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DIETARY CARBOHYDRATE UTILIZATION BY THE MALAYSIAN MAHSEER, Tor tambroides (BLEEKER, 1854)

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DIETARY CARBOHYDRATE UTILIZATION BY THE MALAYSIAN MAHSEER, *Tor tambroides* (BLEEKER, 1854)

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January 2018

Chair: Prof. Mohd Salleh bin Kamarudin, PhD
Faculty: Agriculture

This study was carried out to investigate the utilization of dietary carbohydrate by the Malaysian mahseer, *Tor tambroides* (Bleeker, 1854). Wild mahseer fingerlings were obtained from fish suppliers in Pahang and Kelantan. Different batches of fish were used in different feeding trials and they were acclimatized for three weeks before the start of these trials. The effects of different experimental diets on the growth performance, feed utilization efficiency, body nutrient composition, nutrient retention, liver and intestine morphology, and glucose-6-phosphate dehydrogenase (G6PD) gene expression were measured. This study also attempted to evaluate the physical properties of extruded diets using selected starch sources for suitability in mahseer feeding.

In the first feeding trial, fish were fed four experimental diets containing four carbohydrate levels (15%, 20%, 25% and 30%) using food grade corn starch as the carbohydrate source for 10 weeks. The best growth performance was observed in fish fed 20-25% dietary carbohydrate. Using a second-order polynomial regression analysis on the fish growth, the optimal dietary carbohydrate requirement of Malaysian mahseer was determined at 23.44%. Subsequent feeding trials were then based on this optimum level.

In the second study, three locally grown starch sources, sago (*Metroxylon sagu*), cassava (*Manihot esculenta*) and taro (*Colocasia esculenta*) were tested as replacement for imported corn starch in the production of extruded feed for mahseer. Results showed that sago starch gave good expansion ratio and floatability and thus suitable for the production of floating mahseer feed. These feeds were then fed to mahseer juveniles for 10 weeks to evaluate the suitability of these starches as dietary carbohydrate and energy source for the Malaysian mahseer. Results showed that fish fed with corn starch and taro starch performed significantly better ($P<0.05$) than those fed sago and cassava starch. However, fish fed corn starch had the highest body lipid, lipid retention, and intraperitoneal fat indicating high conversion of

carbohydrate to lipid compared to taro starch. Therefore, taro starch seemed to be the best candidate as a full or partial replacement of corn starch for the production of extruded feed for this species.

The third feeding trial was conducted for 12 weeks to determine the effects of three forms of carbohydrates (starch, disaccharide sucrose and monosaccharide glucose) on the growth performance, feed utilization efficiency, body composition, nutrient retention, and liver and intestine morphology of mahseer. Best performance was observed in fish fed starch which suggested that mahseer benefited from higher complexity of carbohydrates compared to simple carbohydrates.

The final feeding trial was conducted for 10 weeks to evaluate the effect of dietary carbohydrate level and form on the regulation of G6PD gene in mahseer. Fish were fed experimental diets prepared from the first and third feeding trials. Using real time PCR assays, the mRNA expression of G6PD gene in fish liver was estimated. Results showed that G6PD gene expression was significantly elevated ($P<0.05$) in the liver of fish fed 20% carbohydrate and maximum G6PD expression was achieved at 22.2% carbohydrate level which was very close to the optimal dietary carbohydrate requirement obtained in the first experiment. Among fish fed different carbohydrate forms, the highest G6PD gene expression ($P<0.05$) was observed in fish fed glucose. Dietary carbohydrate level and form influenced blood glucose level in mahseer which directly regulated the mRNA expression of G6PD gene during carbohydrate metabolism.

A 20-25% dietary carbohydrate inclusion was recommended for the Malaysian mahseer. A higher or lower inclusion would affect the fish growth. This fish preferred dietary starch with corn and taro starches giving a good growth. High G6PD gene expression indicated increased carbohydrate metabolism and blood glucose level were due to the increasing dietary carbohydrate level. In conclusion, this present study strongly indicated that the Malaysian mahseer has a moderate ability in utilizing dietary carbohydrate inclusion level with a preference for soluble polysaccharides and a limited ability in utilizing starch sources.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGGUNAAN KARBOHIDRAT OLEH KELAH MERAH, *Tor tambroides* (BLEEKER, 1854)

Oleh

SAIRATUL DAHLIANIS BINTI ISHAK

Januari 2018

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Penyelidikan ini dijalankan bagi mengkaji penggunaan karbohidrat dalam diet kelah merah (*Tor tambroides*, Bleeker). Anak ikan kelah liar telah diperoleh daripada pembekal ikan dari Pahang and Kelantan. Kumpulan ikan berbeza telah digunakan dalam eksperimen pemakanan yang berlainan dan kesemuanya diaklimatasi selama tiga minggu sebelum kajian pemakanan dimulakan. Kesan diet ujian berbeza terhadap prestasi pertumbuhan, kecekapan penggunaan makanan, komposisi nutrien badan, pengekalan nutrien, morfologi hati dan usus serta ekspresi gen glukosa-6-fosfat dehidrogenase (G6PD) telah diukur. Kajian ini juga telah menilai sifat fizikal diet yang diekstrusi menggunakan sumber kanji terpilih untuk kebolehsuaian dalam pemakanan ikan kelah.

Dalam kajian pemakanan pertama, kelah diberi makan empat diet ujian yang mengandungi empat kadar karbohidrat (15%, 20%, 25% dan 30%) menggunakan kanji jagung selama 10 minggu. Prestasi pertumbuhan terbaik diperhatikan pada ikan yang diberi 20-25% karbohidrat. Melalui analisis regresi polinomial order kedua, keperluan karbohidrat dietari yang optimum ditentukan pada 23.44%. Eksperimen berikutnya adalah berdasarkan paras optimum ini.

Dalam kajian kedua, tiga sumber kanji tempatan, sagu (*Metroxylon sago*), ubi kayu (*Manihot esculenta*) dan keladi (*Colocasia esculenta*) telah diuji untuk menggantikan kanji jagung yang diimport dalam pengeluaran makanan terapung untuk kelah. Keputusan menunjukkan bahawa kanji sagu memberikan nisbah pengembangan dan keapungan yang baik dan sesuai untuk penghasilan makanan kelah terapung. Kesemua diet ini kemudian diberikan kepada kelah selama 10 minggu untuk menilai kesesuaian kanji ujian sebagai sumber karbohidrat dan tenaga untuk kelah. Keputusan menunjukkan bahawa prestasi ikan yang diberi makan dengan kanji jagung dan keladi ketara lebih baik ($P<0.05$) daripada ikan yang diberi kanji sagu dan ubi kayu. Walau bagaimanapun, ikan yang diberi kanji jagung mempunyai lipid badan, pengekalan lipid, dan lemak intraperitoneal yang tertinggi menunjukkan

penukaran karbohidrat kepada lipid yang tinggi berbanding dengan kanji keladi. Kanji keladi kelihatan sebagai calon terbaik untuk penggantian penuh/separa kanji jagung dalam penghasilan makanan terapung untuk spesies ini .

Eksperimen pemakanan ketiga dijalankan selama 12 minggu untuk menentukan kesan tiga bentuk karbohidrat (kanji, disakarida sukrosa dan monosakarida glukosa) terhadap prestasi pertumbuhan, kecekapan pertukaran makanan, komposisi badan, pengekalan nutrien, serta morfologi hati dan usus kelah. Prestasi terbaik diperhatikan pada ikan diberi kanji yang menunjukkan bahawa kelah mendapat manfaat daripada karbohidrat lebih kompleks berbanding karbohidrat mudah.

Eksperimen pemakanan terakhir dijalankan selama 10 minggu untuk menilai kesan perbezaan paras dan bentuk karbohidrat terhadap regulasi gen G6PD dalam kelah. Ikan diberi makan diet ujian yang disediakan dari eksperimen pemakanan pertama dan ketiga. Menggunakan ujian PCR masa nyata, ekspresi mRNA gen G6PD dalam hati ikan dianggarkan. Keputusan menunjukkan bahawa ekspresi gen G6PD mengalami peningkatan signifikan (P<0.05) dalam hati ikan yang diberi makan karbohidrat 20% dan ekspresi G6PD maksimum dicapai pada paras karbohidrat 22.2% yang menghampiri paras keperluan karbohidrat dietari optimum yang diperolehi dalam eksperimen pertama. Di antara ikan yang diberi makan bentuk karbohidrat yang berbeza, ekspresi gen G6PD tertinggi (P<0.05) diperhatikan dalam ikan yang diberi makan glukosa. Paras dan bentuk karbohidrat mempengaruhi paras glukosa dalam darah ikan kelah yang secara langsung mengawal ekspresi mRNA gen G6PD semasa metabolisme karbohidrat.

Paras karbohidrat dalam makanan yang disyorkan untuk kelah adalah 20-25%. Paras yang lebih tinggi atau rendah akan mengganggu pertumbuhan ikan. Kelah memilih kanji yang mana kanji jagung dan keladi memberikan pertumbuhan yang baik. Ekspresi gen G6PD yang tinggi menunjukkan peningkatan metabolisme karbohidrat dan paras glukosa darah disebabkan kenaikan paras karbohidrat dietari. Sebagai kesimpulan, kajian ini menunjukkan bahawa kelah merah mempunyai keupayaan sederhana dalam menggunakan paras karbohidrat dalam makanan dan lebih cenderung memilih polisakarida larut dengan keupayaan penggunaan sumber karbohidrat yang terhad.

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I certify that a Thesis Examination Committee has met on 19 January 2018 to conduct the final examination of Sairatul Dahlianis binti Ishak on her thesis entitled "Dietary Carbohydrate Utilization by the Malaysian Mahseer, *Tor tambroides* (Bleeker, 1854)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BD	Bulk Density
DEPC	Di-ethyl Pyro-carbonate
DNA	Deoxy-ribonucleic Acid
DOA	Department of Agriculture, Malaysia
DOF	Department of Fisheries, Malaysia
DP	Degree of Polymerization
DPX	Distyrene, Plasticizer and Xylene mix
ER	Expansion Ratio
F	Floatability
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Rate
G6PD	Glucose-6-Phosphate Dehydrogenase
H&E	Haematoxylin and Eosin
HPLC	High Performance Liquid Chromatography
HSI	Hepato-somatic Index
HUFA	Highly Unsaturated Fatty Acids
IPF	Intra-peritoneal Fat
LG	Length Gain
mRNA	Messenger Ribo-nucleic Acid
MSE	Mean Standard Error
mtDNA	Mitochondrial DNA
NADPH	Nicotinamide Adenine Dinucleotide Phosphate reduced
NFE	Nitrogen-Free Extract
NRC	National Research Council, USA
PCR	Polymerase Chain Reaction
PDI	Pellet Durability Index
PER	Protein Efficiency Ratio
RAPD	Random Amplification of Polymorphic DNA
RNA	Ribo-nucleic Acid
RT-PCR	Reverse Transcriptase- Polymerase Chain Reaction
rRNA	ribosomal RNA
SEM	Scanning Electron Microscope
SGR	Specific Growth Rate
SV	Sinking Velocity
TD	True Density
VSI	Viscero-somatic Index
WG	Weight Gain
WS	Water Stability

CHAPTER 1

GENERAL INTRODUCTION

The Malaysian mahseer, *Tor tambroides* (Bleeker, 1854), is a freshwater riverine carp species that is generally distributed throughout Southeast Asian countries (Kottelat, 2000, Rainboth, 1996). This species has long been valued as a game fish for anglers, an ornamental fish for fish hobbyists and also an expensive delicacy served in restaurants. As its fisheries had drastically declined, interest to commercially culture mahseer has intensified (Chowdhury *et al.*, 2016, Esa *et al.*, 2011, Ingram *et al.*, 2006, Ismail *et al.*, 2011, Ismail *et al.*, 2012, Ramezani-Fard and Kamarudin, 2012b, Rashid *et al.*, 2015, Siraj *et al.*, 2007a). Mahseer aquaculture production of Malaysia in 2015 was 24.7 tonnes with the wholesale value of RM2.35 million (DOF, 2016). Meanwhile the retail price of live mahseer at the seafood restaurants in Malaysia and Singapore can reach as high as USD 80-200/kg (Kamarudin *et al.*, 2014).

A good practical, formulated diet must contain satisfactory energy, essential amino acids, lipid, vitamins, minerals and other nutrients to meet the nutritional requirements of the cultured species for a maximum growth with the least cost (Hardy and Barrows, 2002). This means that aquafeed manufacturers must balance the nutritional requirements of the cultured species with the availability and cost of the ingredients. Protein and essential amino acids are important components to ensure growth and the expensive protein ingredients make up the bulk of the feed. Meanwhile feed cost is the highest operational cost in fish farming (Gatlin *et al.*, 2007). De Silva and Anderson (1995) pointed out that extensive research to determine the quantitative essential amino acid requirement for each species is not important because estimates of the requirement is sufficient by using crude protein content. This notion encourages the production of commercial protein-rich diets that can be fed to a broad range of species without regards of their nutritional needs. However, excess protein or amino acids in protein-rich diets may be lost as energy or as waste which contributes to the nutrient loading in environment (Trushenski *et al.*, 2006). Hardy and Barrows (2002) stressed the importance of specific feed tailored for each species with the need to add *n-3* and *n-6* highly unsaturated fatty acids (HUFA) in the feed of marine cultured species in comparison to freshwater species. This is because freshwater species is capable in synthesizing *n-3* and *n-6* HUFA *de novo* unlike their marine counterparts (Sargent *et al.*, 2002, Tocher *et al.*, 2001, Tocher, 2003). As fish have no specific dietary carbohydrate requirement, some form of digestible carbohydrate should be included in the diet as it may serve as precursors for dispensable amino acids and nucleic acids (NRC, 1993). Although carbohydrate is a cheap source of energy, the maximum inclusion level of this component should be determined based on species tolerance (De Silva and Anderson, 1995, NRC, 1993, NRC, 2011). By formulating diets specific to its targeted cultured species, unwanted expenditure on unnecessary expensive ingredients can be avoided (Hardy and Barrows, 2002, Trushenski *et al.*, 2006).

Not many studies have been conducted on the dietary nutritional requirements of mahseers including the Malaysian mahseer. In the last decade, only dietary protein and lipid requirements of juvenile Malaysian mahseer have been determined which are 40% and 5%, respectively (Misieng *et al.*, 2011, Ng *et al.*, 2008, Ng and Andin, 2011, Ramezani-Fard *et al.*, 2012b). This species is also able to utilize poultry offal meal and palm oil as fishmeal and fish oil substitutes, respectively (Ismail *et al.*, 2012, Ramezani-Fard and Kamarudin, 2012b, Ramezani-Fard *et al.*, 2012a). However, the utilization of dietary carbohydrate in this species has not been reported.

It is advantageous to utilize cheap sources of digestible energy such as carbohydrates under practical culture conditions (Kaushik, 1995, Mohanta *et al.*, 2009). Majority of the studies are concentrated on fishmeal and fish oil replacements with focus on the use of grains, oilseeds and legumes as they are inexpensive and contain significant protein and lipid contents. However, plant-based protein replacements also contain high amount of carbohydrates and lack of emphasis on the carbohydrate aspect of the replacement ingredients could lead to poor feed utilization by the fish (Stone *et al.*, 2003). Naturally, fish has the ability to utilize certain types of carbohydrates depending on its species, natural habitats, feeding habits, size and age (Shiau, 1997). These metabolic differences may be due to variation in enzyme activity, hormonal secretion and/or digestion capability between species (Wilson, 1994). As an omnivorous fish, Malaysian mahseer should have a better digestion for carbohydrate components.

Corn starch has been used as an aquafeed binder to stabilize pellet from disintegration in water and prevent nutrient leaching (NRC, 1993, Paolucci *et al.*, 2012). It is also an important ingredient for the production of extruded aquafeeds. Although carbohydrate is considered a cheap form of energy compared to fishmeal or fish oil, the price for corn starch and meal has been increasing in recent years because of increased demand on lignocellulosic biomass from corn stover for biofuel (Baker and Zahniser, 2006, Cate, 2016, Loqué *et al.*, 2015). Starch from sago (*Metroxylon sagu*), cassava (*Manihot esculenta*) and taro (*Colocasia esculenta*) can be good candidates as potential substitutes for corn starch as these plants have socio-economic importance in Malaysia and many tropical developing countries (Awg-Adeni *et al.*, 2010, Lebot *et al.*, 2004, Versino and García, 2014).

Excess carbohydrates consumed by fish are often stored in adipose and liver tissues as lipid via pentose phosphate pathway (Kamalam *et al.*, 2016). Glucose-6-phosphate dehydrogenase (G6PD) plays a major role as cytoplasmic enzyme in the pentose phosphate pathway. In liver, G6PD and 6-phosphogluconate dehydrogenase (6PGD) work mutually with malic enzyme in producing NADPH used for lipid biosynthesis, ribonucleic acids biosynthesis and protection against oxidative stress (Dabrowski and Guderley, 2002, NRC, 2011, Salati and Amir-Ahmady, 2001). This gene has been studied for metabolism changes in teleosts (Chen *et al.*, 2013, Deane and Woo, 2005b, Kamalaveni *et al.*, 2001, Qiang *et al.*, 2014b, Zheng *et al.*, 2013).

The objectives of this study were:

(i) To determine the optimal dietary carbohydrate inclusion level for Malaysian mahseer;
(ii) To evaluate the performances of alternative starch sources (taro, cassava, sago) in the practical diet of Malaysian mahseer;
(iii) To assess the performance of Malaysian mahseer fingerling in utilizing selected carbohydrate forms (monosaccharide, disaccharide, soluble polysaccharide);
(iv) To elucidate the G6PD gene regulation in liver of Malaysian mahseer in regards to carbohydrate utilization.

REFERENCES

Abd-Aziz, S. (2002) Sago starch and its utilisation. *Journal of Bioscience and Bioengineering,* **94,** 526-529.

Abidin, Z.Z., Yusof, Y.A., Ling Ch, N. & Mohamed, S. (2011) Effect of binder on compression characteristics of *Eucheuma cottonii* powder. *Journal of Food, Agriculture & Environment,* **9,** 137-141.

Abimorad, E.G., Carneiro, D.J. & Urbinati, E.C. (2007) Growth and metabolism of pacu (*Piaractus mesopotamicus* Holmberg 1887) juveniles fed diets containing different protein, lipid and carbohydrate levels. *Aquaculture Research,* **38,** 36-44.

Aboubakar, Njintang, Y.N., Scher, J. & Mbofung, C.M.F. (2008) Physicochemical, thermal properties and microstructure of six varieties of taro (*Colocasia esculenta* L. Schott) flours and starches. *Journal of Food Engineering,* **86,** 294-305.

Ah-Hen, K., Lehnebach, G., Lemus-Mondaca, R., Zura-Bravo, L., Leyton, P., Vega-Gálvez, A. & Figuerola, F. (2014) Evaluation of different starch sources in extruded feed for Atlantic salmon. *Aquaculture Nutrition,* **20,** 183-191.

Ahmad, F.B., Williams, P.A., Doublier, J.-L., Durand, S. & Buleon, A. (1999) Physico-chemical characterisation of sago starch. *Carbohydrate Polymers,* **38,** 361-370.

Ahmad, M., Qureshi, T.A. & Singh, A.B. (2012) Effect of dietary protein, lipid and carbohydrate contents on the carcass composition of *Cyprinus carpio communis* fingerlings. *African Journal of Biotechnology,* **11,** 8353-8360.

Al-Hussaini, A.H. (1949) On the functional morphology of the alimentary tract of some fish in relation to differences in their feeding habits: cytology and physiology. *Journal of Cell Science,* **3,** 323-354.

Al-Tameemi, R., Aldubaikul, A. & Salman, N.A. (2010) Comparative study of α-amylase activity in three Cyprinid species of different feeding habits from Southern Iraq. *Turkish Journal of Fisheries and Aquatic Sciences,* **10,** 411-414.

Alava, V.R. & Pascual, F.P. (1987) Carbohydrate requirements of *Penaeus monodon* (Fabricius) juveniles. *Aquaculture,* **61,** 211-217.

Alonso, R., Aguirre, A. & Marzo, F. (2000) Effects of extrusion and traditional processing methods on antinutrients and in vitro digestibility of protein and starch in faba and kidney beans. *Food Chemistry,* **68,** 159-165.

Ambak, M.A., Ashraf, A.H. & Budin, S. (2007) Conservation of the Malaysian mahseer in Nenggiri basin through community action In *Proceedings of the International Symposium on the Mahseer* (Siraj, S.S*., et al.* eds.), Vol. Supplementary, pp. 217-228. Malaysian Fisheries Society, Kuala Lumpur.

Ambak, M.A. & Jalal, K.C.A. (2006) Sustainability issues of reservoir fisheries in Malaysia. *Aquatic Ecosystem Health and Management,* **9,** 165-173.

AOAC (1995) *Official Methods of Analysis of AOAC International,* Association of Official Analytical Chemists Inc., Texas.

Arnesen, P. & Krogdahl, Å. (1993) Crude and pre-extruded products of wheat as nutrient sources in extruded diets for Atlantic salmon (*Salmo salar*, L) grown in sea water. *Aquaculture,* **118,** 105-117.

Aslaksen, M.A., Kraugerud, O.F., Penn, M., Svihus, B., Denstadli, V., Jørgensen, H.Y., Hillestad, M., Krogdahl, Å. & Storebakken, T. (2007) Screening of nutrient digestibilities and intestinal pathologies in Atlantic salmon, *Salmo salar*, fed diets with legumes, oilseeds, or cereals. *Aquaculture,* **272,** 541-555.

Aursnes, I.A., Rishovd, A.L., Karlsen, H.E. & Gjøen, T. (2011) Validation of reference genes for quantitative RT-qPCR studies of gene expression in Atlantic cod (*Gadus morhua* L.) during temperature stress. *BMC Research Notes,* **4,** 104.

Awg-Adeni, D.S., Abd-Aziz, S., Bujang, K. & Hassan, M.A. (2010) Bioconversion of sago residue into value added products. *African Journal of Biotechnology,* **9,** 2016-2021.

Ayadi, F.Y., Muthukumarappan, K., Rosentrater, K.A. & Brown, M.L. (2011) Twin-screw extrusion processing of rainbow trout (*Oncorhynchus mykiss*) feeds using various levels of corn-based distillers dried grains with solubles (DDGS). *Cereal Chemistry,* **88**.

Azaza, M.S., Khiari, N., Dhraief, M.N., Aloui, N., Kraïem, M.M. & Elfeki, A. (2015) Growth performance, oxidative stress indices and hepatic carbohydrate metabolic enzymes activities of juvenile Nile tilapia, *Oreochromis niloticus* L., in response to dietary starch to protein ratios. *Aquaculture Research,* **46,** 14-27.

Azuadi, N.M., Siraj, S.S., Daud, S.K., Christianus, A., Harmin, S.A., Sungan, S. & Britin, R. (2011) Enhancing ovulation of Malaysian mahseer (Tor tambroides) in captivity by removal of dopaminergic inhibition. *Journal of Fisheries and Aquatic Science,* **6,** 740-750.

Azuadi, N.M., Siraj, S.S., Daud, S.K., Christianus, A., Harmin, S.A., Sungan, S. & Britin, R. (2013) Induction of ovulation in F1 Malaysian mahseer, *Tor tambroides* (Bleeker, 1854) by using synthetic and non-synthetic hormones. *Asian Journal of Animal and Veterinary Advances,* **8,** 582-592.

Baeverfjord, G., Refstie, S., Krogedal, P. & Åsgård, T. (2006) Low feed pellet water stability and fluctuating water salinity cause separation and accumulation of dietary oil in the stomach of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* **261,** 1335-1345.

Baker, A. & Zahniser, S. (2006) Ethanol reshapes the corn market. In *Amber Waves*, Vol. 4, pp. 30-35. United States Department of Agriculture (USDA), Washington.

Bakke, A.M., Glover, C. & Krogdahl, Å. (2010) Feeding, digestion and absorption of nutrients In *Fish physiology: The Multifunctional Gut of Fish* (Grosell, M*., et al.* eds.), Vol. 30, pp. 57-110. Academic Press, San Diego.

Ball, S., Guan, H.-P., James, M., Myers, A., Keeling, P., Mouille, G., Buléon, A., Colonna, P. & Preiss, J. (1996) From glycogen to amylopectin: A model for the biogenesis of the plant starch granule. *Cell,* **86,** 349-352.

Bami, M.L., Kamarudin, M.S., Saad, C.R., Ebrahimi, M., Hafid, S.R.A., Chakravarthi, S., Nesaretnam K. & Radhakrishnan, A. K. (2017). Effects of palm oil products on growth performance, body composition and fatty acid profile of juvenile Malaysian mahseer (*Tor tambroides*). *Journal of Oil Palm Research*, **29**, 387-400.

Bami, M.L., Kamarudin, M.S., Saad, C.R., Arshad, A. & Ebrahimi, M. (2017) Effects of canarium fruit (*Canarium odontophyllum*) oil as a dietary lipid source for juvenile mahseer (*Tor tambroides*) performance. *Aquaculture Reports,* **6,** 8-20.

Basade, Y. & Kohli, M.P.S. (2004) Influence of dietary cholecalciferol levels on its digestibility in Deccan mahseer, *Tor khudree* (Sykes). *Indian Journal of Fisheries,* **51,** 123-131.

Bazaz, M.M. & Keshavanath, P. (1993) Effect of feeding different levels of sardine oil on growth, muscle composition and digestive enzyme activities of mahseer, *Tor khudree*. *Aquaculture,* **115,** 111-119.

Berg, O.K. & Bremset, G. (1998) Seasonal changes in the body composition of young riverine Atlantic salmon and brown trout. *Journal of Fish Biology,* **52,** 1272-1288.

Beuk, R.J., Heineman, E., Tangelder, G.-J., Quaedackers, J.S.L.T., Marks, W.H., Lieberman, J.M. & oude Egbrink, M.G.A. (2000) Total warm ischemia and reperfusion impairs flow in all rat gut layers but increases leukocyte–vessel wall interactions in the submucosa only. *Annals of Surgery,* **231,** 96.

Bhagawati, K., Chadha, N.K., Sarma, D., Sawant, P.B. & Akhtar, M.S. (2015) Physiological responses of Golden Mahseer (*Tor putitora*) fry to dietary zinc and assessment of its optimum requirement. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences,* **85,** 499-506.

Bitterlich, G. (1985) Digestive enzyme pattern of two stomachless filter feeders, silver carp, *Hypophthalmichthys molitrix* Val., and bighead carp, *Aristichthys nobilis* Rich. *Journal of Fish Biology,* **27,** 103-112.

Booth, M.A., Moses, M.D. & Allan, G.L. (2013) Utilisation of carbohydrate by yellowtail kingfish *Seriola lalandi*. *Aquaculture,* **376–379,** 151-161.

Boros, M., Massberg, S., Baranyi, L., Okada, H. & Messmer, K. (1998) Endothelin 1 induces leukocyte adhesion in submucosal venules of the rat small intestine. *Gastroenterology,* **114,** 103-114.

Borquez, A., Serrano, E., Dantagnan, P., Carrasco, J. & Hernandez, A. (2011) Feeding high inclusion of whole grain white lupin (*Lupinus albus*) to rainbow trout (*Oncorhynchus mykiss*) effects on growth, nutrient digestibility, liver and intestine histology and muscle fatty acid composition. *Aquaculture Research,* **42,** 1067-1078.

Buhler, D.R. & Halver, J.E. (1961) Nutrition of salmonoid fishes IX. Carbohydrate requirements of chinook salmon. *The Journal of Nutrition,* **74,** 307-318.

Bureau, D.P., Kaushik, S.J. & Cho, C.Y. (2002) Bioenergetics In *Fish Nutrition* (Halver, J.E. & Hardy, R.W. eds.), pp. 1-59. Academic Press, San Diego.

Burns, A.E., Bradbury, J.H., Cavagnaro, T.R. & Gleadow, R.M. (2012) Total cyanide content of cassava food products in Australia. *Journal of Food Composition and Analysis,* **25,** 79-82.

Cappellini, M.D. & Fiorelli, G. (2008) Glucose-6-phosphate dehydrogenase deficiency. *The Lancet,* **371,** 64-74.

Cate, J.H.D. (2016) Alternative Energy: Increased Options for Biofuel Production Using Yeast. *Journal of the Homeland Defense & Security Information Analysis Center,* **2**. https://www.hdiac.org/node/2904

Cavalheiro, J.M.O., de Souza, E.O. & Bora, P.S. (2007) Utilization of shrimp industry waste in the formulation of tilapia (*Oreochromis niloticus* Linnaeus) feed. *Bioresource Technology,* **98,** 602-606.

Chan, A.S., Horn, M.H., Dickson, K.A. & Gawlicka, A. (2004) Digestive enzyme activities in carnivores and herbivores: comparisons among four closely related prickleback fishes (Teleostei: Stichaeidae) from a California rocky intertidal habitat. *Journal of Fish Biology,* **65,** 848-858.

Chatvijitkul, S., Boyd, C.E., Davis, D.A. & McNevin, A.A. (2016) Embodied resources in fish and shrimp feeds. *Journal of the World Aquaculture Society***,** doi: 10.1111/jwas.12360.

Chen, Q.-L., Luo, Z., Pan, Y.-X., Zheng, J.-L., Zhu, Q.-L., Sun, L.-D., Zhuo, M.-Q. & Hu, W. (2013) Differential induction of enzymes and genes involved in lipid metabolism in liver and visceral adipose tissue of juvenile yellow catfish *Pelteobagrus fulvidraco* exposed to copper. *Aquatic Toxicology,* **136,** 72-78.

Cheng, Z.J. & Hardy, R.W. (2003) Effects of extrusion processing of feed ingredients on apparent digestibility coefficients of nutrients for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture Nutrition,* **9,** 77-83.

Chew, P.C., Abd-Rashid, Z., Hassan, R., Asmuni, M. & Chuah, H.P. (2010) Semen cryo-bank of the Malaysian Mahseer (*Tor tambroides* and *T. douronensis*). *Journal of Applied Ichthyology,* **26,** 726-731.

Chinnaswamy, R. & Hanna, M.A. (1988) Relationship between amylose content and extrusion-expansion properties of com starches. *Cereal Chemistry,* **65,** 138-147.

Chong, V.C., Lee, P.K.Y. & Lau, C.M. (2010) Diversity, extinction risk and conservation of Malaysian fishes. *Journal of Fish Biology,* **76,** 2009-2066.

Chow, S. & Nakadate, M. (2004) PCR primers for fish G6PD gene intron and characterization of intron length variation in the albacore *Thunnus alalunga*. *Molecular Ecology Notes,* **4,** 391-393.

Chowdhury, A.J.K., Zakaria, N.H., Abidin, Z.A.Z. & Rahman, M.M. (2016) Phototrophic purple bacteria as feed supplement on the growth, feed utilization and body compositions of Malaysian Mahseer, *Tor tambroides* juveniles. *Sains Malaysiana,* **45,** 135-140.

Chung, M.J., Walker, P.A. & Hogstrand, C. (2006) Dietary phenolic antioxidants, caffeic acid and Trolox, protect rainbow trout gill cells from nitric oxide-induced apoptosis. *Aquatic Toxicology,* **80,** 321-328.

Ciardiello, M.A., Camardella, L., Carratore, V. & di Prisco, G. (1997) Enzymes in Antarctic fish: Glucose-6-phosphate dehydrogenase and glutamate dehydrogenase. *Comparative Biochemistry and Physiology Part A: Physiology,* **118,** 1031-1036.

Ciftci, M., Turkoglu, V. & Coban, T.A. (2007) Effects of some drugs on hepatic glucose 6-phosphate dehydrogenase activity in Lake Van Fish (*Chalcalburnus Tarischii* Pallas, 1811). *Journal of Hazardous Materials,* **143,** 415-418.

Couto, A., Peres, H., Oliva-Teles, A. & Enes, P. (2016) Screening of nutrient digestibility, glycaemic response and gut morphology alterations in gilthead seabream (*Sparus aurata*) fed whole cereal meals. *Aquaculture,* **450,** 31-37.

Couto, A., Peres, H., Oliva-Teles, A. & Enes, P. (2017) Nutritional value of whole cereal meals for European sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture,* **473,** 128-134.

Cui, X.-J., Zhou, Q.-C., Liang, H.-O., Yang, J. & Zhao, L.-M. (2010) Effects of dietary carbohydrate sources on the growth performance and hepatic carbohydrate metabolic enzyme activities of juvenile cobia (*Rachycentron canadum* Linnaeus.). *Aquaculture Research,* **42,** 99-107.

Cummings, J.H. & Stephen, A.M. (2007) Carbohydrate terminology and classification. *European Journal of Clinical Nutrition,* **61,** S5-S18.

Dabrowski, K. & Guderley, H. (2002) Intermediary metabolism In *Fish Nutrition* (Halver, J.E. & Hardy, R.W. eds.), pp. 309-365. Academic Press, San Diego.

De Cruz, C.R., Kamarudin, M.S., Saad, C.R. & Ramezani-Fard, E. (2015) Effects of extruder die temperature on the physical properties of extruded fish pellets containing taro and broken rice starch. *Animal Feed Science and Technology,* **199,** 137-145.

De Silva, S.S. & Anderson, T.A. (1995) *Fish Nutrition in Aquaculture,* Chapman and Hall, London.

Deane, E.E. & Woo, N. (2005a) Expression studies on glucose-6-phosphate dehydrogenase in sea bream: effects of growth hormone, somatostatin, salinity and temperature. *Journal of Experimental Zoology Part A: Comparative Experimental Biology,* **303,** 676-688.

Deane, E.E. & Woo, N. (2005b) Upregulation of the somatotropic axis is correlated with increased G6PDH expression in black sea bream adapted to iso-osmotic salinity. *Annals of the New York Academy of Sciences,* **1040,** 293-296.

Debnath, D., Pal, A.K., Sahu, N.P., Yengkokpam, S., Baruah, K., Choudhury, D. & Venkateshwarlu, G. (2007) Digestive enzymes and metabolic profile of *Labeo rohita* fingerlings fed diets with different crude protein levels. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology,* **146,** 107-114.

Deng, D.-F., Hemre, G.-I., Storebakken, T., Shiau, S.-Y. & Hung, S.S.O. (2005) Utilization of diets with hydrolyzed potato starch, or glucose by juvenile white sturgeon (*Acipenser transmontanus*), as affected by Maillard reaction during feed processing. *Aquaculture,* **248,** 103-109.

DOA (2012) *Sarawak Agriculture Statistics 2012,* Department of Agriculture Sarawak, Kuching.

DOF (2006) *Annual Fisheries Statistics 2005,* Department of Fisheries Malaysia, Kuala Lumpur.

DOF (2013) *Annual Fisheries Statistics 2012,* Department of Fisheries Malaysia, Kuala Lumpur.

DOF (2016) *Annual Fisheries Statistics 2015,* Department of Fisheries Malaysia, Kuala Lumpur.

Dongmeza, E., Steinbronn, S., Francis, G., Focken, U. & Becker, K. (2009) Investigations on the nutrient and antinutrient content of typical plants used as fish feed in small scale aquaculture in the mountainous regions of Northern Vietnam. *Animal Feed Science and Technology,* **149,** 162-178.

Drewe, K.E., Horn, M.H., Dickson, K.A. & Gawlicka, A. (2004) Insectivore to frugivore: ontogenetic changes in gut morphology and digestive enzyme activity in the characid

fish *Brycon guatemalensis* from Costa Rican rain forest streams. *Journal of Fish Biology,* **64,** 890-902.

El-Sayed, A.-F.M. & Garling Jr, D.L. (1988) Carbohydrate-to-lipid ratios in diets for *Tilapia zillii* fingerlings. *Aquaculture,* **73,** 157-163.

Ellis, R.P., Cochrane, M.P., Dale, M.F.B., Duffus, C.M., Lynn, A., Morrison, I.M., Prentice, R.D.M., Swanston, J.S. & Tiller, S.A. (1998) Starch production and industrial use. *Journal of the Science of Food and Agriculture,* **77,** 289-311.

Enes, P., Panserat, S., Kaushik, S. & Oliva-Teles, A. (2006) Effect of normal and waxy maize starch on growth, food utilization and hepatic glucose metabolism in European sea bass (*Dicentrarchus labrax*) juveniles. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology,* **143,** 89-96.

Enes, P., Panserat, S., Kaushik, S. & Oliva-Teles, A. (2008) Growth performance and metabolic utilization of diets with native and waxy maize starch by gilthead sea bream (*Sparus aurata*) juveniles. *Aquaculture,* **274,** 101-108.

Enes, P., Panserat, S., Kaushik, S. & Oliva-Teles, A. (2009) Nutritional regulation of hepatic glucose metabolism in fish. *Fish Physiology and Biochemistry,* **35,** 519-539.

Enes, P., Panserat, S., Kaushik, S. & Oliva-Teles, A. (2011) Dietary carbohydrate utilization by European sea bass (*Dicentrarchus labrax* L.) and gilthead sea bream (*Sparus aurata* L.) juveniles. *Reviews in Fisheries Science,* **19,** 201-215.

Erfanullah & Jafri, A.K. (1995) Protein-sparing effect of dietary carbohydrate in diets for fingerling *Labeo rohita*. *Aquaculture,* **136,** 331-339.

Erfanullah & Jafri, A.K. (1998) Effect of dietary carbohydrate-to-lipid ratio on growth and body composition of walking catfish (*Clarias batrachus*). *Aquaculture,* **161,** 159-168.

Esa, Y., Kamaruddin, K.R., Abd Rahim, K.A., Daud, S.K., Siraj, S.S. & Tan, S.G. (2007) Phylogenetic relationships among three mahseers of the subtribe *Tores* in Malaysia In *Proceedings of the International Symposium on the Mahseer* (Siraj, S.S*., et al.* eds.), pp. 203-214. Malaysian Fisheries Society, Kuala Lumpur.

Esa, Y.B., Siraj, S.S., Daud, S.K., Rahim, K.A.A., Japning, J.R.R. & Tan, S.G. (2008) Mitochondrial DNA diversity of *Tor tambroides* Valenciennes (Cyprinidae) from five natural populations in Malaysia. *Zoological Studies,* **47,** 360-367.

Esa, Y.B., Siraj, S.S., Rahim, K.A.A., Daud, S.K., Chong, H.G.M., Guan, T.S. & Syukri, M.F. (2011) Genetic characterization of two mahseer species (*Tor douronensis* and *Tor tambroides*) using microsatellite markers from other cyprinids. *Sains Malaysiana,* **40,** 1087-1095.

FAO (1998) Carbohydrates in human nutrition (FAO Food and Nutrition Paper 66). Food and Agriculture Organization, Rome.

FAO (2017) FAOSTAT database. Food and Agriculture Organization of the United Nations, Rome.

Ferraro, V., Piccirillo, C., Tomlins, K. & Pintado, M.E. (2016) Cassava (*Manihot esculenta* Crantz) and Yam (*Dioscorea* spp.) crops and their derived foodstuffs: safety, security and nutritional value. *Critical Reviews in Food Science and Nutrition,* **56,** 2714-2727.

Filby, A.L. & Tyler, C.R. (2007) Appropriate 'housekeeping' genes for use in expression profiling the effects of environmental estrogens in fish. *BMC Molecular Biology,* **8,** 10.

Franceschi, V.R. & Nakata, P.A. (2005) Calcium oxalate in plants: formation and function. *Annual Review of Plant Biology,* **56,** 41-71.

Francis, G., Makkar, H.P.S. & Becker, K. (2001) Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture,* **199,** 197-227.

Fu, S.J. (2005) The growth performance of southern catfish fed diets with raw, precooked cornstarch and glucose at two levels. *Aquaculture Nutrition,* **11,** 257-261.

Furné , M., Hidalgo, M.C., Lopez, A., Garcia-Gallego, M., Morales, A.E., Domezain, A., Domezaine, J. & Sanz, A. (2005) Digestive enzyme activities in Adriatic sturgeon *Acipenser naccarii* and rainbow trout *Oncorhynchus mykiss*. A comparative study. *Aquaculture,* **250,** 391-398.

Furuichi, M. & Yone, Y. (1982) Availability of carbohydrate in nutrition of carp and red sea bream. *Bulletin of The Japanese Society of Scientific Fisheries,* **48,** 945-948.

Gabriel, U.U., Akinrotimi, O.A., Bekibele, D.O., Onunkwo, D.N. & Anyanwu, P.E. (2007) Locally produced fish feed: potentials for aquaculture development in subsaharan Africa. *African Journal of Agricultural Research,* **2,** 287-295.

Gatlin, D.M., Barrows, F.T., Brown, P., Dabrowski, K., Gaylord, T.G., Hardy, R.W., Herman, E., Hu, G., Krogdahl, Å., Nelson, R., Overturf, K., Rust, M., Sealey, W., Skonberg, D., J Souza, E., Stone, D., Wilson, R. & Wurtele, E. (2007) Expanding the utilization of sustainable plant products in aquafeeds: a review. *Aquaculture Research,* **38,** 551-579.

German, D.P., Nagle, B.C., Villeda, J.M., Ruiz, A.M., Thomson, A.W., Balderas, S.C. & Evans, D.H. (2010) Evolution of herbivory in a carnivorous clade of minnows (Teleostei: Cyprinidae): effects on gut size and digestive physiology. *Physiological and Biochemical Zoology,* **83,** 1-18.

Ghavidel, R.A. & Prakash, J. (2007) The impact of germination and dehulling on nutrients, antinutrients, in vitro iron and calcium bioavailability and in vitro starch and protein

digestibility of some legume seeds. *LWT - Food Science and Technology,* **40,** 1292-1299.

Gleadow, R., Pegg, A. & Blomstedt, C.K. (2016) Resilience of cassava (*Manihot esculenta* Crantz) to salinity: implications for food security in low-lying regions. *Journal of Experimental Botany,* **67,** 5403-5413.

Glencross, B., Blyth, D., Tabrett, S., Bourne, N., Irvin, S., Anderson, M., Fox-Smith, T. & Smullen, R. (2012) An assessment of cereal grains and other starch sources in diets for barramundi (*Lates calcarifer*)–implications for nutritional and functional qualities of extruded feeds. *Aquaculture Nutrition,* **18,** 388-399.

Glencross, B., Evans, D., Hawkins, W. & Jones, B. (2004) Evaluation of dietary inclusion of yellow lupin (*Lupinus luteus*) kernel meal on the growth, feed utilisation and tissue histology of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* **235,** 411-422.

Glencross, B., Hawkins, W., Evans, D., Rutherford, N., McCafferty, P., Dods, K. & Hauler, R. (2011) A comparison of the effect of diet extrusion or screw-press pelleting on the digestibility of grain protein products when fed to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* **312,** 154-161.

Glencross, B., Hawkins, W., Maas, R., Karopoulos, M. & Hauler, R. (2010) Evaluation of the influence of different species and cultivars of lupin kernel meal on the extrusion process, pellet properties and viscosity parameters of salmonid feeds. *Aquaculture Nutrition,* **16,** 13-24.

Gómez-Requeni, P., Mingarro, M., Calduch-Giner, J.A., Médale, F., Martin, S.A.M., Houlihan, D.F., Kaushik, S. & Pérez-Sánchez, J. (2004) Protein growth performance, amino acid utilisation and somatotropic axis responsiveness to fish meal replacement by plant protein sources in gilthead sea bream (*Sparus aurata*). *Aquaculture,* **232,** 493-510.

Govindasamy, S., Campanella, O.H. & Oates, C.G. (1995) Influence of extrusion variables on subsequent saccharification behaviour of sago starch. *Food Chemistry,* **54,** 289-296.

Grüll, D.R., Jetzinger, F., Kozich, M., Wastyn, M.M. & Wittenberger, R. (2006) Industrial starch platform–status quo of production, modification and application. *Biorefineries-Industrial Processes and Products: Status Quo and Future Directions***,** 61-95.

Gu, M., Kortner, T.M., Penn, M., Hansen, A.K. & Krogdahl, Å. (2014) Effects of dietary plant meal and soya-saponin supplementation on intestinal and hepatic lipid droplet accumulation and lipoprotein and sterol metabolism in Atlantic salmon (*Salmo salar* L.). *British Journal of Nutrition,* **111,** 432-444.

Guerreiro, I., Oliva-Teles, A. & Enes, P. (2015) Improved glucose and lipid metabolism in European sea bass (*Dicentrarchus labrax*) fed short-chain fructooligosaccharides and xylooligosaccharides. *Aquaculture,* **441,** 57-63.

Guo, R., Liu, Y.J., Tian, L.X. & Huang, J.W. (2006) Effect of dietary cornstarch levels on growth performance, digestibility and microscopic structure in the white shrimp, *Litopenaeus vannamei* reared in brackish water. *Aquaculture Nutrition,* **12,** 83-88.

Halver, J.E. & Hardy, R.W. (2002) *Fish Nutrition,* Academic Press, San Diego.

Hamid, N.K.A., Mahayat, M. & Hashim, R. (2011) Utilization of different carbohydrate sources and starch forms by bagrid catfish (*Mystus nemurus*) (Cuv & Val). *Aquaculture Nutrition,* **17,** e10-e18.

Han, D., Shan, X., Zhang, W., Chen, Y., Wang, Q., Li, Z., Zhang, G., Xu, P., Li, J., Xie, S., Mai, K., Tang, Q. & De Silva, S.S. (2016) A revisit to fishmeal usage and associated consequences in Chinese aquaculture. *Reviews in Aquaculture***,** doi: 10.1111/raq.12183.

Hardy, R.W. (2010) Utilization of plant proteins in fish diets: effects of global demand and supplies of fishmeal. *Aquaculture Research,* **41,** 770-776.

Hardy, R.W. & Barrows, F.T. (2002) Diet formulation and manufacture. In *Fish Nutrition* (*Halver, J.E. & Hardy, R.W.* eds.), pp. 505-600. Academic Press, San Diego.

Hashim, R. & Saat, M.A.M. (1992) The utilization of seaweed meals as binding agents in pelleted feeds for snakehead (*Channa striatus*) fry and their effects on growth. *Aquaculture,* **108,** 299-308.

Hemre, G.I., Mommsen, T.P. & Krogdahl, Å. (2002a) Carbohydrates in fish nutrition: effects on growth, glucose metabolism and hepatic enzymes. *Aquaculture Nutrition,* **8,** 175-194.

Hemre, G.I., Mommsen, T.P. & Krogdahl, Å. (2002b) Carbohydrates in fish nutrition: effects on growth, glucose metabolism and hepatic enzymes. *Aquaculture Nutrition,* **8,** 175-194.

Hemre, G.I., Sandnes, K., Lie, Ø., Torrissen, O. & Waagbø, R. (1995) Carbohydrate nutrition in Atlantic salmon, *Salmo salar* L.: growth and feed utilization. *Aquaculture Research,* **26,** 149-154.

Hidalgo, M.C., Urea, E. & Sanz, A. (1999) Comparative study of digestive enzymes in fish with different nutritional habits. Proteolytic and amylase activities. *Aquaculture,* **170,** 267-283.

Higgs, D.A., Dosanjh, B.S., Uin, L.M., Himick, B.A. & Eales, J.G. (1992) Effects of dietary lipid and carbohydrate levels and chronic 3,5,3′-triiodo-L-thyronine treatment on growth, appetite, food and protein utilization and body composition of immature rainbow trout, *Oncorhynchus mykiss*, at low temperature. *Aquaculture,* **105,** 175-190.

Hillestad, M., Johnsen, F. & Åsgård, T. (2001) Protein to carbohydrate ratio in high-energy diets for Atlantic salmon (*Salmo salar* L.). *Aquaculture Research,* **32,** 517-529.

Hilton, J.W., Cho, C.Y. & Slinger, S.J. (1981) Effect of extrusion processing and steam pelleting diets on pellet durability, pellet water absorption, and the physiological response of rainbow trout (*Salmo gairdneri* R.). *Aquaculture,* **25,** 185-194.

Horn, M.H., Correa, S.B., Parolin, P., Pollux, B.J.A., Anderson, J.T., Lucas, C., Widmann, P., Tjiu, A., Galetti, M. & Goulding, M. (2011) Seed dispersal by fishes in tropical and temperate fresh waters: the growing evidence. *Acta Oecologica,* **37,** 561-577.

Hossain, M.A., Hasan, N., Azad Shah, A.K.M. & Hussain, M.G. (2002) Optimum dietary protein requirement of mahseer, *Tor putitora* (Hamilton) fingerlings. *Asian Fisheries Science,* **15,** 203-214.

Hu, W., Zhi, L., Zhuo, M.-Q., Zhu, Q.-L., Zheng, J.-L., Chen, Q.-L., Gong, Y. & Liu, C.-X. (2013) Purification and characterization of glucose 6-phosphate dehydrogenase (G6PD) from grass carp (*Ctenopharyngodon idella*) and inhibition effects of several metal ions on G6PD activity in vitro. *Fish Physiology and Biochemistry,* **39,** 637-647.

Hu, Y.H., Liu, Y.J., Tian, L.X., Yang, H.J., Liang, G.Y. & Gao, W. (2007) Optimal dietary carbohydrate to lipid ratio for juvenile yellowfin seabream (*Sparus latus*). *Aquaculture Nutrition,* **13,** 291-297.

Hung, L.T., Lazard, J., Mariojouls, C. & Moreau, Y. (2003) Comparison of starch utilization in fingerlings of two Asian catfishes from the Mekong River (*Pangasius bocourti* Sauvage, 1880, *Pangasius hypophthalmus* Sauvage, 1878). *Aquaculture Nutrition,* **9,** 215-222.

Hung, S.S.O., Groff, J.M., Lutes, P.B. & Fynn-Aikins, F.K. (1990) Hepatic and intestinal histology of juvenile white sturgeon fed different carbohydrates. *Aquaculture,* **87,** 349-360.

Ingram, B., Sungan, S., Gooley, G., Sim, S.Y., Tinggi, D. & Silva, S.S.D. (2005) Induced spawning, larval development and rearing of two indigenous Malaysian mahseer, *Tor tambroides* and *T. douronensis*. *Aquaculture Research,* **36,** 983-995.

Ingram, B., Sungan, S., Tinggi, D., Sim, S.Y. & Silva, S.S.D. (2007) Breeding performance of Malaysian mahseer, *Tor tambroides* and *T. douronensis* broodfish in captivity. *Aquaculture Research,* **38,** 809-818.

Ingram, B.A., Sungan, S., Tinggi, D., Gooley, G.J., Sim, Y.S. & De Silva, S.S. (2006) Observations on the growth of cage-and pond-reared *Tor tambroides* and *T. douronensis* in Sarawak In *Proceedings of the International Symposium on the Mahseer* (Siraj, S.S.C., A*., et al.* eds.), pp. 145-160. Malaysian Fisheries Society, Kuala Lumpur.

Ings, J.S. & Van Der Kraak, G.J. (2006) Characterization of the mRNA expression of StAR and steroidogenic enzymes in zebrafish ovarian follicles. *Molecular Reproduction and Development,* **73,** 943-954.

Islam, M.S. & Tanaka, M. (2004) Optimization of dietary protein requirement for pond-reared mahseer *Tor putitora* Hamilton (Cypriniformes: Cyprinidae). *Aquaculture Research,* **35,** 1270-1276.

Ishak, S.D., Misieng, J.D., & Kamarudin, M.S. (unpublished). Sugar composition of monosaccharides (glucose, fructose) and disaccharides (sucrose, maltose) of selected indigenous riverine fruits in *Tor* sp. diets.

Ismail, M.F.S., Siraj, S.S., Daud, S.K. & Harmin, S.A. (2011) Association of annual hormonal profile with gonad maturity of mahseer (*Tor tambroides*) in captivity. *General and Comparative Endocrinology,* **170,** 125-130.

Ismail, S., Kamarudin, M.S. & Ramezani-Fard, E. (2012) Performance of commercial poultry offal meal as fishmeal replacement in the diet of juvenile Malaysian mahseer, *Tor tambroides*. *Asian Journal of Animal and Veterinary Advances,* **8,** 284-292.

Jalal, K.C.A., Ambak, M.A., Abol, M.A.B., Hassan, T.H. & Alam, M.Z. (2005) Effect of feed additives on the development of proteolytic enzymes of the tropical sport fish Malaysian Mahseer (*Tor tambroides*-Bleeker) fry. *American Journal of Biochemistry and Biotechnology,* **1,** 132-134.

Jantrarotai, W., Sitasit, P. & Rajchapakdee, S. (1994) The optimum carbohydrate to lipid ratio in hybrid Clarias catfish (*Clarias macrocephalus*×*C. gariepinus*) diets containing raw broken rice. *Aquaculture,* **127,** 61-68.

Jaya Shankar, T. (1988) Effect of dietary protein level on the growth of Deccan Mahseer fry *Tor khudree* Sykes. *Journal of the Indian Fisheries Association,* **18,** 135-140.

Jonsson, N., Jonsson, B. & Hansen, L.P. (1997) Changes in proximate composition and estimates of energetic costs during upstream migration and spawning in Atlantic salmon *Salmo salar*. *Journal of Animal Ecology***,** 425-436.

Jun-Sheng, L., Jian-Lin, L. & Ting-Ting, W. (2006) Ontogeny of protease, amylase and lipase in the alimentary tract of hybrid juvenile tilapia (*Oreochromis niloticus*× *Oreochromis aureus*). *Fish Physiology and Biochemistry,* **32,** 295-303.

Kamalam, B.S., Medale, F., Kaushik, S., Polakof, S., Skiba-Cassy, S. & Panserat, S. (2012) Regulation of metabolism by dietary carbohydrates in two lines of rainbow trout divergently selected for muscle fat content. *Journal of Experimental Biology,* **215,** 2567-2578.

Kamalam, B.S., Medale, F. & Panserat, S. (2016) Utilisation of dietary carbohydrates in farmed fishes: New insights on influencing factors, biological limitations and future strategies. *Aquaculture,* **467,** 3-27.

Kamalaveni, K., Gopal, V., Sampson, U. & Aruna, D. (2001) Effect of pyrethroids on carbohydrate metabolic pathways in common carp, *Cyprinus carpio*. *Pest Management Science,* **57,** 1151-1154.

Kamarudin, M.S., Ishak, S.D., Ramezani-Fard, E., Saad, C.R. & Yusof, Y.A. (2016) Effects of different temperature profiles and corn-sago starch ratios on physical properties of extruded tilapia diets. *Iranian Journal of Fisheries Sciences,* **15,** 715-726.

Kamarudin, M.S., Ramezani-Fard, E., Ishak, S.D., De Cruz, C.R., Bami, M.L., Harris, M.H.I. & Misieng, J.D. (2014) Feeding and nutrition of endangered mahseers: a review. Keynote Paper In *International Conference of Aquaculture Indonesia*. Universitas Padjajaran, Bandung.

Kamarudin, M.S., Ramezani-Fard, E., Saad, C.R. & Harmin, S.A. (2012) Effects of dietary fish oil replacement by various vegetable oils on growth performance, body composition and fatty acid profile of juvenile Malaysian mahseer, *Tor tambroides*. *Aquaculture Nutrition,* **18,** 532-543.

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,** 7973-7979.

Kannadhason, S. & Muthukumarappan, K. (2010) Effect of starch sources on properties of extrudates containing DDGS. *International Journal of Food Properties,* **13,** 1012-1034.

Kannadhason, S., Muthukumarappan, K. & Rosentrater, K.A. (2009) Effects of ingredients and extrusion parameters on aquafeeds containing DDGS and tapioca starch. *Journal of Aquaculture Feed Science and Nutrition,* **1,** 6-21.

Kannadhason, S., Muthukumarappan, K. & Rosentrater, K.A. (2011) Effect of starch sources and protein content on extruded aquaculture feed containing DDGS. *Food and Bioprocess Technology,* **4,** 282-294.

Karim, A.A., Tie, A., Manan, D.M.A. & Zaidul, I.S.M. (2008) Starch from the sago (*Metroxylon sagu*) palm tree—properties, prospects, and challenges as a new industrial source for food and other uses. *Comprehensive Reviews in Food Science and Food Safety,* **7,** 215-228.

Kasemwong, K., Ruktanonchai, U.R., Srinuanchai, W., Itthisoponkul, T. & Sriroth, K. (2011) Effect of high-pressure microfluidization on the structure of cassava starch granule. *Starch-Stärke,* **63,** 160-170.

Kaushik, S.J. (1995) Nutrient requirements, supply and utilization in the context of carp culture. *Aquaculture,* **129,** 225-241.

Keetels, C., Oostergetel, G.T. & Van Vliet, T. (1996) Recrystallization of amylopectin in concentrated starch gels. *Carbohydrate Polymers,* **30,** 61-64.

Khan, K.U., Zuberi, A. & Ullah, I. (2015) Effects of graded level of dietary L-ascorbyl-2-polyphosphate on growth performance and some hematological indices of juvenile mahseer (*Tor putitora*). *International Journal of Agriculture & Biology,* **17**.

Kim, J.D. & Kaushik, S.J. (1992) Contribution of digestible energy from carbohydrates and estimation of protein/energy requirements for growth of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* **106,** 161-169.

Kletzien, R.F., Harris, P.K. & Foellmi, L.A. (1994) Glucose-6-phosphate dehydrogenase: a "housekeeping" enzyme subject to tissue-specific regulation by hormones, nutrients, and oxidant stress. *The FASEB Journal,* **8,** 174-181.

Knauer, J., Britz, P.J. & Hecht, T. (1993) The effect of seven binding agents on 24-hour water stability of an artificial weaning diet for the South African abalone, *Haliotis midae* (Haliotidae, Gastropoda). *Aquaculture,* **115,** 327-334.

Knox, D., Walton, M.J. & Cowey, C.B. (1980) Distribution of enzymes of glycolysis and gluconeogenesis in fish tissues. *Marine Biology,* **56,** 7-10.

Kobayashi, M., Msangi, S., Batka, M., Vannuccini, S., Dey, M.M. & Anderson, J.L. (2015) Fish to 2030: the role and opportunity for aquaculture. *Aquaculture Economics and Management,* **19,** 282-300.

Kortner, T.M., Skugor, S., Penn, M.H., Mydland, L.T., Djordjevic, B., Hillestad, M., Krasnov, A. & Krogdahl, Å. (2012) Dietary soyasaponin supplementation to pea protein concentrate reveals nutrigenomic interactions underlying enteropathy in Atlantic salmon (*Salmo salar*). *BMC Veterinary Research,* **8,** 101.

Kottelat, M. (2000) Notes on taxonomy, nomenclature and distribution of some fishes of Laos. *Journal of South Asian Natural History,* **5,** 83-90.

Krogdahl, Å., Hemre, G.I. & Mommsen, T.P. (2005) Carbohydrates in fish nutrition: digestion and absorption in postlarval stages. *Aquaculture Nutrition,* **11,** 103-122.

Kumar, S., Sahu, N.P., Pal, A.K., Choudhury, D., Yengkokpam, S. & Mukherjee, S.C. (2005) Effect of dietary carbohydrate on haematology, respiratory burst activity and histological changes in *L. rohita* juveniles. *Fish and Shellfish Immunology,* **19,** 331-344.

Lane, J. (2016) Biofuels mandates around the world: 2016. *Biofuels Digest*.

Lebot, V., Prana, M.S., Kreike, N., van Heck, H., Pardales, J., Okpul, T., Gendua, T., Thongjiem, M., Hue, H., Viet, N. & Yap, T.C. (2004) Characterisation of taro (*Colocasia esculenta* (L.) Schott) genetic resources in Southeast Asia and Oceania. *Genetic Resources and Crop Evolution,* **51,** 381-392.

Lee, S.-M., Kim, K.-D. & Lall, S.P. (2003) Utilization of glucose, maltose, dextrin and cellulose by juvenile flounder (*Paralichthys olivaceus*). *Aquaculture,* **221,** 427-438.

Lee, W. (1999) Taro (*Colocasia esculenta*)[Electronic Version]. *Ethnobotanical Leaflets,* **1999,** 4.

Lin, J.-H. & Shiau, S.-Y. (1995) Hepatic enzyme adaptation to different dietary carbohydrates in juvenile tilapia *Oreochromis niloticus* x *O. aureus*. *Fish Physiology and Biochemistry,* **14,** 165-170.

Liu, X.-H., Ye, C.-X., Zheng, L.-M., Ou, C.-C., Wang, A.-L., Ye, J.-D. & Kong, J.-H. (2015) Dietary maize starch influences growth performance, apparent digestibility coefficient, and hepatic enzyme activities of carbohydrate metabolism in obscure puffer, *Takifugu obscurus* (Abe). *Journal of the World Aquaculture Society,* **46,** 102-113.

Lone, A. & Lone, S. (2014a) Effects of dietary protein levels on growth, feed utilization, protein retention efficiency of *Tor tor* (Hamilton 1822). *Journal of Aquaculture Feed Science and Nutrition,* **6,** 1-5.

Lone, A.A. & Lone, S.K. (2014b) Dietary protein inclusion to assess growth and feed utilization in *Tor tor* (Hamilton, 1822). *Walailak Journal of Science and Technology,* **11,** 33-40.

Lopez, V., Pantoja, A., Prakash, A., Gómez, H., García, A. & Ospina, B. (2016) *Cassava in Latin America and the Caribbean: A look at the potential of crop to promote agricultural development and economic growth,* FAO, Rome.

Loqué, D., Scheller, H.V. & Pauly, M. (2015) Engineering of plant cell walls for enhanced biofuel production. *Current Opinion in Plant Biology,* **25,** 151-161.

Luchansky, M.S. & Monks, J. (2009) Supply and demand elasticities in the U.S. ethanol fuel market. *Energy Economics,* **31,** 403-410.

Luna, L.G. (1968) *Manual of Histologic Staining Method of the Armed Forces Institute of Pathology,* McGraw-Hill Book Company, New York.

Luo, Y., Wu, X., Li, W., Jiang, S., Lu, S. & Wu, M. (2016) Effects of different corn starch levels on growth, protein input, and feed utilization of juvenile hybrid grouper (male *Epinephelus lanceolatus*× female *E. fuscoguttatus*). *North American Journal of Aquaculture,* **78,** 168-173.

Luo, Y. & Xie, X. (2010) Effects of high carbohydrate and high lipid diets on growth, body composition and glucose metabolism in southern catfish at two temperatures. *Aquaculture Research,* **41,** e431-e437.

Manners, D.J. (1989) Recent developments in our understanding of amylopectin structure. *Carbohydrate Polymers,* **11,** 87-112.

Mason, P.J., Stevens, D.J., Luzzatto, L., Brenner, S. & Aparicio, S. (1995) Genomic structure and sequence of the *Fugu rubripes* glucose-6-phosphate dehydrogenase gene (G6PD). *Genomics,* **26,** 587-591.

Mathia, W.M. & Fotedar, R. (2012) Evaluation of boiled taro leaves, *Colocasia esculenta* (L.) Schott, as a freshwater shrimp, *Caridina nilotica* Roux protein replacement, in diets of Nile tilapia, *Oreochromis niloticus* (Linnaeus). *Aquaculture,* **356–357,** 302-309.

Mehta, A., Mason, P.J. & Vulliamy, T.J. (2000) Glucose-6-phosphate dehydrogenase deficiency. *Best Practice & Research Clinical Haematology,* **13,** 21-38.

Misieng, J.D., Kamarudin, M.S. & Musa, M. (2011) Optimum dietary protein requirement of Malaysian mahseer (*Tor tambroides*) fingerling. *Pakistan Journal of Biological Sciences,* **14,** 232-235.

Misieng, J.D., Kamarudin, M.S. & Saad, C.R. (2015) Proximate composition and fatty acid profile of selected indigenous riverine fruits commonly consumed by Malaysian mahseer, *Tor tambroides*. *The Korean Society of Fisheries and Aquatic Sciences*, 771-771.

Mizutani, K., Toyoda, M., Otake, Y., Yoshioka, S., Takahashi, N. & Mikami, B. (2012) Structural and functional characterization of recombinant medaka fish alpha-amylase expressed in yeast *Pichia pastoris*. *Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics,* **1824,** 954-962.

Mohan, M., Bhanja, S.K. & Basade, Y. (2009) Performance of chitin incorporated diet on the indigenous Kumaon Himalayan fishes: Snow trout, *Schizothorax richardsonii* (Gray) and golden mahseer, *Tor putitora* (Hamilton). *Indian Journal of Fisheries,* **56,** 135-137.

Mohanta, K.N., Mohanty, S.N., Jena, J., Sahu, N.P. & Patro, B. (2009) Carbohydrate level in the diet of silver barb, *Puntius gonionotus* (Bleeker) fingerlings effect on growth, nutrient utilization and whole body composition. *Aquaculture Research,* **40,** 927-937.

Mohanta, K.N., Mohanty, S.N. & Jena, J.K. (2007) Protein-sparing effect of carbohydrate in silver barb, *Puntius gonionotus* fry. *Aquaculture Nutrition,* **13,** 311-317.

Mohapatra, M., Sahu, N.P. & Chaudhari, A. (2003) Utilization of gelatinized carbohydrate in diets of *Labeo rohita* fry. *Aquaculture Nutrition,* **9,** 189-196.

Mohseni, M., Pourkazemi, M. & Ozório, R.O.A. (2014) Dietary lipid to carbohydrate ratio in beluga, *Huso huso* (Linnaeus, 1758), fed two L-carnitine levels. *Journal of Applied Ichthyology,* **30,** 1637-1642.

Montero, D., Mathlouthi, F., Tort, L., Afonso, J.M., Torrecillas, S., Fernández-Vaquero, A., Negrin, D. & Izquierdo, M.S. (2010) Replacement of dietary fish oil by vegetable oils affects humoral immunity and expression of pro-inflammatory cytokines genes in gilthead sea bream *Sparus aurata*. *Fish and Shellfish Immunology,* **29,** 1073-1081.

Moon, T.W. (2001) Glucose intolerance in teleost fish: fact or fiction? *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology,* **129,** 243-249.

Moreira, I.S., Peres, H., Couto, A., Enes, P. & Oliva-Teles, A. (2008) Temperature and dietary carbohydrate level effects on performance and metabolic utilisation of diets in European sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture,* **274,** 153-160.

Murai, T., Sumalangkay, A. & Pascual, F.P. (1981) The water stability of shrimp diets with various polysaccharides as a binding agent. *SEAFDEC Aquaculture Department Quarterly Research Report,* **5,** 18-20.

Narváez-González, E.D., de Dios Figueroa-Cárdenas, J., Taba, S., Castano Tostado, E., Peniche, R.Á.M. & Rincon Sanchez, F. (2006) Relationships between the microstructure, physical features, and chemical composition of different maize accessions from Latin America. *Cereal chemistry,* **83,** 595-604.

Natalia, Y., Hashim, R., Ali, A. & Chong, A. (2004) Characterization of digestive enzymes in a carnivorous ornamental fish, the Asian bony tongue *Scleropages formosus* (Osteoglossidae). *Aquaculture,* **233,** 305-320.

Ng, W.K., Abdullah, N. & De Silva, S.S. (2008) The dietary protein requirement of the Malaysian mahseer, *Tor tambroides* (Bleeker), and the lack of protein-sparing action by dietary lipid. *Aquaculture,* **284,** 201-206.

Ng, W.K. & Andin, V.C. (2011) The Malaysian mahseer, *Tor tambroides* (Bleeker), requires low dietary lipid levels with a preference for lipid sources with high omega-6 and low omega-3 polyunsaturated fatty acids. *Aquaculture,* **322-323,** 82-90.

Nguyen, T.T.T., Ingram, B., Sungan, S., Gooley, G., Sim, S.Y., Tinggi, D. & De Silva, S.S. (2006) Mitochondrial DNA diversity of broodstock of two indigenous mahseer species, *Tor tambroides* and *T. douronensis* (Cyprinidae) cultured in Sarawak, Malaysia. *Aquaculture,* **253,** 259-269.

NRC (1993) *Nutrient Requirements of Fish, National Research Council,* The National Academies Press, Washington D.C.

NRC (2011) *Nutrient Requirements of Fish and Shrimp, National Research Council,* The National Academies Press, Washington D.C.

Obaldo, L.G., Divakaran, S. & Tacon, A.G. (2002) Method for determining the physical stability of shrimp feeds in water. In *Aquaculture Research*, Vol. 33, pp. 369-377.

Paloheimo, J.E. & Dickie, L.M. (1965) Food and Growth of Fishes.: I. A Growth Curve Derived from Experimental Data. *Journal of the Fisheries Research Board of Canada,* **22,** 521-542.

Pandey, S., Parvez, S., Sayeed, I., Haque, R., Bin-Hafeez, B. & Raisuddin, S. (2003) Biomarkers of oxidative stress: a comparative study of river Yamuna fish *Wallago attu* (Bl. & Schn.). *Science of the Total Environment,* **309,** 105-115.

Paolucci, M., Fabbrocini, A., Coccia, E., Varricchio, E. & Volpe, M.G. (2012) Development of Biopolymers as Binders for Feed for Farmed Aquatic Organisms In *Aquaculture* (Muchlisin, Z. ed., pp. 1-34. INTECH Open Access Publisher, Rijeka.

Papoutsoglou, E.S. & Lyndon, A.R. (2003) Distribution of α amylase along the alimentary tract of two Mediterranean fish species, the parrotfish *Sparisoma cretense* L. and the stargazer, *Uranoscopus scaber* L. *Mediterranean Marine Science,* **4,** 115-124.

Pascual, F.P. & Sumalangcay, A. (1981) Gum arabic, carrageenan of various types and sago palm starch as binders in prawn diets. *SEAFDEC Aquaculture Department Quarterly Research Report,* **5,** 11-15.

Pei-Lang, A.T., Mohamed, A.M.D. & Karim, A.A. (2006) Sago starch and composition of associated components in palms of different growth stages. *Carbohydrate Polymers,* **63,** 283-286.

Pereira, C., Vijayan, M.M., Storey, K.B., Jones, R.A. & Moon, T.W. (1995) Role of glucose and insulin in regulating glycogen synthase and phosphorylase activities in rainbow trout hepatocytes. *Journal of Comparative Physiology B,* **165,** 62-70.

Pettersen, R.C. (1984) The chemical composition of wood In *The Chemistry of Solid Wood. Advances in Chemistry Series* (Rowell, R.M. ed.), Vol. 207, pp. 57-126. American Chemical Society, Washington D.C.

Pfeffer, E., Beckmann-Toussaint, J., Henrichfreise, B. & Jansen, H.D. (1991) Effect of extrusion on efficiency of utilization of maize starch by rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* **96,** 293-303.

Pfister, B. & Zeeman, S.C. (2016) Formation of starch in plant cells. *Cellular and Molecular Life Sciences,* **73,** 2781-2807.

Piedad-Pascual, F., Bandonil, L. & Destajo, W.H. (1978) The effect of different binders on the water stability of feeds for prawn. *SEAFDEC Aquaculture Department Quarterly Research Report,* **2,** 31-35.

Pilkis, S.J. & Granner, D.K. (1992) Molecular physiology of the regulation of hepatic gluconeogenesis and glycolysis. *Annual Review of Physiology,* **54,** 885-909.

Pérez, E., Schultz, F.S. & de Delahaye, E.P. (2005) Characterization of some properties of starches isolated from *Xanthosoma sagittifolium* (tannia) and *Colocassia esculenta* (taro). *Carbohydrate polymers,* **60,** 139-145.

Qiang, J., He, J., Yang, H., Wang, H., Kpundeh, M.D., Xu, P. & Zhu, Z.X. (2014a) Temperature modulates hepatic carbohydrate metabolic enzyme activity and gene

expression in juvenile GIFT tilapia (*Oreochromis niloticus*) fed a carbohydrate-enriched diet. *Journal of Thermal Biology,* **40,** 25-31.

Qiang, J., Yang, H., Ma, X.Y., He, J., Wang, H., Kpundeh, M.D. & Xu, P. (2014b) Comparative studies on endocrine status and gene expression of hepatic carbohydrate metabolic enzymes in juvenile GIFT tilapia (*Oreochromis niloticus*) fed high-carbohydrate diets. *Aquaculture Research*, **47**, 758-768.

Rainboth, W.J. (1996) *Fishes of the Cambodian Mekong,* FAO, Rome.

Ramezani Fard, E., Kamarudin, M.S., Ehteshami, F., Shakiba Zadeh, S., Roos Saad, C. & Zokaeifar, H. (2014) Effect of dietary linolenic acid (18:3n-3)/linoleic acid (18:2n-6) ratio on growth performance, tissue fatty acid profile and histological alterations in the liver of juvenile *Tor tambroides*. *Iranian Journal of Fisheries Sciences,* **13,** 185-200.

Ramezani-Fard, E. & Kamarudin, M.S. (2012a) Effects of vegetable oil source and dietary vegetable-fish oil ratio on the histological alterations of liver and intestine of juvenile Malaysian mahseer, *Tor tambroides*. *Asian Journal of Animal and Veterinary Advances,* **8,** 309-316.

Ramezani-Fard, E., Kamarudin, M.S., Harmin, S.A. & Saad, C.R. (2012b) Dietary saturated and omega-3 fatty acids affect growth and fatty acid profiles of Malaysian mahseer. *European Journal of Lipid Science and Technology,* **114,** 185-193.

Ramezani-Fard, E., Kamarudin, M.S., Saad, C.R., Harmin, S.A. & Meng, G.Y. (2012c) Dietary lipid levels affect growth and fatty acid profiles of Malaysian mahseer *Tor tambroides*. *North American Journal of Aquaculture,* **74,** 530-536.

Ramezani-Fard, E., Kamarudin, M.S., Harmin, S.A., Saad, C.R., Satar, M.K.A. & Daud, S.K. (2011) Ontogenic development of the mouth and digestive tract in larval Malaysian mahseer, *Tor tambroides* Bleeker. *Journal of Applied Ichthyology,* **27,** 920-927.

Rashid, Z.A., Asmuni, M. & Amal, M.N.A. (2015) Fish diversity of Tembeling and Pahang rivers, Pahang, Malaysia. *Check List,* **11,** 1753.

Rathod, R.P. & Annapure, U.S. (2016) Effect of extrusion process on antinutritional factors and protein and starch digestibility of lentil splits. *LWT-Food Science and Technology,* **66,** 114-123.

Rawles, S.D., Smith, S.B. & Gatlin, D.M. (2008) Hepatic glucose utilization and lipogenesis of hybrid striped bass (*Morone chrysops*× *Morone saxatilis*) in response to dietary carbohydrate level and complexity. *Aquaculture Nutrition,* **14,** 40-50.

Reddy, P.P. (2015) Taro, *Colocasia esculenta* In *Plant Protection in Tropical Root and Tuber Crops*, pp. 143-192. Springer, New Delhi.

Ren, M., Habte-Tsion, H.-M., Xie, J., Liu, B., Zhou, Q., Ge, X., Pan, L. & Chen, R. (2015) Effects of dietary carbohydrate source on growth performance, diet digestibility and

liver glucose enzyme activity in blunt snout bream, *Megalobrama amblycephala*. *Aquaculture,* **438,** 75-81.

Riaz, M.N. (2009) Advances in aquaculture feed extrusion. In *17th Annual ASAIM SEA Feed Technology and Nutrition Workshop.*, pp. 1-6Hue, Vietnam.

Riley, C.K., Bahado-Singh, P.S., Wheatley, A.O.B. & Asemota, H.N. (2014) Physicochemical properties of low-amylose yam (*Dioscorea* spp.) starches and its impact on α-amylase degradation in vitro. *International Journal of Nutrition and Food Sciences,* **3,** 448-454.

Roberts, T.R. (1999) Fishes of the cyprinid genus Tor in the Nam Theun watershed (Mekong Basin) of Laos, with description of a new species. *Raffles Bulletin of Zoology,* **47,** 225-236.

Rosentrater, K.A., Muthukumarappan, K. & Kannadhason, S. (2009a) Effects of ingredients and extrusion parameters on aquafeeds containing DDGS and potato starch. *Journal of Aquaculture Feed Science and Nutrition,* **1,** 22-38.

Rosentrater, K.A., Muthukumarappan, K. & Kannadhason, S. (2009b) Effects of ingredients and extrusion parameters on properties of aquafeeds containing DDGS and corn starch. *Journal of Aquaculture Feed Science and Nutrition,* **1,** 44-60.

Russell, P.M., Davies, S.J., Gouveia, A. & Tekinay, A.A. (2001) Influence of dietary starch source on liver morphology in juvenile cultured European sea bass (*Dicentrarchus labrax* L.). *Aquaculture Research*, **32,** 306-314.

Salati, L.M. & Amir-Ahmady, B. (2001) Dietary regulation of expression of glucose-6-phosphate dehydrogenase. *Annual Review of Nutrition,* **21,** 121-140.

Salati, L.M., Szeszel-Fedorowicz, W., Tao, H., Gibson, M.A., Amir-Ahmady, B., Stabile, L.P. & Hodge, D.L. (2004) Nutritional regulation of mRNA processing. *The Journal of Nutrition,* **134,** 2437S-2443S.

Samuelsen, T.A., Mjøs, S.A. & Oterhals, Å. (2013) Impact of variability in fishmeal physicochemical properties on the extrusion process, starch gelatinization and pellet durability and hardness. *Animal Feed Science and Technology,* **179,** 77-84.

Santiago, C.B. & Lovell, R.T. (1988) Amino acid requirements for growth of Nile tilapia. *The Journal of Nutrition,* **118,** 1540-1546.

Saravanan, S., Schrama, J.W., Figueiredo-Silva, A.C., Kaushik, S.J., Verreth, J.A.J. & Geurden, I. (2012) Constraints on energy intake in fish: the link between diet composition, energy metabolism, and energy intake in rainbow trout. *PLoS One,* **7,** e34743.

Sargent, J.R., Tocher, D.R. & Bell, J.G. (2002) The lipids In *Fish Nutrition* (Halver, J.E. & Hardy, R.W. eds.), pp. 181-257. Academic Press, San Diego.

Sawhney, S. (2014) Growth response of mahseer, *Tor putitora* (Ham.) fingerlings to different lipid levels in the diet. *Journal of International Academic Research for Multidisciplinary,* **2,** 177-186.

Sawhney, S. & Gandotra, R. (2010) Growth response and feed conversion efficiency of *Tor putitora* (Ham.) fry at varying dietary protein levels. *Pakistan Journal of Nutrition,* **9,** 86-90.

Schwertner, M.A., Liu, K.K.M., Barrows, F.T., Hardy, R.W. & Dong, F.M. (2003) Performance of post-juvenile rainbow trout *Oncorhynchus mykiss* fed diets manufactured by different processing techniques. *Journal of the World Aquaculture Society,* **34,** 162-174.

Sen, P.R., Rao, N.G.S., Ghosh, S.R. & Rout, M. (1978) Observations on the protein and carbohydrate requirements of carps. *Aquaculture,* **13,** 245-255.

Shiau, S.Y. (1997) Utilization of carbohydrates in warmwater fish—with particular reference to tilapia, *Oreochromis niloticus x O. aureus*. *Aquaculture,* **151,** 79-96.

Simopoulos, A.P. (1996) The Role of Fatty Acids in Gene Expression: Health Implications. *Annals of Nutrition and Metabolism,* **40,** 303-311.

Singh, J., Kaur, L. & McCarthy, O.J. (2007a) Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications—A review. *Food Hydrocolloids,* **21,** 1-22.

Singh, R.K., Balange, A.K. & Ghughuskar, M.M. (2006) Protein sparing effect of carbohydrates in the diet of *Cirrhinus mrigala* (Hamilton, 1822) fry. *Aquaculture,* **258,** 680-684.

Singh, S., Gamlath, S. & Wakeling, L. (2007b) Nutritional aspects of food extrusion: a review. In *International Journal of Food Science & Technology*, Vol. 42, pp. 916-929.

Singh, S.K. & Muthukumarappan, K. (2015) Effect of feed moisture, extrusion temperature and screw speed on properties of soy white flakes based aquafeed: a response surface analysis. *Journal of the Science of Food and Agriculture*, **96**, 2220-2229.

Siraj, S.S., Daud, S.K., Keong, R.B.P. & Ng, C.K. (2007a) Characterisation of the Malaysian mahseer (kelah), *Tor tambroides* In *Proceedings of the International Symposium on the Mahseer* (Siraj, S.S.C., A*., et al.* eds.), pp. 179-201. Malaysian Fisheries Society, Kuala Lumpur.

Siraj, S.S., Esa, Y., Keong, R.B.P. & Daud, S.K. (2007b) Genetic characterization of the two colour-type of Kelah. *Malaysian Applied Biology,* **36,** 23-29.

Skiba-Cassy, S., Lansard, M., Panserat, S. & Médale, F. (2009) Rainbow trout genetically selected for greater muscle fat content display increased activation of liver TOR

signaling and lipogenic gene expression. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology,* **297,** R1421-R1429.

Stabile, L.P., Hodge, D.L., Klautky, S.A. & Salati, L.M. (1996) Posttranscriptional regulation of glucose-6-phosphate dehydrogenase by dietary polyunsaturated fat. *Archives of Biochemistry and Biophysics,* **332,** 269-279.

Stone, D.A.J., Allan, G.L. & Anderson, A.J. (2003) Carbohydrate utilization by juvenile silver perch, *Bidyanus bidyanus* (Mitchell). III. The protein-sparing effect of wheat starch-based carbohydrates. *Aquaculture Research,* **34,** 123-134.

Storebakken, T., Shearer, K.D., Baeverfjord, G., Nielsen, B.G., Åsgård, T., Scott, T. & De Laporte, A. (2000) Digestibility of macronutrients, energy and amino acids, absorption of elements and absence of intestinal enteritis in Atlantic salmon, *Salmo salar*, fed diets with wheat gluten. *Aquaculture,* **184,** 115-132.

Sugita, H., Kawasaki, J. & Deguchi, Y. (1997) Production of amylase by the intestinal microflora in cultured freshwater fish. *Letters in Applied Microbiology,* **24,** 105-108.

Sungan, S., Tinggi, D., Salam, N. & Sadi, C. (2006) Aspects of the biology and ecology of empurau (*Tor tambroides*) and semah (*T. douronensis*) in Sarawak, In *Proceedings of the International Symposium on the Mahseer* (Siraj, S.S*., et al.* eds.), Vol. Supplementary, pp. 29-30. Malaysian Fisheries Society, Kuala Lumpur.

Sá, R., Pousão-Ferreira, P. & Oliva-Teles, A. (2007) Growth performance and metabolic utilization of diets with different protein:carbohydrate ratios by white sea bream (*Diplodus sargus*, L.) juveniles. *Aquaculture Research,* **38,** 100-105.

Sørensen, M. (2012) A review of the effects of ingredient composition and processing conditions on the physical qualities of extruded high-energy fish feed as measured by prevailing methods. *Aquaculture Nutrition,* **18,** 233-248.

Sørensen, M., Nguyen, G., Storebakken, T. & Øverland, M. (2010) Starch source, screw configuration and injection of steam into the barrel affect the physical quality of extruded fish feed. *Aquaculture Research,* **41,** 419-432.

Tacon, A.G.J. & Metian, M. (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture,* **285,** 146-158.

Takei, Y. & Loretz, C.A. (2010) The gastrointestinal tract as an endocrine/neuroendocrine/paracrine organ: organization, chemical messengers and physiological targets In *Fish Physiology: The Multifunctional Gut of Fish* (Grosell, M*., et al.* eds.), Vol. 30, pp. 261-317. Academic Press, USA.

Tan, E.S.P. (1980) Some aspects of the biology of Malaysian riverine cyprinids. *Aquaculture,* **20,** 281-289.

Tan, Q., Wang, F., Xie, S., Zhu, X., Lei, W. & Shen, J. (2009) Effect of high dietary starch levels on the growth performance, blood chemistry and body composition of gibel carp (*Carassius auratus* var. gibelio). *Aquaculture Research,* **40,** 1011-1018.

Tester, R.F. & Morrison, W.R. (1990) Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. *Cereal Chemistry,* **67,** 551-557.

Thomas, M. & Van der Poel, A.F.B. (1996) Physical quality of pelleted animal feed 1. Criteria for pellet quality. *Animal Feed Science and Technology,* **61,** 89-112.

Tian, L.-X., Liu, Y.-J. & Hung, S.S.O. (2004) Utilization of Glucose and Cornstarch by Juvenile Grass Carp. *North American Journal of Aquaculture,* **66,** 141-145.

Tocher, D.R. (2003) Metabolism and functions of lipids and fatty acids in teleost fish. *Reviews in Fisheries Science,* **11,** 107-184.

Tocher, D.R., Agaba, M., Hastings, N., Bell, J.G., Dick, J.R. & Teale, A.J. (2001) Nutritional regulation of hepatocyte fatty acid desaturation and polyunsaturated fatty acid composition in zebrafish (*Danio rerio*) and tilapia (*Oreochromis niloticus*). *Fish Physiology and Biochemistry,* **24,** 309-320.

Tomlinson, J.E., Nakayama, R. & Holten, D. (1988) Repression of pentose phosphate pathway dehydrogenase synthesis and mRNA by dietary fat in rats. *The Journal of Nutrition,* **118,** 408-415.

Tonukari, N.J. (2004) Cassava and the future of starch. *Electronic Journal of Biotechnology,* **7,** 5-8.

Trushenski, J.T., Kasper, C.S. & Kohler, C.C. (2006) Challenges and opportunities in finfish nutrition. *North American Journal of Aquaculture,* **68,** 122-140.

Tung, P.-H. & Shiau, S.-Y. (1993) Carbohydrate utilization versus body size in tilapia *Oreochromis niloticus* × *O. aureus*. *Comparative Biochemistry and Physiology Part A: Physiology,* **104,** 585-588.

Ufodike, E.B.C. & Matty, A.J. (1983) Growth responses and nutrient digestibility in mirror carp (*Cyprinus carpio*) fed different levels of cassava and rice. *Aquaculture,* **31,** 41-50.

Umar, S., Kamarudin, M.S. & Ramezani-Fard, E. (2013) Physical properties of extruded aquafeed with a combination of sago and tapioca starches at different moisture contents. *Animal Feed Science and Technology,* **183,** 51-55.

Venou, B., Alexis, M.N., Fountoulaki, E., Nengas, I., Apostolopoulou, M. & Castritsi-Catharíou, I. (2003) Effect of extrusion of wheat and corn on gilthead sea bream (*Sparus aurata*) growth, nutrient utilization efficiency, rates of gastric evacuation and digestive enzyme activities. *Aquaculture,* **225,** 207-223.

Venugopal, M.N. & Keshavanath, P. (1984) Formulation, stability and keeping quality of three pelleted feeds used in carp culture. *Fishery Technology,* **21,** 11-15.

Versino, F. & García, M.A. (2014) Cassava (*Manihot esculenta*) starch films reinforced with natural fibrous filler. *Industrial Crops and Products,* **58,** 305-314.

Vijayagopal, P. (2004) Aquatic feed extrusion technology-an update. *Fishing Chimes,* **23,** 35-38.

Villeneuve, L., Gisbert, E., Le Delliou, H., Cahu, C.L. & Zambonino-Infante, J.L. (2005) Dietary levels of all-trans retinol affect retinoid nuclear receptor expression and skeletal development in European sea bass larvae. *British Journal of Nutrition,* **93,** 791-801.

Vulliamy, T., Mason, P. & Luzzatto, L. (1992) The molecular basis of glucose-6-phosphate dehydrogenase deficiency. *Trends in Genetics,* **8,** 138-143.

Vásquez-Torres, W. & Arias-Castellanos, J.A. (2013) Effect of dietary carbohydrates and lipids on growth in cachama (*Piaractus brachypomus*). *Aquaculture Research,* **44,** 1768-1776.

Wanapat, M. (2003) Manipulation of cassava cultivation and utilization to improve protein to energy biomass for livestock feeding in the tropics. *Asian Australasian Journal of Animal Sciences,* **16,** 463-472.

Wang, J.-T., Liu, Y.-J., Tian, L.-X., Mai, K.-S., Du, Z.-Y., Wang, Y. & Yang, H.-J. (2005) Effect of dietary lipid level on growth performance, lipid deposition, hepatic lipogenesis in juvenile cobia (*Rachycentron canadum*). *Aquaculture,* **249,** 439-447.

Wang, L.-N., Liu, W.-B., Lu, K.-L., Xu, W.-N., Cai, D.-S., Zhang, C.-N. & Qian, Y. (2014) Effects of dietary carbohydrate/lipid ratios on non-specific immune responses, oxidative status and liver histology of juvenile yellow catfish *Pelteobagrus fulvidraco*. *Aquaculture,* **426,** 41-48.

Wilson, R.P. (1994) Utilization of dietary carbohydrate by fish. *Aquaculture,* **124,** 67-80.

Wu, X., Castillo, S., Rosales, M., Burns, A., Mendoza, M. & Gatlin, D.M. (2015) Relative use of dietary carbohydrate, non-essential amino acids, and lipids for energy by hybrid striped bass, *Morone chrysops*♀× *M. saxatilis*♂. *Aquaculture,* **435,** 116-119.

Zemke-White, W.L. & Clements, K.D. (1999) Chlorophyte and rhodophyte starches as factors in diet choice by marine herbivorous fish. *Journal of Experimental Marine Biology and Ecology,* **240,** 137-149.

Zheng, J.-L., Luo, Z., Zhu, Q.-L., Tan, X.-Y., Chen, Q.-L., Sun, L.-D. & Hu, W. (2013) Molecular cloning and expression pattern of 11 genes involved in lipid metabolism in yellow catfish *Pelteobagrus fulvidraco*. *Gene,* **531,** 53-63.

Zhou, A. & Thomson, E. (2009) The development of biofuels in Asia. *Applied Energy,* **86,** S11-S20.