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Research article

Growth performance of Nile tilapia (*Oreochromis niloticus*) fed blood meal from Pon-Yang-Kham fattening cattle

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Abstract

Slaughter of Pon Yang Kham cattle generates significant blood byproducts, which are largely underutilized, posing waste management challenges. This study aimed to transform this byproduct into blood meal, assess its nutritional value, and evaluate its efficacy as a fish meal substitute in Nile tilapia (*Oreochromis niloticus*) diets. Fresh cattle blood was heat-treated (100°C, 1 hour), dried (60°C, 3 hours to achieve water activity < 0.6), ground into meal, and analyzed. The blood meal contained 61.89% crude protein. Four isonitrogenous (31% crude protein) diets were formulated where fish meal protein was replaced by blood meal protein at 0% (T1control), 25% (T2), 50% (T3) and 75% (T4). These correspond to 0%, 6.25%, 12% and 17.25% blood meal in the total dietary ingredients, respectively. Nile tilapias (initial weight ~15g) were fed these diets for 60 days. Fish fed the T3 diet (50% protein replacement) exhibited the highest final weight (60.09g) and average daily gain (0.71 g/day), comparable to the control (T1). The feed conversion ratio for T3 (4.62) was not significantly different from T1 (4.44). Survival rates exceeded 90% across all treatments, with T3 achieving 100%. Water quality parameters were not adversely affected by blood meal inclusion. The T3 diet also reduced feed costs by 18.75% compared to the control. These findings suggest that Pon-Yang-Kham cattle blood meal is a viable, cost-effective, and sustainable alternative protein source for Nile tilapia feed, contributing to waste valorization.

Keywords: Alternative proteins, Fish meal replacement, Nile Tilapia, *Oreochromis niloticus*, Sustainable aquaculture.

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INTRODUCTION

Pon Yang Kham beef is a Geographical Indication (GI) product of Sakon Nakhon Province, Thailand. Charolais, Limousine and Simmental crossbred cattle were raised by farmers who are members of the Pon Yang Kham livestock cooperative limited (PYK Coop), a local business organization (Umpapol et al. 2014; Wiwatthanapornchai, 2019). The slaughterhouse processes an average of 120–140 cattle per week, resulting in a substantial number of by-products from the slaughtering process. One of the most abundant yet underutilized by-products is cattle blood, which is generated in volumes ranging from 1,200 to 2,800 liters per week. However, less than 10% of the total blood is purchased for household consumption, leaving the majority unused and unexploited for potential benefits. Efforts have been made to utilize surplus bovine blood, which is often discarded in a beneficial manner. Studies have shown high protein content in bovine blood, making it a viable alternative protein source for animal feed (Xavier et al., 2011; Aladetohun and Sogbesan, 2013; Njieassam, 2016; Kirimi et al., 2016). Animal-based proteins are high-quality proteins with amino acid profiles that closely match the nutritional requirements of animals. Animal-based protein sources typically contain protein levels that range from 32% to 90%. Blood-derived proteins in particular are rich in lysine but lack isoleucine. Additionally, animal-based proteins have a high ash content, which contributes to their elevated mineral content, particularly calcium and phosphorus. The fat content in such protein sources varies, depending on the types of raw materials and processing methods. Furthermore, animal-derived protein sources generally contain moderate to high levels of vitamins B and D (Hansen et al., 1993).

Aquaculture is an increasingly important sector that plays a vital role in ensuring global food security, fostering economic development, and promoting sustainable practices. Utilization of blood-derived proteins can effectively reduce the cost of fish farming. For instance, to boost the growth and survival rates of juvenile Nile tilapia, a protein level of 30–40% is required (El-Sayed and Teshima, 1992). The use of bovine blood in this context may lead to a decrease in the production costs associated with Nile tilapia feed. However, cow blood may contain pathogenic organisms obtained from the abattoir. Improper management of this byproduct may result in the proliferation of diseases and contamination of water and soil (Aniebo et al., 2009; Bułkowska and Zielińska, 2024). The total blood volume of a cow depends on the animal's weight (Springell, 1968; Nazifa et al., 2021). Utilizing these waste materials offers a range of beneficial applications, including biogas production and its use as a food component for humans and animals (Ockerman and Basu, 2004; Nollet and Toldrá, 2011; Islam et al., 2023; Bułkowska and Zielińska, 2024). These leftover blood materials, when processed into a suitable form for inclusion in animal feed, have been found to contain as much as 16.5 g of crude protein and provide up to 70 kilocalories of energy per 100 g of blood (Mora et al., 2019).

These protein-rich components can be used as a protein source for animal feed instead of common protein sources, such as fish meal (Xavier et al., 2011; Aladetohun and Sogbesan, 2013; Kirimi et al., 2016; Njieassam, 2016). Utilizing byproducts from animal slaughter for beneficial purposes contributes to sustainability. This approach addresses the issue of declining marine fish populations, as the demand for fishmeal as a protein source in animal feed remains high (Drakeford and Pascoe, 2008; Daniel, 2018). Reducing the use of fishmeal by substitution with bloodmeal will not only reduce pressure on marine resources but also promote environmental sustainability through reduced waste disposal (Donkoh et al., 1999; Csurka et al., 2021). This practice aligns with the principles of the Sustainable Development Goals (SDGs).

The utilization of animal blood by-products from various species has been studied from a nutritional perspective, with the aim of evaluating their potential as alternative protein sources, such as blood from pigs, ducks and chickens, which has been found to contain a high crude protein content, reaching as much as 88–90%. Essential amino acid/non-essential amino acid ratios of pig, chicken and duck blood were found to be 1.06, 1.09 and 1.07, respectively (Sorapukdee and Narunatsopanon, 2017). Therefore, this study aimed to investigate the utilization of beef cattle blood by transforming it into blood powder or blood meal, and to examine the nutritional components of beef cattle blood meal. In addition, we explored the feasibility of processing Pon Yang Kham beef cattle blood into blood meal for fish feed. The nutritional composition of the resulting blood meal would be analyzed prior to its use as a substitute for fish meal, which is a common protein source in the feed of Nile tilapia, an economically important fish in Thailand, during the growth phase in this trial period.

MATERIALS AND METHODS

Ethics approval

This study was approved by the Animal Ethics Committee of Sakon Nakhon Rajabhat University, Sakon Nakhon, Thailand (IACUC-SNRU-009/2024).

Blood collection of Pon Yang Kham fattening cattle

Fresh whole blood was randomly collected from fattened cattle during slaughter at the Pon Yang Kham Livestock Cooperative Limited (PYK Coop) abattoir. The collection was performed during neck cutting to sever the jugular vein. The personnel responsible for carcass processing were assigned to collect the blood directly into sterile bags, which were then securely sealed and transported to the blood meal processing location at Sakon Nakhon Rajabhat University within 30 minutes of collection.

Preparation of Blood Meal from Fattening Cattle for Fish Feed

The production process began with heat treatment to eliminate pathogenic microorganisms and to coagulate the blood, by steaming at 100°C for an hour. The coagulated blood was then cooled before being coarsely ground manually to reduce particle size. The material was subsequently dried using a tray dryer for 1, 2, 3 and 4 hours. The selection of the blood meal to be used for further study was carried out by considering the water activity or a_w value as the main factor to have a longer shelf life using the community product standard criteria of chicken breast powder from the Thai community product standard, standard number 1600/2022 (Thai industrial standards institute, 2022). This was the only community-derived animal product available that could be used for standardization. Finally, the dried blood was finely ground into beef cattle blood powder or blood meal (Figure 1). The product must have an a_w no more than 0.6. The obtained blood meal was analyzed for nutritional quality and composition to inform subsequent fish-feed formulations.

Figure 1 The Pon Yang Kham fattening cattle blood meal

Preparation of Diets

The cattle blood meal was utilized as a partial substitute for fish meal in Nile tilapia (*Oreochromis niloticus*) feed formulations. Four distinct isonitrogenous (31% crude protein) feed formulations were prepared, each incorporating varying concentrations of cattle blood meal as a replacement for fish meal. We selected 31% crude protein as the optimal level, which is in the optimal protein range (Singha et al., 2021). The control group (T1) consisted of 100% fish meal as the primary protein source, while the experimental groups T2, T3 and T4 contained 25, 50 and 75% blood meal, respectively.

The feed components were blended using a semi-automatic mixer and subsequently pelletized using a farmer-customized floating-type extruder. The pellets were then dried in a hot-air oven to achieve a moisture content between 8–10% (Goddard, 1995).

Study site and fish preparation

The experiment was conducted at the Aquatic Culture Farm, Faculty of Agricultural Technology, Sakon Nakhon Rajabhat University, Sakon Nakhon Province, Thailand. All fish were raised in fiberglass ponds of width × length × depth equal to 34 × 44 × 24 inch, with a total of 12 ponds filled with water to a level of 400 liters.

One-month-old Nile tilapia were selected from a farm located in close proximity to the experimental site with a transportation time of less than 30 minutes. Fish with an average initial body weight of 15 g were sourced from a single hatchery to minimize variability. The individuals selected for the experiment were of similar sizes, with body weights ranging from 10 to 20 g. Three days before the experiment, the fish were transported from the original farm to the experimental site to acclimate to the aerated fiber tanks. Water in the tanks was replaced twice per week.

Experimental Treatments

A feeding trial was conducted to evaluate the palatability and growth performance of Nile tilapia fed four different feed formulations. Each formulation was tested in triplicate, with each replicate consisting of 25 fish, for a total of 75 fish per treatment. Fish were fed their respective diets at 6% of their body weight per day, divided into four equal meals. Weight gain was measured weekly over a 60-day period. This study design aligns with standard aquaculture research methodologies as similar protocols have been employed in previous studies assessing the effects of dietary supplements on tilapia growth performance. The stocking density of this experiment was 0.625 kilograms per cubic meter, which is in the optimal range of standard stocking density (Azaza et al., 2013). Water samples were collected from the tanks at 8:30 a.m. once a week; pH, dissolved oxygen, and water temperature were determined.

Parameters measured

A comparative study was conducted to assess growth performance, feed conversion efficiency, and production costs for fish fed different diets. Over a 60-day period, fish were fed one of the four dietary treatments, each replicated three times. The growth performances and feed efficiency considered in this study were defined as follows:

1) Weight Gain (WG), final weight (kg) – initial weight (kg);

2) Average Daily Gain (ADG), weight gain (g)/ time (days);

3) Feed Conversion Ratio (FCR), food consumed (kg)/ weight gain (kg);

4) Specific Growth Rate (SGR), 100 x (Ln final weight (g) – Ln initial weight (g))/ time (days);

5) Survival Rate (SR), number of fish harvested/ number of fish stocked x 100;

6) Average Length Gain, final length – initial length / day.

These parameters are standard metrics used in aquaculture research to assess growth performance and feed efficiency of fish under various dietary conditions (Panase and Mengumphan, 2015; Bahnasawy et al., 2003).

Fish growth was recorded once a week by weighing and measuring the length of the fish. Measurements were obtained randomly from five out of a total of 25 fish in each group, representing 20% of the group. The growth data were recorded on a designated form. Growth performance was evaluated based on increases in weight and length, which were then used to calculate specific growth rate (SGR), average daily gain (ADG), and feed conversion ratio (FCR).

Statistical analysis

In this study, data were analyzed to assess differences among experimental groups using Analysis of Variance (ANOVA) based on a Completely Randomized Design (CRD). Significant differences between group means were further examined using Duncan's New Multiple Range Test at the 95% confidence level. All statistical analyses were performed using SPSS Version 27 for Windows (SPSS Inc., Chicago, IL, USA).

RESULTS

The Pon Yang Kham fattening cattle blood meal

The study revealed that 10 liters of beef cattle blood could be processed into 2,620 g of blood powder or blood meal. The results showed that the criterion (i.e. $a_w \leq 0.6$) was met at 60°C for three hours. The water activity for each drying time exhibited a statistically significant difference ($p<0.05$), as shown in Table 1. The optimal drying temperature and time were chosen.

The nutritional content of the Pon Yang Kham fattening cattle blood meal is shown in Table 2. The results show high crude protein content, indicating that it is a suitable protein source for animal feed.

Table 1 Effect of drying time (hours) at 60°C on the mean water activity (a_w ± SD) of Pon Yang Kham fattening cattle blood meal

Drying time (h)	a_w	p-value
0 (Control)	0.9753 ± 0.0002^e	< 0.001
1	0.9738 ± 0.0014^d	
2	0.6743 ± 0.0003^c	
3	0.2371 ± 0.0001^b	
4	0.1894 ± 0.0004^a	

Note: **The letters a, b, c, d indicate statistical differences ($p<0.05$) between groups.

Table 2 Nutritional contents of Pon Yang Kham fattening cattle blood meal

Parameter		
Moisture	9.91 ± 0.02	%
Ash	3.17 ± 0.02	%
Crude protein	61.89 ± 0.03	%
Ether extract	0.39 ± 0.02	%
Crude fiber	0.72 ± 0.03	%
Ferrous	2,181.89 ± 3.55	mg/kg
Total Plate Count	3.301 ± 0.02	log CFU/g
Total Coliform Bacteria	< 3	MPN/g

The Nile tilapia feed

Based on the nutritional analysis of the prepared Pon Yang Kham cattle blood meal (Table 2), feed formulas were calculated, and the blood meal used for this analysis and subsequent feed production was refrigerated. Other feedstuff was purchased as commercial feedstuff in local shops. Table 3 details the quantities of ingredients for each experimental group, with all formulations containing 31% crude protein (Singha et al., 2021).

Based on the formulation of the fish diets used in this study, the levels of incorporated blood meal were 0%, 6.25%, 12% and 17.25% of the total dietary ingredients. The appearance of each formula feed was different. The color was darker in the feed that contained a high blood meal component, as shown in Figure 2. Moreover, the smell from the control group, which had 0% blood meal, was better than the others.

Table 3 Percentage ingredient composition of Nile tilapia feed in each experimental group

Feedstuff	T1	T2	T3	T4
Fish meal	25	18.75	12	6.25
Soybean meal	28	27	27	27
blood meal	0	6.25	12	17.25
rice bran	10	11	11	11.75
broken rice	11	11	11	11
tapioca flour	15	15	16	15.75
Corn	7	7	7	7
Fish oil	1	1	1	1
Minerals	2	2	2	2
Vitamins	1	1	1	1
Total Feed Weight (kg)	100	100	100	100
Estimated crude protein	31%	31%	31%	31%
Cost of feed (USD/kg)	0.690	0.624	0.559	0.501

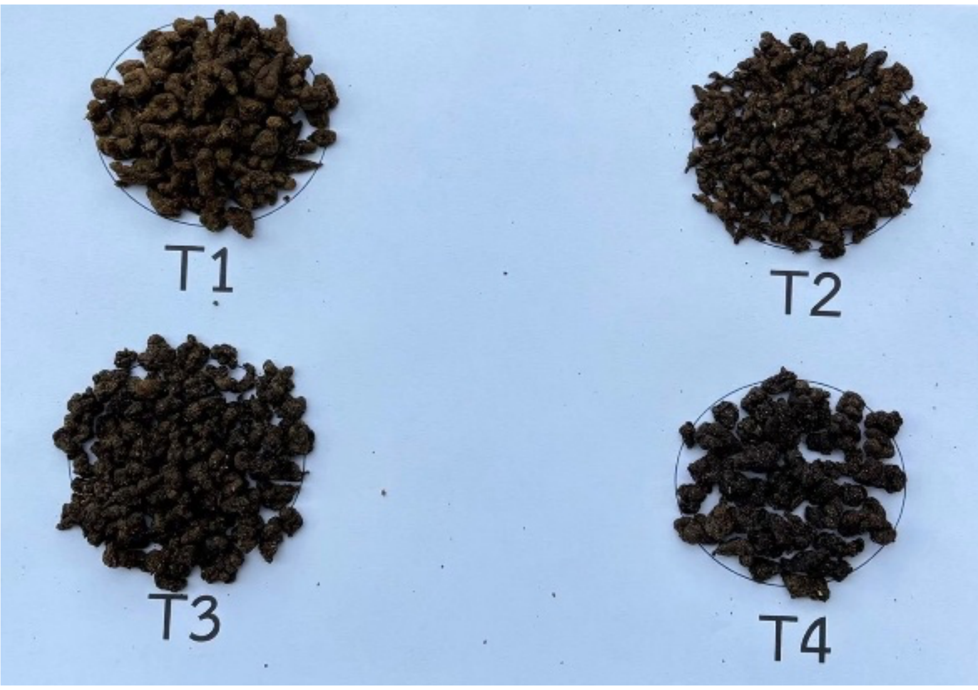

Figure 2 Pelleted experimental diets showing visual appearance for each treatment group: T1 (0% blood meal protein replacement), T2 (25%), T3 (50%), and T4 (75%).

The Growth Performance and Survival rate

The initial weights of all fish did not differ between the groups, whereas the final weights were different (p<0.05). The average maximum final weight (g) was from T3 (60.09±1.24), but was not significantly different from that of T1 (control), and T4 which showed an average final weight of 57.77±1.71 and 57.04±1.28, respectively. Average weight gain (WG) and average daily gain (ADG) also aligned with the average final weight. The results demonstrated that the highest weight gain and average daily gain were observed in T3, followed by T1 and T4. The feed conversion ratios (FCR) were slightly different. The best FCR was noted in T1 (4.44±0.17); however, it was not statistically different from T3 (4.62±0.24). The FCR at T2 and T4 was significantly different from that at T1 and T4 (p<0.05). The survival rate of fish was monitored throughout the study. All the experimental groups had a survival rate of > 90 %. All the growth parameters are shown in Table 4. These results indicate that the experimental conditions were suitable for Nile tilapia fish.

Table 4 Growth performance of Nile tilapia fed on blood meal as a replacement for fish meal in each treatment group

Parameter	Treatment				
	T1	T2	T3	T4	p-value
IW (g)	15.26 ± 1.65	16.01 ± 0.51	16.47 ± 0.99	16.78 ± 0.62	0.370
FW (g)	57.77 ± 1.71^{ab}	53.62 ± 1.49^{a}	60.09 ± 1.24^{b}	57.04 ± 1.28^{ab}	0.024
WG (g)	41.11 ± 1.29^{ab}	37.08 ± 2.02^{a}	43.28 ± 1.37^{b}	40.36 ± 1.46^{ab}	0.036
SGR (%/day)	0.066 ± 0.001	0.066 ± 0.001	0.067 ± 0.001	0.067 ± 0.002	0.410
ADG (g/day)	0.69 ± 0.04^{ab}	0.62 ± 0.05^{a}	0.71 ± 0.03^{b}	0.66 ± 0.06^{ab}	0.041
FCR	4.44 ± 0.17^{a}	4.86 ± 0.13^{b}	4.62 ± 0.24^{a}	4.93 ± 0.16^{b}	0.035
SR (%)	93.33 ± 6.11	98.67 ± 2.31	100.00 ± 0.00	96.00 ± 6.93	0.384

The letters a, b, c, d in the row indicate statistical differences (p<0.05) between groups.

Water Quality

Indicators for water quality from all treatment groups were not significantly different ($p>0.05$). Water quality parameters remained similar across all treatment groups, indicating that the different blood meals did not degrade the water quality beyond that observed in the standard fish meal control diet. Moreover, the average pH, dissolved oxygen and temperature from all treatment groups were in the optimal range for each indicator (Bahnasawy et al., 2003; Makori et al., 2017; Whangchai et al., 2018; Kaewngernsong et al., 2019; Wongsathein et al., 2019).

DISCUSSION

Beef cattle blood is a by-product of the slaughtering process, and is currently underutilized relative to the quantity produced. The Pon Yang Kham livestock cooperative limited (PYK Coop), a local business organization, cannot ignore this biological waste. This underutilization poses environmental and public health risks, as beef cattle blood can be contaminated with zoonotic pathogens such as *Trypanosoma evansi* (Joshi et al., 2005; Van Vinh et al., 2016; Sengupta et al., 2022). These pathogens can be transmitted to various mammalian species, including dogs and rodents, through ingestion of contaminated blood or raw meat (Bhaskara Rao et al., 1995; Desquesnes, 2004; Silva et al., 2007; Vergne et al., 2011). Transmission occurs via mucous membrane penetration but not transplacentally (Raina et al., 1985; WOAH, 2021). The infective stage for carnivores is the live trypomastigote stage, which retains the ability to penetrate the mucous membranes (WOAH, 2021). This stage is detectable in the fresh blood of the infected cattle. Consequently, if fresh untreated blood is discharged into the environment, it may contribute to pathogen dissemination. Given these concerns, we propose repurposing beef cattle blood as an ingredient in animal feed to minimize environmental contamination and enhance resource utilization.

Nutritional analysis of the blood meal revealed a crude protein content of 61.89%. The crude protein content obtained in this study was lower than that reported in previous studies on blood meal processing by Khawaja et al. (2007) and Kirimi et al. (2016). Khawaja et al. (2007) processed fresh cattle blood into a powder form for use as a poultry feed ingredient by boiling it at 100°C for 45 minutes, followed by drying in a hot air oven at 55°C for six days. Although this method required an extended drying period, it yielded blood meal with a crude protein content of approximately 80%, making it a viable alternative protein source for animal feed formulations. Similarly, Kirimi et al. (2016) processed cattle blood into a blood meal for Nile tilapia feed by boiling at 100°C for 45 minutes, followed by moisture removal through heat application with continuous stirring until dry. The partially dried blood was then allowed to cool, was manually ground, and then sun-dried for three days until its moisture content reduced to below 15%, after which it was finely milled into powder form as blood meal for fish feed formulation.

While the processing methods described by Khawaja et al. (2007) and Kirimi et al. (2016) were similar, Njieassam (2016) employed a different approach for producing blood meal to feed African catfish (*Clarias gariepinus*). Fresh blood from slaughterhouses was subjected to heat treatment for 20 minutes, cut into small pieces, sun-dried for three days, and then finely ground into powder. This method is the least complex among the reviewed methods.

The crude protein percentage obtained from the nutritional analysis of the blood meal produced by Khawaja et al. (2007) and Kirimi et al. (2016) was higher than that in the present study. This difference may be attributed to several factors, including variations in processing methods and differences in the initial protein content of fresh blood used, from factors such as age and animal species (Gorbatov, 1990; Sorapukdee and Narunatsopanon, 2017). Similarly, fish meal, which is a primary protein source commonly used in animal feed, exhibits a wide range of protein content (39.2–63.5%), depending on the producer and the inclusion of additional materials such as seashells, crab shells or sand (Hanbungchong et al., 1990).

The study by Njieassam (2016) did not report the crude protein percentage of processed blood meals. However, when comparing the crude protein content of beef cattle blood meal to that of fish meal, which is widely used in animal feed, it was found that their protein levels were comparable. This suggests that blood meal could serve as an alternative protein source to replace fish meal due to its high protein content. Additionally, blood meal is rich in lysine and serves as a good source of arginine, methionine, cysteine and leucine (Adegbenjo et al., 2020).

The beef cattle blood meal produced in this study was used as a protein source for Nile tilapia feed, replacing fish meal in a formulated diet with a crude protein content of 31%, which is the optimal protein level for herbivorous fish. The feed production process was adjusted according to the environmental conditions and available equipment. Because the study was conducted during a period of heavy rainfall and limited sunlight, the moisture content of the fish feed was reduced by drying in a hot air oven at 60°C for 6 hours. However, in periods of strong sunlight, sun-drying can be used as an alternative to oven-drying.

The incorporation of beef cattle blood meal into fish feed in this study was similar to the method described by Njieassam (2016), in which all feed ingredients were mixed according to a formulated recipe, followed by the addition of 1 liter of warm water. The mixture was blended for two minutes and manually shaped into rice-like pellets. These pellets were then placed in fertilizer bags and sun-dried for three to four days. The drying effect of intense sunlight may be comparable to that of a hot-air oven in reducing moisture content. In contrast, Kirimi et al. (2016) used a pelleter to form fish feed pellets with a diameter of 4.5 mm. The pellets were then air-dried in a shaded area to remove moisture and stored in waterproof bags before use in fish feeding trials.

The beef cattle blood meal produced in this study exhibited a high crude protein content, and was therefore investigated as an alternative protein source to replace fish meal in juvenile Nile tilapia (*Oreochromis niloticus*) diets. This study focused on fish with an average weight of approximately 15 g, and their growth performance was evaluated in terms of specific growth rate (SGR), average daily gain (ADG), feed conversion ratio (FCR) and survival rate (SR). The fish in this study were reared for 60 days using a diet containing 31% protein, which differs from the previous study by Kirimi et al. (2016), in which Nile tilapia were fed a diet containing 35% protein for 100 days.

The fingerlings chosen in this experiment had no statistically significant difference in initial weight ($p>0.05$). However, the final weight after 60 days of raising was different. The highest average weight came from T3, which was not statistically different from the control group or T1, but was different from T2 and T4. Average weight gain (ADG) had the same effect. The findings of this study differ from those of Kirimi et al. (2016), in that a higher final weight was observed despite a shorter rearing period and the use of a diet with a lower protein level. This outcome may be attributed to several factors including differences in other dietary components, environmental conditions, and study location.

In this study, the group with the best feed conversion ratio (FCR) was T1 (control group). Group T3 showed a similarly favorable FCR, which was not significantly different from that of T1. Groups T2 and T4 had comparatively higher FCRs, with both showing statistically significant differences from T1 and T3 ($p<0.05$). This result was different from that of a previous study by Kirimi et al. (2016), which indicated that the blood meal level had no adverse effects on the growth rate and feed conversion ratio, and also differed from Hussain et al., (2011) which demonstrated that the crude protein digestibility values of blood meal were significantly lower than fish meal.

All the experimental groups had a survival rate of > 90 %. The highest survival rate was in T3, with 100% survival rate followed by T2, T4 and T1, with no significant differences between the groups, which is consistent with Kirimi et al.

(2016) and Agbebi et al. (2009), who reported that the blood meal level has no adverse effect on the survival rate of fish in their studies. This result indicates the optimal raising conditions. These findings indicate that water quality and management were maintained throughout the experimental period, which is consistent with a previous study (Ronald et al., 2014). Moreover, the optimal stocking density for Nile tilapia ranges from 3 to 12 kilograms per cubic meter, and depends on the culture system and water management practices. Therefore, the specified density of 0.625 kilograms per cubic meter is considered low and is suitable for initial stocking, or for systems where water quality is not strictly controlled (Azaza et al., 2013).

The results indicate that the growth performance in the experimental groups was comparable to that in the control group. However, when compared to the growth performance of commercially cultured fish, which typically requires a FCR ranging from 1.43 to 2.30 (Opiyo et al., 2014), the FCR observed in this study remains higher than the commercial standard. Fish gut health, immune response, blood profile, and protein digestibility should be investigated further in future studies. Nevertheless, a limitation of the present study is that the growth performance was evaluated only in comparison with a control group. Notably, the group in which beef cattle blood meal constituted 50% of the dietary protein source, T3, demonstrated similar FCR results to the control group, while achieving a cost reduction of 18.75%.

In this study, the blood meal content of the T3 diet was 6.25% of the total feed ingredients. This differs from the findings of Njieassam (2016), who reported that the optimal inclusion level of blood meal in catfish diets, based on a 56-day growth trial, was 10%, which resulted in the best growth performance and feed cost efficiency. Both lower and higher inclusion levels led to reduced growth performance and economic efficiency. In contrast, Kirimi et al. (2016) found that Nile tilapia showed the best growth when fed a diet without any blood meal, followed by a diet containing 12.5% blood meal, and the poorest growth was observed in the group receiving 25.5% blood meal. Twahirwa et al. (2021) identified 8.45% as the optimal blood meal inclusion level for black carp (*Mylopharyngodon piceus*). However, Bahrevar and Faghani-Langroudi (2015) concluded that blood meal was not suitable as a feed ingredient for rainbow trout (*Oncorhynchus mykiss*). While many previous studies have suggested that blood meal may not optimize growth performance compared to other protein sources, they often highlight its advantage in reducing feed costs.

These findings suggest that, with further development, cattle blood meal could be successfully incorporated into feed for other animal species beyond Nile tilapia. The essential amino acids and digestibility of the protein in blood meal should be evaluated to provide information for use in the production of other animal feeds. However, fish feed containing a high proportion of blood meal exhibited a less appealing odor than feed formulated with fish meal as the primary protein. This aligns with the findings of Sorapukdee and Narunatsopanon (2017) and Adegbenjo et al. (2020), who reported that blood meals can reduce the palatability of feed. Therefore, it is recommended that blood meal inclusion should not exceed 5% of the feed formulations.

CONCLUSIONS

The findings of this study suggest that Nile tilapia feed incorporating beef cattle blood meal can be a viable alternative to reduce feed costs, while also mitigating environmental concerns associated with the disposal of pathological waste, such as slaughterhouse blood. The nutritional value of beef cattle blood meal indicates that it is a high-protein source, with protein contents ranging from approximately 60%, as observed in this study, to 80% in other studies (Khawaja et al., 2007). This variation may be influenced by the animal species, age, and health status of the individual cattle (Gorbatov, 1990; Sorapukdee and Narunatsopanon, 2017). Therefore, blood meal can be further developed as a viable protein source for animal feed in the future. Increasing the utilization of blood can reduce its disposal into the environment and contribute to sustainability in both beef cattle production and Nile tilapia farming systems.

AUTHORS' CONTRIBUTIONS

Data curation, investigation, methodology, and formal analyses were conducted using KB, TH, AP, AB, and AS. Conceptualization and project administration were managed by KB. Supervision and visualization were overseen by SA. The original draft was written, and subsequent review and editing were performed by KB, TH, AP, and SA. All authors read and approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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