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Effect of Various Leaf Meal Supplementation as a Source of Plant-Based Protein on the Growth of Red Tilapia (*Oreochromis niloticus*)

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Abstract:

This study aims to evaluate the effect of adding various types of leafy greens in artificial feed formulations on the growth rate of red tilapia (Oreochromis niloticus) fingerlings. The research was conducted from January to March 2023 at the Aquatic Resource Management Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, Jatinangor. The research method used was an experimental design with a Completely Randomized Design (CRD), consisting of five treatments with three replications each. The treatments included: Treatment A (control/no leafy green addition), Treatment B (10% Carica papaya leaf meal), Treatment C (10% Alocasia macrorrhiza leaf meal), Treatment D (10% Albizia falcataria leaf meal), and Treatment E (a combination of 3.33% the three various leaves). The results showed that the addition of leafy greens in the feed did not result in significant differences in growth rate and feed efficiency. However, the treatment with 10% Alocasia macrorrhiza leaf meal produced the highest daily growth rate at 1.22% and a feed efficiency of 26.21%. Based on these results, it can be concluded that adding up to 10% leafy greens in feed formulations can be considered an alternative source of plant-based protein for red tilapia fingerlings.

Keywords:

Alocasia macrorrhiza, Albizia falcataria, Flour, papaya leaves, red tilapia,

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Introducation

The aquaculture sector in Indonesia is targeted to reach a production volume of 5 million tons, representing a 56% increase in 2012 compared to 3.2 million tons achieved in 2011 (Ministry of Marine Affairs and Fisheries, 2012). One of the aquaculture species with significant potential for increased production is the red tilapia (*Oreochromis niloticus*), which is an important freshwater commodity in Indonesia. Farmers prefer to cultivate red tilapia because it is relatively easy to culture and market. Furthermore, market demand for red tilapia remains high across various size categories from fry to table-size fish due to its affordable price and wide consumer acceptance.

Red tilapia possesses several advantageous traits, including rapid growth, tolerance to high stocking densities, a favourable feed conversion ratio, and resistance to diseases and suboptimal environmental conditions (Carman & Sucipto, 2009). In intensive aquaculture systems, feed management is one of the key determinants of production success. Feed composition both in quality and quantity strongly influences growth and production efficiency. However, the increasing dependency on imported raw materials such as fish meal, squid meal, crustacean meal, meat bone meal (MBM), poultry meat meal (PMM), soybean meal, wheat flour, and various vitamins and minerals (Directorate of Production, Directorate General of Aquaculture, 2009) has led to rising feed costs, which consequently affect profitability in aquaculture operations.

To overcome these limitations, the development of locally available, affordable, and nutritionally balanced feed ingredients is essential. Soybean meal is a commonly used plantbased protein source due to its high protein content, yet the exploration of other local plant resources with comparable nutritional and functional properties is urgently needed. Several plant leaves such as *Carica papaya*, *Albizia falcataria*, and *Alocasia macrorrhiza* have shown potential as alternative protein sources for fish feed because of their nutritional adequacy, availability, and low cost.

Carica papaya L. is widely cultivated across Indonesia and valued for its multifunctional uses. Its leaves contain 17.0% crude protein, 7.2% crude fiber, and 11.1% ash (Sutama, 2008), while Central Java, East Java, and West Java serve as major papaya producing regions (Kalie, 2010). *Alocasia macrorrhiza* is also used by farmers as supplementary feed in gourami (*Osphronemus goramy*) culture and contains 19.50% crude protein, 7.78% fat, and 17.33% crude fiber (Laboratory of Ruminant Nutrition and Feed Chemistry, 2013). Meanwhile, *Albizia falcataria* leaves containing 20.65% crude protein, 28.34% crude fiber, and 5.13% crude fat (Tanjung, 2000) are abundant by-products of the timber industry and therefore represent an economically valuable raw material for feed production.

These plants contain diverse bioactive compounds such as alkaloids, polyphenols, flavonoids, saponins, tannins, and mimosine, which contribute to antioxidant, antibacterial, and immunostimulant activities. The role of natural antioxidants in fish physiology, particularly in maintaining cellular integrity and pigmentation, has been widely recognized (Andriani et al., 2022). Such bioactive molecules can enhance color quality, immune response, and stress tolerance in fish (Andriani et al., 2020). Papaya leaves also contain proteolytic enzymes such as papain and chymoprotein that catalyze the hydrolysis of complex proteins into simpler, more digestible forms (Munajat & Budiana, 2003; Suhartono, 1992). On the other hand, antinutritional factors such as tannins and mimosine present in *Albizia falcataria* leaves can be reduced through pre-treatments like lime water ($Ca(OH)_2$) soaking and sun-drying (Saifullah, 2005; Santoso, 2001), improving their nutritional suitability.

In addition, fermentation technology has become a promising approach to improving the nutritional and physical characteristics of plant-based and organic materials. Fermentation enhances digestibility, reduces antinutritional compounds, and modifies the texture and palatability of feed ingredients (Andriani et al., 2020; Sulistiyono et al., 2020). Fermented organic matter derived from domestic food waste has been demonstrated to improve fish growth performance and feed conversion efficiency (Andriani et al., 2023), indicating that controlled fermentation can transform underutilized biomass into high-value aquafeed resources.

Furthermore, flavonoid compounds found in *Alocasia macrorrhiza* leaves exhibit antibacterial properties by forming complexes with extracellular proteins and disrupting bacterial membrane integrity (Haitami, 2011). Their mode of action involves protein denaturation and irreversible cell damage, which enhances the host’s disease resistance. Therefore, integrating various leaves combined with appropriate fermentation processes may produce functional fish feeds that promote growth, improve feed utilization, and strengthen immune responses against bacterial infections.

Materials and Methods

Based on the aforementioned background, this study was conducted to evaluate the effect of various types of plant leaves incorporated into formulated feed on the growth performance of red tilapia (*Oreochromis niloticus*) fingerlings. The experiment was carried out at the Laboratory of Aquatic Resource Management, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, from January to March 2023.

The experimental fish used in this study were red tilapia fingerlings with an initial average body weight of 5 g per fish. The fish were obtained from the Citomi Community Hatchery Unit (Unit Pembenihan Rakyat, UPR Citomi) located in Tanggulun Barat Village, Kalijati District, Subang Regency, West Java, Indonesia.

Table 2. Formulation of experimental diets

Feed ingredients	**Treatments / Crude Protein (%)**				
	A (27%)	B (27%)	C (27%)	D (27%)	E (27%)
Fish meal	23,94	22,46	23,50	23,38	23,14
Soybean meal	23,94	22,46	23,50	23,38	23,14
Rice bran	21,05	17,53	16,50	16,61	16,85
Pollard (wheat bran)	21,05	17,53	16,50	16,61	16,85
Carica papaya leaf meal	-	10	-	-	3,33
Alocasia macrorrhiza leaf meal	-	-	10	-	3,33
Albizia falcataria leaf meal	-	-	-	10	3,33
Tapioca flour	7	7	7	7	7
Premix (vitamin–mineral)	2	2	2	2	2
Fish oil	1	1	1	1	1
Total	100	100	100	100	100

The equipment used in this study included twenty aquaria (30 × 30 × 25 cm) that served as rearing tanks for red tilapia (*Oreochromis niloticus*) fingerlings. A digital balance (AND EK-120G, accuracy ±0.01 g) was used to weigh both the fish and feed ingredients. The aeration system consisted of a blower, aeration hoses, valves, air stones, and PVC pipes to provide continuous oxygen supply to each aquarium.

Water quality was monitored using a Water Quality Checker (Hanna Instruments, USA) to measure temperature, dissolved oxygen (DO), and pH. Water temperature was controlled using submersible water heaters (Rena, 75 W), with a total of 24 units installed across treatments. Ammonia concentrations were measured using an API® Ammonia Test Kit (Mars Fishcare, USA) to ensure that water quality remained within optimal conditions for fish growth.

This experiment employed a completely randomized design (CRD**)** consisting of five treatments with three replicates each. The treatments represented different types and proportions of plant leaf meal used as a substitute for plant-based protein sources in the formulated diets, as follows:

- **A:** Diet without any leaf meal (control)
- **B:** Diet supplemented with 10% *Carica papaya* leaf meal
- **C:** Diet supplemented with 10% *Alocasia macrorrhiza* leaf meal
- **D:** Diet supplemented with 10% *Albizia falcataria*
- **E:** Diet containing a combination of various leaf meals (3.33% each)

The linear model for this experimental design was expressed as follows (Gaspersz, 1991): $X_{ij} = \mu + \tau i + \varepsilon_{ij}$

Keterangan :

X_{ij} = observation of the response variable from the *i*-th treatment and *j*-th replication,

μ = overall mean,

τ = effect of the *i*-th treatment, and

ε_{ij} = random error associated with the *i*-th treatment and *j*-th replication.

Research Procedure Preparation of Leaf Meals

The preparation of the plant leaf meals began with the collection of fresh leaves, which were thoroughly washed with running water to remove impurities. The leaves were then soaked in a lime solution ($Ca(OH)_2$) at a concentration of 2% of the leaf weight for 20 minutes to eliminate antinutritional compounds. After soaking, the leaves were rinsed again with clean water and soaked in freshwater for 24 hours. The leaves were subsequently sun-dried until completely dry, separated from the stems, and ground into fine powder using a mechanical grinder. The resulting leaf meal was sieved to ensure uniform particle size and remove coarse residues.

Feed Preparation

Formulated feed was prepared by finely grinding all feed ingredients and sieving them through a standard mesh. Each ingredient was weighed according to the diet formulation calculated using the square method to achieve the desired protein level. The ingredients were thoroughly mixed, starting from those with the smallest proportion to those with the largest, to ensure homogeneity. The mixed feed was then moistened with hot water and stirred until a dough-like consistency was achieved. The dough was extruded using a pelleting machine, and the pellets were sun-dried to constant moisture content before storage and use in the feeding trial.

Experimental Setup and Fish Maintenance

Prior to the experiment, all aquaria and supporting equipment were cleaned thoroughly to prevent contamination and disease transmission. The aquaria were rinsed with clean water, air-dried, and arranged according to the experimental layout. Each aquarium was randomly labeled to represent different treatments.

Freshwater sourced from a natural spring was used as the culture medium and aerated continuously for 24 hours before use to ensure adequate dissolved oxygen levels. The water temperature was maintained between 25°C and 28°C throughout the experiment.

After acclimation, ten red tilapia (*Oreochromis niloticus*) fingerlings were stocked into each aquarium, corresponding to a stocking density of 1 fish per 2 liters of water. Fish were observed daily to monitor behavior and health condition during the rearing period.

Experimental Procedure

A total of ten red tilapia (*Oreochromis niloticus*) fingerlings were stocked into each aquarium that had been prepared for the experiment. Fish were fed with the experimental diets at a feeding rate of 5% of total biomass per day, divided into three feeding times: 08:00, 12:00, and 16:00. Uneaten feed and fecal residues were removed daily by siphoning to maintain water quality throughout the rearing period.

Water Quality Monitoring

Water quality parameters observed during the study included temperature, pH, dissolved oxygen (DO), and ammonia (NH_3) concentration. Measurements were taken periodically to represent the environmental conditions within the rearing aquaria.

Water temperature was recorded daily, while measurements of pH, dissolved oxygen, ammonia, and fish biomass were conducted every 10 days during the 40-day rearing period. These parameters were used to evaluate the environmental stability and suitability of the culture media during the experimental period.

Observation Parameters

The parameters measured during the experiment were used to evaluate the growth performance and water quality of red tilapia (*Oreochromis niloticus*) fingerlings.

1. Daily Growth Rate (DGR)

Daily growth rate was calculated to determine the average daily increase in fish body weight during the experimental period. The formula used was as follows (Effendi, 1997):

$$DGR\ (\%/day) = \frac{(Wt - \ln Wo)}{t} \times 100\%$$

where:

W_o = average final body weight (g),
W_t = average initial body weight (g),
t = duration of the experiment (days).

2. Feed Efficiency (FE)

Feed efficiency was calculated to determine the ability of fish to convert the feed consumed into body weight gain. The formula used was as follows (Zonneveld *et al*.1991):

$$FE\ (\%) = \frac{Wt - Wo}{F} \times 100\%$$

Where:
F = total feed given (g)
W_o = average initial body weight (g)
W_t = average final body weight (g)

The data obtained from this experiment were analyzed using analysis of variance (ANOVA) to determine the effect of each treatment. When significant differences were detected ($p < 0.05$), the results were further analyzed using Duncan's Multiple Range Test (DMRT) at a 95% confidence level, in order to identify which treatments differed significantly from each other.

The experimental feed used in this study was prepared in crumb form, containing approximately 27% crude protein. The feed ingredients consisted of fish meal, soybean meal, rice bran, pollard (wheat bran), oil, premix, and various types of leaf meal according to the respective treatment formulation. All plant leaves used in the preparation of experimental feeds were sourced from the same location, namely Karang Bahagia, Bekasi Regency, West Java, Indonesia, to ensure consistency in raw material characteristics and minimize variability among treatments.

Results and Discussion

Growth is defined as an increase in body length and weight over a certain period of time. It is a complex biological process influenced by various intrinsic and extrinsic factors. Growth occurs as a result of cellular division through mitosis, leading to an increase in both tissue mass and body size. According to Effendi (1997), the factors influencing fish growth can be categorized into internal and external factors. Internal factors include heredity, sex, and age, whereas external factors involve environmental conditions such as feed availability and quality, water temperature, parasitic infections, and disease occurrence. Among these, feed quality particularly its protein content derived from both animal and plant sources play a crucial role in supporting optimal growth and metabolic processes in fish.

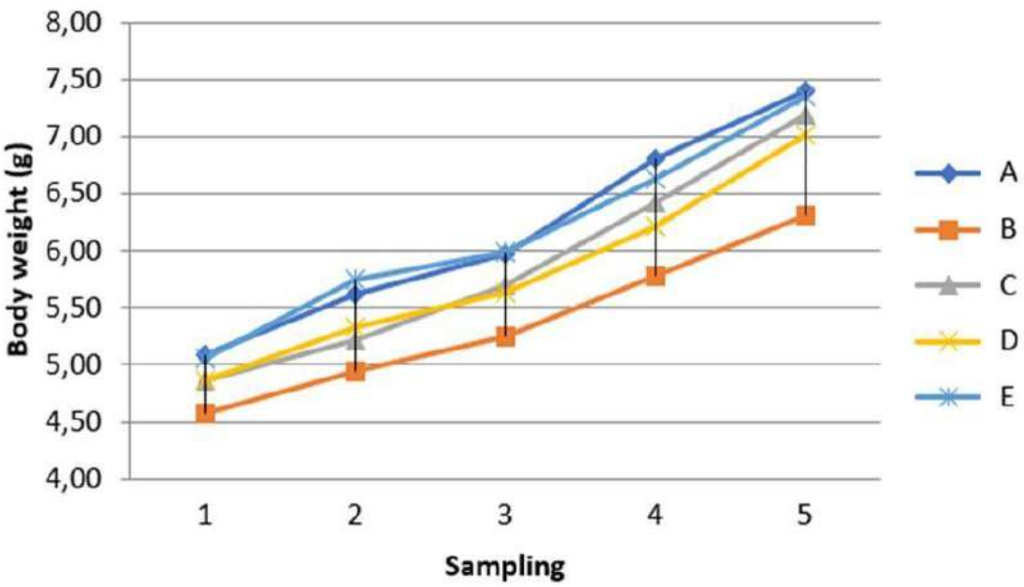

Figure 1. Average body weight of red tilapia (*Oreochromis niloticus*) during the experimental period.

Based on the results presented in Figure 6, the inclusion of different types of plant leaf meal in the formulated diets resulted in variations in body weight gain of red tilapia

(*Oreochromis niloticus*). The highest average body weight at the end of the rearing period was observed in Treatment A (control, without leaf meal addition), reaching 7.40 g, followed by Treatment E, which received a combination of *Carica papaya* leaf meal (3.33%), *Alocasia macrorrhiza* leaf meal (3.33%), and *Albizia falcataria* leaf meal (3.33%), with an average weight of 7.36 g. Treatment D, containing 10% *Albizia falcataria* leaf meal, produced an average body weight of 7.19 g, while Treatment C, with 10% *Alocasia macrorrhiza* leaf meal, reached 7.02 g. The lowest average body weight was recorded in Treatment B, which contained 10% papaya leaf meal, at 6.31 g. These findings indicate that while the control diet (without leaf meal) produced the highest growth, the combination of the three leaf types in Treatment E showed a comparable growth trend, suggesting potential synergistic effects of mixed plant ingredients on fish performance.

Table 1. Average daily growth rate of red tilapia (Oreochromis niloticus) fingerlings

Treatment	Mean daily growth rate (%, ±SD)
A (TH)	1,17±0,1464
B (TDP 10%)	1,01±0,1706
C (TDS 10%)	1,22±0,1127
D (TDSN 10%)	1,15±0,0709
E (TDP 3.33% + TDS 3.33% + TDSN 3.33%	1,17±0,1350

Note: TH = without leaf meal (control); TDP = *Carica papaya* leaf meal; TDS = *Alocasia macrorrhiza* leaf meal; TDSN = *Albizia falcataria* leaf meal.

Based on the analysis of variance, the addition of various plant leaf meals in the formulated diets showed no significant effect on the daily growth rate of red tilapia (*Oreochromis niloticus*) fingerlings during the 40-day rearing period. The mean daily growth rate of red tilapia ranged between 1.01% and 1.22% (Table 4). As shown in Table 4, the highest daily growth rate was observed in Treatment Cwith a value of 1.22%. This result indicates that the diet formulated with *Alocasia macrorrhiza* leaf meal was well digested by the fish and effectively supported growth.

These findings are consistent with the study by Komariah (2002), who reported that the inclusion of *Alocasia macrorrhiza* leaf meal at 10% in gourami feed produced the highest growth rate (4.02%) compared to fish fed diets without *Alocasia macrorrhiza* leaf meal (3.75%). The proximate composition analysis revealed that diets in Treatments C, D, and E contained the lowest crude fiber level (4.38%) among all treatments. The control diet (Treatment A) had a crude fiber content of 4.74%, while Treatment B exhibited the highest crude fiber level (5.33%), which likely contributed to its lowest growth rate (1.01%).

Fish growth is generally associated with the protein and fiber content of the diet. In this study, crude fiber levels ranged from 4.38% to 5.33%. According to Haetami et al. (2006), the tolerance limit for crude fiber in tilapia fingerlings is approximately 4%. Excessive fiber levels can reduce nutrient digestibility. Wahju (1997) stated that high fiber content in fish feed increases fecal output, as undigested fiber binds digestible nutrients and carries them out of the body. Similarly, Mudjiman (2002) noted that digestibility is influenced by feed composition, particularly protein and crude fiber levels. Crude fiber consists of organic components resistant to strong acid and alkali hydrolysis, such as cellulose, hemicellulose, lignin, chitin, and algin.

According to Halver (1989), fish have a limited ability to digest crude fiber because they lack gut microorganisms capable of producing the enzymes amylase and cellulase.
Nonetheless, moderate fiber content is beneficial for intestinal function and metabolic waste excretion. However, when fiber levels are too high, digestibility decreases, as the fish's capacity to degrade fiber depends on the cellulolytic activity of intestinal microflora (Bureau, 1999).

The proximate composition analysis (Table 2) also indicated that the highest crude protein content was found in papaya leaf meal (21.88%), although it did not result in superior growth compared with other leaf meals. This is likely due to the higher crude fiber content (12.16%) in papaya leaf meal compared to *Alocasia macrorrhiza* (6.21%) and *Albizia falcataria* (7.10%) leaf meals, which could have reduced feed digestibility. Protein is one of the most essential nutrients for fish, serving as a structural component for tissue formation and repair, enzyme and hormone synthesis, antibody production, plasma protein formation, and as a secondary energy source.

The protein content of the experimental diets (≈27%) was within the optimal range for tilapia growth. This finding aligns with Sahwan (2003), who reported that the protein requirement for tilapia fingerlings ranges between 25–30%. According to Affandi and Tang (2002), ingested feed undergoes digestion, absorption, transport, and metabolism. Undigested portions are excreted as feces, whereas absorbed nutrients are transported to target organs. Part of the absorbed nutrients is catabolized to produce energy, while the remainder contributes to cell formation, tissue repair, and other vital physiological processes.

Furthermore, Handajani and Widodo (2010) explained that protein digestion in fish is mediated by digestive enzymes secreted by the pancreas, intestinal wall, and stomach. Proteinases such as pepsin play a key role in protein hydrolysis, where dietary proteins are denatured by hydrochloric acid (HCl) in the stomach and subsequently hydrolyzed into simpler peptides for absorption.

Feed Efficiency

Feed efficiency represents the proportion of feed given that is effectively converted into fish body weight gain (Mudjiman, 2004). The amount of feed provided should correspond to the nutritional requirements of the fish. Insufficient feed can lead to competition among individuals, resulting in slow growth and uneven size distribution, while excessive feeding may cause uneaten feed to accumulate, leading to wastage and deterioration of water quality (NRC, 1983).

Calculating feed efficiency is essential in aquaculture management to determine whether feed is being utilized effectively. A higher feed efficiency value indicates better feed quality and improved nutrient utilization. Feed efficiency is directly proportional to body weight gain; thus, an increase in feed efficiency implies that the fish have efficiently converted feed into biomass (Djarijah, 1995).

In the present study, the highest feed efficiency was obtained in Treatment C, which contained 10% *Alocasia macrorrhiza* leaf meal, with an average value of 26.21%, whereas the lowest feed efficiency was recorded in Treatment B, containing 10% papaya leaf meal, with a value of 19.53%. Analysis of variance showed that the inclusion of different types of plant leaf meals in the formulated diets did not result in significant differences in feed efficiency compared with the control diet (without leaf meal addition) (Table 5). This finding suggests that all experimental diets provided comparable feed utilization efficiency, indicating that the incorporation of plant-based ingredients did not negatively affect nutrient assimilation in red tilapia fingerlings.

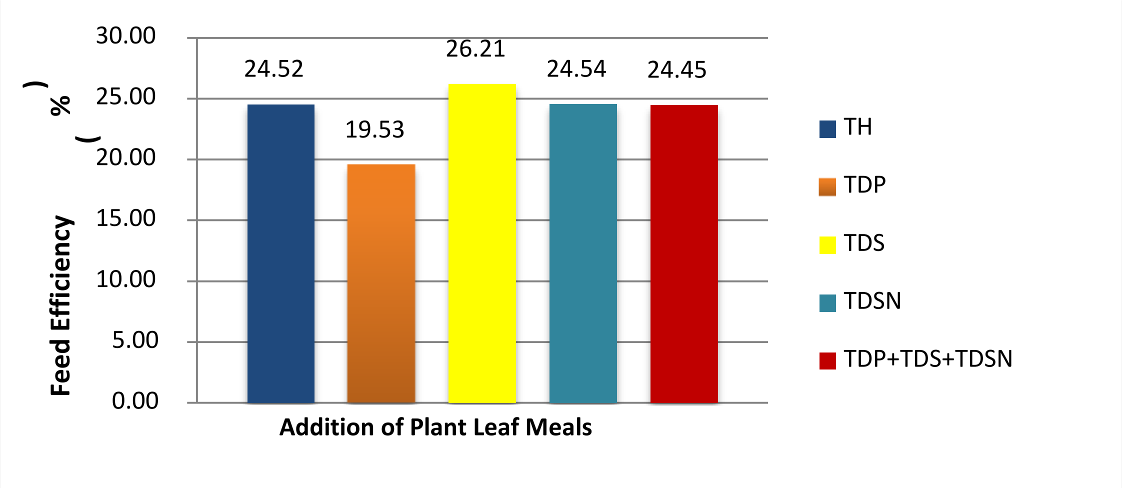

Figure 2. Average feed efficiency of red tilapia (*Oreochromis niloticus*) fingerlings.

According to NRC (1983), the chemical composition of a feed ingredient may appear ideal; however, its value is considered low if it cannot be effectively digested and absorbed by fish. When feed is poorly digested, the amount of nutrients absorbed decreases, thereby limiting the proportion of nutrients available for growth. Handajani and Widodo (2010) stated that feed quality is determined not only by its nutritional composition but also by the ability of fish to digest and absorb it efficiently. Proper digestibility ensures that essential nutrients, particularly proteins and energy sources, are optimally utilized for tissue development and metabolic functions.

Table 2. Mean feed efficiency of red tilapia (*Oreochromis niloticus*) fingerlings.

Treatment	Mean feed efficiency (%)
A (TH)	24,52±2,853
B (TDP 10%)	19,53±1,435
C (TDS 10%)	26,21±3,136
D (TDSN 10%)	24,54±5,326
E (TDP 3,33% + TDS 3,33% + TDSN 3,33%)	24,45±6,148

Note: TH = Without leaf meal (control); TDP = *Carica papaya* leaf meal; TDS = *Alocasia macrorrhiza* leaf meal; TDSN = *Albizia falcataria* leaf meal.

According to Hariati (1989), the highest feed efficiency is achieved in treatments where the feed quality is superior compared to others. Better feed quality allows more energy obtained by fish to be effectively utilized for growth. The present study showed that Treatment C, which contained 10% *Alocasia macrorrhiza* leaf meal, produced the highest feed efficiency value of 26.21%. This finding is consistent with Lestari (1992), who reported that incorporating 10% *Alocasia macrorrhiza* leaf meal in diets for gourami (*Osphronemus goramy*) with an initial body weight of 18 g over a two-month period increased body weight gain by 2.479 g and achieved a feed efficiency of 28.35%. These results indicate that diets containing 10% *Alocasia macrorrhiza* leaf meal were more effective in promoting growth in red tilapia fingerlings than other treatments. A higher feed efficiency value indicates a more efficient conversion of feed into fish biomass, which consequently reduces feed costs in aquaculture production. The calculation of feed efficiency is therefore crucial in aquaculture management to determine the extent to which feed is utilized efficiently. As noted by Djarijah (1995), feed efficiency is directly proportional to body weight gain; hence, a higher feed efficiency value reflects improved feed quality and utilization efficiency.

The lowest feed efficiency value was observed in Treatment B, which contained 10% papaya leaf meal, with an efficiency of 19.53%. This lower efficiency suggests that the fish were less capable of utilizing the diet effectively, resulting in suboptimal growth. The low feed efficiency in this treatment was likely due to the high crude fiber content in papaya leaf meal (12.16%). The corresponding diet also had the highest crude fiber content (5.33%), exceeding the tolerance limit for tilapia fingerlings, which is approximately 4% (Haetami et al., 2006). In addition to the high fiber content, the low feed efficiency observed may also be attributed to the presence of residual antinutritional compounds, particularly tannins and mimosine, in the feed ingredients. According to Handayani and Widodo (2010), mimosine can inhibit growth in fish because it antagonizes essential amino acids required by the body. Mimosine is thermally stable and begins to degrade only at high temperatures of about 227–228°C. Rehena (2008) reported that tannins reduce nitrogen retention and amino acid digestibility, thereby limiting protein utilization for growth.

Handayani and Widodo (2010) further explained that tannins can be reduced through soaking in water, alkali solutions, mechanical processing, or supplementation with methyl donors. Soaking in distilled water at 30°C for 24 hours can decrease tannin content by approximately 31%, while soaking in NaOH or KOH (0.005 M) at the same temperature and duration can reduce tannins by 75–85%. The most effective treatment involves soaking in 1% lime (CaO) solution for 10 minutes, which forms $Ca(OH)_2$ in water. The calcium ions (Ca^{2+}) may bind polyphenolic compounds, thereby neutralizing tannins through ionic bonding. In this study, soaking the leaves in a 2% $Ca(OH)_2$ solution for 20 minutes was expected to reduce tannin content by more than 85%, thus improving feed quality.

The plant leaves used in this study *Carica papaya*), *Alocasia macrorrhiza*, and *Albizia falcataria* contain several bioactive compounds such as alkaloids, polyphenols, flavonoids, saponins, tannins, and mimosine. Papaya leaves also contain proteolytic enzymes such as chymoprotein, lysozyme, and papain (Munajat & Budiana, 2003). According to Suhartono (1992), papain and chymoprotein catalyze the hydrolysis of complex proteins and polypeptides into simpler forms that can be readily absorbed and utilized for growth.Tannins and mimosine, however, are well-known antinutritional compounds commonly found in leguminous plants such as *Albizia falcataria*. Despite this, leguminous plants are still valuable feed ingredients due to their high protein content (25–30%), making them a good alternative source of plant protein for fish feeds (Handayani & Widodo, 2010).

Alocasia macrorrhiza leaves, on the other hand, contain flavonoid compounds with antibacterial properties that act by forming complexes with extracellular proteins and disrupting bacterial cell membrane integrity. This mechanism is believed to involve the denaturation of bacterial cell proteins and irreversible cell damage. For this reason, *Alocasia macrorrhiza* leaves are considered beneficial as a feed additive to enhance fish immunity and disease resistance (Haitami, 2011). It is expected that combining these three types of various leaves in feed formulations could optimize fish growth and enhance resistance to bacterial infections, owing to the synergistic effects of their bioactive components.

The readiness of fish to accept formulated feed containing plant materials may also influence growth rate and feed efficiency. According to Khairuman and Amri (2002), tilapia larvae and fingerlings typically feed on zooplankton such as *Rotifera*, *Moina*, and *Daphnia*, as well as filamentous algae including *Chaetomorpha*, *Enteromorpha*, *Cladophora*, and *Spirogyra*. This aligns with Mudjiman (2004), who stated that the feeding habits of fish encompass both the types of food consumed and the feeding behavior itself. Understanding these feeding habits is crucial for providing feed types that are both nutritionally adequate and palatable to the fish.

Based on the findings of this study, the incorporation of leaf meal in formulated diets did not significantly affect feed efficiency compared to the control diet (without leaf meal addition) (Table 5). Therefore, it can be concluded that leaf meals can serve as alternative plant-based protein sources in fish feed formulations without negatively affecting growth performance or feed efficiency at inclusion levels up to 10%.To further improve feed efficiency, in addition to physical processing (such as grinding into fine meal), biological treatments such as fermentation can be applied particularly for plant ingredients with high crude fiber content. Fermentation helps break down fiber and antinutritional compounds, thereby enhancing digestibility and nutrient absorption in fish.

Water Quality

Water quality measurements were used as supporting parameters throughout the experiment. Water was partially replaced by approximately 50% every week to maintain stable rearing conditions. The observed water quality parameters included temperature, dissolved oxygen (DO), and pH (acidity level). The pH values recorded during the experiment ranged between 7.07 and 8.80, which were within the optimal range for red tilapia (*Oreochromis niloticus*) culture. According to the Indonesian National Standard (SNI, 2009), the optimal pH range for red tilapia culture is 6.50–8.50. Akbar and Sudaryanto (2001) reported that low pH conditions may reduce growth activity, weaken fish, and increase susceptibility to disease, often resulting in higher mortality rates.

Water temperature was maintained at approximately 28°C using automatic heaters. This range is considered optimal for red tilapia growth, as SNI (2009) recommends a temperature between 25°C and 32°C. The Marine and Fisheries Extension Center (2011) stated that tilapia growth becomes impaired at temperatures ≤18°C or ≥32°C. Therefore, the temperature during this study remained within the suitable range for red tilapia culture. Water temperature plays a vital role in regulating fish growth and appetite; as temperature decreases, metabolic rate and feeding activity also decline.Dissolved oxygen (DO) concentrations were influenced by water movement, photosynthetic activity, respiration, and organic matter input (Effendi, 2003). During the experiment, DO levels remained within the optimal range for red tilapia. The optimal DO concentration for red tilapia is ≥3 mg/L (SNI, 2009), while the measured range in this study was 10.4–15.7 mg/L, which exceeds the minimum requirement. Adequate dissolved oxygen is essential for fish respiration and overall survival.

The ammonia concentration in the rearing media was also monitored throughout the study. For freshwater fish, safe ammonia levels should remain below 1 ppm. Water containing more than 1.5 ppm ammonia indicates potential pollution. According to Government Regulation No. 82 of 2001 (Class II), the maximum allowable ammonia concentration for sensitive fish species is ≤0.02 mg/L. In this study, ammonia levels ranged between 0.762 mg/L and 1.740 mg/L, indicating that the ammonia concentration remained within acceptable limits and did not negatively affect the rearing environment or the health of red tilapia.

CONCLUSION

This study demonstrated that the incorporation of various plant leaf meals in red tilapia (*Oreochromis niloticus*) diets affected growth rate and feed efficiency, although the effects were not statistically significant. The addition of 10% *Alocasia macrorrhiza* leaf meal resulted in the highest feed efficiency (26.21%) and the best daily growth rate (1.22%), indicating that *Alocasia macrorrhiza* leaf meal is more suitable for use in feed formulations compared to other leaf meals. In contrast, the inclusion of 10% papaya leaf meal reduced both feed efficiency and growth rate, likely due to its high crude fiber content, which impairs nutrient digestibility. Although the protein levels of all tested leaf meals were within the nutritional requirements for red tilapia, the high fiber content of certain ingredients such as papaya leaves adversely affected feed utilization. Furthermore, the presence of antinutritional compounds such as tannins and mimosine in some plant materials may have limited digestion and nutrient absorption. Good water quality, characterized by pH within the optimal range and stable temperature, also played an important role in supporting fish growth and maintaining overall culture performance. Overall, the findings indicate that plant leaf meals can serve as alternative plant-based feed ingredients in aquaculture. However, further processing, such as fermentation, is recommended to reduce crude fiber content and improve feed efficiency and digestibility for optimal growth performance in red tilapia culture.

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