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Feasibility of Pre-Harvest Sago Frond as State-of-the-Art Resources to Produce Animal Feed

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ABSTRACT

Global crises such as climate change, war and borderless diseases are the factors that lead to limited supply and unstable prices of the raw material to produce animal feed placing a major burden on the farmers and smallholders to produce livestock at a reliable cost. Malaysia is among the most affected country due to its high dependency on imported resources to produce animal feed. Hence, cheap and locally available raw material is the key to producing sustainable and safety-ensured animal feed for domestic consumption. Due to the adaptability and resilient nature of sago palm towards extreme environmental distress, sago frond was selected as an alternative raw material to produce animal feed in the form of silage. Sago frond was pruned from growing sago palm (age between 3-7 years), then leaves and rachis were pulverised before vacuum packed into silo bag. Analysis shows that optimised sago frond silage (1:1 RSF/SL) possessed five ideal characteristics that include dry matter (47.76 %), acid detergent fibre (31.98 %), total water-soluble sugar (2.4 g/Kg), minimum pH (4.3) and protein content (16.85 %). Hence, the ensiling technique applies to produce high-quality animal feed from optimum formulated sago frond by preserving nutrient content and improving in-vitro digestibility of the silage designated for ruminant consumption. The feeding trial shows significant growth performance of animal models (Malin Breed Sheep) fed with optimised SFSil with Average Daily Gain (61.12 g/day) and Feed Conversion Ratio (9.64 g/g). Therefore, manufacturing animal feed from pre-harvest sago frond provides the solution to high dependency on imported animal feed and also offers a new lucrative commodity for the sago farmers while waiting for the sago palm to be harvestable.

Keywords: Silage, rachis, ensiling, ruminant, silo bag.

INTRODUCTION

The Malaysian National Beef Policy was introduced in 2006 to enhance the growth of the livestock industry and is expected to increase the cattle population to 470 000 (1.15 million total population) in 2010 and 610 000 (1.5 million total population) in 2015. The concern on Malaysia dependency on imported food is reflected through the deficit of meat production from ruminant compared to domestic consumption from 2014 to 2020 (DVS, 2021). Significant with the increment of cattle population, the Self-Sufficient Level (SSL) was projected to increase from 18% to 21% in 2010 and continue to increase up to 40% in 2015. However, the policy was failed to be executed; in fact, the population of the ruminant and SSL of the meat were eventually decreasing and continuously dependent on imported meat (Sujang, 2020). The substantial deficit of meat that was required to fulfil Malaysian domestic consumption is covered by imported frozen meat from Australia, New Zealand and India. The increase of import value and lower SSL of meat for domestic consumption resulted from the reduction of the local meat production, as shown in Figure 1.8. In general, Malaysia is experiencing a negative trade balance in the ruminant industry involves not only fresh meat but also milk, animal feed, and downstream product derived from milk and meat for domestic consumption need to be covered through importation (Sujang, 2020).

Dependency on imported meat raised several issues that have compromised food security and safety in Malaysia. As a Muslim-majority country, Malaysian authorities obligate imported meat products (except pig) to obtain halal certificate from the Halal Certification Agency of the respected county accredited by the Department of Islamic Development Malaysia (JAKIM). The exporter who fails to comply with the Halal regulation will be prohibited from exporting meat products to Malaysia. In 2005, New Zealand beef import was banned by the Malaysian authorities due to unethical slaughtering methods. As a direct impact of this prohibition, Malaysia losses 6% to 8% of beef supply for domestic consumption. However, after two years, the banned was lifted to break up the monopoly by the local cartels and bring balance to the beef's market price (Ritikos, 2007).

The Malaysian Halal regulation also needs to be complied by the local importer before the imported meat is allowed to enter the Malaysian market. Malaysia, in shock after the blew-up scandal of counterfeit Halal status of imported meat, was affronted by the local meat cartel in 2020. About 1000 tons of meat imported from Brazil was distributed to 202 retailers all over the country with a fake Halal logo. The incident triggers hesitation from the Muslim consumer on the halal status of the imported meat that existed in the market. The modus operandi of the syndicate was to repack the imported meat into the box labelled with a fake halal logo; hence, the hygiene of the imported meat cannot be confirmed. In general, it raised concern not only to Muslims but the whole consumer in Malaysia (Shazwani, 2021).

Due to the potential risk, currently, the consumer prefers to buy local meat even though the price of fresh meat is far more expensive and unstable. This circumstance generates massive demand for local meat; however, the current production capacity of livestock, especially ruminants, is limited and creates a substantial deficit between production and demand.

According to Sujang (2020), the main challenge in the livestock production industry is the availability of local and imported animal feed. Lack of plantation area for forage cultivation is caused by competition with the more profitable industrial crop. This factor contributes to the minimum productivity of local feed and high dependency on imported feed. The feed cost accommodates 70% of the total cost of livestock production; hence, the slight change in the feed price will cause a major influence on the total cost of livestock production.

Malaysia imports RM 3.2 billion worth of animal feed annually to support the sustainability of the livestock industry. Argentina dominates the supply of maize as the raw material for animal feed production to Malaysia with an 80-90 % share. A few major factors influence the availability and price of raw materials for animal feed production. First, the policy of the developed country to preserve the environment by replacing the use of non-renewable energy with renewable energy for fuel. The United States of America produces 7.5 billion gallons of bioethanol from 2.8 billion-bushel maize as substrate. Second, the usage of maize in multiple industries, such as for the production of food, food additive, chemical and fuel manufacturing, creates intensive competition on the demand of maize from the global market (MARDI, 2017).

Lastly, the impact of climate change on the productivity of the feed crop can directly influence the availability of raw materials for animal feed production in the global market. Climate change is predicted to intensify the vulnerability of the feed crop productivity and efficiency due to prolonged hot and dry seasons, increase of the global temperature, carbon dioxide level and nitrogen deposition (Hidossa & Guyo, 2017).

Hence, alternative local food crops that can be grown under extreme conditions with a by-product that can be utilised without affecting the requirement of the main commodity for food production must be identified. Therefore, to promote animal feed production to support the local livestock industry and eventually reduce dependency on imported feed and food.

Silage is the conventional feed used to fed ruminant livestock organically produced through anaerobic fermentation also known as ensiling process of fodder such as Napier grass and corn. The main purpose of ensiling is to preserve fodder for long term feeding especially during extreme weather conditions such as winter when most feed crops cannot grow. Application of ensiling technique on locally available crop's by-product can be ecologically and economically sustainable source of feed to support local livestock industry by reducing dependency on imported feed. Utilizing industrial crop by-product that resilient against climate change like Sago palm frond into animal feed is the innovative solution by turning the problem of Sago palm long maturation period significantly into opportunity as ethical and reliable source of raw material to produce lactic acid and animal feed (Ahmad et al, 2022).

Sago palm was typically utilised as source of starch which is used to produce wide variety of traditional delicacies and commercial food such as noodle. Besides, sago starch is used as the binder for the formulation of poultry feed. The excessive composition of amylopectin compare to amylose in sago starch is less suitable for the production of animal feed. In addition, utilisation of sago starch to produce animal feed will raise conflict of using limited food crop either to produce feed or human foodstuff. However, sago industry also produces massive amount of biomass upon the extraction of the starch from the trunk. Conventional sago starch production will release abundance of residual fibre known as 'Sago hampas' was used to fed free ranch livestock such as pigs, and dried hampas used to fed chicken (Ahmad, 2022). Application of modern technology such as solid-state fermentation able to improve the formulated sago hampas to be developed as low-cost fish feed (Khalil et al, 2016).

However, application sago frond is limited for making traditional roof and handicraft at the moment. The rachis of sago frond contain sap possess free sugar of combination between glucose and xylose. Those free sugar can be ideally utilised as carbon source to cultivate probiotic such as lactic acid bacteria to produce high quality silage. Traceable amount of minerals (Mg, Mn, Cu and Zn) in the sago frond will stimulate the growth performance of the microflora to accelerate the ensiling process which highly influence the quality of the silage. The performance of the ensiling process exhibited through the ability to prolong the storage time and maintain the nutritional content of the silage (Ahmad, 2022).

Therefore, sago frond possessed the advantages to be utilised as feasible raw material to produce animal feed complementary to the development of livestock production in order to reduce dependency on imported food and feed from the global market.

MATERIALS AND METHODS

Sago Frond

In this research, sago frond was used as the raw material. The Sago frond is the top part of the sago palm, which consists of numerous long and slender leaves attached to a solid stalk or rachis (Figure 1). The rachis can be spiny (as used here) or smooth, depending on the variety of the sago palm.

Figure 1: A cluster of 3 to 5-year-old sago palm

Fronds used for our study was obtained from palms aged between 3 to 5 years old in a 0.41 ha sago plantation harbouring 315 sago clusters (medium density) near Saratok, Sarawak. Leaves and spines were removed, and the rachis was cut into shorter sticks of about 1 m in length without removing the tough skin. The spines were carefully discarded while the leaves and rachis were kept for further studies.

Formulation and Production of Sago Frond Silage (SFSil)

Sago leaves and pressed sago rachis from the extraction of the sap (named residual sago fibre) are the main ingredients in the production of sago frond silage. This was pulverised separately using a mobile shredder (Kasei, Malaysia). Subsequently, pulverised sago leaves and residual fibre are mixed according to the designated ratio, as shown in Table 1.

Table 1: Formulation on mixtures for making sago frond silage (SFSil)

Mixing Ratio	Formulation	Composition (fresh weight)
RSF	100% RSF	1000 g RSF
3:1RSF/SL	75% RSF : 25% SL	750 g RSF + 250 g SL
1:1RSF/SL	50% RSF : 50% SL	500 g RSF + 500 g SL
1:3 RSF/SL	25% RSF : 75% SL	250 g RSF + 750 g SL
SL	100% SL	1000 g SL

Note: RSF: Residual Sago Fibre (from the extraction of the sap), SL: Sago leaves

The ideal mixture or formulation (Dry matter, Acid Detergent Fibre, Total Water Soluble Sugar, minimum pH and Protein Content) was used later for mass production of sago silage in our feeding trials. These factions were packed into double layer plastic bags, and the air was removed by using a vacuum cleaner.

Feeding Trial

The growth performance of the sheep upon consumption of the formulated SFSil was analysed based on weight gain, dry matter digestibility and feed efficiency. Based on expected dry matter intake of the target animal model at 4% of body weight and the average of sheep's body weight selected are around 20 Kg, about 3 tons of silage needed to be prepared for the feeding trial for accommodate 90 days of the feeding trial.

Weight Gain

The twenty (20) sheep were weighed before the feeding trial started as initial weight and to determine the growth stage of the animal. Once the feeding trial commenced, the sheep were weighed every week to determine their weight gain. The growth performance of the sheep was analysed using Equation 1 presented as Average Daily Gain (ADG).

$$\text{Average Daily Gain (g/day)} = \frac{\text{Final Weight} - \text{Initial Weight}}{\text{Total day of feeding trial}} \qquad \text{Equation 1}$$

Dry Matter Digestibility

The digestion efficiency of in-vivo dry matter in the silage must be determined in order to postulate the ability of the targeted sheep to absorb nutrients from the feed served. Dry matter digestibility (DMD) was studied by determining the dry matter of the faeces collected weekly from the individual septic box placed under the paddock. This was calculated using Equation 2 (Stockdale & Rathbone, 1992).

$$\frac{\text{Dry feed (for one week)} - \text{Dry faeces (for one week)}}{\text{Dry feed (for one week)}} \text{ X } 100\% = \text{DMD (\%)} \qquad \text{Equation 2}$$

Feed Efficiency

Feed efficiency was analysed to determine the effects of feed according to on the growth performance of the sheep. Feed Conversion Ratio (FCR) and Residual Feed Intake (RFI) methods were applied as indicators to determine the efficiency of the feed served to the sheep. FCR was used to determine the amount of feed required to contribute to the weight gain of the sheep where the lower values are more favourable (Lima et al., 2017). FCR is calculated using Equation 3.

$$\text{Feed Conversion Ratio (g/g)} = \frac{\text{Average Dry Matter Intake (g)}}{\text{Average Daily Gain (g)}} \qquad \text{Equation 3}$$

Residual Feed Intake (RFI) is described as the difference between actual feed intake and estimated feed intake based on the bodyweight of the sheep where the lower values are more favourable (Lima et al., 2017). RFI is calculated using Equation 4.

$$\text{Residual Feed Intake (g/day)} = \text{Actual DMI (g/day)} - \text{Expected DMI (g/day)} \qquad \text{Equation 4}$$

Cellulose Digestion

The population and viability of the cellulolytic bacteria influence the efficiency of the ruminant digestive system. The efficiency of the cellulolytic bacteria in the rumen of the sheep was determined using a modified in vitro cellulose digestion method (Claydon & Teresa, 1959). The experiment was conducted by adding 10 mL rumen fluid and 0.3 mL 16% glucose solution in a test tube containing a pre-weighed cellulose filter paper. The test tube was incubated at 39 ℃ for 72 hours, following which the filter paper was removed and dried at 50 ℃ for 24 hours. The final weight of the filter paper was recorded. The digestion activity of cellulolytic bacteria in the rumen fluid is calculated using Equation 5:

$$\text{Cellulolytic Bacteria Digestion Activity } (\mu\text{g/mL/hour}) = \left[\frac{(W-F)}{\text{Incubation time}}\right] \qquad \text{Equation 5}$$

W = Initial weight of cellulose Filter Paper
F = Final weight of cellulose Filter Paper

Glucose Fermentation

The capacity of microorganisms isolated from the rumen fluid to utilise glucose solution is the indicator used to determine the viability of the rumen microflora (Alsaad, 2019). The viability and population of the microbes can affect the amount of gas produced during fermentation. Rumen fluid with a higher population and active microorganisms will produce more gas in a shorter duration. The gas is captured and measured using syringes attached to test tubes using our set up named as modified saccharometers, as shown in Figure 2.

Figure 2: Determination of gas produced from glucose fermentation by rumen microbes using modified saccharometers

RESULT AND DISCUSSION

Physical Characteristics of Sago Frond

This study was conducted to determine the physical aspects of the sago frond to estimate the amount of silage produced. The analysis can determine the feasibility of sago frond to be utilised as raw material to produce animal feed. Table 2 shows the physical characteristics of fronds collected from a sago farm located at Kampung Kaba, Saratok, Sarawak.

Table 2: Physical characteristics of the sago frond

Description	Sago Frond (SF)
Source	Kampung Kaba, Saratok, Sarawak
Size of the sampling area	0.2 hectare
Amount of cluster	30
Amount of palm/cluster	5-7
Quantity of frond/palm	7-12
Quantity of leaves/frond	150-200
Fresh weight of leaves/frond	10-12 kg
Amount of SF obtained	Rounded to 7,000 kg from 700 fronds

Sago palm produces a new frond every month, which becomes fully grown within the subsequent two months (Flach, 1996). Harvesting of sago frond is a common practice in sago farming, similar to pruning of suckers as a practice by local sago farmers in Sarawak. It has been shown that the presence of numerous daughter suckers can negatively affect the development of the mother trunk (matured palm), resulting in reduced starch production (Nabeya et al., 2013). The density of the suckers must be regulated for optimum growth space; hence need to be removed to prevent rampant growth while the fronds are pruned to promote healthy growth of the mother trunk. Before our study on converting the fronds and leaves to silage, these raw materials were usually abandoned and left to dry and decay on the farm potentially become fire hazard during drought season.

As shown in Table 2, harvesting of fronds from selected sago farms resulted in 700 fronds, corresponding to 7 tons of raw material for the production of silage. From here, it can be postulated that 35 tons of raw material can be utilised to produce silage as animal feed from every hectare of sago palm plantation. Based on all this information, it is proposed that fronds can be harvested from the same sago palm at a duration of 8-10 months cycle to sustain continuous production of silage.

The extensive study shows that sago leaves possess an average 4.1 kg/frond equivalent to 44.27% of the fresh weight removed from the frond. On the other hand, sago rachis contributes 55.71% of the fresh weight per frond after the sago frond sap extraction equivalent to 5.1 kg/frond. The analysis shows that there is no significant difference of fresh weight between sago leaves and rachis per frond that indicate that the average ratio of rachis and leaves per frond is parallel with the ideal formulation of the silage with 50% SL and 50% RSF that will ease the large scale production of the silage and completely utilise all the resources.

Determination of Ideal Formulation for Large Scale SFSil Production

The compilation of parameters is shown in Table 3 below. This table is coded into three different colours representing the ideal, acceptable and poor parameters. It is possible to choose the best mixtures associated with the chosen parameters for the large-scale production of silage in our subsequent feeding trials.

Table 3: Summary of parameters in different formulations of sago fibre and leaves to study the ideal mixture in producing sago frond silage

Formulations	**DM (%)**	**Fibre**		**TWSS (%)**	**Minimum pH**	**% Final Protein (% loss)**
		NDF (%)	**ADF (%)**			
RSF	41.34	30.27	31.12	9.42	4.03	6.1 (10.80)
3:1RSF/SL	41.4	36.68	34.84	5.0	4.2	10.56 (10.37)
1:1RSF/SL	46.85	40.07	31.98	4.22	4.3	16.85 (13.22)
1:3 RSF/SL	48.5	42.37	34.67	2.05	4.6	17.86 (20.55)
SL	56.77	46.9	49.28	2.1	4.7	16.54 (36.4)

Ideal Acceptable Poor

Evidently, using sago leaves on its own (SL) generates very low-quality silage from the defective fermentation process, which will lead to several health problems when consumed by the ruminants. Mixtures of sago fibre and sago leaves at 1:3 RSF/SL has two acceptable parameters (% DM and % ADF) coupled with four poor parameters (% NDF, TWSS, pH and Final Protein content).

Residual Sago Fibre formulation possesses two ideal parameters: low ADF and NDF content representing the higher edibility and digestibility of the silage produced and three acceptable conditions. However, only one parameter labelled as poor, which is the minimum pH, was extremely low that may cause acidosis to the selected sheep. The 3:1 RSF/SL SFSil formulation shows all parameters (DM, ADF, NDF, TWSS, Minimum pH and Final protein) with the acceptable condition that can be selected to produce silage under restricted circumstances due to low protein content that might lead to malnutrition to the targeted sheep if used for long term consumption.

Undoubtedly, 1:1 RSF/SL SFSil formulation hold the possession of ideal formulation for the production of silage from sago frond where five (DM, ADF, TWSS, minimum pH and Final Protein) over 6 of the parameters scored as the ideal condition for the production of high-quality silage. Only NDF content was labelled as the acceptable parameter. However, it can be improved by introducing additives into the formulation, such as the addition of cellulolytic enzyme or inoculation of selected lactic acid bacteria to enhance the fibre's degradation. Therefore, 1:1 RSF/SL SFSil formulation was selected for large scale production of silage for the consumption of targeted sheep to discover the potential of sago frond to be developed as a novel source of animal feed.

Growth Performance and Feeding Efficiency

Study on the overall growth of the sheep as targeted animal involved the amount of feed consumed and weight gain as the indicator for feed efficiency. Sheep were fed with sago frond silage against the commercial feed that contained different nutrients designated for different growth needs. By comparing the growth and physical properties of these sheep. A result from this 3-month study on the twenty sheep was shown in Table 4.

Table 4: Comparison between feed efficiency and weight gain of sheep that consume sago frond silage and commercial feed

Parameters	**Types of Feed**	
	SFSil	Commercial Feed
Average Feed Intake (AFI, g/day)	960.86±14.01[a]	978.75±29.78[a]
Dry Matter Intake (DMI, g/day)	360.32±5.25[b]	910.24±27.69[a]
Average Daily Gain (ADG, g/day)	61.12±12.62[a]	97.67±14.07[a]
Residual Feed Intake (RFI, g/day)	-168.68±40.72[b]	81.48±55.43[a]
Feed Conversion Ratio (FCR, g/g)	9.64±2.5[a]	12.93±3.8[a]

Statistical analysis was determined using One ANOVA and Tukey tests. Each value is the mean ± SE of 10 replicates. Means with the same letter are not significant at $p < 0.05$.

These trials revealed that sheep fed with different feed types had no significant difference on the Average Feed Intake (AFI) after 90 days of the feeding trial. The daily silage consumption for sheep fed with SFSil and commercial feed was 960.86±14.01 g/day and 978.75±29.78 g/day, respectively. This indicates that the preference of the sheep on sago frond silage as their daily feed was almost similar to the commercial feed.

Meanwhile, the results show that the dry matter intake (DMI) of sheep fed with SFSil was significantly lower compared to those fed with commercial feed (910.24±27.69 g/day) due to higher moisture content in SFSil, at 40.6% compared to the latter at 91.5%. Analysis of Average Daily Gain (ADG) is used to indicate the effect of the ADI and DMI on the targeted animals. No significant difference was observed on ADG between SFSil (61.12±12.62 g/day) and commercial feed (97.67±14.07 g/day). This suggested that the growth of the targeted sheep fed with SFSil was comparable with commercial feed as daily animal feed. Hence, the ADG of sheep fed with commercial feed reflects that high DMI does not correspond to their growth. This implies that the commercial feed's nutrients were not efficiently absorbed by the sheep for growth. According to Klinger et al. (2007), the ad libitum feeding system increased the DMI of the high grain feed by the ruminant up to 17.5% higher compared with the restricted feeding system. Yet, the ADG of the ruminant shows no significant difference followed by 31% higher faecal DM output by the ruminant fed with ad libitum feeding compared with the restricted feeding method. High faecal DM output indicates low digestibility of the high grain feed by the ruminant by ad libitum feeding due to high passage rate that leads to a reduction in holding time in the digestive tract, which limits the time for digestion (Loerch, 1990). Hence, nutrients from high grain feed cannot be appropriately absorbed, which were required for the growth of the ruminant leading to lower ADG. Meanwhile, the unabsorbed nutrient is wasted and removed from the digestive system together with the undigested substance, subsequently increasing the faecal DM.

The correlation between DMI and ADG of the sheep influenced the feeding efficiency of the feed expressed through Residual Feed Intake (RFI) and Feed Conversion Factor (FCR). In the analyses of RFI and FCR, the lower value is favourable to indicate the higher efficiency of the feed. Based on the result, the RFI of SFSil was significantly lower compared to commercial feed, where the RFI of SFSil -125.35±43.6 g/day compared to commercial feed was 81.48±55.43 g/day. The negative RFI value of SFSil suggested that the actual DMI of the silage was lower than expected DMI represent high efficiency of the feed where less amount of feed required to contribute in the viable growth performance of the sheep as expected DMI used as the benchmark for the amount of daily feed intake required to maintain the growth of the tested animals.

On the other hand, positive RFI value from commercial feed revealed the actual DMI was higher than expected as a result of less feeding efficiency where the animals required more daily feed intake to maintain good growth. As reported by Elolimy et al. (2018), the residual feed intake is positively correlated with the ruminal bacterial activity in the digestive system of the ruminant. High ruminal microfloral activity, especially cellulose-degrading bacteria, is imperative to induce fermentation of fibres such as cellulose and glucose to produce volatile fatty acid (succinate, acetate and formate) as fuel for ketogenesis to generate energy for the growth of the ruminant. The application of high grain feed such as commercial feed used in this study lead to the alteration of the ruminal microflora community and lead to the massive production of lipopolysaccharide in the peripheral blood as a result of the rapid death of gram-negative bacteria that mostly responsible for the fermentation of the fibre in the digestive system (Zhang et al., 2018). Thus, the existence of natural anaerobic bacteria in the SFSil increased the population of the probiotic bacteria, which stimulates microflora activity associated with cellulose degradation in the targeted sheep that eventually leads to low RFI value.

In addition to the RFI, FCR analysis was conducted to determine feeding efficiency that relates to the growth performance of the sheep. The FCR value indicates the ratio of the DMI to the ADG of the animal feed reveal the productivity of the feed consumed transformed into the biomass of the sheep. Based on our result, there were no significant differences in FCR between SFSil and commercial feed. Hence, the result indicates that the overall feeding efficiency SFSil was comparable with commercial feed toward the productivity of feed to meat conversion. As claimed by Reddy (2019), a few factors affect the FCR, including species verity, growth stage, and feed quality. The ideal FCR for sheep for high concentrate rations was between 4.5 to 5, where 5.5 is on good quality forage and FCR more than 6 indicate low feeding efficiency, and it can be as high up as 30 on straw ration diet (Abdulquadri, 2018). Therefore, the analysis of FCR was conducted according to the growth stage of the ruminants to identify the ideal feeding strategy using SFSil as a steady diet for the ruminant.

Rate of Nutrient Absorption

Dry matter digestibility was analysed to determine the total nutrient intake from the given feed. This reflects the efficiency of the digestive system to process and absorb nutrients from the tested feed types. Table 5 shows the digestibility of these feeds in our trials on sheep.

Table 5: Comparison on digestibility of SFSil and commercial pellet

Feed Type	SFSil	Commercial Pellet
FDM, %	57±2.33[a]	46.42±3.32[b]
DMD, %	50.89±2.21[b]	77.86±3.02[a]

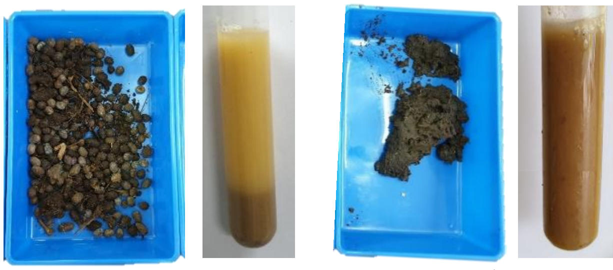
* FDM: Feed Dry Matter, DMD: Dry Mater Digestibility

Statistical analysis was determined using One ANOVA and Tukey tests. Each value is the mean ± SE of 3 replicates. Means with the same letter are not significant at $p < 0.05$.

Based on the result, sheep fed with commercial feed produced lower faeces dry matter content (46.42±3.32&) compared to SFSil at 57±2.33%. Increased moisture content in faeces suggests increased water intake and water reabsorption as responses towards excessive dry matter of the feed. According to Garcia et al. (2010) dry matter intake of the ruminant positively correlated with the water intake since water is required in the metabolism of digestible energy. Hence, the increase in dry matter intake leads to a higher concentration of digestible energy consumed by the ruminant that requires more water intake to process the energy. It was reported by Aganga (1992) that the high dry matter content of the feed increased the water intake of sheep.

The result of increased water intake from consuming a certain type of feed is established by this study. Comparison in conditions of residual feed in the rumen of sheep fed with sago frond silage SFSil and the commercial pellet is shown in Figure 3. It is shown here that residual feed in the rumen of sheep fed with SFSil remains in bolus formation with the minimum amount of water. It was revealed in that water content in the faeces regulates the consistency, shape and texture of the faeces. Faeces and ruminal fluid obtained from sheep fed with the SFSil and commercial pellet shown in Figure 4.

Figure 3: Residual feed condition in the rumen of a slaughtered sheep fed with (a) SFSil and (b) commercial pellet



(a) (b)

Figure 4: Physical properties of Faeces and Ruminal Fluid collected from sheep fed with (a) SFSil and (b) Commercial pellet

It is shown here that residual feed in the rumen of sheep fed with SFSil remains in bolus formation with the minimum amount of water. This is due to the ideal moisture content of SFSil, which dilute salt concentration in the feed to prevent the suppression of saliva in the ruminant. The moisture content in SFS also acts as the source of water for the ruminant required for the formation of bolus during chewing and assist in swallowing. This reduces the dependency on the secretion of saliva, rendering the sheep less thirsty and consumed water at normal quantity. In contrast, sheep fed with commercial pellets tend to be thirstier, drink more water and end with water accumulation in the rumen.

The ideal level of rumen wall osmolality reduces the mobilisation of water absorption in the digestive system, preventing the water accumulation in the rumen. Excessive water contained in the ruminant was discharged from the body through urine, transpiration and faeces. A large amount of water can be removed through faeces, which influence the moisture content and structural integrity of the faeces. Analysis of the water balance of sheep fed diets formulated with forage palm (low dry matter fresh feed) and concentrate feed (high dry matter feed) shows that feed formulated with higher concentrate leads to higher water intake and water balance. On the other hand, increasing forage palm content in the formulated feed decreases water intake and water balance. Hence, increasing water intake and water balance significantly increases water loss through faeces (Garcia et al., 2010).

The shape, texture and consistency of faeces are usually used as early indicators to diagnose the health condition of animals. Under normal conditions, sheep droppings should be in the form of a consistent firm pellet, light to mid-brown colour and loose into fine pieces. The faeces condition of the sheep fed with SFSil and commercial pellet are consistent with information as reported previously where the high dry matter content of the commercial pellet leads to higher water intake. This causes water accumulation in the rumen, resulting in vast water loss via faeces which affects its shape and texture (Lynn et al., 2009). Watery faeces are common symptoms of sheep experiencing diarrhoea due to parasite manifestation, rumen acidosis and nutritional factor. Sheep may suffer from diarrhoea due to imbalance ratio of excessive fluid to dry matter intake that violates the normal habit of the sheep. Also, the consumption of a large amount of high grain diet leads to rumen acidosis that interrupts the rumen acidity, leads to inflammation of the rumen wall, and reduces the microflora population involved in fibre digestion (Schoenian, 2007).

Study on the rumen fluid confirmed the prognosis of sheep which may experience rumen acidosis, the pH of the rumen fluid was analysed where sheep fed with commercial pellet exhibit significantly low pH value at 5.24±0.13 compared to SFSil fed sheep at 6.38±0.15 pH value obtained from 3 slaughtered individuals animal model from each treatment (3 over 10). According to Petrovski (2017), the type of diet is the major factor that influences the pH of the rumen fluid in ruminants. Ruminants fed solely with pasture diet normally contain rumen fluid with pH 6.0 to 7.2. A rumen pH of 6.0 to 6.8 is common for ruminants on a diet containing high crude fibre. On the other hand, easy-digestible carbohydrates will give a rumen pH of 6.0 to 5.0. Highly acidic rumen condition is normally due to inappropriate feeding practice from consistent consumption of simple fermentable carbohydrates such as cereal meal. Extremely acidic rumen pH of 4.0 to 5.0 will immediately confirm the diagnosis of rumen acidosis. Alternatively, persistent pH less than 5.5 is the prognosis to subacute ruminal acidosis (SARA) when the accumulation of pH reading of 3 over 12 of the ruminant from the same group of feed tested have a rumen pH less than 5.5 will confirm the feed contribute to SARA.

Rumen Microflora Efficiency

The ability of active cellulolytic microflora to metabolise cellulosic components of the fibre in the rumen will provide sufficient fermentable carbohydrate to the ruminant. Later, the fermentable carbon used as fuel to generate energy for growth and lactation for milk Analysis of the effects feeding with SFSil and high grain feed on the activity of cellulolytic bacteria and glucose consumption is shown in Table 6.

Table 6: Cellulose digestion activity

Sample	Cellulolytic Activity (µg/mL/Hour)	Glucose Consumption (mL/Hour
SFSil	2.06±0.04[a]	1.1±0.1[a]
Commercial Pellet	1.54±0.15[b]	0.175±0.06[b]

Result shows that cellulose metabolised in the rumen fluid obtained from sheep fed with SFSil at 2.06±0.04 µg/mL/hour, which is significantly higher than those fed with commercial feed at 1.54±0.15 µg/mL/hour. Rumen fluid extracted from sheep fed with commercial pellets shows alarmingly low cellulolytic bacteria activity hence affecting the efficiency of cellulose digestion. The rumen pH was the major factor affecting the productivity of the cellulolytic bacteria. According to Miyazaki et al. (1992), cellulolytic bacteria are normally sensitive to low pH, and the population of important cellulolytic bacteria such as *Ruminococcus* and *Fibrobacter* are suppressed below pH 6.1. Since the rumen fluid was extracted from sheep diagnosed to have suffered from ruminal acidosis and with a pH value less than 5.5, obviously, the activity of the cellulolytic bacteria has considerably diminished.

The rumen microflora also consumes glucose to maintain the ideal population to keep up the digestive system metabolise feed efficiently to provide the animal with a sufficient amount of crucial nutrient such as volatile fatty acid and produce gases as a by-product. Evidently, sheep fed with SFSil produced a substantial amount of gas from the metabolism of the glucose, indicating signs of high microflora activity in the rumen. In line with the analysis of cellulose digestion, glucose fermentation in the rumen fluid extracted from sheep fed with commercial pellet was extremely low gas productivity at 0.175 mL/hour, indicating low bacterial activity utilizing glucose in the rumen. According to Zhang et al. (2017), the production of hydrogen gas from the degradation of fibre by rumen microflora was under the major influence by the pH level of the rumen fluid where the most productive rumen microflora activity was at pH 6.5 produced 178 mL/L hydrogen gas by utilizing 81.3% cellulose within 48 hours meanwhile, under the acidic condition at pH value 5.5 suppressed hydrogen producer bacteria such as *Clostridium* sp. and *Enterococcus* sp. explains low gas production from the glucose fermentation of the rumen fluid obtained from sheep fed with commercial pellet.

The capability of the rumen microflora metabolism covers crucial aspects, including to provide a source of energy, manipulating cell membrane charge, substrate degradation and producing a series of metabolic materials for the ruminant directly dependent on pH level which the microorganism involved in cellulose degradation and glucose fermentation are sensitive to pH even slight reduction will sink their population and activity also will alter the species paradigm allow the acid tolerance microorganism to dominate the total population of the rumen microflora which mostly not involve in feed digestion will increase bacterial endotoxins leading to series of negative impact to the ruminant health (Wu et al., 2017).

Comparative Analyses of Malin Sheep Production Costs between SFSil and Commercial Feed

Feed efficiency is very important to regulate and to sustain productivity of any livestock industries. Part of the sustainability comes from maximizing the profit margin between cost of the feed and the final product since this constitutes a major portion of the total venture. In this study, the feed cost was analysed according to the AFI and ADG of the sheep based on the selected types of feed as shown in Table 7.

Table 7: Approximate analyses of different types of feed

Analysed Parameters	Types of Feed Used: SFSil	Types of Feed Used: Commercial Pellet
ADG (g/day)	61.12	97.67
Number of days required for the sheep to reach 30 Kg (ideal weight for sale)	490	307
AFI (g/day)	960.86	978.75
Amount of feed required for the sheep to reach 30 Kg/sheep	470.82	300.48
Cost of feed (RM)/Kg	0.65	1.80
Cost of feed required for the sheep to reach 30 Kg/sheep	306.03	540.86
Maintenance Cost/sheep (RM0.4/day x No. days to reach 30Kg)	196.00	122.8
Total Cost/livestock (RM/30Kg)	502.03	662.8
Profit Margin based on Price/livestock (RM1050/30Kg)	547.97	387.2

It is apparent from our results that sheep fed with sago frond silage (SFSil) significantly reduced the overall cost of the livestock production by almost 25 to 32%. However, this is compensated by the fact that feeding with commercial feed accumulates 70% of the total cost of the livestock production business, hence slight reduction in the feed cost will contribute to major change to the total cost for livestock production. Utilization of sago frond as sole ingredient to produce silage reduce the feed cost by 43.42%.

A particular observation was that feeding sheep with SFSil increased the duration for the livestock to reach the ideal weight for sale between 405 to 470 days as compared to 307 days for sheep fed with commercial pellet. This eventually may lead to increment of maintenance costs. As such, that difference of 97-183 days is totally acceptable. This is supported by (Alqaisi et al., 2011) where, reduction of the feed cost definitely contributes to the exceptional profit margin that will improve the farmer's income. The revenue of a sheep (30Kg) according to local price is RM 1050 (RM35/Kg) may generate profit margin between RM 548 to RM 605 through SFSil feeding practice and projected 41.6%- 56.3% higher income to the farmer compare to commercial pellet (RM 387) feeding regime. Cheap and accessible source of main ingredient to produce SFSil absolutely amplify the profit margin that can counterbalance the extra maintenance cost from using SFSil as long term feed in livestock production.

The most significant advantage is that sago farmers are able to generate extra income by producing cheaper animal feed from readily available sago frond while waiting for the sago palm to be harvestable. This is not only profitable but also an obvious advantage to the environment compared to where the fronds are dumped to decompose, as is currently practised in all sago farms in Sarawak. Table 8 shows the production cost of sago frond silage based on our study.

It should be noted that loads of sago fronds are actually disposed in sago farms upon harvesting and allowed to degrade without any treatment. This is potentially hazardous due to harbouring of pests and pose fire hazards when dried. The idea of using these fronds as a substrate to produce silage not only reduces the cost of animal feed but concomitantly benefits the environment

Based on these cost analyses, sago farmers can obtain substantial lucrative deal from the production of sago frond silage as a novel animal feed to fulfil the large demand of animal feed market and to provide sustainable animal feed supply to the livestock industry in Sarawak.

Table 8: Production cost for 1 ton of Sago frond silage

Item	Price
Sago Fronds	100 fronds should be sufficient to produce 1 ton, at a price of RM 0.50/frond (100 x 0.50) = RM 50.00/ton
Calculated Wage	RM 300/ton for 6 labourers: pruning (2), processing (2) and packaging (2)
Silage bags (to pack 20 Kg) at RM 0.50/bag)	Need 50 bags/ton (RM 0.50 x 50 bags) = RM 25.00
Approximate overhead (electricity and petrol)	RM 10.00/ton
Total Cost	RM 435.00/ton
Selling Price of SFSil	RM 700.00/ton
Profit Margin for SFSil	RM 265.00/ton (without SaFLact)
Price of commercial pellet	RM 1800.00/ton

CONCLUSION

The utilisation of SFSil from pre-harvest sago palm fronds is ecologically sustainable without compromising starch production. It also does not raise any ethical concern on the usage of food resources as raw materials for the production of chemicals. The 1:1 mixture of residual sago fibre (RSF) and sago leave (SL) has been determined to be the ideal formulation for the production of sago frond silage exhibit five ideal characteristics to be developed as high-quality silage from sago frond. The feed efficiency analysis suggests that SFSil was productive for long term feed to keep up the growth performance of the growing ruminant until it reached the finisher growth stage. The autopsy on sheep fed with commercial pellet discovered excessive water accumulated in the rumen; meanwhile, the residual feed in the rumen of the sheep fed with SFSil was intact in bolus formation with the minimum amount of water influences the moisture content and structural integrity of the faeces. Subsequently, ruminal acidosis reduces the efficiency of the ruminal microflora suggested that long term feeding of a high grain diet (commercial pellet) may cause sub-acute ruminal acidosis (SARA) to the ruminant.

SFSil feeding practice will be beneficial for the farmers to reduce the production cost due to the efficient amount of feed required compared to commercial pellet to keep up the production of the ruminant. We projected the feed cost to produce a sheep using SFSil is between RM 280.00 to RM 300.00 compared to Commercial Pellet at RM 540.00 per sheep. Hence, the application of SFSil as stable feed practice can reduce the feed cost by around 44-48%. The practice of feeding livestock with locally available resources such as SFSil not only can reduce the overall production cost between 24-33% but also can ensure the sustainable supply of the feed, which is the survival key to the smallholders in the livestock industry. Maintaining the availability of the feed by utilization of locally available raw material such as sago frond can help the smallholders to control the price of the feed and prevent domination by the feed cartel. Meanwhile, the confidence of the smallholders to utilize domestic industrial crops such as sago to produce feed is important to reduce dependency on imported feed as an assurance to the national food safety and security.

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