Maejo International Journal of Energy and Environmental Communication

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

ARTICLE

Effect of pineapple juice and dried papaya peel in the diet on growth performances of channel catfish (*Ictalurus punctatus*)

Tipsukhon Pimpimol[1], Daracha Thiammueang[1], Karnchana Karnchanamayoon[2], Kittikorn Kanjanamayoon[2], Sudaporn Tongsiri[1,*]

[1]Faculty of Fisheries and Aquatic Resources, Maejo University, Chiang Mai, 50290 Thailand
[2]Siam Farm Services Cooperation Limited, Ko kha, Lampang, 52130 Thailand

ARTICLE INFO

Article history:
Received 15 January 2020
Received in revised form
25 February 2020
Accepted 27 February 2020

Keywords:
Channel catfish
Pineapple juice
Papaya peel
RAS

ABSTRACT

The papaya and pineapple are the major agricultural food products in Thailand. Their by-products contain protease enzyme, papain and bromelain, which can breakdown proteins. The objective of this study was to investigate the growth performances of channel catfish (*Ictalurus punctatus*) fed with feed mixed with pineapples juice (PA) and dried papaya peel (PP) in a recirculating aquaculture system (RAS). Three experimental feeds controlled at 25% isonitrogenous formulation containing 5 ml/kg feed PA, 5 g/kg feed PP, mixed PP-PA (5 ml/kg) feed pineapple juice mixed with 5 g/kg feed papaya peel (PP-PA) and a commercial control feed were fed to catfish for 90 days. Each treatment had 3 replicates. The channel catfish (5 g/fish) were allocated in 12 (1 x 1 x 1 m) placed in RAS concrete tanks. The water quality in this research was within the recommended nets levels by the Pollution Control Department, Thailand. The results showed that weight gain, length gain, average daily gain, feed conversion efficiency and protein efficiency ratio was highest in catfish fed with PP and which was significantly different ($p < 0.05$) from control. The survival rate of all treatments was not significantly different ($p > 0.05$). In conclusion, 5 g of dried papaya peel mixed in the 1 kg of diet could be applied for channel catfish culture to improve growth performances.

1. Introduction

Channel catfish (*Ictalurus punctatus*) is the most important aquaculture species in the United States (Tucker and Hargreaves, 2004). The channel catfish is distributed between southern Canada and northern Mexico (Wang, 2011). The production of channel catfish in the United States, accounting for more than 60% of all aquaculture (Liu et al., 2016). These catfish have introduced to China and Thailand also. The systems for channel catfish culture in the United States are various, including ponds, cages, raceways, and tanks (Helfrich and Libey, 2006). While the demand for healthy, tasty, and affordable fish products is expanding, the clean water is a shortage and the cost of land is very expensive. The new method, Recirculating Aquaculture System (RAS), is offered to enhance fish productivity. RAS filters clean the water, and removes or detoxifies harmful waste products; the recycling water is subsequently back through fish culture tanks (Helfrich and Libey, 1991). Only a little water is added to make up after evaporation. RAS is much more suitable for warm water fish cultures such as channel catfish, striped bass, and tilapia that can tolerate lower water quality conditions and high temperatures (Helfrich and Libey, 1991).

In Thailand, channel catfish are imported by the Department of Fisheries, Asian Institute of Technology, for more than 30

* Corresponding author.
E-mail address: sudaporn@mju.ac.th (Sudaporn Tongsiri)

years (Thapakorn, 2014). The channel catfish in Thailand are cultured in the cages along the river and fed with commercial diets containing 30 % protein (Thapakorn, 2014). The main problem of channel catfish culture in Thailand is water quality, especially the high turbidity and low dissolved oxygen in the river (FAO, 2020). In addition, the rising cost of aquaculture feed and its ingredients is another challenge for the channel catfish culture (Thapakorn, 2014).

Nowadays, many researchers have investigated the effect, feasibility, and efficacy of aquafeed to improve growth performances, enhance immunity, and lower feed conversion ratio (Bahi et al., 2017). The low-cost feed from agricultural by-products such as faba bean, soybean meal and fish wort has been formulated and applied as feed additives in aquaculture (Azaza et al., 2009; Lin and Luo, 2011). Aquafeed additives; for example, bioactive compounds, prebiotic, probiotics, and digestive enzymes have been added during feed preparation to improve the feed quality and feeding efficiency of the fishes leading to better growth and health performances (Liu et al., 2019; Hahor et al., 2019; Srichaiyo et al., 2020; Arungamol et al., 2018).

Nomenclature and abbreviation	
RAS	Recirculating Aquaculture System
CRD	Completely Randomized Design
PA	Pineapple
PP	Papaya peel
NFE	Nitrogen Free extract
WG	Weight gain,
LG	Length gain,
ADG	Average daily growth
FCR	Feed Conversion Ratio
FCF	Food Conversion Efficiency
SR	Survival Rate
PER	Protein Efficiency Ratio

The protease enzyme from agricultural by-products such as pineapple juice has been used in numerous industrial applications, including a meat tenderizer, a beer clarifier, a tooth whitening agent, animal feed, cosmetic substances, and in the textile industry (Kodagoda and Marapana, 2017). For aquafeed, pineapple juice is used for hydrolyzing soybean meal to replace the fishmeal in tilapia feed (Arungamol et al., 2018). The 0.5 ml crude extract from pineapple was added into 1 kilogram of the diet was able to improve the growth of climbing perch and decrease feed conversion ratio (Tongsiri and Pimpimol, 2019).

Moreover, the by-product of papaya, such as papaya peel, has proteolytic enzymes and papain (Kumar and Mishra, 2019). Mo et al. (2016) informed that papaya was added into soybean meal replacing the fishmeal in the moist pellets for marine fish provided higher growth than fish fed with the control pellets. The objective of this study was to determine the growth performances of channel catfish fed with feed mixed with pineapples juice and dried papaya peel.

2. Materials and methods

2.1. The experimental unit

The 1 x 1 x 1 m (width x length x depth) twelve nets were used in this study. These nets were set in the recirculating aquaculture system (RAS). Channel catfish were received from the farm in Chiang Mai Province, Thailand. A total of 120 fish were allocated into 4 treatments. The average weight of each fish before the experiment was 5 g.

2.2. Preparation of pineapple and papaya

The pineapples were received from a local market in Chiang Mai, Thailand. The pineapples were blended, filtered pass the filter cloth, the crude enzyme was then collected and kept in 4^{o}C. The papaya was received from a local market in Chiang Mai, Thailand. The papaya peel was dried in the hot air oven for 48 hours at 60 ^{o}C, blended, and kept in -20 ^{o}C.

2.3. Experimental design

The Completely Randomized Design (CRD) was applied. The different feeding combinations (4 formulas of isonitrogenous, 25%) were prepared as follows:
Treatment 1, the commercial feed (Control),
Treatment 2, the commercial feed mixed a 5 ml/kg feed crude extract from pineapple (PA),
Treatment 3, the commercial feed mixed a 5 g/kg feed dried papaya peel (PP),
Treatment 4, the commercial feed mixed a 5 ml/kg feed pineapple and a 5 g/kg feed dried papaya peel (PA+PP).

2.4. Proximate composition

The feeds were dried at 105°C for 24 h before analyzing protein, lipid, fiber, and ash, as described by the AOAC (2005). The proximate analysis of feeds was shown in Table 1. The percentage of protein in 4 formulas was 25 percentage, and all treatments were not significantly different ($p > 0.05$) (Table 1). The feeds were packed in plastic bags and kept in the refrigerator at -20oC throughout the experiment.

Fish were fed two times each day at 5% of body weight, for a 90-day experimental period. In this study, the feeding rates were adjusted every 2 weeks. Also, water quality parameters were monitored every 2 weeks. The weight and length of the fish were measured individually.

Growth performance parameters were calculated as the following formula:
The body weight gain (g/fish) = total final weight- total initial weight/ number of fish
Length gain (cm/fish) = total final length – total initial length/ number of fish
Average daily gain (g/d) = total final weight- total initial weight/ days
Feed conversion rate (FCR) = (feeding weight in grams/ weight gain of fish in grams) x100

Food Conversion Efficiency (FCE) = (final weight − initial weight) / feeding weight) ×100
Survival rate (%) = (number of fish in the final/number of fish in the beginning) x 100
Protein Efficiency Ratio (PER) = body weight gain (g)/protein intake (g).

Table 1
The proximate composition analysis of four formulas (%).

Parameter	Treatments			
	control	PA	PP	PA+PP
Moisture	9.90± 0.18^a	14.90± 0.18^b	14.66± 0.05^b	16.22± 0.45^c
Ash	5.52± 1.14^a	5.60± 1.41^a	6.86± 1.44^a	6.67± 0.74^a
Lipid	5.11± 0.16^a	3.63± 0.03^c	4.40± 0.18^b	3.75± 0.11^c
Fiber	6.69± 1.08^a	8.71± 0.43^a	8.92± 0.26^a	9.13± 0.44^a
Protein	24.67± 1.16^a	24.10± 0.75^a	24.69± 0.32^a	24.39± 0.51^a
Nitrogen Free extract (NFE)	48.04± 3.39^a	43.03± 1.56^a	40.45± 1.52^a	39.82± 1.22^a

*Values are Means ±SE and values in the same row with different superscripts are significantly different ($p < 0.05$).

2.4. Water quality analysis

The water quality monitoring, temperature (°C), pH, dissolved oxygen, ammonia nitrogen, nitrite-nitrogen, nitrate-nitrogen, total phosphorus and alkalinity were measured monthly by standard methods (APHA, 1995).

2.6. Statistic analysis

Data were expressed as mean ±standard error in triplicate observations. One-Way Analysis of Variance was used for evaluating growth performance parameters. Significant differences between means were ranked using Turkey's multiple range test at a 95% significance level.

3. Results and Discussion

3.1. Growth performance

The Recirculating Aquaculture System (RAS) is an amazing system for culture high densities fish and safe the environment (Bahnasawy et al., 2009). The water quality in RAS is good because this system has a filter and the water is clean up by recycling back through fish culture tanks. After catfish were cultured for 90 days, the results showed that weight gain was highest in catfish fed with a commercial feed mixed with 5 g/kg feed dried papaya peel (PP), 29.94±0.95 g which was significantly different from the ones in control, a commercial feed mixed with 5 ml/kg crude extract from pineapple (PA) and a commercial feed mixed with 5 ml/kg feed pineapple juice and 5 g/kg feed papaya peel (PP-PA) ($p < 0.05$).

Length gain was longest in catfish fed with PP, 8.86±0.19 cm. But the lowest length gain was found in catfish fed with PA+PP, 7.03±0.03 cm. And there was significantly different ($p < 0.05$). The average daily gain was significantly higher in catfish fed with PP, 0.25±0.01 g/day than the one in control, 7.43±0.42 g/day ($p < 0.05$). The feed conversion rate of catfish fed with PP, 1.29±0.14 was lower than the ones in control, PA and PP+PA which were 2.17±0.13, 1.93±0.02 and 2.19±0.12, respectively ($p < 0.05$) (Table 2). The Food conversion efficiency was significantly highest in catfish fed with PP, 78.77±7.76 ($p < 0.05$). The survival rates of all treatments were not significantly different ($p > 0.05$) (Table 2).

Table 2
The growth performances of channel catfish fed with feed mixed with pineapples juice and dried papaya peel.

Parameter	Treatment			
	control	PA	PP	PA+PP
WG (g/fish)	20.11± 2.46^b	22.01 ± 0.85^b	29.94± 0.95^a	19.73± 0.90^b
LG (cm/fish)	7.43± 0.42^b	7.76± 032^{ab}	8.86± 0.19^a	7.03± 0.03^b
ADG (g/day)	0.17± 0.02^b	0.18± 0.01^b	0.25± 0.01^a	0.16± 0001^b
FCR	2.17± 0.13^a	1.93± 0.02^a	1.29± 0.14^b	2.19± 0.12^a
FCE	46.43± 2.89^b	51.83 ± 0.61^b	78.77± 7.76^a	45.86± 2.65^b
SR (%)	90.00± 5.09^a	95.55 ± 2.22^a	93.33± 0.00^a	93.33± 3.85^a
PER	0.67± 0.08^b	0.73± 0.03^b	1.00± 0.03^a	0.66± 0.03^b

*Values are Means ±SE and values in the same row with different superscripts are significantly different ($p < 0.05$)
WG=Weight gain, LG=Length gain, ADG=Average daily growth, FCR=Feed conversion ratio, FCE= Food conversion efficiency, SR=Survival Rate, PER= Protein efficiency ratio.

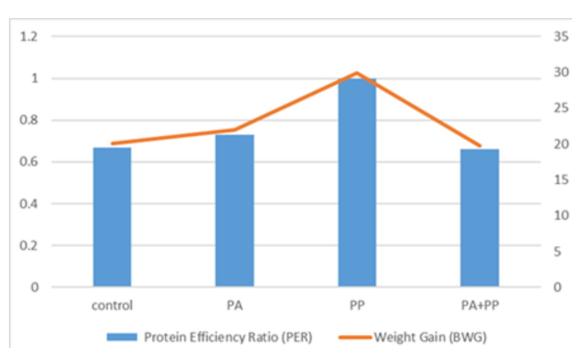

Fig. 1. The relationship between protein efficiency ratio and weight gain of channel catfish fed with feeds mixed with pineapples juice and dried papaya peel.

Papaya is one of the leading agricultural products in Thailand and other tropical countries. The processing of papaya results in organic waste. This study showed an alternative to the environmental-friendly treatment of organic wastes.

Feed mixed with a dried papaya peel showed the highest feed conversion efficiency because papaya peel had a crude papaya laxted, called papain, this enzyme acts like protease enzyme (Esti et al., 2013). As a result, this enzyme can break down protein and generate free amino acids in which fish can uptake efficiently. Papain is commonly found in many organisms that have been used in food industries and aquafeed. The papain is applying in aquafeed in terms of ingredient material.

The papain is immobilized as a cross-linked enzyme with neutral-production to hydrolyze bean protein and the structure of bean was changed to make it easier to be digested (Chen et al., 2017). Soybean meal mixed with papain to partially replace animal protein for culturing three marine fish species was studied. It was found that papain can promote better growth of marine fish and lower the adverse impact of trash fish and fishmeal on the water quality of the marine culture zones. (Mo et al., 2016).

Pineapple and papaya, which had been reported to produce commercial proteases (named bromelain and papain) showed high protease activities of 27.6 U/g and 23.1 U/g, respectively (Sun et al., 2016). These proteases have been used in the food industries and used as food additives. Many researchers tried to apply this protease enzyme from agricultural by-products to improve the feedstuff quality. Kang et al. (2010) reported that papaya processing wastes were served as a substrate for yeast growth. The product contained an average of 45% crude protein, and 50% of papaya processing wastes diets were used for feed to shrimp compared with commercial feed.

The improved quality of feedstuff such as soybean can be done by pineapple juice hydrolysis at 1:2 for 90 minutes and replaced with a fish meal in diet formula. The results showed that soybean hydrolysate could be digested with pineapple juice would be high at 25% without affecting growth rate (Arungamol et al., 2018). Similar results were found in a common lowland frog fed with feed mixed with bromelain supplementation at 0, 0.25, 0.5 and 1 ml/g feed.

The bromelain supplementation was able to increase the efficiency of protein digestibility of tadpole and frog with the appropriate levels of bromelain at 1 and 0.5 ml/g feed, respectively (Khahan and Sirithanawong, 2016). The digestibility of soybean meal was improved by mixing with 0.05-0.1% of bromelain. After that, this modified soybean meal has the potential to be used as a fishmeal substitution (Li et al., 2014).

In addition, the protein efficiency ratio was highest in catfish fed with PP, which was significantly different ($p < 0.05$). The higher value of protein efficiency ratio makes the weight of fish increasing, for example, tilapia (Abdel-Tawwab et al., 2010; Arungamol et al., 2018) hybrid catfish (Hahor et al., 2019) and African catfish (Okomoda et al., 2019). The feed conversion ratio of channel catfish was in the range 1.20 - 1.80 (Refaey et al., 2018; Jiang et al., 2012) which was the same as our research, 1.29±0.14 in PP treatment. Proteases like papain from low-cost ingredient or organic wastes were added into animal feed in order to increase protein assimilation and bio-availability, which translates into significant economic savings. The papain and bromelain to use for hydrolyzing food wastes to make fish feed. The application of feeds supplemented with these mixtures of proteases improved the growth, lipid accumulation and immunity of grass carp (Ctenopharyngodon idella) (Fernandez-Lucas et al., 2017).

3.2. Water quality

The water quality parameters measured during this research (Table 3) were shown that the temperature was range 22.97±0.90-25.84± 1.17 °C, pH was range 7.80±0.15-8.20±0.05. Dissolved oxygen was range 6.70±0.34 - 7.63±0.24 mg/l, respectively. The nutrient in nitrogen group as ammonia-nitrogen, nitrite-nitrogen and nitrate-nitrogen were range 0.40±0.01- 0.50±0.00, 0.02±0.00 - 0.05 ±0.02 and 0.08±0.02 - 0.43±0.08 mg/l, respectively. Total phosphorus was range 0.01±0.00 - 0.06 ± 0.03 mg/l. All parameters were not significantly different ($p > 0.05$) (Table 3).

Table 3

Water quality in 4 treatments during channel catfish culture in Recirculating Aquaculture System (RAS) for 90 days.

	Treatment			
Parameter	**control**	**PA**	**PP**	**PA+PP**
Temperature (°C)	25.84± 1.17^{a}	22.97± 0.90^{a}	25.63 ±1.07 ^{a}	24.91± 0.51^{a}
pH	8.03± 0.12^{a}	7.80± 0.15^{a}	8.20± 0.05^{a}	7.80 ± 0.15^{a}
Dissolved oxygen (mg/l)	6.70 ± 0.34^{a}	6.83± 0.33^{a}	7.30± 0.37^{a}	7.63± 0.24^{a}
ammonia nitrogen (mg/l)	0.44± 0.02^{a}	0.48± 0.00^{a}	0.40 ± 0.01^{a}	0.50 ± 0.00^{a}
Nitrite-nitrogen (mg/l)	0.02 ± 0.00^{a}	0.04± 0.01^{a}	0.02± 0.00^{a}	0.05± 0.02^{a}
Nitrate-nitrogen (mg/l)	0.08 ± 0.02^{a}	0.25± 0.09 ^{a}	0.22± 0.19^{a}	0.43± 0.08^{a}
Total phosphorus (mg/l)	0.06± 0.03^{a}	0.01± 0.00^{a}	0.05± 0.02^{a}	0.01± 0.00^{a}
Alkalinity (mg/l)	107.50± 1.32^{a}	104.66± 1.45^{a}	108.16 ±0.92 ^{a}	105.00 ±1.44 ^{a}

*Values are Means ±SE and values in the same row with different superscripts are significantly different ($p < 0.05$)

The water quality during this research were within the recommended levels in a Water Quality Standard by Pollution Control Department (2008).

4. Conclusion

Reducing fish feed costs and improving the efficacy of feed management is significant for the aquaculture system. Moreover, the utilization of waste materials from agricultural or industrial wastes (by-products), the fruit juice is habitually applied to overcome the problem of feed shortage in the fishery industry. The channel catfish fed with feed mixed with a 5 g/kg feed dried papaya peel (PA) was able to improve growth performances. Therefore, this study results suggested that papaya peel added value in the channel catfish feeding management.

Declaration of competing interest

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

Acknowledgement

This research was supported by the National Research Council of Thailand (NRCT) and the office of Agricultural Research and Extension, Maejo University, Chiang Mai, Thailand.

References

Abdel-Tawwab, M., Ahmad, M. H., Khattab, Y. A., & Shalaby, A. M. 2010. Effect of dietary protein level, initial body weight, and their interaction on the growth, feed utilization, and physiological alterations of Nile tilapia, *Oreochromis niloticus* (L.). Aquaculture, 298(3-4), 267-274.

AOAC. 2005. Official Methods of Analysis of AOAC International, 18th ed. Association of Official Analytical Chemists. Maryland. USA.

APHA. 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edition, American Public Health Association Inc., New York.

Arungamol, S., Rapankum, N., & Patchanee N. 2018. Effect of using soybean meal hydrolysate with pineapple juice in diet on growth performance, stress tolerance and disease resistance. Khon Kaen Agriculture Journal 46 (Suppl.1), 1011-1018.

Azaza, M. S., Wassim, K., Mensi, F., Abdelmouleh, A., Brini B., & Kraïem M. N. 2009. Evaluation of faba beans (Vicia faba L. var. minuta) as a replacement for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis niloticus*. Aquaculture 287(1-21), 174-179.

Bahi, A., F. A., Guardiola, C., Messina, A., Mahdhi, R., Cerezuela, Santulli, A., Bakhrouf, A., & Esteban, M. A. 2017. Effects of dietary administration of fenugreek seeds, alone or in combination with probiotics, on growth performance parameters, humoral immune response and gene expression of gilthead seabream (*Sparus aurata* L.). Fish and Shellfish Immunology 60, 50-58.

Bahnasawy, M. H., El-Ghobashy, A. E., & Abdel-Hakim N. F. 2009. Culture of the Nile tilapia (*Oreochromis niloticus*) in a recirculating water system using different protein levels. Egyptian Journal of Aquatic Biology and Fisheries 13(2), 1-15.

Chen, Z., Wang, Y., Liu, W., Wang, J., & Chen, H. 2017. A novel cross-linked enzyme aggregates (CLEAs) of papain and neutrase-production, partial characterization and application. International Journal of Biological Macromolecules 95, 650-657.

Esti, M., Benucci, I., Lombardelli, C., Liburdia,K., Garzillo A. M. V. 2013. Papain from papaya (*Carica papaya* L.) fruit and latex: Preliminary characterization in alcoholic–acidic buffer for wine application. Food and Bioproducts Processing 91, 595-598.

FAO. 2020. Aquaculture Feed and Fertilizer Resources Information System:Channel catfish. http://www.f ao.org/fishery/affri s/species-profile s/channel-catfish/channel-catfish-home/en/.

Fernández-Lucas, J., Castañeda, D., & Hormigo, D. 2017. New trends for a classical enzyme: Papain, a biotechnological success story in the food industry. Trends in Food Science and Technology 68, 91-101.

Helfrich L.A., & Libey, G. 1991. Fish farming in recirculating aquaculture systems (RAS). Virginia Cooperative Extension.

Hahor, W., Thongprajukaew, K., & Suanyuk, N. 2019. Effects of dietary supplementation of oligosaccharides on growth performance, gut health and immune response of hybrid catfish (*Pangasianodon gigas* × *Pangasianodon hypophthalmus*). Aquaculture 50, 97-107.

Jiang, G. Z., Liu, W. B., Li, G. F., Wang, M., & Li, X. F. 2012. Effects of different dietary glycyrrhetinic acid (GA) levels on growth, body composition and plasma biochemical index of juvenile channel catfish, *Ictalurus punctatus*. Aquaculture 338, 167-171.

Kang, H. Y., Yang, P. Y., Dominy, W. G., & Lee, C. S. 2010. Bioprocessing papaya processing waste for potential aquaculture feed supplement–Economic and nutrient analysis with shrimp feeding trial. Bioresource Technology 101(20), 7973-7979.

Ketnawa, S., Chaiwut, P., & Rawdkuen, S. 2012. Pineapple wastes: A potential source for bromelain extraction. Food and Bioproducts Processing 90(3), 385-391.

Klahan, R., & Sirithanawong, B. 2016. In vitro protein digestibility of bromelain from pineapple crown and enzyme from gastrointestinal tract of common lowland frog. Khon Kaen Agriculture Journal 44 (Suppl.1):630-635.

Kodagoda, K. H. G. K., & Marapana, R. A. U. J. 2017. Utilization of fruit processing by-products for industrial appltions: A review. International Journal of Food Science and Nutrition 2(6), 24-30.

Kumar, A., & Mishra S., 2019. Formulation and Processing of papaya by products. International Journal of Food Science and Nutrition 4(5), 143-148.

Lin, S., & Luo L. 2011. Effects of different levels of soybean meal inclusion in replacement for fish meal on growth, digestive enzymes and transaminase activities in practical diets for juvenile tilapia, *Oreochromis niloticus* × *O. aureus*. Animal Feed Science and Technology 168(1-2), 80-87.

Liu, C., Liu, H., Xu, W., Han, D., Xie, S., Jin, J., & Zhu, X. 2019. Effects of dietary Arthrospira platensis supplementation on the growth, pigmentation, and antioxidation in yellow catfish (*Pelteobagrus fulvidraco*). Aquaculture 510, 267-275.

Li, C. Y., Lu, J. J., Wu, C. P., & Lien, T. F. 2014. Effects of probiotics and bremelain fermented soybean meal replacing fish meal on growth performance, nutrient retention and carcass traits of broilers. Livestock Science 163, 94-101.

Liu, Z., Liu, S., Yao, J., Bao, L., Zhang, J., Li, Y., & Zhou, T. 2016. The channel catfish genome sequence provides insights into the evolution of scale formation in teleosts. Nature Communications 7(1), 1-13.

Mo, W. Y., Lau, R. S. S., Kwok, A. C. K., & Wong, M. H. 2016. Use of soybean meal and papain to partially replace animal protein for culturing three marine fish species: Fish growth and water quality. Environmental Pollution 219, 815-820.

Okomoda, V. T., Aminem, W., Hassan, A., & Martins, C. O. 2019. Effects of feeding frequency on fry and fingerlings of African catfish *Clarias gariepinus*. Aquaculture 511, 734232.

Pollution Control Department. 2008. Notification of the Ministry of Natural Resources and Environment: Effluent Standard for Inland. Aquaculture 125.

Refaey, M. M., Li, D., Tian, X., Zhang, Z., Zhang, X., Li, L., & Tang, R. 2018. High stocking density alters growth performance, blood biochemistry, intestinal histology, and muscle quality of channel catfish *Ictalurus punctatus*. Aquaculture 492, 73-81.

Srichaiyo, N., Tongsiri, S., Hoseinifar, S. H., Dawood, M. A., Esteban, M. Á., Ringø, E., & Van Doan, H. 2020. The effect of fishwort (*Houttuynia cordata*) on skin mucosal, serum immunities, and growth performance of Nile tilapia. Fish and Shellfish Immunology 98, 193-200.

Sun, Q., Zhang, B., Yan, Q. J., & Jiang, Z. Q. 2016. Comparative analysis on the distribution of protease activities among fruits and vegetable resources. Food Chemistry 213, 708-713.

Thapakorn Limbanchong. 2014. The cultivation channel catfish in the cage. The brochure for extension. (Thai)

Tongsiri, S., & Pimpimol, T. 2019. Growth Performances of the climbing perch fed with diet mixed with crude extract from pineapple. Proceedings of the University Academic Cluster International Summer Conference in Hokkaido July 27-29, 2019, 1-7.

Tucker, C.S., & Hargreaves, J. A. 2004. Biology and Culture of Channel Catfish. Elsevier, Amsterdam, 676.

Wang, J.C.S. 2011. Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California: A Guide to Early Life Histories.Tracy Fish Collection Facility Studies. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center. Volume 44.