



Energy, Protein and Fiber Digestibility of Arrowroot Plant (*Maranta arundinacea* L.) as Feed for Native Pigs

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Abstract: Arrowroot is an underutilized tuber crop with high starch content and potential as an alternative feed ingredient for swine. This study evaluated the energy, protein, and fiber metabolizability of arrowroot-based feedstuffs in native pigs. Fifteen native pigs representing three age groups (2, 4, and 7 months) were assigned to five treatments in a randomized complete block design: fasted pigs for endogenous loss determination (control), commercial feed, ensiled arrowroot whole plant, arrowroot tuber meal, and fresh arrowroot whole plant. Commercial feed recorded the highest true COD_{energy} (92.54%), followed by fresh arrowroot whole plant (90.42%), arrowroot tuber meal (89.51%), and ensiled arrowroot whole plant (86.94%), although differences were not significant ($p=0.1779$). True COD_{protein} differed significantly ($p=0.0034$), with commercial feed (93.61%) and fresh arrowroot whole plant (88.27%) showing higher values compared with arrowroot tuber meal (72.50%) and ensiled arrowroot whole plant (68.27%). Fiber digestibility was generally high, with fresh arrowroot whole plant exhibiting the highest neutral detergent fiber (94.69%) and acid detergent fiber (96.07%) utilization. Voluntary feed intake was significantly higher in pigs fed commercial feed (304.17 g/day) compared with arrowroot-based diets, although fresh whole plant (232.08 g/day) and tuber meal (202.08 g/day) showed acceptable intake levels. These findings suggest that arrowroot, particularly in its fresh whole-plant form, has potential as an alternative energy and fiber source for native pigs under controlled digestibility conditions. However, since this study focused only on coefficient of digestibility (energy, protein, fiber), further research is needed to evaluate growth performance, feed efficiency, carcass characteristics, and economic feasibility.

Keywords: Arrowroot; native pigs; true metabolizable energy; true metabolizable protein

1. Introduction

Arrowroot (*Maranta arundinacea* L.) is an underutilized tuber crop with high potential as a feed ingredient due to its nutrient composition. In many regions, it remains neglected compared to other root crops, despite its carbohydrate-rich profile. Previous studies have shown that arrowroot contains more than 85% starch on a dry-weight basis [1] and up to 98.10% on a wet-weight basis [2], making it a highly digestible energy source [3]. Digestibility

trials conducted by Kumari et al. [4] revealed that arrowroot exhibits an in vitro digestibility of 30.07% and an in vivo digestibility of 95.7%. Erdman and Erdman [5] found that ensiled arrowroot aerial biomass and processing residues have digestibility values ranging from 38.5% to 60.03% of dry matter, with crude protein (CP) contents ranging from 10.8% to 21.1%, ether extract (EE) contents between 11.2% and 30.2%, and ash levels of 3.8% to 17.0%. These findings underscore arrowroot's potential as a nutrient-rich and digestible feed resource. Although arrowroot is primarily valued for its carbohydrate content, it also contains moderate levels of crude protein (2.9–5.3% CP on a dry weight basis) [6] and small amounts of crude fat (2.2–8.5% in aerial parts) [7]. When its aerial parts are preserved through ensiling, arrowroot contains about 12.1% crude protein (CP), 1.99% ether extract (EE), 16.19% ash, and 66.54% neutral detergent fiber (NDF), with a gross energy value of roughly 3,723 calories per gram [7]. It's also packed with essential amino acids, including lysine, methionine, leucine, and valine, as well as minerals such as calcium, magnesium, potassium, and phosphorus [6]. These nutrients support protein synthesis, metabolic processes, and overall animal health, suggesting that arrowroot is a viable supplementary protein and mineral source for livestock.

Despite its nutritional potential, arrowroot also contains antinutritional factors (ANFs), such as alkaloids, glycosides, saponins, phenols, tannins, and flavonoids, that may hinder nutrient availability for animal absorption and utilization [8,9]. However, several studies have shown that fermentation and ensiling can significantly reduce ANFs in feedstuffs [10–12], thereby improving the nutritional value of alternative feed ingredients, including arrowroot. Using alternative feed resources is crucial in swine production, where feed costs can reach up to 70% of total production expenses. Native pigs are important for smallholder and backyard farming systems in the Philippines because they adapt well to tropical climates, thrive on low-quality feeds, and support rural livelihoods [13–15]. Due to their natural eating behavior, these pigs can tolerate high-fiber diets, making them ideal for testing unconventional feed resources like arrowroot. In previous years, arrowroot has been studied as a feed for ruminants and rabbits, but its use in swine diets remains limited, particularly regarding its nutrient digestibility. To assess its potential as feed for native pigs, evaluating its energy and protein contributions, along with its digestibility, is crucial. Therefore, this study aims to evaluate the nutrient digestibility of arrowroot as a feed for native pigs with emphasis on its crude protein, energy value, and digestibility. The findings of this study could support smallholder farmers and reduce reliance on costly commercial feeds.

2. Methodology

2.1 Ethical Considerations in the Use of Pigs in the Study

The ethical treatment of pigs in this study was guaranteed by following established animal welfare protocols and securing authorization from the Institutional Animal Care and Use Committee (IACUC) of the Matias H. Aznar Memorial College of Medicine, Inc. Every procedure focused on the animals' welfare, aiming to reduce any pain or stress throughout the study. Appropriate care, handling, and humane euthanasia techniques were employed in line with ethical guidelines to ensure that the animals' welfare was prioritized at all times.

2.2 Silage Preparation

Arrowroot whole plants were harvested and chopped using a forage chopper into 1–2 cm lengths, following the method described by Hang et al. [16]. The chopped materials were then sun-dried to achieve a target moisture content of approximately 60–70%, as recommended by Lan et al. [17]. This moisture level is considered optimal before ensiling to minimize nutrient losses from effluent seepage and support proper fermentation. The prepared materials were packed into 25-kg polypropylene bags (approximately 61 cm × 74 cm). Air was removed using a vacuum machine to create anaerobic conditions and reduce the risk of undesirable microbial growth during fermentation. The bags were then tightly sealed using rubber bands, weighed, and properly labeled. The sealed silage bags were stored in a room maintained at 20–30°C, consistent with recommended silage fermentation conditions reported by Bai et al. [18]. The materials were allowed to ferment for 21 days before use in the feeding trial. After the 21-day fermentation period, the silage achieved a final pH of 4.96, indicating successful fermentation and good preservation quality suitable for feeding.

2.3 Metabolism Trial

The metabolism trial was conducted to determine the true coefficient of energy digestibility (COD_{energy}), and true coefficient of protein digestibility ($COD_{protein}$) of native pigs, following the protocol of Moughan et al. [19]. A total of 15 native pigs were used, representing three age groups: 2, 4, and 7 months. At the start of the trial, each pig was weighed to record its initial body weight, which served as the basis for calculating the feed allowance. The pigs were given a seven-day adaptation period to acclimate them to the test diets. On the eighth day, they fasted to ensure their digestive tracts were free of residual feed that could affect the digestibility results. On the ninth day, the pigs were fed with a ration equivalent to 4% of their body weight, as recommended by Dong et al. [20]. The ration was divided into two equal meals, administered at 8:00 AM and 4:00 PM. Clean drinking water was provided ad libitum through nipple drinkers throughout the trial. Total fecal collection commenced on the tenth day of the trial and continued for 4 days. Each grab sample of feces collected in the morning and afternoon was weighed, placed in 250 mL plastic containers, and placed in a solar dryer. Both diet and excreta samples were oven-dried for 48 hours at 60–70°C and subsequently weighed. The samples were analyzed for gross energy using bomb calorimetry, as well as for crude protein, ash, NDF, and ADF, following the procedures of the Association of Official Analytical Chemists [21]. Urine was collected in the morning and afternoon during the 4-day collection period. To prevent nitrogen volatilization in urine, 1 mL of sulfuric acid was added per liter of urine [22]. Cotton was soaked in the acidified urine solution and oven-dried at 60–70°C for 24 hours to prepare it for energy and nitrogen analyses.

2.4 Research Design

The study was laid out as a one-factor experiment using a Randomized Complete Block Design (RCBD). The experiment consisted of five treatments: control for endogenous loss, commercial feed, ensiled whole plant, tuber meal, and fresh whole plant. Each treatment was blocked by native pig age. The pigs were housed in uniform metabolism pens equipped with separate sections for feces and urine collection to facilitate accurate sample gathering. Pigs were sourced from reliable native swine raisers in Baybay City. The pens were placed under consistent temperature and humidity conditions to minimize stress-induced variability. Water was provided ad libitum to prevent any potential effects of feed deprivation or dehydration. Health status was monitored daily, and the same personnel handled the pigs throughout the study to minimize variations in handling techniques that could influence behavior and metabolism.

2.5 Data Collection

The data obtained were true coefficient of energy digestibility (COD_{energy}), true coefficient of protein digestibility ($COD_{protein}$), true coefficient of fiber digestibility (COD_{fiber}). The COD_{energy} was determined by quantifying gross energy intake (GE_i) and subtracting the energy losses through feces (GE_f), urine (GE_u), and endogenous sources (GE_{end}). The resulting value was then divided by GE_i and multiplied by 100 to obtain COD_{energy} as a percentage:

$$COD_{energy} (\%) = \frac{GE_i - (GE_f + GE_u - GE_{end})}{GE_i} \times 100 \quad (1)$$

True Coefficient of protein Digestibility ($COD_{protein}$). The $COD_{protein}$ was calculated by measuring total protein intake (P_i) and subtracting protein losses in feces (P_f), urine (P_u), and endogenous sources (P_{end}). The value was divided by P_i and expressed as a percentage:

$$COD_{protein} (\%) = \frac{P_i - (P_f + P_u - P_{end})}{P_i} \times 100 \quad (2)$$

True Coefficient of fiber Digestibility (COD_{fiber}). Fiber digestibility was computed by measuring neutral detergent fiber (NDF_i) or acid detergent fiber (ADF_i) intake and subtracting the undigested fiber excreted in feces (NDF_f or ADF_f). The digestibility was expressed as a percentage of intake:

$$COD_{fiber} (\%) = \frac{NDF_i \text{ or } ADF_i - NDF_f \text{ or } ADF_f}{NDF_i \text{ or } ADF_i} \times 100 \quad (3)$$

2.6 Data Analysis

Data were analyzed using analysis of variance (ANOVA) in a one-factor Randomized Complete Block Design. Statistical analyses were performed using the Proc General Linear Model in SAS Version 9.4.

Significant differences among treatment means were tested using Tukey's Honest Significant Difference (HSD) test and declared significant at $\alpha = 0.05$.

3. Results and Discussion

3.1 Nutrient composition of feedstuffs

The proximate composition of the experimental diets is presented in Table 1. Commercial feed exhibited the highest crude protein (CP, 16.0%) and gross energy (3,234 cal/g), reflecting its formulated balance of protein and energy sources. In contrast, arrowroot-based feedstuffs contained considerably lower CP levels, ranging from 3.34% in tuber meal to 4.60% in fresh whole plant, consistent with earlier reports that arrowroot is primarily an energy crop with limited protein content [6]. Ether extract (EE) was markedly higher in fresh whole plant (9.82%) compared with both ensiled (0.51%) and tuber meal (6.66%). This indicates that the aerial portion contributes lipid fractions, which may enhance energy density but can also be susceptible to oxidative rancidity if not properly processed [7]. Fiber fractions differed substantially among diets. Ensiled arrowroot whole plant showed the highest neutral detergent fiber (NDF, 42.91%) and acid detergent fiber (ADF, 30.39%), reflecting the structural polysaccharides of mature foliage. Conversely, tuber meal had very low ADF (4.13%), aligning with its starchy nature. Such variation is critical because high fiber generally reduces nutrient availability in monogastrics [21]. Interestingly, commercial feed contained the lowest fiber content (NDF, 10.70%; ADF, 2.67%), highlighting the deliberate formulation to optimize nutrient digestibility. The high ash content in ensiled material (10.91%) compared to tuber meal (0.89%) suggests that foliage contributes greater mineral fractions, supporting the role of arrowroot aerial biomass as a mineral source. Similar findings were reported by Heuzé et al. [6], who documented higher mineral content in arrowroot aerial parts compared with tubers. Likewise, Tarique et al. [7] reported that arrowroot foliage contains appreciable ash and mineral components, reinforcing its potential as a mineral-rich feed resource.

Table 1. Nutrient composition of arrowroot-based feedstuffs and commercial diet fed to native pig (DM basis).

Diets	DM (%)	OM (%)	GE (cal/g)	CP (%)	EE (%)	NDF (%)	ADF (%)	HC (%)	Ash (%)
Ensiled arrowroot whole plant	70.55	89.09	2906	4.33	0.51	42.91	30.39	9.19	10.91
Arrowroot tuber meal	28.0	99.11	3298	3.34	6.66	15.74	4.13	11.62	0.89
Fresh arrowroot whole plant	16.99	98.10	3087	4.60	9.82	40.32	28.18	12.14	1.84
Commercial Feed	87.58	95.86	3234	16.00	1.63	10.70	2.67	16.92	4.14

Note: Values represent the mean of replicated laboratory analyses of feed samples.

3.2 Average daily feed intake and feed refusal of native pigs

The voluntary feed intake and average feed refusal of native pigs fed different arrowroot-based feedstuffs are presented in Table 2. Average daily feed intake (ADFI) of native pigs was significantly affected by diet ($P = 0.0114$), with intake increasing from ensiled arrowroot whole plant to commercial feed. Pigs fed commercial feed recorded the highest ADFI (304.17 g/day), followed by fresh arrowroot whole plant (232.08 g/day¹) and arrowroot tuber meal (202.08 g/day), while the lowest intake was observed in pigs fed ensiled arrowroot whole plant (114.17 g/day). The reduced intake in pigs fed ensiled whole-plant arrowroot indicates lower palatability, likely associated with higher fiber content and fermentation end products, such as organic acids. High dietary fiber levels have been reported to reduce voluntary feed intake in pigs due to increased gut fill and slower gastric emptying, thereby limiting feed consumption in monogastric animals [23]. In addition, fermentation acids formed during ensiling may negatively affect feed palatability and reduce intake, as reported by Simwaka et al. [12]. Despite lower intake compared with commercial feed, fresh arrowroot whole plant and tuber meal demonstrated acceptable intake levels, suggesting that native pigs can adapt to alternative feed resources. Native pig breeds have been reported to tolerate fibrous and unconventional feed ingredients, owing to enhanced hindgut fermentation and greater feeding adaptability compared with improved breeds [23].

Table 2. Voluntary feed intake (ADFI) and average feed refusal (AFR) of native pigs fed with different arrowroot feedstuffs and commercial feed

Diets	ADFI (g)	ADFR (g)
Ensilaged arrowroot whole plant	114.17b	0.01
Arrowroot tuber meal	202.08ab	0.03
Fresh arrowroot whole plant	232.08ab	0.02
Commercial Feed	304.17a	0.06
SEM	25.84	0.02
P-Value	0.0114	0.4006

Means with the same letter are not significantly different at ($p > 0.05$).

Average feed refusal (AFR) was not significantly affected by diet ($p = 0.4006$), indicating similar acceptance across treatments. Although pigs fed commercial feed showed numerically higher refusal (0.06 g) than those fed arrowroot-based diets (0.01–0.03 g), the differences were minimal and statistically non-significant. The low feed refusal across treatments suggests that all diets were generally acceptable to native pigs and resulted in minimal feed wastage. Similar findings were reported in studies involving indigenous pig breeds, where acceptable palatability of alternative feed ingredients resulted in low feed refusal and efficient feed utilization [14].

3.3 Coefficient of Digestibility of arrowroot-based diets

True coefficient of energy digestibility (COD_{energy}) was not significantly affected by diet ($p = 0.1779$), although fresh arrowroot whole plant showed higher numerical values (90.42%) next to commercial feed (92.54%), arrowroot tuber meal (89.51%), and ensiled arrowroot whole plant (86.94%). The higher COD_{energy} in fresh arrowroot indicates better energy availability from readily digestible carbohydrates, while the slightly lower values in ensiled material suggest possible energy losses during fermentation. These results are consistent with the growing interest in plant-based and forage resources as sustainable alternative feeds for livestock in tropical regions [23]. Similar findings were reported by Coulibaly et al. [11], who noted that ensiling tropical forages may reduce energy availability due to fermentation-associated nutrient losses. Comparable variation in the estimated metabolizable energy of fermented agricultural biomass and cassava-based by-products has likewise been reported in ruminant feeding studies [24], underscoring how processing method influences the energy contribution of alternative feedstuffs.

Table 3. Nutrient metabolizability of arrowroot-based feedstuffs and commercial diet in native pigs

Diets	COD_{energy} (%)	$COD_{protein}$ (%)	COD_{fiber}	
			NDF (%)	ADF (%)
Ensilaged arrowroot whole plant	86.94	68.27 ^b	86.48	86.47 ^b
Arrowroot tuber meal	89.51	72.50 ^b	88.97	87.56 ^b
Fresh arrowroot whole plant	90.42	88.27 ^a	94.69	96.07 ^a
Commercial Feed	92.54	93.61 ^a	93.99	94.91 ^a
SEM	1.53	3.15	1.82	2.04
P-Value	0.1779	0.0034	0.0513	0.0330

Means with the same letter are not significantly different at ($P > 0.05$).

True $COD_{protein}$ was significantly affected by diet ($p = 0.0034$), with commercial feed (93.61%) and fresh arrowroot whole plant (88.27%) showing higher values compared with ensiled arrowroot whole plant (68.27%) and arrowroot tuber meal (72.50%). This indicates improved protein utilization in commercial feed and fresh plant material, while processing through ensiling or tuber extraction reduced protein availability. The reduced $COD_{protein}$ in fermented feeds may be associated with protein degradation and formation of less digestible nitrogen compounds during ensiling, as similarly observed in tropical silage systems [12] and supported by reports on antinutritional factors affecting protein utilization in root crops [9]. Neutral detergent fiber (NDF) digestibility was not significantly affected by diet ($p = 0.0513$), although fresh arrowroot whole plant exhibited

the highest numerical value (95.69%), followed by commercial feed (93.99%), arrowroot tuber meal (88.97%), and ensiled whole plant (86.48%). The higher fiber utilization in fresh arrowroot suggests efficient microbial fermentation of structural carbohydrates in the hindgut of native pigs. This supports the findings of Ngoc et al. [25], who reported that native pigs possess a strong fiber-digesting capacity due to enhanced hindgut fermentation. Acid detergent fiber (ADF) digestibility was significantly affected by diet ($p = 0.0330$), with fresh arrowroot whole plant (96.07%) and commercial feed (94.91%) showing higher values compared with arrowroot tuber meal (87.56%) and ensiled whole plant (86.47%). The higher ADF digestibility in fresh arrowroot indicates improved digestibility of cellulose and lignified fractions when fed in fresh form, consistent with previous reports that forage freshness enhances fiber degradation in monogastric herbivores [11]. Despite these findings, several limitations should be considered. The study used a small sample size ($n = 3$ per treatment) due to the high cost and limited availability of native pigs, which may affect the statistical power of the results. In addition, the metabolism trial was conducted under controlled conditions with restricted feeding, which may not fully reflect practical production systems. Antinutritional factors (ANFs) were not directly measured, as the study focused on the metabolizability of energy, protein, and fiber and relied on existing literature for ANF-related explanations. Furthermore, economic analysis was not included in this study, as it is being addressed in a separate ongoing investigation.

4. Conclusions

This study evaluated the coefficient of digestibility and voluntary feed intake of arrowroot-based feedstuffs in native pigs under controlled metabolism trial conditions. The results showed that fresh arrowroot whole plant exhibited the highest numerical values for true coefficient of energy and fiber utilization, while ensiled arrowroot generally resulted in lower intake and reduced nutrient metabolizability compared with other treatments. True coefficient of protein digestibility was significantly higher in commercial feed and fresh arrowroot whole plant, indicating better protein utilization in these diets, whereas arrowroot tuber meal and ensiled forms showed lower values, reflecting limited protein availability and possible processing-related losses. However, this study was limited to measurements of digestibility and intake under a controlled experimental setup. Therefore, further studies are recommended to evaluate growth performance, feed efficiency, carcass characteristics, and economic viability, and to optimize processing methods, such as ensiling, to improve nutrient utilization and reduce antinutritional factors.

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