Maejo International Journal of
Energy and Environmental
Communication

Journal homepage: https://ph02.tci-thaijo.org/index.php/MIJEEC

ARTICLE

Replacement of fish meal using pig manure as a protein source for Nile tilapia culture

Buncha Tongmee[1,*], Niwooti Whangchai[1], Sudaporn Tongsiri[1], Yuwalee Unpaprom[2]

[1]Faculty of Fisheries Technology and Aquatic Resources, Maejo University, Chiang Mai, 50290 Thailand
[2]Program in Biotechnology, Faculty of Science, Maejo University, Chiang Mai 50290, Thailand

ARTICLE INFO

Article history:
Received 14 March 2020
Received in revised form
23 April 2020
Accepted 8 May 2020

Keywords:
Nile Tilapia
Freshwater fish culture
Pig manure
Ponding system
Fish farming

ABSTRACT

The cost of fish feed is a significant constraint to freshwater fish farming in Asia. In the aquaculture value chain, feed is a responsible factor and accounts for nearly 75% of the total cost of fish production in many countries. Therefore, this study focuses on the feasibility of using pig manure fermentation to formulate feed pellets to culture the tilapia fish in the cement pond. The cultured using ready-made feed containing the residue from the manure fermentation at different ratios. Accordingly, the experimental studies were approached by two types of experiments, namely, experiment 1 (focused on the nutrients in pig manure collected from an anaerobic system farm) and experiment 2 (which studied the appropriate level of pig manure to be used as a raw material for fish feeding). The five months' fermentation of pig manure contains 17.09% protein, which is the highest amount of nutrition source. Digestate manure was estimated; other primary macronutrients, including nitrogen, phosphorus, and potassium, were 2.73, 0.55 and 1.22 %, respectively. Also, a considerable number of essential micronutrients, for example, copper, manganese and zinc, were found in the digestate. Nile tilapia were grown at the cement ponds for 120 days. The maximum verified dry matter and protein digestibility in tilapia was attained for diets containing 10 % pig manure at 89.28 ± 4.09 and 56.64 ± 1.43 ($p > 0.05$), respectively. In this study, experimental results indicated that fish meal consisting of 15% manure was the most acceptable substitute source of protein for tilapia production. This implies that the cost of fish meal production using fermented pig manure can be significantly lowered, gain higher profit and provide significant economic benefits to farmers.

1. Introduction

Aquatic reservoirs are essential for food production and also provide obligatory recreational values and services. The fish in general and freshwater fish, in particular, are among the fast-growing sectors with collective helps in the nutrition security of consumers. However, the fisheries sector considers the nutrition of millions of people around the world. FAO (2018) stated that fish and other aquatic products accounted for about 26 % of the animal proteins consumed in the least developed countries against 11 % for developed countries. Aquaculture provided about 47 % of fish on the world market, with Asia contributing about 89 % of global aquaculture production during the last 20 years (Adéyèmi et al., 2020). Freshwater aquaculture is probably the most effective form of aquaculture for the time being, and fish is the leading product in freshwater aquaculture.

Fish and fishery products represent a valuable source of animal protein, as a portion of 150 g of fish provides about 50–60% of the daily protein requirements for an adult. The robust growth in fisheries and aquaculture production in the last 50 years, more so

* Corresponding author.
E-mail address: buncha_t@mju.ac.th (Buncha Thongmee)

in the last two decades, has enhanced the world's capacity to consume diversified and nutritious food. A healthy diet includes sufficient proteins containing all essential amino acids, essential fats, vitamins and minerals. Actuality a rich source of these nutrients, fish can be nutritionally vital (Viola and Arieli, 1983. Robinson et al., 1984; Lovell, 1989). It is rich in various vitamins as well as minerals, mainly if eaten whole. It is a source of easily digested, high-quality proteins containing all essential amino acids (Tacon et al., 1987; 1995). Fish provides health benefits in protection against cardiovascular diseases and assists in developing the brain and nervous system in the fetus and infants (Barik, 2017). However, aquaculture production heavily depends on the external aquafeeds or nutrients supply to the aquaculture system.

Nomenclature and abbreviation

ADG	Average Daily Weight Gain
FCR	Food Conversion Ratio
CRD	Completely Randomized Design
FAO	Food and Agriculture Organization
ANOVA	Analysis of Variance
DMRT	Duncan's New Multiple Range Test

High nutrients and the necessary taste of grouper fish affect the high mandate in grouper fish in the prevailing market. On the other hand, wild catch grouper fish in the current prevailing market supply is limited and insufficient to meet the cyclical nature of high demand in grouper fish consumption leading to the high price (Sakamoto and Yone, 1979; Nakamura and Yamada, 1980; Clark, 1989; Soong et al., 2016). For that reason, grouper fish is worth farming. Hence, there is a need to formulate the fish feed since it is essential to have the correct nutrients requirement for feed formulation to ensure the adequacy of the diet for the grouper fish. Recently, aquafeeds production has been widely recognized as one of the fastest expanding agricultural industries globally, and the annual growth rate of aquafeed production reached higher in the animal feeds market.

Notably, the use of manure in aquaculture, as practised for centuries, is compared with ordinary feedstuffs. Maximum yields per unit area are higher with high-protein feeds than manure but are obtained at a higher cost. When manure is a regular input in aquaculture, manure disposal problems are mainly avoided, and integrating aquaculture with animal husbandry appears to result in the most rational manure utilization. When manure is applied to fishponds, the best results are achieved with frequent applications. The food web, leading from the manure applied to the fish-flesh produced, is discussed in terms of direct feeding, minerals for autotrophic production, and organic matter for heterotrophic production.

The best alternative is the organic manures on the pond ecosystem to utilize fully decomposed/digested organic manures compared to undigested or semi-digested organic manures (Kaur and Ansal, 2010). Small-scale fish farmers generally practice aquaculture using low-input and low-level technology. It is especially true for aquaculture production in earthen ponds, where traditional practices favour primary productivity and limit inputs of exogenous food, primarily commercial pellets, which is cost-effective. Therefore, manure (digestate) based formulated pellets could be helpful for local farmers. Digestate is rich in all types of major and minor nutrients, vitamins, enzymes, antibiotics, growth promoters etc. It is a form of organic manure, which can be produced from various organic wastes (cow dung, poultry waste, piggery waste, agricultural waste, etc.). Agriculture is the primary occupation of Thai people despite the constant industrial growth occurring in many parts of Thailand (Dussadee et al., 2016).

The two primary activities in the agriculture area are cultivating crops (54%) and integrated crop-livestock farming (35%). The primary forms of livestock abundant in Thailand are pigs, chicken and cattle. The leading resource is represented by animal manure and slurries from cattle and pig production units (Dussadee et al., 2014). In this study, digested pig manure embassies as fish feed for tilapia (Nile tilapia) production. Nile tilapia (*Oreochromis niloticus*) is a type of freshwater fish easy to propagate and has a good taste, can live in fresh and brackish water. Suitable to be cultured in the pond. It has become popular and widely cultivated in Asia. This study aims to quantify the nutrients balances in cement ponds used for the production of tilapia (Heylor et al., 1988; Dabrowska et al., 1989). Here, increased aquaculture production was considered using formulated pig manure pellets as the unique sources of fish feed.

Therefore, this study focused on the appropriate level or amount of minerals that can be added into the diet for red tilapia, which should be able to enhance the growth of red tilapia that gave higher production with lower cost and to be a guideline for farmers can continue to produce pellet food for their use in the farm.

2. Materials and Methods

2.1. Culture facility, experimental fish, and growth trial

The experiment was performed in controlled conditions where cement ponds (the diameter of 100 centimetres, height of 50 centimetres) were used. Nile tilapia (*Oreochromis niloticus*) were used for this study. This study was carried at the experimental field site (Fig.1), Faculty of Fisheries Technology and Aquatic Resources, Maejo University, San Sai District, Chiang Mai Province, Thailand.

2.2. Experimental diets

Four experiments were carried for feed formulations. Fermented pig manure was used for the following feed preparations procedures (1) pig waste residue level that replaces fish meal in food 0%; (2) pig waste residue level, which is used to replace fish meal in 5%; (3) pig waste residue level that replaces fish meal in the diet by 10% and (4) pig waste residue level, which is used to replace fish meal in the diet by 15%.

2.3. Growth studies and feed utilization efficiency

Fig. 1. Controlled field tilapia culture

At the end of the experiment, fish were harvested, counted, and weighed (Fig. 2). The growth performance and feed utilization parameters were calculated as follows:

A) Specific growth rate (SGR) = [(ln FBW-ln IBW)/t] × 100

where FBW and IBW = final mean weight and the initial mean weight, respectively; T=feeding period in days.

B) Survival rate %=[(NF/Ni) × 100]
where NF=final total number of fish;
Ni=initial total number of fish.

C) Feed conversion ratio (FCR)=Total feed intake (g)/ Total weight gain(g)

D) Protein efficiency ratio (PER) = Total weight gain (g)/ Protein intake

E) Body weight gain (BWG)=Wt–Wi Ten fish individuals were randomly sampled

Fig. 2. Measuring the length and initial weight of the tilapia (A-B)

2.4. Statistical data analysis

The data were obtained for statistical analysis. By analyzing the variance (Analysis of Variance) to compare the statistical differences between the experimental groups at a 95 % confidence level using SPSS for Window, compare the mean differences using Duncan's New Multiple Range Test methods using SPSS version 11.5.

3. Results and Discussion

The dry matter content of formulated feed samples was gravimetrically determined after a water loss, and the results are presented in Table 1.

Table 1. Nutrient values for each tilapia experiment set used in the experiment

Nutritional value (%)	Swine residue levels to replace fishmeal in food (%)			
	0	5	10	15
Moisture	4.36±0.77[b]	4.35±0.46[b]	4.33±0.45[b]	6.50±1.41[a]
Protein	25.82±0.26	25.33±0.23	25.76±0.26	25.64±0.29
Fat	13.56±3.19	11.66±3.64	18.77±6.11	15.68±2.04
Fiber	8.47±0.56	8.66±0.51	7.75±0.53	8.31±0.48
Ash	10.40±0.79	13.89±1.31	11.74±1.17	12.06±1.51

Note: The average ± SD with horizontal characters shows a statistical difference ($p < 0.05$).

Fig. 3. (A-E) Raw feed ingredients used in cooking and dry fermented pig manure used in the experiment

Fig. 4. (A-C) Cooking process with pig manure as a substitute for fish meal

The feed composition of crude protein ingredients is shown in Table 1. The protein content of 0, 5, 10, and 15% feed formulations were having 25.82±0.26, 25.33±0.23, 25.76±0.26 and 25.64± 0.29%, respectively. The raw feed ingredients were used in cooking and dry fermented pig manure in the experiment process, as exhibited in Fig. 3. Moreover, feed manufacturing and pelleting approaches are revealed in Fig. 4. After the fish production, the weight gain percentage showed no significant difference (p> 0.05). Tilapia cultured in a feed formula with pig manure to replace fishmeal with 0% had the highest mean weight gain rate of 256.16 ± 21.85. The following percentages were tilapia fed with pig manure mixtures that were substituted for fish meals 15, 5, and 10% were 244.80 ± 29.15, 236.00 ± 44.04 and 220.16 ± 70.79%, respectively.

The growth rate per day (g/day) was found to be not statistically different (p> 0.05). In the experiments fed with a 15% feed with pig manure, substituted for fishmeal, the rate was the highest average daily growth was 0.63 ± 0.06 g/day, followed by tilapia fed with pig residue mixtures that were substituted for a fish meals 10, 5, and 0% were 0.59 ± 0.15, 0.53 ± 0.09 and 0.50 ± 0.050 g/day, respectively. The conversion rate was not statistically different (p> 0.05). The feed conversion rate was the highest in the experimental set of 0% of the feed to replace fishmeal. 1.17 ± 0.07 followed by the tilapia fed with pig residue mixtures used as a substitute for fish meal 5, 10 and 15% were 1.14 ± 0.12, 1.06 ± 0.18 and 1.00 ± 0.07%, respectively. The efficiency of converting food to meat (%) was found to be statistically no different (p> 0.05). In the experiments fed with 15% of the pig manure-substituted feed formula, the highest mean was 30.02 ± 2.18%.

The following were tilapia fed with pig manure mixed with the fish meal as a substitute for fish meal 10, 5 and 0%, which were 28.84 ± 5.30, 26.58 ± 3.30 and 25.60 ± 1.63 percent, respectively. Yields (g) were found to be not statistically different (p> 0.05). In the experiments fed with 15 percent of the pig manure feed formula, the highest average yield was 1,002.80 ± 72.88. The following were tilapia cultured with pig manure mixtures used to replace fish meals 10, 5 and 0% were 963.40 ± 176.97, 888.00 ± 110.09 and 855.16 ± 54.62 g, respectively. Therefore, it is possible that manganese at 11.6 mg/kg (diet3) diet showed higher specific growth rates and food efficiency than the control. Consequently, the present study results indicated that formulated pig manure is a suitable replacement for fish meals and is practically applicable.

4. Discussion

Tilapia is a fish that can be easily reproduced—fast-growing Good adaptation to the environment, and economically significant. In the year 2004, it was found that Thailand had a total yield of 160,241 tons of tilapia, which came from the production of the pond, the most equal to 131,181 tons and tended to increase because it is a fish that has Good price. Not faced with the problem of epidemic disease, Making it popular and widely cultured. At present, tilapia can be classified as a product exported to foreign countries in the fillet. The major markets include Japan, the United States, Italy, etc. (Department of Fisheries, 2014). Tilapia can be cultured in rice fields, ponds, cages and blended farming, etc. The 1-year farming period has a growth rate of up to 500. The size of the fish required by the market is approximately 300 - 400 grams each. Food costs are the main cost of aquaculture production. By reducing the cost of feed, the production profit can be increased (Ayyappan and Ahamad Ali, 2007). In keeping tilapia in the cage, the average food cost was 69.5%.

There is approximately 9.8 million swine productions in Thailand per year. The major pig production sites are the central region yielded 52.6%, followed by the north. The Northeast and the south have yields of 18.9, 18.5 and 9.8%, respectively. These products are used for domestic consumption, approximately 98-99%. Today, Thai people consume an average of 11-12 kg of pig meat per person per year. When comparing the consumption of other meats, pork was the most popular. A 1993 survey by the Agricultural Statistics Center and the Department of Livestock Development found that 90% of all farmers nationwide were small-scale farmers, raising no more than 10 per individual, but the number of pigs produced by small breeders was only an estimated. 20 percent of the pigs produced in the country (Department of Fisheries, 2014)

This is because the nutrients that pigs consume can be decomposed and used to benefit the body. The remainder possibly is excreted more than 60% (Flachowsky and Hennig, 1990), while Ansa and Jiya (2002) reported that the amount of pig manure and urine across the country is at least 26 million tons per year. The effluent from washing the pigpen is approximately 30-40 litres per animal or approximately 392 million liters per day. Solving the problem by utilizing pig manure contains essential minerals such as nitrogen, phosphorus, and potassium (White and Brown, 2020). It can be utilized in several ways. Used as an ingredient in animal feed (Newton et al., 2005).

But there must be no significant number of harmful pathogens. No other additives lower the nutritional value (Watanabe et al., 1980; Watanane, 1988). Therefore, it can be reused as animal feed used to grow the fish—the pattern for bringing pig manure for fish feed by building a pig farm on the fishpond. When the pigs excrete, they drop into the pond. Alternatively, use scooping pig manure raised from other sources and put it in a fishpond (Cottrell and McNichols, 2011).

Bringing pig manure to cultivate fly worms to serve as a substitute for high-priced protein food sources pig manure can be fermented through biogas because biogas is the main component of methane (Ramaraj and Unpaprom, 2016; Unpaprom et al., 2020). Therefore, it has good ignition properties and can be used as renewable energy in various forms, such as burning to utilize direct heat (Wannapokin et al., 2018). Burned for heating and used to drive machinery such as for heating and to generate electricity.

Organic fertilizers or pig manure are the by-products of fermentation residues. It has properties that can be used as organic fertilizers, which is also found to contain relatively high nitrogen content, which can be used as organic fertilizers for crop cultivation. The selling price is about 0.5–1 baht per kilogram. This is considered as an additional income to the pig farm owners in one way. However, another approach that is interesting today is supplementary freshwater aquaculture on farms. The study found that the population in the northern region had a high annual consumption of freshwater animals per person per year (Piumsombun, 2001). According to the data of the Chiang Mai Freshwater Aquaculture Cooperative. It was found that the demand for freshwater fish in Chiang Mai province was up to 40,000 kg per day (Ungsethaphand et al., 2003).

Therefore, to increase the income of the farm another way. The farm should have raised tilapia. Using the residue from the fermentation of pig manure as feed material increase income for the pig farm (Unpaprom et al., 2020). Moreover, help reduce environmental problems and a new body of knowledge in food and tilapia farming.

In addition, at present, there is widespread awareness of food safety (Food safety). Furthermore, the operation of aquaculture according to good practice (Good Aquaculture Practice, GAP), but aquaculture often faces the problem of bad smell or muddy smell (Off-flavor) is a crucial factor for aquatic animal export. This is caused by Actinomycete bacteria and some blue-green algae that produce a muddy or unpleasant odour in fish meat (Shim and Ng, 1988; Klapper 1991, Yamada et al., 1994). Osmin (geosmin) and MIB (MIB) make aquatic animals less popular, low cost, muddy odour problems arising from fish ingesting the muddy odour compound directly or being contaminated with what the fish eat. On the other hand, pass into the fish by absorption in the organs (Tanchotikul and Hsieh, 1990). Therefore, there is a concept to develop tilapia fish production in ponds by applying pig manure through an anaerobic treatment system. They were used as raw materials for animal feed to reduce costs and add value to the pig manure.

5. Conclusion

The residue from pig manure fermentation over 5 months was found to have 17.44% protein content. They have nitrogen, phosphorus and potassium content. The micronutrients were copper, manganese and zinc were found. The feed formula with pig manure was used to replace fish meal 15%% after the trial period for 120 days. The phytoplankton content in the cement pond at the residue level of pig manure replaces a fish meal. Digestion of Tilapia Fish meal was found that the pig manure residue formula used to replace fish meal 10% contained dry matter and protein digestion. Pig manure residue formula that can be used as a substitute fish meal in the feed can be an essential ingredient in tilapia feed. To replace high-priced protein foods, it is the use of the residual waste to be used and add higher value. This study suggested that formulated pig manure pellet feeds are possible directly beneficial to the farmers. This study exposed various local feed ingredients and available animal manure that could formulate fish feeds with adequate nutritional composition to empower resourceful fish farming.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Acknowledgements

This study was partially supported by the project “Innovation of the economic aquatic production system in 4.0 for the Northern Thailand food industry, Maejo University, 2020”.

References

Adéyèmi, A. D., Kayodé, A. P. P., Chabi, I. B., Odouaro, O. B. O., Nout, M. J., & Linnemann, A. R. 2020. Screening local feed ingredients of Benin, West Africa, for fish feed formulation. Aquaculture Reports 17, 100386.

Ansa, E. J., & Jiya, J. 2002. Effects of pig manure on the growth rate of *Oreochromis niloticus* under integrated fish cum pig farming system. Journal of Aquatic Sciences 17(2), 85-88.

Ayyappan, S., & Ahamad Ali, S.A. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development, pp. 192-219. FAO Fisheries Technical Paper No. 497. Rome, FAO. pp. 510.

Barik, N. K. 2017. Freshwater fish for nutrition security in India: Evidence from FAO data. Aquaculture Reports 7, 1-6.

Clark, J. S., 1989. Nutritional requirements of finfish (A review). in: D. M. Akiyama (Editor), Proceedings of the Peoples Republic of china Aquaculture and Feed Workshop 1989, American Soybean Association, Singapore, pp. 288-302.

Cottrell, A., & McNichols, J. 2011. The Urban Farm Handbook: City-Slicker Resources for Growing, Raising, Sourcing, Trading, and Preparing What You Eat. Skipstone.

Dabrowska, H. Guntther, K. D., & Meyer-Bburgdorff, K. 1989. Availability of various magnesium compounds to tilapia (*Oreochromis niloticus*). Aquaculture 269-276.

Department of Fisheries. 2014. Statistics of freshwater aquaculture production 2014. Department of Fisheries Ministry of Agriculture and Cooperatives. Bangkok. Thailand pp. 67. [In Thai]

Dussadee, N., Reansuwan, K., & Ramaraj, R. 2014. Potential development of compressed bio-methane gas production from pig farms and elephant grass silage for transportation in Thailand. Bioresource Technology 155, 438-441.

Dussadee, N., Unpaprom, Y., & Ramaraj, R. 2016. Grass silage for biogas production. Advances in Silage Production and Utilization, 153.

FAO. 2018. La situation mondiale des pêches et de l’aquaculture. Atteindre les objectifs de développement durable, Rome 2018. [Online] http://www.fao.org/3/i9540fr/i9540fr.pdf (Accessed 10 January 2020).

Flachowsky, G., & Hennig, A. 1990. Composition and digestibility of untreated and chemically treated animal excreta for ruminants—a review. Biological wastes 31(1), 17-36.

Heylor, G. S., Beveridge, M. C. M., & Jauncey, K. 1988. Phosphorus nutrition of juvenile *Oreochromis niloticus*. P.341-345. *In* R.S.V. Pullin, T. Bhukaswan, K.Tonguthai & J. L. Maclean (eds). The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceeding 15, 623 p.

Kaur, V. I., & Ansal, M. D. 2010. Efficacy of vermicompost as fish pond manure–Effect on water quality and growth of *Cyprinus carpio* (Linn.). Bioresource Technology, 101(15), 6215-6218.

Klapper, H. 1991. Control of Eutrophication in Inland Waters. New York: Ellis Horwood.

Lovell, T. 1989. Nutrition and feeding of fish. Van Nostrand Reinhold. New York. pp. 260.

Newton, L. A. R. R. Y., Sheppard, C. R. A. I. G., Watson, D. W., Burtle, G. A. R. Y., & Dove, R. O. B. E. R. T. 2005. Using the black soldier fly, *Hermetia illucens*, as a value-added tool for the management of swine manure. Animal and Poultry Waste Management Center, North Carolina State University, Raleigh, NC, 17.

Nakamura, Y., & Yamada, J. 1980. Effects of dietary calcium levels, Ca/P ration, and calcium components on the calcium absorption rate in carp. Bulletin of the Faculty of Fisheries Hokkaido University 31, 277-282.

Piumsombun, S. 2001. Production, accessibility and consumption patterns of aquaculture products in Thailand. FAO Fisheries Circular No. 973.

Ramaraj, R., & Unpaprom, Y. 2016. Effect of temperature on the performance of biogas production from Duckweed. Chemistry Research Journal 1(1), 58-66.

Robinson, E. H., Rawles, S.D., Yette, H. E., & Greene, L. W. 1984. An estimate of the dietary calcium requirement of fingerling *Tilapia aurea* reared in calcium-free water. Aquaculture 41(4), 389-393.

Rowena, C. Dato-Cajegas., & Yakupityyage, A. 1996. The need for dietary mineral supplementation for Nile tilapia, (*Oreochromis niloticus)* cultured in a semi-intensive system. Aquaculture 144(1-3), 227-232.

Sakamoto, S., & Yone, Y. 1979. Availabilities of phosphorus compounds as dietary phosphorus sources for red sea bream. Journal of the Faculty of Agriculture, Kyushu University 23, 177-184.

Shim, K. F., & Ng, S. H. 1988. Magnesium requirement of the guppy (*Poecilia reticulata* Peters). Aquaculture 73(1-4), 131-141.

Soong, C. J., Razamin, R., & Rosshairy, A. R. 2016. Investigating nutrient requirements of grouper fish for feed formulation. Journal of Telecommunication, Electronic and Computer Engineering 8(8), 19-25.

Tanchotikul, U., & Hsieh, T. C. Y. 1990. Methodology for quantification of geosmin and levels in rangia clam (*Rangia cuneata*). Journal of Food Science 55(5), 1233-1235.

Tacon, A. G. L. 1987. Essential nutrients – mineral. The nutrition and feeding of farmed fish and shrimp, A Training Manual, vol. 1. The Essential Nutrients. FAO/UN, Brazilia pp. 70-84.

Tacon, A. G. L. 1995. Application of nutrient requirement data under practical condition special problem of intensive an semi intensive fish farming systems. Journal of Applied Ichthyology 11, 205-214.

Ungsethaphand, T., Chaibu, P., & Maneesri, S. 2003. Finfish production status of Chiangmai province, Northern Thailand. In Asian-Pacific Aquaculture 2003 Conference (pp. 22-25).

Unpaprom, Y., Pimpimol, T., Whangchai, K., & Ramaraj, R. 2020. Sustainability assessment of water hyacinth with swine dung for biogas production, methane enhancement, and biofertilizer. Biomass Conversion and Biorefinery 1-12.

Viola, S., & Arieli, Y. 1983. Alternative dietary protein sources for farmed tilapia, *Oreochromis* spp. Aquaculture 179(1-4), 149-168.

Wannapokin, A., Ramaraj, R., Whangchai, K., & Unpaprom, Y. (2018). Potential improvement of biogas production from fallen teak leaves with co-digestion of microalgae. 3 Biotech, 8(2), 123.

Watanabe, T., Takeuchi, T., Murakami, A., & Ogino, C. 1980. The availability of *Tilapia nilotica* of phosphorus in white fish meal. Bulletin of the Japanese Society of Scientific Fisheries 46 (7), 897-899.

Watanane, T. 1988. Fish nutrition and mariculture. JICA textbook the general aquaculture course. pp. 233.

White, P. J., & Brown, P. H. 2010. Plant nutrition for sustainable development and global health. Annals of botany 105(7), 1073-1080.

Yamada, N., Murakami, N., Kawamura, N., & Sakakibara, J. 1994. Mechanism of an early lysis by fatty acids from axenic *Phormidium tenue* (musty odor-producing cyanobacterium) and its growth prolongation by bacteria. Biological and Pharmaceutical Bulletin 17(9), 1277-1281.