Research article

Effect of Seasons on the Quality of Fresh Semen in Thai Native Chickens: Deang Dok Koon and Pradu Hang Dam

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Abstract This study investigated the impact of seasonal variations on the quality of fresh semen in two Thai Native chicken breeds: Deang Dok Koon (DDK) and Pradu Hang Dam (PD). A 3 × 2 factorial experiment was conducted using a completely randomized design (CRD). The factors considered were season (summer, rainy, and winter) and breed (DDK and PD) of the cows. Twelve roosters per breed (aged 1 year) and 40 commercial laying hens were housed in open-air conditions. Semen was collected twice a week for 24 weeks (48 total collections). Semen volume, mass movement, sperm progressive motility, sperm concentration, total sperm count, sperm viability, sperm morphology, and fertility were evaluated. No significant interaction was found between season and breed. While the season did not affect mass movement, sperm progressive motility, and total sperm count, it significantly influenced semen volume, sperm concentration, sperm viability, sperm morphology, and fertility. Winter had the highest sperm concentration (4.51×10^9 sperm/mL), followed by summer (4.16×10^9 sperm/mL) and the rainy season (3.82×10^9 sperm/mL). Summer had the lowest sperm viability (93.45%), whereas rainy (95.49%) and winter (95.22%) seasons were similar. Sperm morphology was higher in summer (6.79%) than in the rainy season (5.66%) and winter (5.18%); however, the rainy season and winter were not significantly different. Fertility rates were highest in winter (86.81%) and the rainy season (85.88%), with summer (77.99%) being the lowest. Breed significantly affected mass movement, sperm progressive motility, sperm concentration, and sperm viability, but not fertility. The PD breed showed superior semen quality compared to DDK. Overall, seasonal variations significantly impacted fresh semen quality, with winter providing optimal conditions compared to summer and rainy seasons.

Keywords semen quality, sperm motility, fertility, seasonal variation, Thai native chicken

INTRODUCTION

The Deang Dok Koon (DDK) chicken, a novel synthetic breed developed in Thailand, presents a viable pathway for enhancing employment opportunities in small-scale agricultural sectors. This dual-purpose breed, meticulously selected for meat and egg production, demonstrates exceptional adaptability to free-range environments and exhibits remarkable resilience in high-temperature conditions. With an annual egg output ranging from 220 to 240 eggs per hen (Kunhareang et al., 2023), the DDK breed has garnered significant demand among farmers, necessitating a concerted effort to augment the breeding stock. Artificial insemination (AI) is a highly efficient breeding technique that is contingent on the availability of superior-quality semen. Global warming elevates the Earth's surface and atmospheric temperatures, exacerbating climate variability. This phenomenon can induce significant stress in animals, including poultry. The temperature-humidity index (THI) quantifies heat stress by considering temperature and humidity. Although THI thresholds vary across species, elevated temperatures compromise avian immune function and male reproductive health, affecting semen quality (McDaniel et al., 2008; McDaniel et al., 1996). Thailand's tropical climate, characterized by high temperatures and humidity, presents significant heat stress challenges for poultry. In Thai native PD chickens, a THI of 74 marks the onset of heat stress, which impacts egg production (Loengbudnark et al., 2023). However, the influence of environmental factors on semen quality in Thai native roosters remains uncertain (Sonseeda et al., 2013), potentially due to breed-specific heat tolerance and interannual climatic variations. Given the dearth of research on DDK semen quality concerning environmental conditions, this study investigated the impact of seasonal temperature and humidity variations on semen quality. These findings provide crucial insights for optimizing DDK breeding programs under Thailand's challenging climatic conditions.

OBJECTIVE

This study aimed to investigate the impact of seasonal variations in temperature and relative humidity on the quality of fresh semen from DDK and PD roosters. This study aimed to establish baseline semen quality data for both breeds, with PD serving as a reference standard for the semen quality of native Thai chickens. These findings will inform future efforts to enhance semen quality in both DDK and PD roosters.

METHODOLOGY

Animals and Management

This study was approved by the Institutional Animal Care and Use Committee of Khon Kaen University (Thailand) (approval no. IACUC-KKU-81/66), adhering to the ethical guidelines for animal experimentation established by the National Research Council of Thailand. The study utilized 12 roosters per breed (DDK and PD), aged 52 weeks and weighing 2.5-3 kg. In addition, 40 commercial laying hens were used for AI evaluations.

Semen Collection and Evaluation

The experiment employed a 3 × 2 factorial design within a completely randomized design (CRD). Data analysis was performed using analysis of variance (ANOVA) to assess mean differences, implemented using the Statistical Analysis System (SAS) software (SAS Institute, 1996).

RESULTS AND DISCUSSION

Data collected at the experimental site revealed significant seasonal variations in temperature, relative humidity, and THI. Specifically, the average THI during the summer and rainy seasons was 81.41 and 80.34, respectively (Table 1). These values fall within the "emergency" zone for heat stress in laying hens, indicating a severe level of heat stress (Kim et al., 2021). Based on studies examining the impact of THI on egg production and physiological responses in laying hens, four distinct heat stress zones have been defined: no stress (THI < 70), alert (THI 70-75), danger (THI 76-81), and emergency (THI > 81).

Effect of Seasons on Quality of Fresh Semen

An evaluation of fresh semen quality in two breeds revealed significant seasonal variations in several key parameters. Specifically, semen volume, sperm concentration, sperm viability, sperm morphology, and fertility were influenced by the season ($p < 0.05$), as shown in Table 2. In contrast, no seasonal effects were observed for mass movement, sperm progressive motility, or total sperm count ($p > 0.05$). No significant interaction was observed between the breed and season ($p > 0.05$). Elevated ambient temperatures, particularly during the summer and rainy seasons, contribute to elevated THI values, leading to heat stress in livestock. This stress adversely affects the male reproductive function. Studies have demonstrated that heat stress can damage Sertoli cells, resulting in decreased semen volume (Guo et al., 2021), sperm concentration, and increased sperm mortality (Telangana et al., 2021). Consistent with these findings, Elagib et al. (2012) observed a negative correlation between sperm concentration and increasing temperature in White Leghorn chickens in Sudan. Similarly, Adamu et al. (2019) reported a decrease in semen concentration in indigenous Nigerian chickens during the late rainy season, which was characterized by lighter semen color. Furthermore, Pimprasert et al. (2023) observed the highest sperm concentration during winter and the lowest during the rainy season in Thailand.

Table 1 Maximum, minimum and average temperature, relative humidity, and THI for each season at the experimental location

Observations	Maximum	Minimum	Average	SD
Temperature (°C)				
Summer	39.20	22.40	30.28	1.99
Rainy	34.20	23.30	28.02	1.07
Winter	32.80	14.19	24.18	1.89
Relative humidity (%)				
Summer	98.80	39.90	67.77	9.48
Rainy	99.70	57.00	84.73	4.58
Winter	96.70	40.20	74.66	4.44
THI				
Summer	90.50	70.74	81.41	1.78
Rainy	86.78	72.25	80.34	1.25
Winter	84.81	56.06	73.43	3.18

Note) Data were collected from the Integrated Farm of the Department of Animal Science, Faculty of Agriculture, Khon Kaen University.

Heat stress induces oxidative stress, leading to increased lipid peroxidation and the generation of reactive oxygen species (Yongjie, 2020). These reactive species damage cell membranes, increase sperm mortality (Tselutin et al., 1999), and disrupt the spermatogenesis process, increasing abnormal sperm morphology (Fouad et al., 2016). However, these findings contrast with those of Sonseeda et al. (2013), who reported no significant seasonal effects on the semen quality. This discrepancy may be attributed to differences in experimental conditions, including a lower range of average temperatures (20.6-31.2°C) and relative humidity (53.5-82.2%) in the Sonseeda et al. (2013) study compared to the present study (average temperature: 24.18-30.28°C; average relative humidity: 67.77-84.73%). It is also important to consider that, despite being of the same breed (PD), the genetic makeup of these animals may have evolved to prioritize their productivity. High-yielding animals often exhibit reduced fertility (Walsh et al., 2011), which can manifest as a lower semen quality.

This study observed significant seasonal variations in fertility rates, with the lowest fertility rate (77.99%) recorded during the summer season compared to the rainy (85.88%) and winter (86.81%) seasons. The summer season, characterized by the highest THI, induces the greatest heat stress in chickens. While spermatogenesis continues during heat stress, leading to the production of viable sperm, these spermatozoa may exhibit DNA damage (Banks et al., 2005). This damage can compromise sperm integrity and reduce their lifespan within the hen reproductive tract (Wang et al., 2014), thereby limiting the availability of sperm for fertilization (King et al., 2002). These findings align with those of McDaniel et al. (1996), who demonstrated a 42% reduction in fertility in broilers exposed to 32°C compared with those maintained at 21°C. Moreover, McDaniel et al. (1995) observed a reduced ability of sperm from heat-stressed roosters to penetrate the perivitelline layer of the egg. The current study, with an average summer temperature of 30.28°C, further emphasizes the sensitivity of rooster fertility to elevated temperatures. These results suggest that temperatures below 32°C can induce heat stress and adversely affect semen quality in roosters.

Table 2 Effect of seasons and breeds on the quality of fresh semen in DDK and PD.

Factors	Semen volume (ml)	Mass movement (scores)	Sperm progressive motility (%)	Sperm concen-tration (x10^{9}sperm /ml)	Total sperm count (x10^{9} /ejaculate)	Sperm viability (%)	Sperm morphology (%)	Fertility (%)
Seasons								
Summer	0.45±0.08^{b}	4.24±0.37	59.58±11.04	4.16±1^{ab}	1.56±1.56	93.45±1.91^{b}	6.79±1.57^{a}	77.99±6.78^{b}
Rainy	0.47±0.05^{ab}	4.34±0.30	60.44±4.64	3.82±0.56^{b}	1.63±1.63	95.49±1.72^{a}	5.66±1.21^{b}	85.88±3.96^{a}
Winter	0.49±0.05^{a}	4.36±0.25	62.69±4.44	4.51±0.60^{a}	1.60±1.60	95.22±3.20^{a}	5.18±0.60^{b}	86.81±5.89^{a}
p-value	0.046	0.37	0.41	0.0064	0.99	0.02	0.001	0.003
Breeds								
DDK	0.44±0.05^{b}	4.14±0.33^{b}	57.96±7.47^{b}	3.84±1^{b}	1.33±1.33^{b}	93.64±2.84^{b}	6.17±1.49	82.19±6.94
PD	0.50±0.05^{a}	4.48±0.17^{a}	63.85±6.28^{a}	4.48±1^{a}	1.87±1.87^{a}	95.80±1.47^{a}	5.58±1.15	84.92±6.59
p-value	0.01	0.01	0.004	0.004	0.001	0.004	0.89	0.13
Seasons *Breeds	0.96	0.32	0.13	0.59	0.44	0.30	0.45	0.71
SEM	0.04	0.09	1.07	0.36	0.48	0.36	0.20	1.05

$^{a,\,b}$ different superscript letters within columns indicate significant differences ($p<0.05$).

Effect of Breeds on Quality of Fresh Semen

Breed significantly influenced semen volume, sperm mass movement, sperm progressive motility, sperm concentration, and sperm viability ($p < 0.05$), whereas no significant breed effects were observed on sperm morphology and fertility rate ($p > 0.05$), as shown in Table 2. The effect of breed on semen quality in this study showed that the semen quality of PD was higher than that of DDK. Although DDK has a bloodline of Thai native chickens, being raised in Thailand's environment impacts the semen quality of DDK. The overall quality of DDK is lower than PD, which is consistent with the study of Peters et al. (2008) in Nigeria, who found that seven different breeds, namely Black Nera, White Leghorn, Giriraja, Naked necked, Frizzled, Normal Feathered, and hybrid breed, had different semen volume and sperm concentration. This is due to genetic differences between regions, resulting in different abilities to adapt to the environment of the region.

Tabatabaei et al. (2009) reported that Iranian native chickens had lower sperm concentration and abnormal sperm percentage than Ross-308 but had higher sperm motility and sperm viability than Ross-308. In India, a study was conducted on the semen quality of Naked neck and Bantam chickens and found that the semen quality of the two breeds was different, except for sperm concentration, indicating that the genetic structure of chickens was different, resulting in different semen qualities (Shanmugam et al., 2012). In Thailand, the study by Sonseeda et al. (2013) on Thai native chickens (Lueng hang kaow, Pradoo hang dam, and Chee) reported that the influence of breeds did not significantly affect semen quality. This may be because all three breeds are genetically similar Thai native chickens, resulting in minimal differences in semen quality (Choomee and Worananthakij, 2017).

In this experiment, breed did not affect the fertility rate ($p > 0.05$), with the average fertility rates of DDK and PD being 82.19 ± 6.94 and 84.92 ± 6.59%, respectively (*Table 2*). Although the semen quality of DDK and PD differed, the fertility rate did not, indicating that the fresh semen quality of DDK was still viable and did not affect fertility rate. Semen quality does not affect the conception rate as long as certain thresholds are met, including a semen volume of not less than 0.2 ml, mass movement of not less than score 2, sperm progressive motility of not less than 60% (Iswati et al., 2018), sperm concentration of not less than 150 × 106 sperm/dose (Kheawkanha et al., 2024), sperm viability of not less than 70% (Iswati et al., 2018), and sperm morphology of not exceeding 20-25% abnormality (Vongpralub, 2016). Therefore, fresh DDK semen is still considered good quality and adaptable to Thailand's environment, and it does not affect fertility rate.

CONCLUSION

A study on the effects of season and breed on the quality of fresh semen in DDK and PD revealed that the summer season resulted in the lowest quality of fresh semen, while the winter season resulted in the highest quality. However, although seasons and breeds affect semen quality, DDK and PD remain within the range of good-quality semen and do not affect the fertility rate, indicating that these chicken breeds can tolerate the environment in Thailand.

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Research article

Watermelon Peels and Rinds as a Food Preservative and Additive in Pork *Longganisa* (Sausage)

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Abstract Food products in the Philippines mostly use synthetic preservatives, including the curing powder for pork *longganisa* (sausages) (PL), a widely consumed cured meat. Currently, there is an emerging trend to look for natural alternatives to increase the nutritional value of food while ensuring its stability during storage. In Sibalom, Antique, 41.9% or 11,250pcs. of watermelons are surveyed to be rejected and left on the field to rot after harvest. The development of these rejects as food preservatives and additives from the rinds and peels of red-fleshed "*Sweet 16"* (RF16) and yellow-fleshed "*Sweet Gold"* (YFSG) watermelons was conducted. The peels and rinds were oven-dried at 60^{O}C were powdered and added at 6% to the PL. A positive control using Prague powder (PRP) and a negative control (NC) were used alongside the treatments. The sensory evaluation results showed a significant difference in odor among the PRP, RF16, and YFSG samples on day 16. Meanwhile, no significant differences were found between the color, texture, and flavor of all samples. The free fatty acid content of PRP and NC increased on day 27, whereas it decreased for RF16 and YFSG, suggesting better shelf-life stability. When analyzing the nutritional content, no significant differences were observed in the moisture content of all samples, whereas the crude fat content did not differ between YFSG and PRP. Crude protein was highest in PRP, whereas the crude fiber content of YFSG and RF16 was significantly higher and even increased on day 27. The use of watermelon peels and rind powders from the rejects was comparable to that of the commercial preservative, as it further improved the nutritional content and shelf-life stability of pork *longganisa*, promoting a circular food system that can also be introduced to a wide variety of food products.

Keywords food preservative, food additive, watermelon rejects, peels and rinds, food losses

INTRODUCTION

In the Philippines, synthetic preservatives are used in a wide variety of food products to increase shelf-life stability, prevent microbial spoilage, reduce lipid oxidation, and maintain sensory properties. Despite its popular use, there is growing concern regarding the use of synthetic preservatives, such as curing powder, locally referred to as *Prague powder*, as it contains nitrates and nitrites that can be converted to carcinogenic nitrosamines, causing adverse health effects to consumers (Shi et al., 2024). Due to this concern, natural preservatives are being explored from plant extracts that can potentially replace the synthetic preservatives in the market. One of these is the use of watermelon waste. Kumar et al. (2018) assessed the lipid peroxidation of pork patties with watermelon rinds (WMR) and found results comparable to those of the positive control (treated with 0.02% butylated hydroxytoluene). The results also showed a significant reduction in lipid peroxidation compared to that in the untreated samples, indicating its effectiveness as a preservative. Currently, there are no studies in the Philippines applying watermelon waste in food products or its use as a natural preservative and additive, as most studies are geared toward the extraction of its pectin, candying rinds, and its use as a rejuvenating agent (Lo et al., 2019; Back et al., 2016).

The annual production of watermelon in 2021 was estimated at 135, 845.60 tons in the Philippines (FAO, 2024), with Western Visayas being the highest producer in the country at 51, 781 tons, comprising 41.5% of the total watermelon production (Philippine Statistics Authority, 2023). Due to higher watermelon production, great watermelon waste is also generated, as observed in a surveyed site in Cubay-Napultan, Sibalom, Antique, wherein almost half of the watermelons are considered waste (41.9% or 11,250 pcs), and are left in the field to rot (Aposaga et al., 2025). The use of watermelon waste in the form of its peels and rinds as a natural food preservative and value additive has potential, especially in Western Visayas, the highest watermelon producer in the Philippines. In this study, the use of watermelon powder (WamPow) from the top two grown cultivars of the red-fleshed Sweet 16 (RF16) and yellow-fleshed Sweet Gold (YFSG) watermelons as a potential replacement for synthetic preservatives was evaluated in pork longganisa (sausage).

OBJECTIVE

This study aimed to determine the potential of watermelon peel and rind from watermelon rejects left on the field after harvest in Cubay-Napultan, Sibalom, Antique, Philippines, to be used as a natural food preservative and additive when added to pork *longganisa.*

METHODOLOGY

Around 100 pcs. of RF16 and YFSG were collected in Cubay-Napultan, Sibalom, Antique, in February 2023. Only the watermelons that were considered rejects and left in the field but were still in good condition were collected as samples. The watermelons were washed with potable water, dipped in 100ppm ppm chlorine solution for 5 min, rinsed with potable water, air-dried, and stored in a well-ventilated area before preparation. The peels and rinds were thoroughly separated from the flesh and cut into 1x1cm^3. The two cultivars of YFSG and RF16, labeled YFSG 60°C and RF16 60°C, respectively, were dried at 60°C and powdered.

In formulating the pork *longganisa* with WamPow, the percentage of WamPow added to pork *longganisa* was examined through a preliminary test ranging from 3%, 6%, and 9%, wherein the most acceptable result came from pork *longganisa* treated with 6% WamPow and was used in the final formulation. Controls were also prepared alongside the treatments using Prague powder and one without any preservatives or additives. The samples were then analyzed for *Escherichia coli, Staphylococcus aureus,* and Aerobic Plate Count for microbial quality, sensory evaluation using the 7-point hedonic scale from seven trained panelists, free fatty acid content based on the modified method from the AOAC 41.121 for crude and refined oils, and proximate nutrient content (AOAC International, 2019). In analyzing the results, the two-way analysis of variance (ANOVA) was performed, with Fisher's least significant difference (LSD) as the post-hoc using the StatPlus software (Build 8.0.3/Core v7.8.11). The level of significance was set at $P<0.05$.

RESULTS AND DISCUSSION

Microbiological Analysis

Over 27 days, the APC test was conducted to monitor the progress of bacterial growth in the cooked *longganisa,* as shown in Fig. 1. Analysis on Day 0 showed a high count for RF16 60°C samples; however, it was still within the set limit for ready-to-eat (RTE) food. The sudden drop in count in all samples on Day 7 was mainly due to the longer storage period at -2°C to -5°C, which affected the metabolic activity and nutrient uptake of the microorganisms, leading to a partial reduction in the microbial population. From days 14 to 27, the increase in APC may be associated with the increased resistance of the remaining bacterial population to the frozen conditions and may have multiplied once heated due to its longer storage period. Despite the increase in microbial count, all samples passed the microbiological test during the 27-day storage period and were within the limit. This indicates the safety of watermelon rejects when added to food.

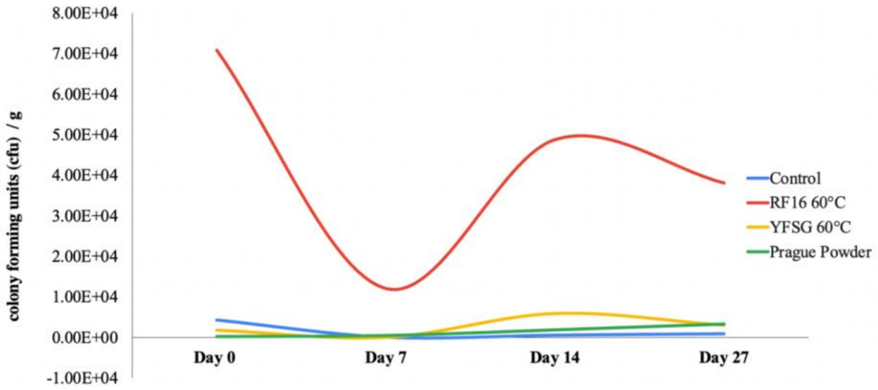

Fig. 1 APC monitoring of cooked pork *Longganisa*

Further microbiological tests were conducted through the assessment of the indicator organisms, *E.coli* and *S. aureus*. All samples tested showed negative growth for *E.coli*, while monitoring for *S. aureus* showed growth, but all within the acceptable limit, with the lowest recorded at ≤25 cfu/g for pork longganisa mixed with RF16 60°C and the highest at $9x10^1$ cfu/g from the Prague powder. The maximum limits of the indicator organisms were based on the Food Standards Australia New Zealand (2025). The results indicate how WamPow was able to reduce the growth of *S. aureus* compared to the synthetic preservative.

Sensory Evaluation

The sensory characteristics of the pork *longganisa* with WamPow, Prague powder, and those without any preservatives or additives did not significantly vary in terms of its color, texture, odor, and flavor during the storage at days 1, 7, and 16.

Effect of the Treatments on the Color of the Pork *Longganisa*

The color, as seen in Table 1 of the samples remained stable throughout the storage period, with Prague powder exhibiting the highest acceptability due to its distinct red color in the pork *longganisa*. The color of the sample treated with RF16 at 60°C had the highest acceptability the longer it was stored. On the 7^{th} and 16^{th} days of storage, the pork longganisa with WamPow did not significantly differ from that with Prague powder. The green color in the pork *longganisa* from the WamPow was still considered new, and uncommon for pork products by the panelists. Green is mostly associated with non-meat products, which still serves as an area for improvement during product development.

Effect of the Treatments on the Texture of the Pork *Longganisa*

The texture of each sample during the whole storage period from day 1, 7, and 16 did not significantly differ. However, for the control, its texture was found to be highly acceptable at the end of its storage period, as seen in Table 1. Based on the comments of the panelists, the texture of the RF16 60°C pork *longganisa* on day 1 was quite dry but improved the longer its storage period, similar to YFSG 60°C. The texture of the WamPow-treated pork *longganisa* on day 1 was less juicy and moist due to the observed high absorbency of the WamPow, which soaked up the water, oils, and juices in the pork *longganisa*, resulting in lower scores for its texture. Over time, the texture of the WamPow improved when stored longer and became comparable with the control and Prague powder on days 7 and 16.

Effect of the Treatments on the Odor of the Pork *Longganisa*

The odor, as shown in Table 1 of the samples, did not significantly differ during the whole storage period, with the highest rating given to the control and the Prague powder. YFSG 60°C had the most acceptable score among the WamPow-treated samples on days 7 and 16. The odor of the WamPow-treated pork *longganisa* was generally similar to one other, having leafy and grassy notes described as having an interesting odor when incorporated into the meat. Since the addition of WamPow has not yet been previously explored in the Philippines, the combination of its odor with meat was considered new and predominantly different. However, higher acceptability values were noted as the duration of storage increased, as the smell became less distinct compared to day 1.

Table 1 Sensory evaluation results of the cooked pork *Longganisa*

Sample	Color attribute during storage		
	Day 1	Day 7	Day 16
Control	$6.67 \pm 1.94^{a,A,B}$	$5.00 \pm 2.52^{a,A}$	$4.43 \pm 2.07^{a,B}$
RF16 60°C	$5.22 \pm 1.30^{a,B}$	$5.86 \pm 1.21^{a,A}$	$6.86 \pm 1.07^{a,A}$
YFSG 60°C	$4.89 \pm 1.05^{a,B}$	$5.43 \pm 2.07^{a,A}$	$5.29 \pm 1.50^{a,A,B}$
Prague powder	$7.11 \pm 1.9^{a,A}$	$6.57 \pm 2.64^{a,A}$	$7.29 \pm 1.60^{a,A}$
Sample	Texture attribute during storage		
	Day 1	Day 7	Day 16
Control	$7.44 \pm 1.67^{a,A}$	$6.86 \pm 2.19^{b,A}$	$7.14 \pm 1.21^{a,b,A}$
RF16 60°C	$4.67 \pm 1.00^{a,C}$	$6.57 \pm 1.13^{a,A}$	$5.71 \pm 2.06^{a,A}$
YFSG 60°C	$5.44 \pm 1.42^{a,B,C}$	$6.14 \pm 1.77^{a,A}$	$5.71 \pm 1.89^{a,A}$
Prague powder	$7.33 \pm 1.58^{a,A}$	$5.14 \pm 2.41^{a,A}$	$7.00 \pm 1.91^{a,A}$
Sample	Odor attribute during storage		
	Day 1	Day 7	Day 16
Control	$5.78 \pm 1.92^{a,A}$	$4.86 \pm 2.12^{a,A}$	$6.29 \pm 1.60^{a,A,B}$
RF16 60°C	$4.33 \pm 1.66^{a,A}$	$4.14 \pm 2.04^{a,A}$	$5.29 \pm 1.70^{a,B}$
YFSG 60°C	$4.33 \pm 1.58^{a,A}$	$5.43 \pm 1.62^{a,A}$	$5.57 \pm 1.5^{a,A,B}$
Prague powder	$6.11 \pm 1.83^{a,A}$	$5.57 \pm 2.44^{a,A}$	$7.71 \pm 1.60^{a,A}$
Sample	Flavor attribute during storage		
	Day 1	Day 7	Day 16
Control	$6.67 \pm 2.24^{a,A}$	$7.14 \pm 2.40^{a,A}$	$6.00 \pm 2.52^{a,A}$
RF16 60°C	$4.56 \pm 1.24^{a,A}$	$4.86 \pm 1.95^{a,A}$	$6.00 \pm 2.08^{a,A}$
YFSG 60°C	$6.11 \pm 1.96^{a,A}$	$6.14 \pm 2.34^{a,A}$	$5.71 \pm 2.14^{a,A}$
Prague powder	$5.89 \pm 2.76^{a,A}$	$5.57 \pm 2.88^{a,A}$	$6.71 \pm 2.81^{a,A}$

Data are presented as mean ± standard deviation (n=9 for day 1, and n=7 for days 7 and 16). Mean values in the same row per attribute, with similar superscript small letters (a-b), are not significantly different at p <0.05. Mean values in the same column per attribute, with similar superscript capital letters (A-D), are significantly different at p<0.05.

Effect of the Treatments on the Flavor of the Pork *Longganisa*

Flavor is considered an important sensory characteristic of a food product, as it is a major determinant factor in terms of food preference. The sensory evaluation results showed the flavor profile of the samples during the storage period, and when compared with one another, did not generally significantly differ at days 7 and 16, indicating that the taste of WamPow-treated pork longganisa can be compared with that of Prague powder-treated samples. The WamPow samples were noted to have an improved flavor, from a strong leafy taste that became faint the longer its storage, which was noted by the panelists as the reason for its higher rating at day 7. This indicates that a longer storage period aids in enhancing the overall flavor profile of pork *longganisa* treated with WamPow, as it was able to compete with the controls, as detailed in Table 1.

Free Fatty Acid (FFA)

FFA are prone to oxidation and are indicators of rancidity. The %FFA from Day 0 to Day 27, as shown in Table 2, increased for the control and Prague powder-treated samples, while the FFA of RF16 60°C and YFSG 60°C decreased over time. The lower %FFA value of WamPow-treated pork *longganisa* indicates the pork is less rancid, and implies a slower degradation process, making the samples shelf-stable. Based on the results, WamPow can act as a natural preservative and enables the reduction of %FFA values during its storage period, indicating the influence of the WamPow on lowering lipid oxidation. The RF16 60°C contributed to a much lower FFA.

Table 2 Free fatty acid (FFA) values of cooked pork *Longganisa* samples

Sample	Day of storage (FFA (%), cooked samples)			
	0	7	16	27
Control	$0.33\pm0.1^{a,B}$	$0.50\pm0.06^{a,C}$	$0.59\pm0.15^{a,B}$	$0.70\pm0.10^{a,A,B}$
RF16 60°C	$0.86\pm0.21^{a,A}$	$0.72\pm0.15^{a,A,B,C}$	$0.77\pm0.08^{a,A,B}$	$0.61\pm0.05^{a,B}$
YFSG 60°C	$0.71\pm0.28^{a,A,B}$	$1.05\pm0.10^{a,A}$	$0.93\pm0.17^{a,A,B}$	$0.70\pm0.02^{a,A,B}$
Prague powder	$0.42\pm0.31^{a,A,B}$	$0.55\pm0.14^{a,B,C}$	$0.65\pm0.09^{a,B}$	$0.84\pm0.31^{a,A,B}$

Data are presented as mean ± standard deviation (n=3). Mean values in the same row with similar superscript small letters (a-b) are not significantly different at p <0.05. Mean values in the same column with similar superscript capital letters (A-B) are significantly different at p<0.05.

Nutritional Composition of Cooked Pork *Longganisa*

The proximate nutrients of the cooked pork *longganisa* were evaluated on days 0 and 27.

Moisture Content (MC)

The %MC of the pork *longganisa* samples, as shown in Table 3, did not significantly vary among the treatments and between the storage times (Day 0 and 27). This indicates that WamPow does not significantly affect the %MC of pork *longganisa*.

Ash Content

The %Ash of pork *longganisa* for all treatments decreased by day 27. The highest value of ash was reported to be RF16 at 60°C, with a value of 8.68% on day 0. The lowest ash value was recorded for the control at 5.51% on day 27. The higher ash values of pork *longganisa* with WamPow may be due to the number of inorganic compounds, such as minerals, present in the dried watermelon peels and rinds, as detailed in Table 3.

Crude Protein (CP)

The %CP of pork *longganisa* decreased with storage period, except for YFSG 60°C, which increased on day 27 (Table 3). On day 0, the highest %CP was recorded for Prague powder at 32.62%, and the lowest %CP was recorded for YFSG 60°C at 24.44%. The %CP of Prague powder was significantly higher than that of the WamPow-treated pork *longganisa* at days 0 and 27 due to the presence of nitrates and nitrites. For the control, the %CP by day 27 was not significantly different from that of the Prague powder-treated samples and YFSG 60°C. The results show that the RF16 cultivar at 60 °C may have affected the %CP of the pork *longganisa* samples during the storage period.

Crude Fat (CFt)

The %CFt of pork *longganisa* did not significantly differ over the storage period from day 0 to day 27, except for the control, which significantly decreased by day 27, as shown in Table 3. As preservatives were not added to the control, the fat may have oxidized, resulting in a much lower value. No significant differences were found in the reduced %CFt of the other samples by day 27, indicating the effect of minimizing fat oxidation through the addition of Prague powder and WamPow to pork *longganisa.*

Crude Fiber

Higher crude fiber values were found in the YFSG treated at 60°C. The WamPow-treated pork *longganisa* was significantly higher and even increased by day 27 compared to Prague powder and control. This indicates the ability of WamPow to add value to pork *longganisa* and other food products. The significant increase in the crude fiber at day 27 for YFSG 60°C by 1.33% shows the positive interaction of WamPow with the nutrient matrix of the pork *longganisa*. No significant increase in the crude fiber of the Prague powder and control by the end of its 27-day storage period was observed as presented in Table 3. The results show that the addition of WamPow can further increase the marketability of pork products, which were previously low in fiber.

Table 3 Proximate nutrient results of the cooked pork *Longganisa*

Sample	Moisture content (%) during storage, cooked samples	
	Day 0	Day 27
Control	$3.86 \pm 0.01^{a,A}$	$3.84 \pm 0.03^{a,A}$
RF16 60°C	$3.85 \pm 0.02^{a,A}$	$3.87 \pm 0.01^{a,A}$
YFSG 60°C	$3.87 \pm 0.01^{a,A}$	$3.83 \pm 0.02^{a,A}$
Prague powder	$3.83 \pm 0.05^{a,A}$	$3.84 \pm 0.01^{a,A}$
Sample	Ash content (%) during storage, cooked samples	
	Day 0	Day 27
Control	$5.67 \pm 0.09^{a,E}$	$5.51 \pm 0.16^{a,E}$
RF16 60°C	$8.68 \pm 0.08^{a,A}$	$8.63 \pm 0.11^{a,A}$
YFSG 60°C	$6.88 \pm 0.05^{a,C}$	$6.71 \pm 0.01^{a,C}$
Prague powder	$6.54 \pm 0.05^{a,D}$	$6.35 \pm 0.10^{a,D}$
Sample	Crude protein (%) during storage, cooked samples	
	Day 0	Day 27
Control	$29.78 \pm 0.85^{a,B}$	$29.33 \pm 2.17^{a,A,B}$
RF16 60°C	$30.36 \pm 2.80^{a,B}$	$26.76 \pm 0.59^{b,B,C}$
YFSG 60°C	$24.44 \pm 0.20^{a,B}$	$25.14 \pm 1.69^{a,C}$
Prague powder	$32.62 \pm 3.01^{a,A}$	$32.55 \pm 1.13^{a,A}$
Sample	Crude fat (%) during storage, cooked samples	
	Day 0	Day 27
Control	$45.44 \pm 1.44^{a,A}$	$39.50 \pm 2.93^{b,A,B}$
RF16 60°C	$37.95 \pm 2.80^{a,B}$	$36.58 \pm 5.5^{a,B}$
YFSG 60°C	$43.71 \pm 2.21^{a,A}$	$41.80 \pm 2.30^{a,A}$
Prague powder	$42.48 \pm 0.23^{a,A,B}$	$42.33 \pm 1.21^{a,A}$
Sample	Crude fiber (%) during storage, cooked samples	
	Day 0	Day 27
Control	$0.30 \pm 0.08^{a,B}$	$0.51 \pm 0.07^{a,B}$
RF16 60°C	$3.52 \pm 0.13^{a,A}$	$3.78 \pm 0.04^{a,A}$
YFSG 60°C	$3.32 \pm 0.16^{b,A}$	$4.65 \pm 0.16^{a,A}$
Prague powder	$0.39 \pm 0.01^{a,B}$	$0.58 \pm 0.04^{a,B}$

Data are presented as mean ± standard deviation (n=3). Mean values in the same row per test, with similar superscript small letters (a), are not significantly different at p<0.05. Mean values in the same column per test, with similar superscript capital letters (A), are significantly different at p<0.05.

CONCLUSION

The production of watermelon powders (WamPow) from the red-fleshed *Sweet 16* and yellow-fleshed *Sweet Gold* in the province of Antique, Philippines, has great potential for commercialization and use in a wide variety of food products as a natural food preservative and value additive, as it performs similarly to synthetic preservatives in reducing the production of free fatty acids during storage and even adding fiber to pork *longganisa.* In comparing the WamPow powders, RF16 60°C had higher values of color, crude ash, and crude protein, and lower FFA, while YFSG 60°C had higher results for odor, flavor, crude fat, and crude fiber.

This study addresses the research gaps in utilizing watermelon peels and rinds as natural preservatives and value additives for potential use in a wide variety of food products. Overall, the results of the study produced a technology that adds economic value and addresses the problems of watermelon losses and waste during watermelon harvests in the Philippines, while simultaneously increasing the marketability of pork *longganisa*.

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Research article

Sustainable Palm Oil Downstream Value Chain in Industrial Zones: A Case Study in Riau Province, Indonesia

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Abstract Indonesia, the world's top palm oil producer, yielded 46.99 million tons in 2023. The province of Riau, which leads in both production and plantation area, has initiated three industrial zones focused on palm oil cultivation. Of all the industrial estates, only the Dumai Industrial Estate (DIE) is implementing downstream processing by 2025, potentially enhancing the sector's value-added contribution. Although numerous studies have been conducted on the palm oil value chain in Indonesia, no research has focused on specific regions or examined the relationships between the entities within those regions. This study examines the structure and governance of the value chain in DIE. DIE has four distinct value chains: Wilmar International Group (WIG), First Resources Group (FRG), Permata Hijau Group (PHG), and Sumber Jaya Oleo Group (SJIOLEO). These four supply chains function independently with no horizontal integration. DIE specializes in palm oil-based products, including oleofood, oleochemicals, and oleofuel (biodiesel). Notably, only the WIG chain, through PT Wilmar Nabati Indonesia, employs RSPO-certified CPO for its export products. PT Wilmar Bioenergi Indonesia, operating within the WIG, FRG, PHG, and SJIOLEO chains, does not procure RSPO-certified CPO because its production of biofuels and oleochemicals primarily serves the domestic market. In DIE, not all downstream palm oil activities focus on exports, and value chain governance, whether based on RSPO or non-RSPO certification, follows a hierarchy type.

Keywords downstream, governance, industrial zones, palm oil industry, value chain

INTRODUCTION

Over the last ten years, palm oil has become the most widely produced vegetable oil globally. Valued for its high vitamin E content (Kuppithayanant et al., 2014), it represents around 40% of the global vegetable oil market (Gandhi and Takanashi, 2025). Southeast Asia leads the sector, producing over 80% of palm oil and nearly one-third of all vegetable oils (OECD/FAO, 2024). Over the past five years, Indonesia has established itself as the world's largest palm oil producer. In 2023, Indonesia produced 47.08 million tons of Crude Palm Oil (CPO) (BPS, 2024), sourced from 16.83 million hectares of palm oil plantations. Domestic palm oil consumption reached 23.13 million tons in 2023, an increase from 21.24 million tons in 2022 (GAPKI, 2024). This increase was largely attributed to the implementation of the biodiesel (B35) policy, which significantly increased domestic palm oil demand for biodiesel production. Conversely, Indonesian palm oil exports have steadily declined in the past five years. In 2023, exports totaled 38.23 million metric tons, with a value of USD 25.61 billion (Ministry of Agriculture, 2024). The palm oil industry is a vital component of Indonesia's economic development. However, growing international concerns regarding the environmental and social sustainability of its supply chain have intensified in recent years (Carmagnac et al., 2022). In particular, regulatory and consumer pressures from the EU have compelled the industry to enhance transparency and align its operations with globally recognized sustainability standards. Few sectors actively promote certification participation among their members as strongly as the palm oil industry, particularly with schemes such as the Indonesian Sustainable Palm Oil (ISPO) and the Roundtable on Sustainable Palm Oil (RSPO). These initiatives play a significant role in shaping industry practices, as certification for product safety and differentiation has been shown to influences entire value chains across various sectors (Gereffi and Lee, 2009). Riau Province is a leading palm oil producer in Indonesia, with a total production of 8.79 million tons from 2.87 million hectares of plantations. As a key province in palm oil production, the Riau Provincial Government has established three industrial zones focused on the palm oil sector: Dumai Industrial Estate (DIE), Tanjung Buton Industrial Estate (TBIE), and Tenayan Industrial Estate (TIE). Among these, only DIE currently accommodates downstream palm oil industry. Although several studies have examined Riau's palm oil value chain, its structure and governance palm oil value chain remain largely unexplored.

OBJECTIVE

This study analyzes the structure and governance of the palm oil industry value chain in the DIE.

METHODOLOGY

The value chain describes the entire product creation chain (Porter, 1985). In a broader sense, value chain analysis refers to the activities within a single company to bring a product to market. Meanwhile, in a broad sense, the value chain looks at a series of vertically and horizontally complex activities carried out by various actors to bring raw materials and final products through the chain to the sales. Lazarrini developed the net chain concept, a critical theoretical framework in this study, to show vertical and horizontal value chain linkages (Lazzarini et al., 2001). Vertical integration reflects the flow of products and services from primary producers to final consumers (i.e., value chain or supply chain). The horizontal dimension represents the relationships between actors in the same chain. Gereffi and Fernandez-Stark (2016) identified five types (market, modular, relational, captive and hierarchy) of global value chain (GVC) governance: high to low levels of explicit coordination and power asymmetry between buyers and suppliers. The governance type is determined by four key variables: complexity of transactions, ability to codify transactions, capabilities in the supply base, and degree of explicit coordination and power asymmetry.

Source: Modified from PT KID by authors (2024).

Fig. 1 Research area

Understanding GVC governance is crucial as it reveals power dynamics, affects risk and reward distribution, improves labor and environmental standards, and enables value chain upgrading. This study adopted a comprehensive case study approach. The chain analysis steps carried out in this study were data collection, value chain, and governance analysis. The researcher collected secondary data from documents, statistical records, research studies, and reports related to the DIE. This data was analyzed by reviewing relevant documents in the study. This holistic approach ensures a comprehensive understanding of the subject matter. Primary data were collected through semi-structured interviews conducted during the field survey to examine the profiles of actors operating in DIE. DIE is located at Jl. P.Sumatera No.1, Dumai Industrial Area, Pelintung, Medang Kampai, Dumai City (Fig. 1). Dumai City is in Riau Province, Indonesia, on the East Coast of Sumatra Island. Dumai officially became a city on April 20, 1999, after being part of Bengkalis Regency. Dumai has an area of approximately 2,065.59 km² with 7-36 villages. In 2023, the population of Dumai is estimated to reach 338,064 people. Dumai is known as the "Oil City" because it has a rapidly growing oil and gas industry and serves as a center for palm oil processing. Dumai has a strategic port for international trade, especially with Malaysia and Singapore. The DIE plays a major role in Dumai's regional economic growth, with observable positive impacts on the GRDP and industrial diversification (Sumarno et al., 2001). The author conducted a study on DIE in September 2024.

RESULTS AND DISCUSSION

Entities Operating in Dumai Industrial Estate

DIE is the largest industrial area in the Riau Province, with a total land area of 1,792 ha. The basis of the Industrial Estate Policy regulation is Presidential Decree No. 53 of 1989. DIE was officially recognized as a National Vital Object in the Industrial Sector under Ministerial Decree No. 805/M-IND/Kep/12/2017. Eligible investors receive incentives such as reduced income tax, VAT exemption, and import duty reliefs. In addition to these fiscal benefits, non-fiscal incentives are available, including support for constructing and managing power plants. Regional tax incentives may include reductions, reliefs, or exemptions from land ownership taxes and street-lighting levies.

Table 1 List of companies invested in Dumai industrial estate

No	Company	Established	Product	Activity	Land area (ha)	Country
1	PT Sentana Adi Daya Pratama	1999	KCl (potassium chloride) crown fertilizer, Peruvian rock phosphate crown fertilizer, ZA (ammonium sulfate) crown fertilizer, TSP (triple super phosphate) crown fertilizer	Fertilizer production	16.63	Singapore
2	PT Murini Sam Sam II	2006	Palm kernel and CPO	Palm oil mill	7.18	Singapore
3	PT Wilmar Nabati Indonesia	2008	Olein, stearin and PFAD	Refinery, fractionation, oleochemical and flour mill	53.43	Singapore
4	PT Wilmar Bioenergi Indonesia	2008	Fatty acid methyl esters	Refinery for biodiesel	11.50	Singapore
5	PT Petro Andalan Nusantara	2008	Oil	Fuel oil trading	2.71	Singapore
6	PT Wilmar Chemical Indonesia	2008	Methanol	Methanol trading	1.81	Singapore
7	PT Ciliandra Perkasa	2009	FAME, PFAD, crude glycerine, fatty mater	Refinery for biodiesel	5.08	Singapore
8	PT Bumi Karyatama Raharja	2014	Activated clay/ bleaching earth	Chemical industry for mining	9.20	Singapore
9	PT Samator Indo Gas	2015	Nitogen	Nitrogen (N2) plant	3.01	Indonesia
10	PT Pelita Agung Industry	2019	FAME, PFAD, crude glycerine, fatty mater, palm kernel expeller	Refinery for biodiesel	21.20	Indonesia
11	PT Perusahaan Listrik Negara	2020	Electricity	Powerplant	40.60	Indonesia
12	PT Sumber Jaya Industri Oleo	2022	RBDO (refined, bleached, deodorized oil), PFAD, RBDPO (refined, bleached, deodorized palm olein)	Refinery	4.57	Indonesia

Source: Authors' field survey and document review (2024).

On August 31, 2010, the Indonesian Government designated DIE as a Palm Oil Industry Cluster, although it is also open to various other types of industries. In 2024, there are 12 tenants, four from Indonesia and eight from Singapore. Seven of the 12 companies are subsidiaries of the Wilmar International Group. The 12 tenants employ 9,524 permanent and 176 outsourcing workers. DIE is managed by PT Kawasan Industri Dumai (KID), a subsidiary of the Wilmar International Group Ltd.

Palm Oil Value Chain and Governance in Dumai Industrial Estate

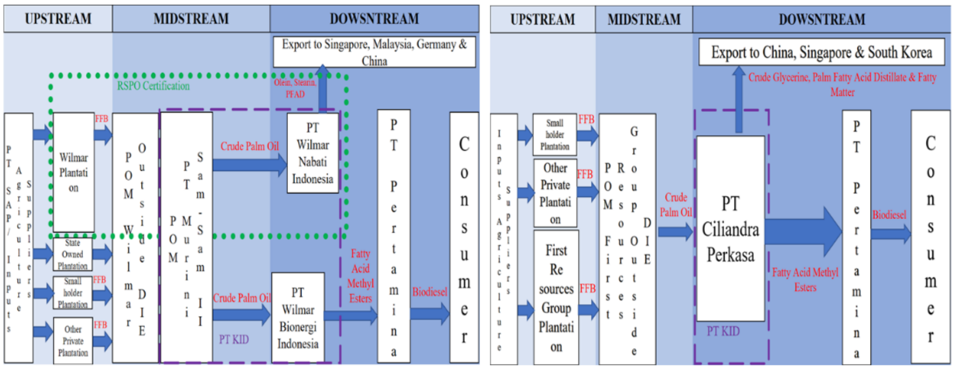
1. The Wilmar International Group (WIG): The WIG, founded on April 1, 1991, has grown from a small trading company into Asia's leading agribusiness group. Today, WIG is a global leader in agribusiness with over 500 manufacturing plants worldwide and a diverse portfolio including oil palm cultivation, edible oils refining, oilseeds crushing, consumer products, specialty fats, oleochemicals, biodiesel manufacturing, sugar milling, and refining with its headquartered in Singapore. The WIG Value Chain involves four companies located in the DIE. Three companies, PT Murini Sam Sam II (POM), PT Wilmar Nabati Indonesia (Refinery), and PT Wilmar Bioenergi Indonesia (Refinery) are in the downstream palm oil industry. Meanwhile, PT Sentana Adi Daya Pratama (PT SADP) is involved upstream as a supplier of agricultural inputs in the form of fertilizers for oil palm plantations owned by WIG outside the DIE. POM PT Murini Sam-Sam II (PT MSSII) obtains RSPO-certified Fresh Fruit Bunches (FFB) from Wilmar plantations and non-RSPO-certified FFB from private plantations and smallholders. PT MSSII produces RSPO-certified CPO for PT Wilmar Nabati Indonesia (PT WNI), which is used as a raw material for oleofood production. PT MSSII also produces non-RSPO-certified CPO for PT Wilmar Bioenergi Indonesia (PT WBI), which is used as a raw material for oleofuels. To meet its production needs, in addition to PT MSSII, PT WBI and PT WNI also obtain CPO supplies from WIG's POMs located outside the DIE. In DIE, PT WBI produces Fatty Acid Methyl Ester (FAME), which is sold domestically to PT Pertamina as biodiesel. PT WNI produces Olein, Stearin, and Palm Fatty Acid Distillate (PFAD), which are exported to WIG subsidiaries in Singapore, Malaysia, Germany, and China. In the WIG value chain, there are no horizontal or vertical relationships with tenants outside the WIG, indicating that Wilmar International manages its transactions independently from upstream to downstream.

2. The First Resources Group (FRG): The FRG was established in 1992 and has been listed on the Singapore Exchange since 2007. FRG is a leading palm oil producer in Southeast Asia, headquartered in Singapore. The company manages over 200,000 hectares of oil palm plantations across Indonesia's Riau, East Kalimantan, and West Kalimantan Provinces. The core business activities include oil palm cultivation, harvesting, and CPO and PK processing. The FRG has one DIE refinery company, PT Ciliandra Perkasa (PT CP). PT CP obtains its CPO supply from POM FRG, which is located outside the DIE. PT CP produces Crude Glycerine, PFAD, and Fatty Mater, which are exported to China, Singapore, and Korea. In addition, PT CP produces FAME, which is sold domestically to PT PERTAMINA as a biodiesel. PT CP (FRG Value Chain) does not utilize RSPO-certified raw materials and has no horizontal or vertical relationships with other tenants in the DIE.

3. The Permata Hijau Group (PHG): PHG is a fully integrated palm oil corporation founded in 1984, with its headquarters in Medan. The company's core business is palm oil plantations, and it has since expanded to cover the entire palm oil value chain. PHG's operations span from upstream plantation to midstream and downstream industries and produce value-added products. PHG manages a total land area of 24,500 ha for oil palm cultivation. PHG operates six POMs, six refineries, five palm kernel oil mills, three biodiesel plants, two oleochemical plants, and a specialty fat plant, all of which are located in Indonesia. PHG has a refinery company located in DIE, PT Pelita Agung Industri (PT PAI). PT PAI obtains its raw material supply as CPO from POM PHG outside the DIE. PT PAI produces Crude Glycerine, PFAD, Fatty Mater, and Palm Kernel Expeller (PKE), which are exported to Singapore. In addition, PT PAI produces FAME, which is sold domestically to PT PERTAMINA as a biodiesel. The PT PAI (PHG Value Chain) does not utilize RSPO-certified raw materials and has no horizontal or vertical relationships with other tenants in the DIE.

4. The Sumber Jaya Industry Oleo Group (SJIOLEO): SJIOLEO is an Indonesian-based fully integrated palm oil company focusing on downstream operations, with its head office in Jakarta. The company's scope ranges from producing, sourcing, refining, and trading palm oil and its products. SJIOLEO has a refinery company located in DIE, PT Sumber Jaya Industri Oleo (PT SJIOLEO). PT SJIOLEO is the newest company to operate in DIE in 2022. PT SJIOLEO obtains its raw materials from POM PT SJIOLEO outside the DIE. PT SJIOLEO produces Refined, Bleached, Deodorized Oil (RBDO), PFAD, and Refined, Bleached, Deodorized Palm Olein (RBDPO), which are sold to the domestic oleochemical and oleo food industries. PT SJIOLEO does not utilize RSPO-certified raw materials and has no horizontal or vertical relationships with other tenants of DIE.

Based on the four palm oil value chains in DIE (Fig.2), value chain governance in DIE can be divided into two types: governance with RSPO certification and without RSPO certification (Fig. 3). The majority of industries in DIE use non-RSPO certification (ISPO) because they are domestically oriented. The types of interactions between actors in RSPO and non-RSPO palm oil value chain governance vary significantly at the upstream, midstream and downstream levels. Overall, at the upstream and downstream levels, these two types of value chain governance differ. However, at the midstream level, both follow a hierarchical structure. The discussion primarily focuses on midstream value chain governance because this study was conducted in DIE.



(1) The Wilmar International Group (2) The First Resources Group

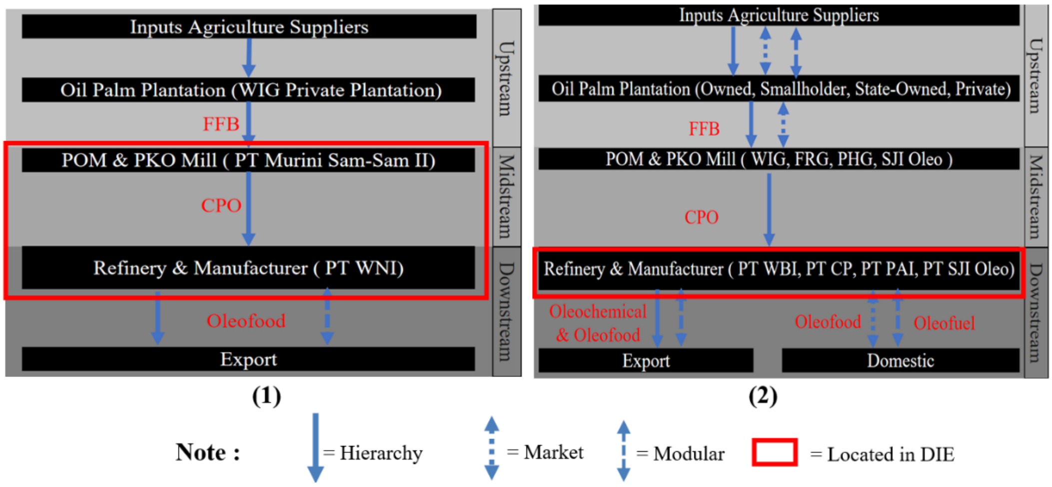
(3) The Permata Hijau Group (4) The Sumber Jaya Industry Oleo Group

Source: Authors' field survey and document review (2024).

Fig. 2 Four palm oil value chains in DIE

RSPO Certification Value Chain Governance at DIE

At DIE, the interaction between PT MSSII and PT WNI involves the transaction of RSPO-certified CPO as a raw material for producing RSPO-certified oleofood ingredients. The production process must comply with seven RSPO sustainability requirements, necessitating actors with specialized capabilities. This leads to high transaction complexity in terms of linkages, capabilities, codification and product/process specifications. However, because the commodities already meet RSPO standards, the ability to codify transactions is low. Both companies are subsidiaries of Wimar International (WI), with top management control exercised through WI's head office in Singapore, resulting in high explicit coordination and significant power asymmetry. Consequently, their supply base management capabilities are low, and the governance structure between PT MSSII and PT WNI is hierarchical owing to high transaction complexity, low codification ability, low supply management capabilities, and a high degree of explicit coordination and power asymmetry.



Source: Authors' field survey and document review (2024).

Fig. 3 RSPO (1) and non-RSPO (2) certification governance value chains

Non-RSPO Certification Value Chain Governance at DIE

Non-RSPO certification governance occurs within the WIG value chain (PT WBI), the FRG value chain (PT CP), the PHG value chain (PT PAI), and the SJIOLEO value chain (PT SJIOLEO). In the interactions between PT MSSII and PT WBI, PT CP and POM FRG, PT PAI and POM PHG, and PT SJIOLEO and POM SJIOLEO at DIE, the transacted product is non-RSPO CPO. As the production of non-RSPO CPO does not require raw materials and production processes that comply with the seven RSPO sustainability requirements, actors with specialized capabilities are not necessary. Based on this explanation, the transaction complexity—including linkages, actors' capabilities, codification, and product and process specifications—for commodities transacted in these interactions is low. PT MSSII and PT WBI are subsidiaries of WI, PT CP and POM FRG are subsidiaries of FRG, PT PAI and POM PHG are subsidiaries of PHG, and PT SJIOLEO and POM SJIOLEO are subsidiaries of SJIOLEO. The top management of PT MSSII, PT WBI, PT CP, POM FRG, PT PAI, POM PHG, PT SJIOLEO, and POM SJIOLEO can only exercise direct administrative control through the head offices of each group (WIG, FRG, PHG, and SJIOLEO). The top management at the head office holds authority over subordinates in the company's vertically integrated subsidiaries or affiliates. Direct control by the head office management implies a high level of explicit coordination and significant power asymmetry. Consequently, the capabilities of PT MSSII, PT WBI, PT CP, POM FRG, PT PAI, POM PHG, PT SJIOLEO, and POM SJIOLEO in managing the supply base, including the exchange of relevant information, buyer input, monitoring and intervention, switching costs, and explicit coordination with buyers, are low. Although the transacted commodities do not adhere to standards such as RSPO, the ability to codify transactions between PT MSSII and PT WBI, PT CP and POM FRG, PT PAI and POM PHG, and PT SJIOLEO and POM SJIOLEO remains low because administrative control, including transaction codification, requires approval from the head office of PT WBI. Based on the description above, it can be concluded that the governance value chain between PT MSSII and PT WBI, PT CP and POM FRG, PT PAI and POM PHG, and PT SJIOLEO and POM SJIOLEO is hierarchical because it meets three out of the four hierarchy requirements: low ability to codify transactions, low capabilities in supply base management, and a high degree of explicit coordination and power asymmetry. The only unmet requirement is low transaction complexity.

CONCLUSION

Based on the results and discussion, it is known: Firstly, DIE has four distinct value chains: WIG, FRG, PHG, and SJIOLEO. These four chains operate independently and are not horizontally integrated into each other. Secondly, only PT WNI in the WIG chain uses RSPO-certified CPO. PT WBI in the WIG, PT CP in the FRG, PT FAI in the PHG, and PT SJIOLEO in the SJIOLEO group chain do not use RSPO-certified CPO because they produce biofuels and oleochemicals that are primarily used domestically. Not all downstream palm oil activities in the DIE are export-oriented. Thirdly, the value chain governance type that uses RSPO or non-RSPO certification in DIE is hierarchical.

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Technical Report

Field-Based Insights into the Challenges of Sustainable Forest Management in Tboung Khmum Province, Cambodia

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Abstract In Cambodia, forest cover decreased from 73% in the 1960s to 41% in 2020. The causes of deforestation and forest degradation include forest clearing and agricultural expansion, large-scale illegal logging, and timber trade following the issuance of Economic Land Concessions (ELCs). The impact of deforestation continues due to the overexploitation of forest resources by the growing population and unofficial ELCs. The massive forest loss in Cambodia has increased the risk of natural disasters, decreased the biological and genetic diversity of indigenous trees, and jeopardized local livelihoods where residents have traditionally relied on forest resources. Therefore, the Institute of Environmental Rehabilitation and Conservation (ERECON) has been addressing the challenges of forest loss with the aim of sustainable community development across Cambodian provinces. Initiatives are formed by integrating all three organizational programs, including: 1. Environmental Rehabilitation and Conservation – We recommend promoting participatory reforestation and management activities, enhancing carbon sequestration through agroforestry, conserving biodiversity through mixed planting of native tree species, and promoting genetic diversity through the propagation of seedlings. 2. Utilization of Natural Resources: Enhancing natural resource circulation through agroforestry, compost making using locally available organic resources, and promoting sustainable forest resource utilization. 3. Environmental Education: Promoting capacity building of local communities through workshops, training sessions, and participatory rural appraisal methods; formulating management groups that play a central role in managing planted seedlings; strengthening the capacity of schoolteachers; and promoting environmental education in elementary schools. In the program year of 2024, the project on promoting school environment greening, aiming for forest environmental education in Tboung Khmum Province, as well as the project on promoting reforestation and education for sustainable development in Siem Reap Province, were implemented. Based on the cases implemented in both provinces, the achievements and challenges of sustainable forest management in Cambodia are discussed.

Keywords reforestation, forest conservation, natural resource management, environmental education, Cambodia

INTRODUCTION

In Cambodia, forest cover declined from 73% in the 1960s (FA Cambodia, 2006) to 41% in 2020 (FAO, 2020). The first major deforestation phase occurred between the 1970s and the 1990s during the Khmer Rouge regime and the subsequent activities of its remnants, reducing forest cover by 59% by the year 2000 (FAO, 2020). The main factors contributing to deforestation include the forced relocation of residents to rural areas, agricultural collectivization, overexploitation of forest resources, and war-related forest destruction. From the early 2000s to the early 2010s, the expansion of agricultural land through Economic Land Concessions (ELCs) in Cambodia became full-scale. Since 2014, some ELCs have been reclaimed and returned to residents; however, illegal logging and unofficial ELCs remain significant threats. The decrease in forest resources increases the risk of natural disasters, decreases the biological and genetic diversity of forests, and jeopardizes the local livelihoods of residents who have traditionally relied on forest resources. As deforestation has become one of the most critical threats to ecological, social, and economic systems, the sustainable management and utilization of forest resources to meet current and future needs is one of the important sustainable development goals elucidated by the Royal Government of Cambodia (RGC).

Additionally, rural residents in Cambodia often have limited educational opportunities, resulting in limited knowledge of sustainable natural resource utilization, and a lack of awareness can jeopardize their livelihoods through unplanned forest consumption. Therefore, it is crucial to improve their environmental knowledge and awareness, paving the way for the development of a society that promotes sustainable forest resource management.

Education for Sustainable Development (ESD) empowers individuals and communities by promoting the knowledge, skills, attitudes, and values necessary for creating a more sustainable and equitable society. It also supports countries in achieving their sustainable development goals (SDGs). UNESCO's Green Education Partnership has advanced the 'Green School' as a whole-institution approach to ESD, enabling schools to empower learners as active citizens engaged in promoting sustainable lifestyles and climate action (UNESCO, 2023).

The Institute of Environmental Rehabilitation and Conservation (ERECON) has promoted various projects to create harmony between agricultural and urban development and the natural environment. Since 2021, the organization has expanded its reforestation efforts as part of environmental conservation and Education for Sustainable Development (ESD), leading to the creation of new initiatives across provinces in Cambodia.

PROGRAM AIMS

New initiatives are formed by integrating all three organizational programs, including:

1. Environmental Rehabilitation and Conservation

We recommend promoting participatory reforestation and management activities, enhancing carbon sequestration through agroforestry, conserving biodiversity through mixed planting of native tree species, and promoting genetic diversity through seedling propagation.

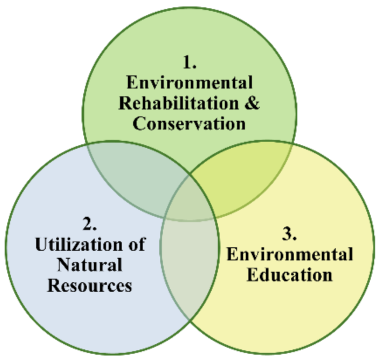

Fig. 1 ERECON's programs

2. Utilization of Natural Resources

Enhancing natural resource circulation through agroforestry, composting local organic materials, and promoting sustainable forest resource utilization.

3. Environmental Education

Promoting training and participatory workshops for the capacity building of local communities, forming management groups by residents, strengthening the capacity of school teachers, and promoting environmental education in schools.

PROJECT SITES

The new projects were promoted across three provinces in Cambodia in collaboration with the Provincial Department of Agriculture, Forestry, and Fisheries of each province and local communities. The Project on Promoting Reforestation for Rehabilitating Rural Environment in Kampong Cham Province, Cambodia, was conducted to promote participatory reforestation and management activities across all ten districts in the province. The Project on Promoting School Environment Greening, aiming for Forest Environmental Education in Tboung Khmum Province, Cambodia, promoted forest environmental education in primary schools in the province.

Lastly, "The Project on Promoting Reforestation and Education for Sustainable Development in Siem Reap Province, Cambodia" was implemented for promoting agroforestry, seedling propagation, and compost making, as well as participatory extension activities in Siem Reap Province.

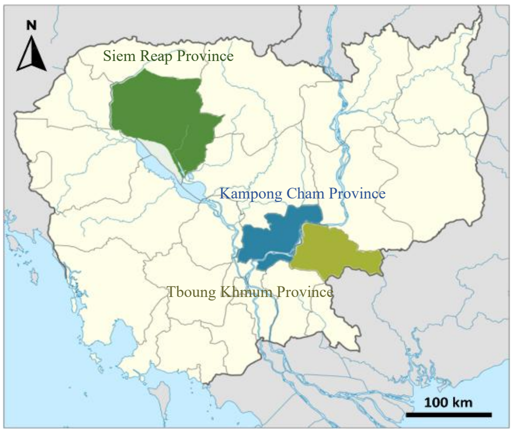

Fig. 2 Project sites in Cambodia

ACHIEVEMENTS

The achievements of each project are shown in Table 1, including restoration approaches, the number of active participants, and extension approaches.

Table 1 The achievements of each project

Project title	Project year	Restoration approaches	Number of active participants	Extension approaches
Promoting Reforestation for Rehabilitating the Rural Environment in Kampong Cham Province	2021-2023	- Community greening at 39 sites in the common area of 30 ha	1,585	- Form management groups at 39 sites - Conduct workshops on the importance of forest conservation
Promoting School Environment Greening, aiming for Forest Environmental Education in Tboung Khmum Province	2022-2024	- School greening at 26 local schools and lake sides in 18 ha - Produce 6,000 local tree seedlings at model schools - Utilize the planting site as an education platform	1,560	- Form teachers' groups at 26 schools - Promote competition among schools on the management practices as a part of environmental education - Facilitated teachers in creating nature games and in developing an environmental education guidebook.
Promoting Reforestation and Education for Sustainable Development in Siem Reap Province	2024	- Promote Agroforestry with local trees and cash crops in 15 ha - Produce 10,000 local tree seedlings - Make compost using organic materials collected from communities	136	- Promote a series of ESD workshops through Participatory Rural Appraisal (PRA), which facilitated the residents to 1) be aware of current situations caused by forest loss, 2) identify the issues to be tackled, and 3) plan for the future greening initiative.

1. Project on Promoting Reforestation for Rehabilitating Rural Environment in Kampong Cham Province, Cambodia (2021-2023)

Fig. 3 Planting activity in Kampong Cham Province

The project promoted reforestation activities across all ten districts in Kampong Cham Province, focusing on the common areas such as pagodas, schools, and along the roads. In total, 30,000 native tree seedlings were planted at more than 30 sites in collaboration with over 1,700 active participants, aiming to restore the environment of rural areas for future generations. In addition, workshops on the "Importance of Forest and Biodiversity Conservation" were conducted to raise the environmental awareness of the residents. The planting sites are being managed by Forest Management Groups formed by residents at each site, who play a central role in management practices to maintain the tree survival rate.

Based on the questionnaire survey conducted among residents after the workshop, approximately 65% of residents understood what they learned in the workshop, and more than 90% were aware of the importance of being involved in management practices after planting by themselves. The results highlight the importance of continuing awareness programs through tree planting activities at the grassroots level.

2. Project on Promoting School Environment Greening aiming for Forest Environmental Education in Tboung Khmum Province, Cambodia (2022-2024)

Fig. 5 Nature game workshop facilitated by school teachers in Tboung Khmum Province

The project promotes a green environment in primary schools and forest environmental education at local schools in Tboung Khmum Province. Various environmental conservation activities were practiced across schools as part of environmental education by promoting planting sites as a nature-based learning platform at schools. In Phases 1 and 2 (2022-2023) of the project, school greening activities engaged more than 1,300 students and teachers from 26 primary schools across districts. In addition to the workshop on "The Importance of Forest and Biodiversity Conservation," each school held a competition on "Seedling Management" to enhance students' active participation in watering and weeding activities, leading to a higher tree survival rate at most of the schools. In Phase 3 (2024), the greening initiative was expanded to include lake conservation around Chitheang Lake, where local farmers and fishers depend on its natural resources for their livelihood. Primary school students and their families participated in planting activities on their own land.

Additionally, two model schools practiced seedling propagation under the supervision of the Forestry Administration, producing 6,000 native tree seedlings that were used for replanting in the communities. Moreover, the capacity building of the school teachers was further strengthened through workshops, where 16 school teachers from three schools developed their original Nature Games, and performed them for their students at the planting sites of Chitheang Lake. At the end of the project, these three schools were awarded under the title of "Excellence in Forest Environmental Education" in recognition of their greater engagement in promoting forest environmental education in Cambodia, acknowledged by the Tboung Khmum Provincial Department of Education, Youth and

Sport (TBK DoEYS), the Tboung Khmum Provincial Department of Agriculture, Forestry, and Fisheries (PDAFF), and the Institute of Environmental Rehabilitation and Conservation (ERECON).

During the project period, monitoring and evaluation practices were conducted to assess the project's impact. The results identified factors in students' awareness and attitudes that showed positive correlations with their active participation in management practices, leading to higher tree survival rates (Aoki et al., 2024). Additionally, the study indicated that comprehensive awareness of the diverse benefits of trees may be positively connected to students' awareness of the importance of forest conservation, which is further connected to their responsible environmental actions (Aoki et al., 2024). This finding could contribute to the development of strategic environmental education to effectively address students' awareness and attitudes toward environmental issues.

3. Project on Promoting Reforestation and Education for Sustainable Development in Siem Reap Province, Cambodia (2024)

The project targeted a rural area of Siem Reap Province, which experienced severe deforestation due to infrastructure and agricultural land development after 2000. To rehabilitate the deforested area in the Banteay Srei District, an agroforestry-based reforestation approach was promoted in a 15-ha plot, subdivided into 15 blocks, where 9,000 native trees of four local species were planted alongside cash crops such as upland rice. A nursery was established to enable the annual propagation of over 10,000 native seedlings, ensuring genetic diversity for future reforestation efforts in the region. Additionally, organic materials were recycled to produce compost, which is used for maintaining the agroforestry site and seedling propagation. Based on a survey of the survival rate conducted in November 2024, it was confirmed to be 79%, and replanting activity was conducted to maintain forest cover.

Fig. 6 Reforestation activity under agroforestry system in Siem Reap Province

To foster local engagement, a series of ESD workshops was conducted through participatory approaches in Kna Krao Village in Svay Leu District. The activities included a workshop on "Sustainable Land Management through Agroforestry," a participatory planting activity, and participatory rural appraisal (PRA) with a gender-sensitive evaluation method. The participatory planting site in a common area became an agroforestry demonstration site, initiated voluntarily by residents.

Fig. 7 Participatory rural appraisal for discussing on a greening plan in Siem Reap Province

In addition, another workshop on PRA encouraged participants to create PRA tools such as a forest resource map, a scoring table for forest resource utilization, and a timeline for land use changes, enabling them to be aware of issues and challenges resulting from the forest loss in their community. The community further developed conservation strategies by creating another PRA tool, the "Future Resource Map for Greening Plan," which served as a valuable opportunity to collect meaningful information on the community's needs for reforestation. It also highlights the risk of losing traditional practices rooted in forest resources due to ongoing forest loss. Through these activities, local awareness of deforestation has significantly improved.

Through the analysis of qualitative and quantitative data acquired through the observation of the workshops, PRA tools, and questionnaire surveys, the key deforestation drivers and their impacts on local communities were identified. The findings highlight the urgent need to develop a forest resource management system and long-term capacity-building programs in the community. Participatory Rural Appraisal (PRA) has been proven to be an effective approach that contributes to raising environmental awareness among local people while enabling outsiders to gather the overall real information of the local context. Moving forward, we will continue to collaborate with stakeholders to enhance forest conservation efforts and strengthen sustainable development strategies in Siem Reap Province.

FUTURE CHALLENGES

International NGOs play a vital role in addressing environmental conservation and human resource development challenges in Cambodia. To respond to the urgent need for greater stakeholder engagement in sustainable practices, promoting a comprehensive approach centered on education is essential. In line with international frameworks, our initiative aims to promote community-based and context-specific agroforestry, as advocated by the Center for International Forestry Research (CIFOR, 2020), as well as Education for Sustainable Development (ESD), promoted by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2014). As part of this effort, we are integrating agroforestry models into various land types, including farmlands, schoolyards, common areas, and residential spaces, to develop practical and localized solutions that reflect the needs of local communities. Moreover, we recognize the critical role of traditional knowledge in these processes, which not only contributes to sustainable resource use but also supports biodiversity through the preservation of cultural practices. Furthermore, by embedding environmental education into school curricula, we are investing in long-term human resource development, which is essential for achieving sustainable development in Cambodia.

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Technical Report

Enhancing Participative Community Development through School Construction and Renovation in Cambodia

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Abstract In rural Cambodia, inadequate school facilities and a shortage of classrooms continue to constrain children's access to education, despite increasing parental demand for schooling. Equally critically, the legacy of the Pol Pot era disrupted traditional forms of cooperation, eroded trust among villagers, and left many communities with limited experience in collective action. These conditions have made the concept of 'community' fragile and underdeveloped, posing significant challenges for rural development. To address both the educational and social dimensions, this project introduced school construction not as an end, but as a strategic entry point for community development. In the fiscal year 2024, the project was implemented in four primary schools in Tboung Khmum Province. At each site, school construction committees composed of local residents and teachers mobilized donations and labor, supervised construction progress, and practiced joint decision-making and accountability. Through these processes, residents began to rebuild trust and recognize the value of working together for a shared public good. After construction, contributions were reinvested into community development funds, which initiated small-scale businesses, such as community loans, chicken raising, fertilizer sales, and agricultural product collection. The profits from these activities are intended to be reinvested in education as revenue grows, reinforcing a cycle that links improved learning environments with community-led economic activities. The results suggest that school construction, when strategically positioned as a driver, can not only improve educational infrastructure but also foster cooperation, ownership, and self-reliance among rural Cambodian communities that have historically lacked strong traditions of collective action.

Keywords community development, school construction and renovation, self-sustaining community, importance of education

BACKGROUNDS AND OBJECTIVE

In rural Cambodia, the educational environment remains inadequate, with shortages of classrooms, limited school facilities, and insufficient hygiene infrastructure. Although parental demand for children's education has been rising, these structural constraints continue to hinder access to quality learning opportunities. Meanwhile, the legacy of the Pol Pot era has severely disrupted community life: traditional forms of mutual support were dismantled, trust among villagers was eroded, and opportunities for collective action have remained limited. Consequently, the concept of "community" has become fragile, posing significant challenges for rural development.

This project was therefore designed to address both educational and social challenges by integrating school construction with community development. School construction was introduced not as an end in itself, but as a practical entry point for fostering cooperation, accountability, and ownership among local residents. By engaging community members in school construction committees, mobilizing local contributions of funds and labor, and subsequently reinvesting these resources into community development funds, the project aimed to create a cycle in which improvements in the educational environment stimulate community-led initiatives, while the benefits of those initiatives are reinvested into education. The ultimate objective was to promote self-reliance and sustainable development within rural Cambodian communities.

Accordingly, this report explores the factors that influence the enhancement of local self-help efforts by creating a sustainable educational environment to improve the livelihoods of local residents and promote sustainable rural development.

STRATEGIES FOR PROJECT IMPLEMENTATION

The project was undertaken in four primary school communities in Tboung Khmum Province, Cambodia (Fig. 1). Its implementation was structured in three interrelated phases, each designed to situate school construction as a driver of community development.

In the first phase, school construction committees were constituted at each site, comprising local residents and teachers. These committees assumed responsibility for mobilizing financial and labor contributions, liaising with construction companies, and ensuring procedural transparency through systematic reporting. The committees were intended to enhance local capacity in collective decision-making, accountability, and negotiation.

In the second phase, new physical infrastructure, including school buildings, toilet blocks, and handwashing stations, was constructed under the oversight of the committees. This phase not only addressed the shortage of educational facilities but also provided an opportunity for community members to engage in collective action directed toward a public good. Simultaneously, hygiene education initiatives were introduced, thereby linking the provision of physical facilities with behavioral improvements in school health practices.

In the third phase, community development fund committees were established. These bodies were trained in bookkeeping and financial management and were tasked with planning and implementing small-scale community businesses adapted to local contexts. Initiatives included community loan schemes, poultry raising, fertilizer sales, and the collection and marketing of agricultural products. The revenues generated from these activities were intended to be reinvested in education, establishing a feedback loop in which improved educational infrastructure and community-driven economic activities mutually reinforced one another. For example, loan schemes were prioritized in Damril Primary School, while cashew nut collection was initiated in Chhuk Sandal, reflecting the adaptation of business activities to local conditions.

Through this sequenced approach, the project sought to demonstrate that school construction could transcend its immediate function of infrastructure provision and operate as an entry point for cultivating community organization, participation, and self-reliance.

ACHIEVEMENTS OF THE PROJECT

The project produced notable achievements in terms of educational infrastructure, community awareness, and the initiation of community businesses. At the same time, it also revealed challenges and limitations that are instructive for future activities. These outcomes are presented in three main domains.

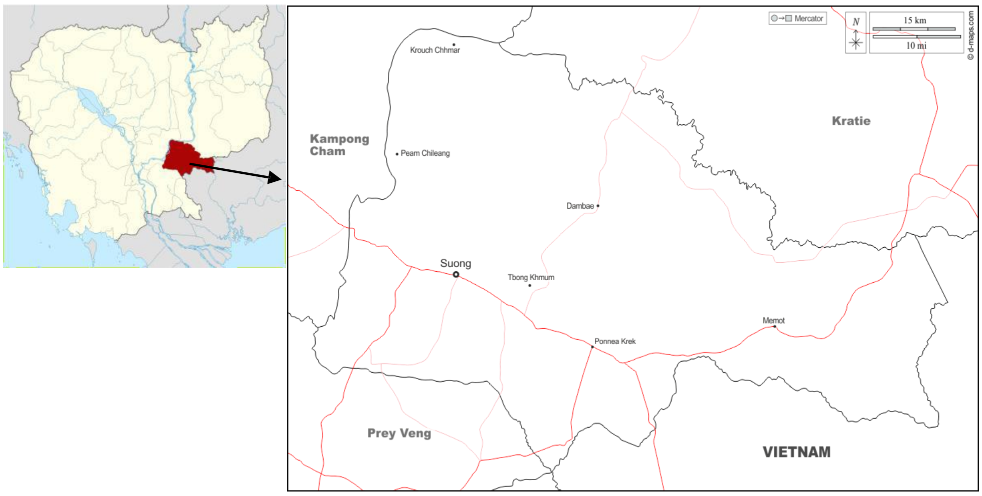

Fig. 1 Project sites for community development through school construction in Tboung Khmum Province, Cambodia

1. Establishment of School Construction Committees

Committees were successfully established in all four target schools. The members organized fundraising, mobilized labor, and monitored construction in collaboration with contractors. Weekly progress reports were produced to ensure transparency and accountability. Committee activities strengthened local capacity in negotiation and management; for example, signing a memorandum of agreement (MoA) with construction companies demonstrated enhanced procedural formality. Residents increasingly recognized that schools were being "built by themselves," rather than externally provided, indicating an emerging sense of ownership. Nevertheless, participation levels varied across schools, with weaker engagement observed in sites where household constraints limited contributions of time and resources (Fig. 2).

Fig. 2 Meetings between the Trapeang Russey Primary School committee and the constructor for MoA signing

2. Improvement of Educational Infrastructure and Environment

The project resulted in the construction of one school building, one toilet block, and one handwashing facility at each site. Specific outcomes included six new classrooms at the Damril Primary School, a staff room and library at Chhuk Sandal (rare in rural contexts), improved space allocation and office functions at Trapeang Russey, and the introduction of afternoon classes at Chimoan, which increased facility utilization. These improvements contributed to compliance with the Ministry of Education, Youth, and Sport (MoEYS) standards, which recommend class sizes of 35-45 students in the lower grades and 40-50 students in the upper grades. Prior to the project, some classes had more than 50 students (Fig. 3).

Hygiene education was also institutionalized. Although MoEYS promoted handwashing during the COVID-19 pandemic, these practices were not consistently sustained. With the installation of new toilets and handwashing stations, hygiene education was reintroduced in a systematic manner. Teachers were trained to deliver lessons on handwashing and toilet cleaning using posters and practical demonstrations, thereby linking new facilities with daily practices and reinforcing continuity (Fig. 4).

In addition to the above, teacher surveys revealed differences in involvement and perceptions of the project. At Chhuk Sandal and Trapeang Russey, all teachers participated in the project, whereas only 64% were involved at Damril and 67% at Chimoan. Moreover, variations were evident in the perceived importance of the project for improving educational quality and community development: 88% of teachers at Chhuk Sandal regarded the project as "very important" or "important," compared to 68% at Damril, 68% at Chimoan, and 60% at Trapeang Russey. These findings indicate differing levels of teacher engagement and recognition of the project's significance across sites (Table 1).

Fig. 3 Inauguration ceremonies at Trapeang Russey Primary School (left) and Chimoan Primary School (right)

Fig. 4 Hygiene workshops at primary schools of Damril (left) and Chimoan (right)

Table 1 Teachers' involvement in, and perceptions of the school construction project

Primary school	Teacher involvement (%)	Perceived importance for educational and community development (%)
Damril Primary School	64%	68%
Chhuk Sandal Primary School	100%	88%
Trapeang Russey Primary School	100%	60%
Chimoan Primary School	67%	68%

3. Establishment of Community Development Funds and Businesses

Community development fund committees were created in all four sites, although business activities commenced only in Damril and Chhuk Sandal within the fiscal year. In Damril, where many households rely on migrant labor and are often composed of grandparents and grandchildren, a community loan project was selected as it required less intensive labor input. This scheme offered lower interest rates than microfinance institutions, thereby reducing household financial burdens.

At Chhuk Sandal, agricultural marketing initiatives were prioritized under the strong leadership of the school principal and village chief. Their capacity to mobilize and coordinate the community enabled the committee to explore multiple business ideas. During the 2025 harvest season, the committee collected and sold 18,871 kg of cashew nuts, generating a profit of USD 152.78. In contrast, an attempt to establish a rice collection scheme faced major difficulties. Insufficient initial communication with villagers and opportunistic selling to external wholesalers offering higher prices undermined the system. This outcome highlighted the importance of early consensus-building, transparent information-sharing, and incentive alignment with community members. Learning from this setback, the committee adjusted its approach in subsequent initiatives, placing greater emphasis on trust and communication, which contributed to the success of the cashew nut project.

Plans for fertilizer sales were also launched, and pilot production of organic compost was initiated to address declining cassava yields, marking an initial step toward sustainable agriculture. However, the labor-intensive nature of compost production poses potential barriers to adoption, and sustained community commitment will be required to ensure its viability.

In Trapeang Russey and Chimoan, where school completion occurred later in the fiscal year, business activities had not yet started, although discussions on potential initiatives were underway.

As the community businesses had only recently been initiated, the revenues generated from these activities remained modest and had not yet been reinvested into education. At this stage, committees were expected to develop clear plans, in consultation with schools, on how future profits could be allocated for educational purposes. For example, in Damril, the committee identified the installation of an incinerator as a priority for improving the school environment. Such initiatives illustrate the process through which schools and committees are expected to work together to shape concrete plans for educational improvement. Thus, the feedback loop between community businesses and educational development was still in the process of formation.

Fig. 5 Cashew nut collection in Chhuk Sandal Primary School community

Summary of Outcomes

Taken together, the results demonstrate that the project improved the educational environment through infrastructure provision, fostered new practices of transparency and collective action, and initiated community businesses that connected local economic activity with educational sustainability. At the same time, the challenges encountered—including limited teacher engagement in some schools, household constraints on participation, and the failure of the rice collection scheme—underscore that successful community development depends on local leadership, communication strategies, and the alignment of activities with community capacities. The variations across sites offer valuable lessons for scaling up community development efforts in rural Cambodia.

CONCLUSIONS AND FUTURE PERSPECTIVES

In fiscal year 2024, the project engaged four primary school communities in Tboung Khmum Province to improve educational environments and foster community development through the integrated processes of school construction and committee management. The outcomes demonstrated that school construction can function as more than an infrastructure intervention; it served as an entry point for cultivating collective action, transparency, and ownership among local residents. Teacher surveys further indicated that, although levels of involvement and perceived importance varied, the project contributed to greater awareness of the link between education and community development. Several challenges also emerged. In some communities, household structures, such as reliance on migrant labor or elderly caregivers, constrained active participation. Variations in leadership capacity also influenced outcomes, with Chhuk Sandal's strong village chief and school principal enabling diverse business initiatives, while other sites faced difficulties in mobilization. The unsuccessful rice collection scheme further highlighted the risks of inadequate communication and the need for consensus-building prior to launching community businesses. These experiences underscore that school construction alone cannot guarantee community empowerment; rather, the quality of facilitation, leadership, and participation strongly conditions the results.

Looking ahead, the project provides useful insights for scaling up community development through educational infrastructure. First, continued support for committee capacity building—especially in bookkeeping, communication, and negotiation—will be critical to sustaining both educational and business activities. Second, tailoring community projects to the specific socioeconomic contexts of each community is essential, as demonstrated by the appropriateness of the loan scheme in Damril and the cashew nut initiative in Chhuk Sandal. Third, building mechanisms for continuous monitoring and reflection will help communities learn from both successes and setbacks, thereby reinforcing self-reliance. These findings also have practical implications for policy, suggesting that school construction initiatives should be integrated with capacity-building and community engagement strategies to maximize their developmental impact.

In conclusion, this project aims to improve the sustainability of local communities through the integration of school construction with community development. The outcomes of this project are expected to contribute not only to improved educational infrastructure but also to the long-term formation of self-sustaining and resilient rural communities in Cambodia. Increasing local residents and governmental officers' understanding of ESD is indispensable for scaling up and replication in other areas.

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