Apparent Digestibility Coefficients of Feed Ingredients for Black Carp, *Mylopharyngodon piceus*

Tran Quang Hung[1], Mintra Seel-audom[1] and Tran Thi Nang Thu[2*]

[1]Department of Animal and Aquatic Science, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand
[2]Department of Aquaculture, Faculty of Animal Science and Aquaculture, Vietnam National University of Agriculture, Hanoi, Vietnam

**Corresponding author. E-mail: trannangthu@vnua.edu.vn*

ABSTRACT

The apparent digestibility coefficients of dry matter, crude protein, crude lipid, ash, and gross energy in five test ingredients – fishmeal, meat and bone meal, soybean meal, cornmeal, and brewers yeast (Saccharomyces cerevisiae) – were determined for black carp, Mylopharyngodon piceus (78.3±2.5g), at the Aquaculture Laboratory, Vietnam National University of Agriculture, Vietnam. A reference diet and test diets (a 70:30 mixture of the reference diet to test ingredient) were used with 1% chromic oxide (Cr_2O_3) as an external indicator. Experimental fish were stocked in 500-L composite tanks at a density of 10 fish per tank. Faeces were collected by faecal collection column. The results indicated that the apparent digestibility coefficients of all test ingredient nutrients, except ash, differed statistically ($P < 0.05$). The apparent digestibility coefficients were 78.4-90.2% for dry matter, 71.2-92.6% for crude protein, 66.0-87.0% for crude lipid, 52.6-61.9% for ash, and 54.1-80.9% for gross energy. Findings from this study will help formulate cost-effective feed for black carp.

Keywords: Black carp, *Mylopharyngodon piceus*, Apparent digestibility coefficients, Ingredients

INTRODUCTION

Black carp, *Mylopharyngodon piceus*, is an economically important freshwater-cultured fish for food product markets in China and northern Vietnam, due to its high meat yield, delicate flavor, and high nutritional value (Leng and Wang, 2003; Nico et al., 2005). In China, black carp is the one of the four most famous pond-cultured fish species, with annual farming production of more than 380,000 tonnes (Hu et al., 2014). In Vietnam, black carp has been widely farmed in the northern provinces, including Hai Duong, Ninh Binh, Hung Yen, Vinh Phuc, and Bac Ninh. For black carp, the average net profit was VND 54.2 million ha/year (USD 2,555) in poly-culture systems and VND 68.0 million ha/year (USD 3,205) in monoculture systems in 2008 (Phuong et al., 2009), and up to VND 464.0 million ha/year (USD 21,871) for intensive farming in 2009 (Van et al., 2010).

In aquaculture systems, the black carp diet is primarily homemade or commercial pelleted feeds (Phuong et al., 2009; Van et al., 2010). Black carp, as a carnivorous species, requires a high percentage of protein in its diet, ranging from 35-40% (Leng and Wang, 2003; Van and Thu, 2013; Hu et al., 2014). The diets for most farmed carnivorous fish are still largely based on fishmeal, the major dietary protein source, commonly accounting for 20-60% of aquafeeds (FAO, 2012; Glencross et al., 2007; Watanabe, 2002). Recently, the cost of aquafeed has tended to increase with the rising price of fishmeal. FAO (2012) reported that the cost of aquafeed increased by 73% worldwide from 2005 to 2008. As black carp aquaculture is projected to continue expanding in northern Vietnam, the demand for commercial feed will increase accordingly. This will be a major challenge for thousands of local small-scale farmers, as the feed is a major component of total production costs and many fish farmers still rely heavily on fishmeal (Tacon and Metian, 2008). Moreover, using fishmeal is not a sustainable long-term feeding strategy, because of its many associated market risks in terms of fluctuating availability, price, and quality (Naylor et al., 2009). Options for alternative feed ingredients are needed to reduce costs and the reliance on fishmeal (Glencross et al., 2007; Lim et al., 2008; Hardy, 2010; Burr et al., 2012).

Little is currently known about nutrient and energy digestibility of alternative feed ingredients for black carp. Therefore, the objective of this study was to evaluate the apparent digestibility coefficients of dry matter, protein, lipid, ash, and gross energy for fishmeal, meat and bone meal, soybean meal, cornmeal, and brewers yeast. The data obtained will be useful for formulating least-cost feeds for black carp.

MATERIALS AND METHODS

Fish and experimental conditions

The black carp used in this study were purchased from Research Institute for Aquaculture No.1, Bac Ninh Province, Vietnam, and acclimatized in a single composite tank ($2m^3$ water) for one month at the Laboratory of Aquaculture, Vietnam National University of Agriculture, Hanoi, Vietnam. During this period, fish were fed with commercial feed, Aquaexel 7434 (Cargill, Vietnam), twice daily (0900 and 1600 h) to apparent satiation.

The experiment was conducted according to a completely randomized design and triple replicated. Each diet was fed into three 500L-composite tanks, each containing 10 fish with an initial mean weight of 78.33±2.45 g. The water was constantly replaced in the tank by continuous flow at a rate of 250 ml/min to provide oxygen and remove excess nitrogenous wastes.

Diet preparation

The reference diet (Table 1) was formulated to satisfy the protein and lipid requirements of black carp (Leng and Wang, 2003; Van and Thu, 2013; Hu et al., 2014). Five test diets were produced containing a mixing ratio of reference diet (70%) and test feed ingredient (30%). Chromic oxide (Cr_2O_3, 1%) was used as the inert digestion indicator (Austreng, 1978).

The tested ingredients consisted of corn meal was originated from Northern mountainous region of Vietnam where its crop is abundantly produced throughout the year; brewers yeast (BM), *Saccharomyces cerevisiae*, was purchased from AB Mauri (Beijing) Food Sales and Marketing Co. Ltd; fishmeal, meat and bone meal, and soybean meal were obtained locally from commercial source.

Feeding and fecal collection

During the trial, black carp were fed by hand to visual satiety once a day (0900h). Fecal samples were collected by fecal collection column system, referred to as the design of Sang-Min Lee (Lee, 2002).

About two hours after feeding, the rearing tank and collection column were brushed out to remove uneaten feed and fecal residues. Fecal samples were collected for 30 days in the morning (0830h) into 250 mL plastic bottles and frozen at -20°C until further analyses.

Table 1. Composition of the reference diet and proximate analysis of experimental diets for black carp *(Mylopharyngodon piceus)*.

Ingredients	% in reference diet
Fish meal	47.80
Hipro70[a]	5.00
Wheat gluten	5.00
Cassava powder	16.61
Rice bran	12.00
Fish oil	10.00
Vitamin &Mineral mix[b]	2.00
Antifungal	0.07
Antioxidant[c]	0.02
Adhesive	0.50
Chromium oxide III (Cr_2O_3)	1.00

Proximate analysis (%)	Reference diet	Test diets				
		FM	MBM	SM	CM	BY
Dry matter	89.70	91.12	90.18	88.95	92.12	90.15
Crude protein	35.12	31.15	30.78	30.13	29.45	32.06
Crude lipid	10.70	7.86	7.74	8.15	8.23	7.04

Note: FM, fishmeal; MBM, meat and bone meal; SM, soybean meal; CM, corn meal; BY, brewers yeast. [a]Purchased from RT Chemtronics GmbH, Germany. [b]Product name: Customix 5199, Purchased from Bayer Vietnam. [c]Antioxidant (mg/g): butylated hydroxytoluene, 12.5.

Analytical methods

Diets and fecal samples were analyzed for proximate composition (AOAC, 1995) and chromic oxide (Czarnocki et al., 1961; Fenton and Fenton, 1979). The apparent digestibility coefficients for dry matter, crude protein, lipid, and ash in the reference and test diets were calculated as described by Cho et al. (1982):
Where:

$$\text{ADCs diet (\%)}=100-100 \times \left(\frac{\%\text{M diet}}{\%\text{M feces}} \times \frac{\%\text{Nutrient feces}}{\%\text{Nutrient diet}}\right)$$

%M = marker concentration (% in dry matter) and %N = nutrient content (% in dry matter).

The apparent digestibility coefficient of each test ingredient was calculated as described by Bureau and Hua (2006):

$$+\left((\text{ADCs test diet} - \text{ADCs reference diet}) \times \frac{0.7\text{xD reference diet}}{0.3\text{xD ingredient}}\right)$$

Where:

D reference diet = % nutrient of reference diet and D ingredient = % nutrient of test ingredient.

Statistical analyses

All digestibility data were statistically analyzed by one-way analysis of variance (ANOVA), using Tukey's post-hoc ANOVA test for individual comparisons ($P<0.05$ level of significance). A significance level of 5% was used for all comparisons.

RESULTS

The chemical composition of experimental diets and test ingredients used in this study are shown in Tables 1 and 2.

Table 2. Chemical composition (% dry matter) and gross energy (Kcal/kg dry matter) content of test ingredients.

	Test ingredients				
	FM	**MBM**	**SM**	**CM**	**BY**
Dry matter	91.00	91.70	92.00	89.58	93.03
Crude protein	60.10	49.10	41.70	9.45	46.10
Crude lipid	8.73	9.27	15.90	4.29	3.98
Ash	25.70	32.60	3.20	1.91	7.29
Gross energy	4,360	3,850	4,080	4,235	3,569

Note: FM, fishmeal; MBM, meat and bone meal; SM, soybean meal; CM, corn meal; BY, brewers yeast.

The apparent digestibility coefficients of dry matter, crude protein, crude lipid, ash, and gross energy are presented in Table 3.

The apparent digestibility coefficients of dry matter, crude protein, crude lipid, and gross energy differed significantly ($P<0.05$) for fishmeal, meat and bone meal, soybean meal, and brewers yeast; ash did not differ significantly ($P>0.05$) (Table 3).

Apparent digestibility coefficients of dry matter in the test ingredients

ranged from 78.4-90.2% (Table 3). Dry matter–apparent digestibility coefficients were significantly higher with fishmeal (90.2%) than meat and bone meal (78.4%) ($P<0.05$), while values for soybean meal (83.0%), cornmeal (88.3%), and brewers yeast (82.4%) were similar.

Apparent digestibility coefficients of crude protein and crude lipid were relatively high for all the test ingredients, ranging from 71.2-92.6% and 66.0-87.0%, respectively. The crude protein–apparent digestibility coefficients, from highest to lowest, were fishmeal (92.6%), brewers yeast (86.8%), soybean meal (85.8%), meat and bone meal (79.1%), and cornmeal (71.2%). Fishmeal, soybean meal, and brewers yeast did not differ significantly ($P>0.05$), but they were significantly higher ($P<0.05$) than cornmeal.

Table 3. Apparent digestibility coefficients (%) of dry matter, crude protein, crude lipid, ash, and gross energy in test ingredients for black carp (*Mylopharyngodon piceus*).

	Dry matter	Crude protein	Crude lipid	Ash	Gross energy
Fishmeal	90.15 ± 3.70^{a}	92.62 ± 4.95^{a}	86.95 ± 5.64^{a}	52.61 ± 7.15^{a}	80.90 ± 4.41^{a}
Meat bone meal	78.42 ± 7.64^{b}	79.07 ± 8.25^{bc}	75.20 ± 14.59^{ab}	56.98 ± 7.77^{a}	60.00 ± 5.66^{bc}
Soybean meal	82.95 ± 5.41^{ab}	85.82 ± 3.91^{ab}	84.36 ± 4.98^{a}	57.12 ± 4.40^{a}	72.77 ± 6.19^{ab}
Cornmeal	88.34 ± 4.91^{ab}	71.17 ± 3.88^{c}	65.96 ± 4.38^{b}	61.85 ± 3.03^{a}	54.13 ± 1.45^{c}
Brewers yeast	82.38 ± 3.99^{ab}	86.82 ± 4.15^{ab}	75.03 ± 4.01^{ab}	54.45 ± 3.15^{a}	70.27 ± 4.54^{ab}

Note: Data represent mean ± SD (Standard deviation). Values in the same column with different superscript alphabets are significantly different ($P<0.05$).

Crude lipid–apparent digestibility coefficients of fishmeal (87.0%) and soybean meal (84.4%) were significantly higher ($P<0.05$) than cornmeal (66.0%), while meat and bone meal (75.2%) and brewers yeast (75.0%) did not differ significantly ($P>0.05$) from other ingredients in this study.

Ash–apparent digestibility coefficients, ranging from 52.6-61.9%, did not differ significantly ($P>0.05$) among the test ingredients.

The apparent digestibility coefficient of energy for fishmeal (80.9%) was significantly higher than meat and bone meal (60.0%) and cornmeal (54.1%), while there was no significant difference ($P>0.05$) between soybean meal and brewers yeast.

DISCUSSION

Dry matter digestibility

In black carp, the dry matter–apparent digestibility coefficients ranged from 78.4-90.2% (Table 3). The high value for fishmeal (90.2%) was similar to those reported in Atlantic cod, *Gadus morhua* (Tibbetts et al., 2006); rainbow trout, *Oncorhynchus mykiss* (Gaylord et al., 2008); and hybrid juvenile tilapia (Zhou and Yue, 2012). Prior studies have reported dry matter–apparent digestibility coefficients of meat and bone meal and soybean meal ranging from 61.9-91.7% and 68.0-90.1%, respectively (Zhou and Yue, 2012; Da et al., 2013; Li et al., 2013;

Yu et al., 2013); our results fell within these ranges. Meat and bone meal (78.4%) had the lowest dry matter–apparent digestibility coefficient in our study; this may be attributed to the high ash content (32.6%) of this feedstuff. Our findings also agreed well with that of Bureau et al. (1999), Wu et al. (2006), and Masagounder et al. (2009). Moreover, the variation in dry matter–apparent digestibility coefficients might be explained by the fiber content present in plant ingredients. Prior studies have shown a negative correlation between dietary fiber content and apparent digestibility coefficients of dry matter (Falge et al., 1978; Hilton et al., 1983; Spannhof and Plantikow, 1983; Silva et al., 1990; NRC, 1993; Sullivan and Reigh, 1995; McGoogan and Reigh, 1996). These findings corroborated our observations on dry matter–apparent digestibility coefficients of cornmeal (88.3%) and soybean meal (83.0%). Our cornmeal results were similar to the 89.0% registered for grass carp by Thu (2012) and slightly higher than earlier publications (67.8%, Law, 1986; 81.9%, Mohanta et al., 2006; 82.2%, Guimarães et al., 2008; 82.0%, Da et al., 2013). Brewers yeast (*S. cerevisiae*), a natural product from the bakery industry, has been widely in aquafeeds (Oliva-Teles and Goncalves, 2001; Lara-Flores et al., 2003; Abdel-Tawwab et al., 2010; Ozório et al., 2010). Dry matter in brewers yeast was well digested by black carp, as reported in redclaw crayfish, *Cherax quadricarinatus* (Pavasovic et al., 2007).

Protein digestibility

The apparent digestibility coefficient values for crude protein are the fractional sums of the apparent digestibility coefficient values for amino acids and other nitrogenous compounds in feed ingredients (NRC, 2011). Fishmeal protein in our study was well digested by black carp; this finding agrees with those reported for some cultured fish species (Willson and Poe, 1985; Sugiura et al., 1998; Lee, 2002; Zhou et al., 2004; Tibbetts et al., 2006; Li et al., 2007; Luo et al., 2009; Yu et al., 2013). Soybean meal, a plant protein-rich source, had a relatively high crude protein–apparent digestibility coefficient of 85.8% in this study, indicating that soybean meal can be used efficiently as partial protein sources in black carp diet. The data on crude protein–apparent digestibility coefficients of soybean meal in this study were similar to those in carp (86.8%, Kim, 1974); channel catfish (85.0%, Brown et al., 1985); Nile tilapia, *Oreochromis niloticus* (87.4%, Köprücü and Özdemir, 2005); and snakehead, *Ophiocephalus argus* (83.4%, Yu et al., 2013); and slightly higher than the 80.0% observed for salmonids (Smith et al., 1980). Crude protein–apparent digestibility coefficients of meat and bone meal in black carp (79.1%) was consistent with those reported in rainbow trout (Cho and Cowey, 1991), hybrid striped bass (Sullivan and Reigh, 1995), and snakehead, *O.argus* (Yu et al., 2013); and was slightly lower than the 83.0-89.0% found in rainbow trout, *O.mykiss* (Bureau et al., 1999).

The lowest crude protein–apparent digestibility coefficients among test ingredients were observed for cornmeal at 71.2%. This result is comparable with that observed for Nile tilapia by Hanley (1987), Guimarães et al. (2008); and higher than the 66.0% reported for striped catfish, *Pangasianodon hypophthalmus* (Da et al., 2013), 64.5% for grass carp (Lin et al., 2001), and 51.9% for tropical catfish,

Mystus nemurus (Khan, 1994). The results of the digestibility trial demonstrated that brewers yeast had a crude protein–apparent digestibility coefficient of 86.8%. Some authors reported low crude protein–apparent digestibility coefficients of brewers yeast, ranging from 57-70% (Cheng et al., 2004; Lin et al., 2004; Zerai et al., 2008). On the other hand, Oliva-Teles and Goncalves (2001) and Pavasovic et al. (2007) reported protein–apparent digestibility coefficients of 88.3% and 93.1%, respectively for brewers yeast. This variability might be explained by the different sources and processing methods of brewers yeast used in each of these experiments (Zerai et al., 2008).

In general, crude protein–apparent digestibility coefficients of soybean meal, meat and bone meal, and brewers yeast in this study were relatively high. This indicated that these ingredients might be used efficiently as a partial protein source for black carp.

Lipid digestibility

Lipids are almost completely digestible by fish and seem to be favored over carbohydrates as an energy source (Cho et al., 1985). In the current study, the crude lipid–apparent digestibility coefficients ranged from 66.0% to 87.0% for five tested ingredients, which was similar to the earlier study confirming that the crude lipid–apparent digestibility coefficients of common carp range between 53.0-90.0% (Kirchgessner et al., 1986). The low lipid digestibility in black carp for meat and bone meal and cornmeal could be partly explained by the per-oxidation of lipid during high temperature processing and subsequent storage (Yu et al., 2013), and the high saturated fatty acid content of the lipids of animal protein ingredients (meat and bone meal) (Cho and Kaushik, 1990; Ai et al., 2006; Martins et al., 2009).

Ash digestibility

The apparent digestibility coefficients of ash registered here (52.6-61.9%) were higher than those reported for Nile tilapia, *O. niloticus* (Köprücü and Özdemir, 2005), but lower than those registered for rainbow trout, *O.mykiss* (Cheng and Hardy, 2002); mud crab, *Scylla serrata* (Catacutan et al., 2003); and dourado, *Salminus brasiliensis* (Boghesi et al., 2009). The lower apparent digestibility coefficients of ash in black carp than mud crab could be explained by the high level of ash in the mud crab exoskeleton and crustaceans consume their exuvia after ecdysis (Catacutan et al., 2003). Of tested ingredients, although the total ash concentration was higher in fishmeal and meat and bone meal, soybean meal and cornmeal had higher ash–apparent digestibility coefficients. This indicated that the lower the dietary concentration of ash, the better its digestibility, which had been previously confirmed for common carp (Kim et al., 1998), mud crab *S.serrata* (Catacutan et al., 2003), and Nile tilapia (Köprücü and Özdemir, 2005).

Energy digestibility

In this digestibility trial, black carp digested the energy in all of the feed ingredients tested. However, the apparent digestibility coefficients of energy in

soybean meal and cornmeal were lower than those in fishmeal. This might be because of the higher carbohydrate (Brunson et al., 1997; Lupatsch et al., 1997; Irvin and Williams, 2007) and fiber content (McGoogan and Reigh, 1996) in these plant ingredients. Our study demonstrated that meat and bone meal was poorly digested by black carp, perhaps due to the presence of low digestible ash and nitrogen-free extract, as was also observed for rainbow trout (Bureau et al., 1999), bluegill, *Lepomis macrochirus*, and largemouth bass, *Micropterus salmoide* (Masagounder et al., 2009).

In conclusion, this study has demonstrated that in black carp, the highest protein– and energy–apparent digestibility coefficients were observed in fishmeal and soybean meal. Of the ingredients tested, meat and bone meal had the lowest crude lipid–apparent digestibility coefficients, while a relatively high nutrient and energy digestibility was obtained in brewers yeast. Cornmeal appeared to be well digested by black carp in dry matter and ash. Additional research is needed to evaluate the effects of replacing fishmeal by individual ingredients or by various mixtures of soybean meal, meat and bone meal, brewers yeast, and cornmeal.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the International Foundation for Science (IFS) and IDRC-SEARCA, Ref. No. GCS13-2583 Scholarship for financial supporting the research conducted at Vietnam National University of Agriculture.

REFERENCES

Abdel-Tawwab, M., M. A. A. Mousa, and M. A. Mohammed. 2010. Use of live baker's yeast, *Saccharomyces cerevisiae* in practical diet to enhance the growth performance of Galilee Tilapia, *Sarotherodon galilaeus* (L.), and its resistance to environmental copper toxicity. Journal of the World Aquaculture Society 41: 214-223. doi: 10.1111/j.1749-7345.2010.00361.x

Ai, Q., K. Mai, B. Tan, W. Xu, Q. Duan, H. Ma, and L. Zhang. 2006. Replacement of fish meal by meat and bone meal in diets for large yellow croaker, *Pseudosciaena crocea*. Aquaculture Nutrition 260: 255-263. doi: 10.1016/j.aquaculture.2006.06.043

AOAC. 1995. Official methods of analysis of the association of analytical chemistry, 16th edition. AOAC, Washington, DC.

Austreng, E. 1978. Digestibility determination in fish using chromic oxide marking and analysis of contents from different segments of the gastrointestinal tract. Aquaculture 13: 265-272. doi: 10.1016/0044-8486(78)90008-X

Borghesi, R., J. K. Dairiki, and J. E. P. Cyrino. 2009. Apparent digestibility coefficients of selected feed ingredients for dourado *Salminus brasiliensis*. Aquaculture Nutrition 15: 453-458. doi: 10.1111/j.1365-2095.2008.00610.x

Brown, P. B., R. J. Strange, and K. R. Robbins. 1985. Protein digestibility coefficient for yearling channel catfish fed high protein feedstuffs. The Progressive Fish-Culturist 47: 94-97. doi: 10.1577/1548-8640(1985)47<94:PDCFYC>2.0.CO;2

Brunson, J. F., R. Romaire, and R. C. Reigh. 1997. Apparent digestibility of selected ingredients in diets for white shrimp *Penaeus setiferus* L. Aquaculture Nutrition 3: 9-16. DOI: 10.1046/j.1365-2095.1997.00068.x

Bureau, D. P., and K. Hua. 2006. Letter to the editor of aquaculture. Aquaculture 252 (2-4): 103-105. doi: 10.1016/j.aquaculture.2006.01.028

Bureau, D. P., A. M. Harris, and C. Y. Cho. 1999. Apparent digestibility of rendered animal protein ingredients for rainbow trout (*Oncorhynchus mykiss*). Aquaculture 180: 345-358. doi: 10.1016/S0044-8486(99)00210-0

Burr, G. S., W. R. Wolters, F. T. Barrows, and R. W. Hardy. 2012. Replacing fishmeal with blends of alternative proteins on growth performance of rainbow trout (*Oncorhynchus mykiss*), and early or late stage juvenile Atlantic salmon (*Salmo salar*). Aquaculture 334-337: 110-116. doi: 10.1016/j.aquaculture.2011.12.044

Catacutan, M. R., P. S. Eusebio, and S. Teshima. 2003. Apparent digestibility of selected feedstuffs by mud crab, *Scylla serrata.* Aquaculture 216 (1-4): 253-261. DOI: 10.1016/S0044-8486(02)00408-8

Cheng, Z. J., R. W. Hardy, and N. J. Huige. 2004. Apparent digestibility coefficients of nutrients in brewer's and rendered animal by-products for rainbow trout (*Oncorhynchus mykiss* (Walbaum)). Aquaculture Research 35: 1-9. doi: 10.1111/j.1365-2109.2004.00941.x

Cheng, Z.J., and R.W. Hardy. 2002. Apparent digestibility coefficients of nutrients and nutritional value of poultry by-product meal for rainbow trout Oncorhynchus mykiss measured in vivo using settlement. Journal of the World Aquaculture Society 33: 458-465. doi: 10.1111/j.1749-7345.2002.tb00025.x

Cho, J.Y., and C.R. Cowey. 1991. Rainbow trout, *Oncorhynchus mykiss.* p. 131-143. In Handbook of Nutrient Requirements of Finfish (edited by R. P. Wilson). CRC Press, Bocaaton, FL, USA.

Cho, C. Y., and S. J. Kaushik. 1990. Nutritional energetics in fish: energy and protein utilization in rainbow trout (*Salmo gairdneri*). In: Aspects of Food Production, Consumption and Energy Values (Bourne, G.H. ed). World Review of Nutrition and Dietetics 61: 132-172.

Cho, C. Y., C. B. Cowey, and T. Watanabe. 1985. Finfish nutrition in Asia. p. 103-107: In Methodological approaches to research and development. International Development Research Centre, Ottawa, Canada.

Cho, C. Y., S. L. Slinger, and H. S. Bayley. 1982. Bioenergetics of salmonid fishes: energy intake, expenditure and productivity. Comparative Biochemistry and Physiology 73B: 25-41. doi: 10.1016/0305-0491(82)90198-5

Czarnocki, J., I. R. Sibbald, and E. V. Evans. 1961. The determination of chromic oxide in samples of feed and excreta by acid digestion and spectrophotometry. Canadian Journal of Animal Science 41: 167-179. doi: 10.4141/cjas61-024

Da, C. T., T. Lundh, and J. E. Lindberg. 2013. Digestibility of dietary components and amino acids in plant protein feed ingredients in striped catfish (*Pangasianodon hypophthalmus*) fingerlings. Aquaculture Nutrition 19: 619-628. doi: 10.1111/anu.12011

Falge R., L. Schpanof, and K. Jurss. 1978. Amylase, esterase and protease activity in the intestine content of rainbow trout *Salmo gairdneri* R. after feeding with feed containing different amounts of starch and protein. Journal of Ichthyology 18: 283-287.

FAO. 2012. The state of world fisheries and aquaculture 2012. Food and Agriculture Organization of the United Nation 00153 Rome, Italy. 230p.

Fenton, T. W., and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and faeces. Canadian Journal of Animal Science 59: 631-634. doi: 10.4141/cjas79-081

Gaylord, T. G., F. T. Barrows, and S. D. Rawles. 2008. Apparent digestibility of gross nutrients from feedstuffs in extruded feeds for rainbow trout, *Oncorhynchus mykiss*. Journal of the World Aquaculture Society 39: 827-834. doi: 10.1111/j.1749-7345.2008.00220.x

Glencross, B. D., M. Booth, and G. L. Allan. 2007. A feed is only as good as its ingredients - a review of ingredient evaluation strategies for aquaculture feeds. Aquaculture Nutrition 13: 17-34. doi: 10.1111/j.1365-2095.2007.00450.x

Guimarães, I. G., L. E. Pezzato, M. M. Barros, and L. Tachibana. 2008. Nutrient digestibility of cereal grain products and by-products in extruded diets for Nile tilapia. Journal of the World Aquaculture Society 39: 781-789. doi: 10.1111/j.1749-7345.2008.00214.x

Hanley, F. 1987. The digestibility of foodstuffs and the effects of feeding selectivity on digestibility determinations in tilapia, *Oreochromis niloticus* (L.). Aquaculture 66: 163-179. doi: 10.1016/0044-8486(87)90229-8

Hardy, R.W. 2010. Utilization of plant proteins in fish diets: effects of global demand and supplies of fishmeal. Aquaculture Research 41: 770-776. doi: 10.1111/j.1365-2109.2009.02349.x

Hilton, J. W., J. L. Atikinson, and S. J. Slinger. 1983. Effect of increased dietary fiber on the growth of rainbow trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquaculture Sciences 40: 81-85. doi: 10.1139/f83-012

Hu, Y., Y. Huang, F. Feng, L. Zhong, Q. Ai, T. Xiao, and H. Wen. 2014. Effect of soybean meal replacement by cottonseed meal on growth, feed utilization and some blood physiological/biochemical indices of juvenile black carp, *Mylopharyngodon piceus*. Aquaculture Research. doi: 10.1111/are.12409.

Irvin, S. J., and K. C. Williams. 2007. Apparent digestibility of selected marine and terrestrial feed ingredients for tropical spiny lobster *Panulirus ornatus*. Aquaculture 269: 456-463. doi: 10.1016/j.aquaculture.2007.05.013

Khan, M. S. 1994. Apparent digestibility coefficients for common feed ingredients in formulated diets for tropical catfish, *Mystus nemurus* (Cuvier and Valenciennes). Aquaculture Research 25: 167-174. doi: 10.1111/j.1365-2109.1994.tb00572.x

Kim, J. D., J. Breque, and S. J. Kaushik. 1998. Apparent digestibilities of feed components from fish meal or plant protein based diets in common carp as affected by water temperature. Aquatic Living Resource 11 (4): 269-272. doi: 10.1016/S0990-7440(98)80011-9

Kim,Y. K. 1974. Determination of true digestibility of dietary protein with Cr2O3 containing diet. Bulletin of Japanese Society Science Fish 40: 651-654.

Kirchgessner, M., H. Kürzinger, and F. J. Schwarz. 1986. Digestibility of crude nutrients in different feeds and estimation of their energy content for carp (*Cyprinus carpio* L.). Aquaculture 58 (3-4): 185-194. doi: 10.1016/0044-8486(86)90084-0

Köprücü, K., and Y. Özdemir. 2005. Apparent digestibility of selected feed ingredients for Nile tilapia (*Oreochromis niloticus*). Aquaculture 250: 308-316. doi: 10.1016/j.aquaculture.2004.12.003

Lara-Flores, M., M. A. Olvera-Novoa, B. E. Guzmán-Méndez, and W. López-Madrid. 2003. Use of bacteria *Streptococus faecium* and *Lactobacillus acidophilus*, and the yeast *Saccharomyces cerevisiae* as growth promoters in Nile tilapia *Oreochromis niloticus*. Aquaculture 216: 193-201. doi: 10.1016/S0044-8486(02)00277-6

Law, A. T. 1986. Digestibility of low-cost ingredients in pelleted feed by grass carp (*Ctenopharyngodon idellus*). Aquaculture 51: 97-103. doi: 10.1016/0044-8486(86)90131-6

Lee, S. M. 2002. Apparent digestibility coefficients of various feed ingredients for juvenile and grower rockfish (*Sebastes schlegeli*). Aquaculture 207: 79-85. doi: 10.1016/S0044-8486(01)00751-7

Leng, X. J., and D. Z. Wang. 2003. Nutrient requirements and feed manufacturing technology of *Mylopharyngodon piceus* Richardson. Journal of Shanghai Fisheries University 12 (3): 265-270.

Li, H. T., K. S. Mai, Q. H. Ai, L. Zhang, C. X. Zhang, W. B. Zhang, and Z. G. Liufu. 2007. Apparent digestibility of selected protein ingredients for large yellow croaker *Pseudosciaena crocea*. Acta Hydrobiologica Sinca 35: 105-114. (*In Chinese with English abstract*).

Li, M. H., D. F. Oberle, and P. M. Lucas. 2013. Apparent digestibility of alternative plant-protein feedstuffs for channel catfish, *Ictalurus punctatus* (Rafinesque). Aquaculture Research 44: 282-288. doi: 10.1111/j.1365-2109.2011.03035.x

Lim, C., C. D. Webster, and C. S. Lee. 2008. Alternative protein sources in aquaculture diets. The Haworth Press, Taylor & Francis Group. (Editors: Chhorn Lim, Carl D. Webster, Cheng-Sheng Lee). United State and Canada. 571p.

Lin, H., Y. Liu, L. Tian, J. Wang, W. Zheng, J. Huang, and P. Chen. 2004. Apparent digestibility coefficients of various feed ingredients for grouper *Epinephelus coioides.* Journal of the World Aquaculture Society 35: 134-142. doi: 10.1111/j.1749-7345.2004.tb01069.x

Lin, S., L. Luo, and Y. Ye. 2001. Apparent digestibility of crude proteins and crude fats in 17 feed ingredients in grass carp. Journal of Fishery Sciences of China 8: 59-64. (*In Chinese with English abstract*)

Luo, Z., X.D. Li, S.Y. Gong, and W.Q. Xi. 2009. Apparent digestibility coefficients of four feed ingredients for *Synechogobius hasta.* Aquaculture Research 40: 558-565. doi: 10.1111/j.1365-2109.2008.02131.x

Lupatsch, I., G.W. Kissil, D. Sklan, and E. Pfefer. 1997. Apparent digestibility coefficients of feed ingredients and their predictability in compound diets for gilthead seabream *Sparus aurata* L. Aquaculture Nutrition 3: 81-89. doi: 10.1046/j.1365-2095.1997.00076.x

Martins, D. A., L. M. P. Valente, and S. P. Lall. 2009. Apparent digestibility of lipid and fatty acids in fish oil, poultry fat and vegetable oil diets by Atlantic halibut, *Hippoglossus hippoglossus* L. Aquaculture 294: 132-137. doi: 10.1016/j.aquaculture.2009.05.016

Masagounder, K., J. D. Firman, R. S. Hayward, S. Sun, and P. B. Brown. 2009. Apparent digestibilities of common feedstuffs for bluegill *Lepomis macrochirus* and largemouth bass *Micropterus salmoides* using individual test ingredients. Aquaculture Nutrition 15: 29-37. doi: 10.1111/j.1365-2095.2008.00565.x

McGoogan, B. B., and R. C. Reigh. 1996. Apparent digestibility of selected ingredients in red drum (*Sciaenops ocellantus*) diets. Aquaculture 141: 233-244. doi: 10.1016/0044-8486(95)01217-6

Mohanta, K. N., S. N. Mohanty, J. K. Jena, and N. P. Sahu. 2006. Apparent protein, lipid and energy digestibility coefficients of some commonly used feed ingredients in formulated pelleted diets for silver barb, *Puntius gonionotus*. Aquaculture Nutrition 12: 211-218. doi: 10.1111/j.1365-2095.2006.00403.x

Naylor, R. L., R. W. Hardy, D. P. Bureau, A. Chiu, and M. Elliott. 2009. Feeding aquaculture in an era of finite resources. Proceeding of the National Academy of Sciences of the United States of America (PNAS) 36: 15103-15110.

Nico, L. G., J. D. Williams, and H. L. Jelks. 2005. Black carp: biological synopsis and risk assessment of an introduced fish. American Fisheries Society Special Publication 32: 337p.

NRC. 1993. Nutrient requirements of fish. National Research Council of the National Academy Press Washington, D.C., USA. 105p.

NRC. 2011. Nutrient requirements of fish and shrimp. National Research Council of the National Academies Washington, D.C (U.S.). 363p.

Oliva-Teles, A., and P. Goncalves. 2001. Partial replacement of fishmeal by brewers yeast *Saccaromyces cerevisae* in diets for sea bass *Dicentrarchus labrax* juveniles. Aquaculture 202 (3-4): 269-278. doi: 10.1016/S0044-8486(01)00777-3

Ozório, R. O. A., B. G. S. Turini, G. V. Môro, L. S. T. Oliveira, L. Portz, and J. E. P. Cyrino. 2010. Growth, nitrogen gain and indispensable amino acid retention of pacu (*Piaractus mesopotamicus*, Holmberg 1887) fed different brewers yeast (*Saccharomyces cerevisiae*) levels. Aquaculture Nutrition 16: 276-283. doi: 10.1111/j.1365-2095.2009.00662.x

Pavasovic, A., A. J. Anderson, P. B. Mather, and N. A. Richardson. 2007. Influence of dietary protein on digestive enzyme activity, growth and tail muscrude lipide composition in redcrude lipidaw crayfish, *Cherax quadricarinatus* (von Martens). Aquaculture Research 38: 644-652. doi: 10.1111/j.1365-2109.2007.01708.x

Phuong, N. T. D., V. V. Trung, and K. V. Van. 2009. Status of black carp culture in Red river Delta. Journal of Science and Technology (Ministry of Agriculture and Rural Development, Vietnam) 2: 80-85.

Silva, S. S., K. F. Shim, and O. A. Khin. 1990. An evaluation of the method used in digestibility estimations of a dietary ingredient and comparisons on external and internal markers, and time of faeces collection in digestibility studies in the fish *Oreochromis aureus* (Steindachner). Reproduction Nutrition Development 30: 215-226.

Smith, R. R., M. C. Peterson, and A. C. Allred. 1980. Effect of leaching on apparent digestion coefficients of feedstuffs for salmonids. The Progressive Fish-Culturist 42: 295-299. doi: 10.1577/1548-8659(1980)42[195:EOLOAD]2.0.CO;2

Spannhof, L., and H. Plantikow. 1983. Studiers on carbohydrate digestion in rainbow trout. Aquaculture 30: 95-108. doi: 10.1016/0044-8486(83)90155-2

Sugiura, S. H., F. M. Dong, C. K. Rathbone, and R. W. Hardy. 1998. Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonids feeds. Aquaculture 159: 177-202. doi: 10.1016/S0044-8486(97)00177-4

Sullivan, J. A., and R. C. Reigh. 1995. Apparent digestibility of selected feedstuffs in diets for hybrid striped bass (*Morone saxatilis* ♀ x *Morone chrysops* ♂). Aquaculture 138: 313-322. doi: 10.1016/0044-8486(95)01071-8

Tacon, A. G. J, and M. Metian. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture 285 (1-4): 146-158. DOI: 10.1016/j.aquaculture.2008.08.015

Tibbetts, S. M., J. E. Milley, and S. P. Lall. 2006. Apparent protein and energy digestibility of common and alternative feed ingredients by Atlantic cod, *Gadus morhua* (Linnaeus, 1758). Aquaculture 261 (4): 1314-1327. doi: 10.1016/j.aquaculture.2006.08.052

Thu, T. T. N. 2012. Determination of the digestibility of some plant ingredients for grass carp (*Ctenopharyngodon idella*). Journal of Science and Development (Vietnam National University of Agriculture) 10: 986-992.

Van, K. V., T. A. Tuyet, T. D. Hoai, and K. T. Dung. 2010. Initial results of black carp monoculture in ponds in Hai Duong province. Journal of Science and Development (Vietnam National University of Agriculture) 8 (3): 481-487.

Van, K. V, and T. T. N. Thu. 2013. Effect of dietary protein levels on black carp (*Mylopharyngodon piceus*) growth performance in semi-intensive. Journal of Science and Technology (Thai Nguyen University, Vietnam) 101 (1): 81-84.

Watanabe, T. 2002. Strategies for further development of aquatic feeds. Fisheries Science 68(2): 242–252. doi: 10.1046/j.1444-2906.2002.00418.x

Willson, R. P., and W. E. Poe. 1985. Apparent digestibility of protein and energy in feed ingredients for channel catfish. The Progressive Fish-Culturist 47: 154-158. doi: 10.1577/1548-8640(1985)47<154:ADPAEC>2.0.CO;2

Wilson, R.P. 2002. Amino acid and protein (Chapter 3). p. 143-179. In Halver, J. E. and Hardy, R.W. Fish nutrition. Elsevier Science Imprint.

Wu, X. Y., Y. J. Yong, L. X. Tian, K. S. Mai, and H. J. Yang. 2006. Apparent digestibility coefficients of selected feed ingredients for yellowfin seabream, *Sparus latus*. Journal of the World Aquaculture Society, 37: 237-245. doi: 10.1111/j.1749-7345.2006.00034.x

Yu, H. R., Q. Zhang, H. Cao, X. Z. Wang, G. Q. Huang, B. R. Zhang, J. J. Fan, S. W. Liu, W. Z. Li, and Y. Cui. 2013. Apparent digestibility coefficients of selected feed ingredients for juvenile snakehead, *Ophiocephalus argus*. Aquaculture Nutrition 19: 139-147. doi: 10.1111/j.1365-2095.2012.00947.x

Zerai, D. B., K. M. Fitzsimmons, R. J. Collier, and G. C. Duff. 2008. Evaluation of brewer's waste as partial replacement of fish meal protein in Nile tilapia, Oreochromis niloticus, diets. Journal of the World Aquaculture Society 39: 556-564. doi: 10.1111/j.1749-7345.2008.00186.x

Zhou, Q. C., and Y. R. Yue. 2012. Apparent digestibility coefficients of selected feed ingredients for juvenile hybrid tilapia, *Oreochromis niloticus* × *Oreochromis aureus*. Aquaculture Research 43: 806-814. doi: 10.1111/j.1365-2109.2011.02892.x

Zhou, Q. C., B. P. Tan, K. S. Mai, and Y. J. Liu. 2004. Apparent digestibility of selected feed ingredients for juvenile cobia (*Rachycentron canadum*). Aquaculture 24: 441-451. doi: 10.1016/j.aquaculture.2004.08.044