suitable for sugarcane production. Other marginally suitable areas can also be seen in Maramag, Kadingilan and Damulog.

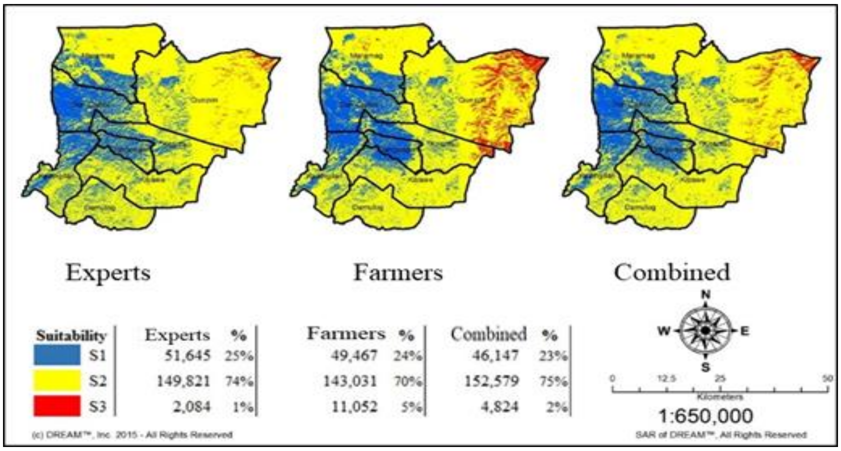

Fig. 4. Land suitability to sugarcane maps generated from AHP for the 3 different evaluator groups.

Quantitatively, the map generated from the Experts has the largest area (25%) identified as highly suitable followed by the Farmers and the Combined Groups with 24% and 23%, respectively. In contrast, the Combined Groups has the largest area (75%) identified under moderately suitable areas over the Experts and Farmers with 75% and 70%, respectively. On the other hand, the map for the Farmers has the largest (5%) area of marginally suitable for sugarcane production while the map with the least (1%) identified marginally suitable areas was from the Experts.

Validation of the land suitability assessments. The three suitability assessments were validated by comparing the results with the actual sugarcane yields obtained from the socio-economic survey and the correlation analysis. Sugarcane yields obtained from farm samples were grouped according to their suitability classes for the 3 suitability evaluator groups. Comparison of yield levels between suitability classes showed consistent yield trends corresponding to the suitability classes for all evaluator groups (Table 3). Highest yields came from the highly suitable areas, followed by moderately suitable and marginally suitable having the lowest yield. Meanwhile, classification for not suitable area (N) was not included in this analysis as there is no areas covered that falls under N classification. Further, this indicates the applicability of AHP in sugarcane suitability assessment. The results of the correlation analysis shown that most of the important factors identified from AHP application, *i.e.* elevation, slope, and water holding capacity have significant influence on sugarcane yield. While soil depth, which was identified as an important factor in the AHP application, has no significant influence on yield in the correlation analysis (Table 4). Although the 3 evaluators have identified soil depth as a very important factor since sugarcane is deep rooted crop and necessary for its cultivation using heavy machinery, soil depth data obtained from the sample farms have similar values, hence, may not be considered a variable in the locality and need not be included in the evaluation.

Table 3. Mean sugarcane yields (t/ha^{-1}) under different sugarcane suitability classes for the different evaluator groups. 3rd District, Bukidnon.

Evaluator Groups	Suitability Classes		
	Highly	**Moderately**	**Marginal**
Experts	59.60	54.02	-
Farmers	59.48	54.30	50.87
Combined Groups	59.10	54.57	-

Table 4. Descriptive statistics of significant factors affecting yield of sugarcane.

Variable	Correlation Coefficient	Mean^n	SD
N kg ha^{-1}	0.39*	137.96	54.00
P_2O_5 kg ha^{-1}	0.29*	38.69	31.57
K_2O kg ha^{-1}	0.39*	26.74	32.30
Elevation	-0.14*	398.12	128.77
Slope	-0.15*	8.87	7.78
WHC	0.17*	41.74	1.63
Slope Orientation	-0.01^{ns}	175.90	96.81
Soil Depth	-0.13^{ns}	59.65	1.56
Soil Texture	-0.11^{ns}	1.27	0.84

n = 191, * = significant, ns = not significant

Improving sugarcane production under high suitable areas. Some highly suitable areas identified in the suitability assessment have lower yields compared with those in the moderately suitable areas. This could be attributed to the exclusion of other factors, which are important in sugarcane production. One of these was fertilizer application. Survey results showed high variability in fertilizer application among the farmer respondents. None of them followed the recommended fertilizer rate with many applying more N than the recommended rate and less P and K levels. Following the recommended rate might be essential in achieving optimum yield. Fertilizer application, which was not included in the AHP application was significantly correlated with sugarcane yield particularly N and K application, having correlation coefficient values of 0.39 and 0.39, respectively. Farmers' average fertilizer application of 138-39-27 kg NPK ha^{-1} was low compared to the recommended rate of 128-92-120 kg NPK ha^{-1} specially for P and K. Literature would show that among the macro elements, N and K is the most needed by sugarcane followed by P (Tu Khao 2007).

Elevation, which was one of the important factors identified in AHP varies with the different areas. Some areas in the central and eastern portion of Quezon have high elevation with lower temperature that is unfavorable elevation for sugarcane. This could be attributed to the fact that at higher altitudes, temperature is cooler and makes sugarcane production period longer before maturity (Deressa *et al*, 2005). Sugarcane grows well where the temperature ranges between 20 and 35 °C. The use of varieties adaptable to high elevation would be essential in improving the yield in these areas. WHC significantly influence the yield of sugarcane but the sugarcane areas in the municipalities of Kadingilan, Kitaotao, Kibawe and Damulog have relatively low WHC than the other municipalities. Zero tillage or minimum tillage of 2:1 or 3:1 row-furrow ratio and retaining trash on the field could help increase WHC in the areas. The steep slope areas in the municipalities of Maramag, Quezon, Kadingilan and Kitaotao, could be susceptible to soil erosion. The practice of zero tillage or contour farming on the sloping areas could help in minimizing soil erosion and improve sugarcane yield.

Applicability of AHP on land suitability. The land suitability maps generated from the 3 evaluator groups showed relatively similar maps on the degree of highly and moderately suitable areas. However, the better suitability assessment was from the farmers' assessment since it clearly identifies obviously the marginally suitable areas. Comparing the generated suitability map with the SRA report, it was found out that the marginally suitable areas are considered not suitable areas and are not planted with sugarcane. While, some areas classified either as moderately or highly suitable areas were not planted with sugarcane as reported by SRA. Thus, this could be attributed to other reasons, one of which is the accessibility. Further, none of the area being studied was classified as not suitable for sugarcane production regardless of other factors. AHP was shown to be applicable in land suitability assessment especially in hilly regions (Pramanik 2016). The suitability map generated from AHP would show the areas' potential performance of sugarcane and can be applied in land use planning (Memarbashi et al 2017) but should be accompanied with good management practices like fertilizer application.

CONCLUSION

The results of the study shown the applicability of AHP in generating LSI to sugarcane production and effectively use for land suitability but with some limitations such as their cultural practices. As indicated in the validation of the results, suitability classes were consistent with the actual yield levels, *i.e.* highly suitable areas have higher actual yields and marginally suitable areas have the lowest actual yields. However, among the LSI performance parameters included, water holding capacity was consistently ranked high in AHP and correlation analysis. Soil depth was ranked high in AHP but not significantly correlated to sugarcane yield. Slope and elevation were correlated with sugarcane yield but was ranked second and fourth in AHP, respectively.

ACKNOWLEDGEMENTS

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Report from ISSAAS Secretariat

ISSAAS Board of Directors Meeting 2018

Date: 11 October 2018, 19:00-20:30
Venue: Lady Suite, 3rd Floor, Riverside Majestic Hotel Kuching

AGENDA
(Presided by ISSAAS Secretary General Hironobu Shiwachi)

1. Greetings by ISSAAS President Dr. Abdul Shukor Juraimi

2. Activities Report 2018 (October 2017-September 2018): Approved

(a) International Congress 2017
Dates: 14-16 October 2017
Venue: Vietnam National University of Agriculture, Hanoi, Vietnam
Theme: *Green Agriculture in Southeast Asia: Theories and Practices*
(b) Board of Directors Meeting
Date: 13 October 2017, 18:30-20:00
Venue: Meeting Room, Army Guest House

Decisions made:
(1) Ms. Carla Calumpang will serve as the additional ISSAAS technical editor. Related additional costs for her service have been approved.
(2) Technical editorial fee will be increased from 75,000 yen to 100,000 yen per issue.
(3) Membership fee is valid for 1-year from January to December. Only those with active membership may present in the ISSAAS congress and publish in Journal of ISSAAS.
(4) There is a need to update ISSAAS website, including offering e-journals. But there is a need for further discussion regarding the costs to be incurred.
(5) Journal of ISSAAS
a. There is a need to consider increasing page charge (Suggestion: USD15).
b. There is a need to add DOI to all papers.
c. There is a need to increase the impact factor.

3. Board of Directors Meeting
Agenda: Possible Transfer of ISSAAS Office to SAEDA
Date: 1 May 2018
Venue: Email Conference
Decisions made: ISSAAS HQ can start discussions with SAEDA regarding the possible transfer of office. Details and terms of transfer are still for discussion.

4. Board of Directors Meeting
Agenda: Call for Nominations for ISSAAS Officers to be invited by SAEDA
Date: 5 July 2018
Venue: Email Conference

Decisions made: Invited officers were as follows:

Indonesia Chapter: Dr. Yusman Syaukat and Dr. Dadang
Malaysia Chapter: Dr. Abdul Shukor Juraimi and Dr. Mohd Desa Hassim
Philippine Chapter: Dr. Fernando C. Sanchez, Jr. and Dr. Simplicio Medina
Thailand: Dr. Sukanya Rattanatabtimtong and Asst. Prof. Cherdpong Kheerajitt
Technical Editor: Dr. Susan May F. Calumpang

5. Board of Directors Meeting
Agenda: Granting of ISSAAS MATSUDA AWARD
Date: 7 September 2018
Venue: Email Conference

Decision made: In accordance with the recommendation from the Award Screening Committee, the Members of the Executive Board have approved the granting of the following:

8th ISSAAS MATSUDA AWARD to Datin Paduka Dato Dr Aini Ideris for her distinguished contribution to the advancement of science, research, and trainings on agricultural development in Southeast Asian region, specifically on her pioneering avian research in Malaysia.

The awards will be given during the ISSAAS General Meeting to be held at Riverside Majestic Kuching, Sawarak, Malaysia on 12 October 2018.

(e) Publications of Journal
Vol.23, No.2: Published in December 2017
Vol.24, No.1: Published in June 2018

(f) Others
Co-sponsored the 17th International Students Summit in 25-26 September 2017

3. Financial Report 2018: Approved

4. Auditors' Report for 2018: Approved

5. Business Plan for 2019 (October 2018-September 2019)
(a) International Congress 2018
Dates: 12-14 October 2018
Venue: Majestic Riverside Kuching, Sarawak, Malaysia
Theme : Industry 4.0: Agriculture Technologies Advancement
(b) Board of Directors Meeting
Date: 11 October 2018, 19:00-20:30
Venue: Lady Suite, 3rd Floor, Riverside Majestic Hotel Kuching
(c) Publications of Journal
Vol.24, No.2: To be published in December 2018
Vol.25, No.1: To be published in June 2019
(d) Others
Co-sponsored the 18th International Students Summit,
Tokyo University of Agriculture, 27-28 September 2018

6. Budget 2019: Approved

7. ISSAAS AWARDS
ISSAAS MATSUDA AWARD: Datin Paduka Dato Dr Aini Ideris (Malaysia)

8. Letter of Appreciation
Dr. Tran Duc Vien: ISSAAS President 2016-2017

9. Donations from TUA and SAEDA
(a) Tokyo University of Agriculture: 300,000 Japanese Yen
(b) Society for Agricultural Education-Research
Development Abroad (SAEDA): 200,000 Japanese yen

10. Activities Report for 2018 by Each Chapter

Indonesia	Vice President Yusman Syaukat
Japan	Acting Regional Secretary Dr. Shuhei Saito
Malaysia	Vice President Abdul Shukor Juraimi
Philippines	Vice President Fernando C. Sanchez, Jr.
Thailand	Dr. Sukanya Rattanatabtimtong (Representative of Vice-President)
Vietnam	Regional Secretary Nguyen Thi Bich Thuy

10. Plan for 2019 International Congress
Theme：*Reshaping Agriculture for Sustainable Development*
Dates: 18-20 October 2019
Venue: Universiti Putra Malaysia, Selangor, Malaysia

Schedule: October 17 (Thurs): Arrival of Participants (Board Meeting in the Evening)
October 18 (Fri): Opening Ceremony, General Meeting and Symposium
October 19 (Sat): Individual Presentations, Closing Ceremony
October 20 (Sun): Congress Tour
October 21 (Mon): Departure of Participants

11. Other Matters
   a. Submission of papers to Journal of ISSAAS has doubled. Good support from reviewers has been received.
   b. Increase page charge from USD10 to USD15 per B/W page is approved and will be implemented from Journal of ISSAAS 26(1) Issue (December 2020).
   c. Increase number of issues per year will be considered.
   d. Except for the Philippine Chapter, all other chapters showed positive response to possible shift from printed journal to online access only. In order to address concerns of all chapters, further discussions have to be made on this matter.
   e. Adding DOI for all papers will be done. However, transition phase is important.

<u>ISSAAS General Meeting 2018</u>

Date: 12 October 2018, 8:30-12:00
Venue: Lady Suite, 3rd Floor, Riverside Majestic Hotel Kuching

AGENDA

1. Greetings from ISSAAS President
   Dr. Abudul Shukor Juraimi
2. Activities Report 2018 (Oct 2017-Sep 2018)
   Presented by Dr. Hironobu Shiwachi, and Approved
3. Financial Report 2018
   Presented by Dr. Hironobu Shiwachi, and Approved
4. Auditors' Report for 2018
   Presented by Dr. Hironobu Shiwachi, and Approved
5. Business Plan for 2019 (Oct 2018-Sep 2019)
   Presented by Dr. Hironobu Shiwachi, and Approved
6. Budget 2019
   Presented by Dr. Hironobu Shiwachi, and Approved

7. ISSAAS AWARDS
   ISSAAS MATSUDA AWARD: Datin Paduka Dato Dr Aini Ideris (Malaysia)

8. Donations from TUA and SAEDA
   (1) Tokyo University of Agriculture: 300,000 Japanese Yen
   (2) Society for Agricultural Education-Research Development Abroad (SAEDA): 200,000 Japanese yen

9. Activities Report for 2018 by Each Chapter

Indonesia	Vice President Yusman Syaukat
Japan	Acting Regional Secretary Dr. Shuhei Saito
Malaysia	Vice President Abdul Shukor Juraimi
Philippines	Vice President Fernando C. Sanchez, Jr.
Thailand	Dr. Sukanya Rattanatabtimtong (Representative of Vice-President)
Vietnam	Regional Secretary Nguyen Thi Bich Thuy

11. Plan for 2019 International Congress
    Theme：*Reshaping Agriculture for Sustainable Development*
    Dates: 18-20 October 2019
    Venue: Universiti Putra Malaysia, Selangor, Malaysia

    Schedule: October 17 (Thurs): Arrival of Participants (Board Meeting in the Evening)
    October 18 (Fri): Opening Ceremony, General Meeting, Symposium and Individual Presentations,
    October 19 (Sat): Individual Presentations, Closing Ceremony
    October 20 (Sun): Congress Tour
    October 21 (Mon): Departure of Participants

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