UNIVERSITI PUTRA MALAYSIA

DIETARY ASTAXANTHIN FOR GROWTH AND HEALTH ENHANCEMENT OF ASIAN SEABASS, Lates calcarifer (BLOCH, 1790)

LIM KENG CHIN

FP 2021 37

DIETARY ASTAXANTHIN FOR GROWTH AND HEALTH ENHANCEMENT OF ASIAN SEABASS, *Lates calcarifer* (BLOCH, 1790)

By

LIM KENG CHIN

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

November 2020

DEDICATION

I would like to sincerely dedicate this dissertation to my precious treasures in life:

LIM ENG SENG & HEW YEAT CHEN
My beloved parents,

TEOH HOOI CHING & MILEY LIM THYA
My lovely wife and daughter,

and

LIM KENG LEE & LIM KENG LIANG
My loving brothers

for their endless love, support, encouragement, and prayers, which they are surrounding me with throughout my educational career.

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

DIETARY ASTAXANTHIN FOR GROWTH AND HEALTH ENHANCEMENT OF ASIAN SEABASS, *Lates calcarifer* (BLOCH, 1790)

By

LIM KENG CHIN

November 2020

Chair: Professor Fatimah Md. Yusoff, PhD
Faculty: Agriculture

Astaxanthin is renowned for its commercial application in numerous industries comprising cosmetic, food, aquaculture, nutraceutical, and pharmaceutical. The freshwater green microalga *Haematococcus pluvialis* is the richest bio-resource of natural astaxanthin. The supreme antioxidant property of astaxanthin reveals its tremendous potential to offer manifold health benefits amongst aquatic animals. Like many cultured fish species, the intensive farming of Asian seabass *Lates calcarifer* under stressful circumstances has posed several major problems, including sluggish growth, poor survival, and susceptibility to pathogenic diseases. This study investigated the effects of supplementation with astaxanthin (dose-response manner) on growth performance, survival, hemato-biochemical indices, innate immunity, histopathological responses, and disease resistance of the Asian seabass.

A two-stage process was employed for the astaxanthin-rich biomass production of *H. pluvialis* in the airlift annular photobioreactor. Astaxanthin content was quantitatively determined via the high-performance liquid chromatography (HPLC) analytical method. Four experimental diets, including a control diet (CD), and diets containing various dietary levels of astaxanthin (AX50, 50 mg kg^{-1} diet; AX100, 100 mg kg^{-1} diet; and AX150, 150 mg kg^{-1} diet) supplemented with astaxanthin-containing lyophilized *H. pluvialis* biomass (~37.94 ± 0.41 mg astaxanthin g^{-1} dry weight) were produced for different feeding trials.

Findings from the first trial revealed that fish exhibited significant linear increments ($P < 0.05$) in specific growth rate, weight gain, feed utilization efficiency, survival, and serum growth hormone (GH) availability when fed diets with escalating levels of astaxanthin during distinct feeding phases (short-term, medium-term and long-term). Significant positive correlations ($P < 0.05$) were noted between serum GH level and SGR of fish from all groups following three

consecutive feeding phases, denoting a robust cause-and-effect relationship. Circulating serum GH concentration was recognized as a sensitive biomarker of growth performance in the Asian seabass.

Moreover, in the second trial, fish displayed profound enhancements ($P < 0.05$) in hematological indices (white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin, and hematocrit) when fed diets with elevated doses of astaxanthin over different phases of feeding (short-term, medium-term and long-term). Serum concentrations of alanine aminotransferase (ALT), aspartate aminotransferase (AST), glucose, cholesterol, triglyceride, and cortisol in the treated fish reduced significantly ($P < 0.05$) with increasing dietary inclusion levels throughout the specified feeding phases. Correspondingly, the supplemented fish registered remarkably higher ($P < 0.05$) serum total protein content. Immunological parameters (lysozyme activity, phagocytic activity, respiratory burst activity, and total serum immunoglobulin) of fish were significantly stimulated ($P < 0.05$) in response to dietary intervention with astaxanthin.

Experimental infection with *Vibrio alginolyticus* unveiled that supplemented fish demonstrated significant improvements ($P < 0.05$) of hematological parameters (WBC and RBC counts, and hemoglobin and hematocrit levels) when fed diets with elevating supplemental doses of astaxanthin through distinct post-infection periods (0-, 7-, and 14-day). Furthermore, the administration of dietary astaxanthin at escalating levels markedly enhanced ($P < 0.05$) the serum biochemical profile (AST, ALT, glucose, cortisol, cholesterol, and triglyceride contents) of challenged fish, resulting in better welfare. Significantly higher ($P < 0.05$) contents of serum total protein were discernible in supplemented fish, as opposed to the control. Additionally, non-specific defense mechanisms (lysozyme activity, phagocytic activity, respiratory burst activity, and total serum immunoglobulin) of challenged fish were pronouncedly elicited ($P < 0.05$) following the ingestion of astaxanthin. Histopathological alterations in target organs (liver, kidney, and spleen) of challenged fish were observed to be significantly reduced progressively ($P < 0.05$) with increasing dietary intake of astaxanthin. Besides, supplementation with dietary astaxanthin significantly augmented ($P < 0.05$) the post-challenge survival rate of fish.

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

ASTAXANTHIN DIETARI UNTUK PENINGKATAN PERTUMBUHAN DAN KESIHATAN IKAN SIAKAP, *Lates calcarifer* (BLOCH, 1790)

Oleh

LIM KENG CHIN

November 2020

Pengerusi: Profesor Fatimah Md. Yusoff, PhD
Fakulti: Pertanian

Astaxanthin terkenal dengan aplikasi komersialnya di dalam pelbagai bidang termasuk kosmetik, makanan, akuakultur, nutraseutikal, dan farmaseutikal. *Haematococcus pluvialis* merupakan sejenis mikroalga hijau jenis air tawar yang kaya dengan biosumber astaxanthin semulajadi. Keunggulan properti antioksidan astaxanthin memperlihatkan potensinya yang menakjubkan dalam menawarkan pelbagai manfaat kesihatan di kalangan haiwan akuatik. Seperti kebanyakan spesies ikan kultur, penternakan intensif ikan siakap dalam keadaan yang tertekan telah menimbulkan pelbagai permasalahan terutamanya kelambatan pertumbuhan, kadar survival yang rendah, serta kecenderungan untuk berhadapan dengan pelbagai jangkitan patogen. Oleh yang demikian, satu kajian telah dilaksanakan bagi tujuan menguji kesan suplementasi astaxanthin (hubungan dos-respons) terhadap prestasi pertumbuhan, survival, indeks hemato-biokimia, imuniti bawaan, respon histopatologi, dan rintangan terhadap penyakit di dalam ikan siakap.

Proses pengkulturan dua peringkat telah diaplikasikan untuk penghasilan biomas *H. pluvialis* yang mengandungi astaxanthin di dalam fotobireaktor annular dengan aliran pengudaraan terangkat. Kandungan astaxanthin ditentukan secara kuantitatif menerusi kaedah analitikal kromatografi cecair berprestasi tinggi (HPLC). Sebanyak empat jenis diet ujikaji, termasuk diet kawalan (CD), dan juga diet-diet dengan konsentrasi astaxanthin yang berlainan (AX50, 50 mg kg^{-1} diet; AX100, 100 mg kg^{-1} diet; dan AX150, 150 mg kg^{-1} diet) telah dihasilkan melalui penambahan biomas *H. puvialis* kering yang mengandungi astaxanthin (~37.94 ± 0.41 mg astaxanthin g^{-1} berat kering) untuk beberapa ujian pemakanan.

Hasil kajian daripada ujian pertama mendedahkan bahawa ikan menunjukkan peningkatan secara linear yang signifikan ($P < 0.05$) dalam kadar pertumbuhan

spesifik (SGR), berat badan, kecekapan penggunaan makanan, survival, dan ketersediaan hormon pertumbuhan (GH) serum apabila diberikan berlainan diet dengan kandungan astaxanthin yang bertambah ketika fasa pemakanan yang berbeza (jangka pendek, jangka sederhana dan jangka panjang). Korelasi positif yang signifikan ($P < 0.05$) turut diperlihatkan antara tahap GH serum dan SGR dalam semua kumpulan ikan berikutan tiga fasa pemakanan yang berturutan, sekaligus menandakan satu hubungan sebab-akibat yang mantap. Tahap kepekatan GH serum telah dikenalpasti sebagai penanda bio untuk prestasi pertumbuhan ikan siakap.

Selain itu, dalam percubaan kedua, ikan memaparkan kenaikan yang ketara ($P < 0.05$) dari segi indeks hematologi (kiraan sel darah putih, WBC; kiraan sel darah merah, RBC; hemoglobin; dan hematokrit) apabila menerima berlainan diet dengan peningkatan dos astaxanthin sepanjang fasa pemakanan yang berbeza (jangka pendek, jangka sederhana dan jangka panjang). Tahap kepekatan alanine aminotransferase (ALT), aspartate aminotransferase (AST), glukosa, kolesterol, trigliserida, dan kortisol di dalam serum ikan yang terawat didapati berkurangan secara signifikan ($P < 0.05$) dengan dos pemberian astaxanthin berikutan fasa pemakanan yang berbeza. Sehubungan itu, ikan yang diberi suplemen astaxanthin mencatatkan jumlah kandungan protein serum yang lebih tinggi dan signifikan ($P < 0.05$). Beberapa parameter imunologi ikan (aktiviti lysozyme, aktiviti fagositik, aktiviti respiratory burst, dan jumlah imunoglobulin serum) telah dirangsang secara signifikan ($P < 0.05$) sebagai respon terhadap suplementasi astaxanthin.

Jangkitan *Vibrio alginolyticus* secara eksperimen mendedahkan bahawa ikan menunjukkan peningkatan parameter hematologi (kiraan WBC, kiraan RBC, hemoglobin, dan hematokrit) yang signifikan ($P < 0.05$) berikutan pemberian pelbagai diet dengan dos suplementasi astaxanthin yang semakin bertambah menerusi jangka masa pasca-jangkitan yang berlainan (0, 7, and 14 hari). Ikan yang dicabar dengan bakteria turut mendaftarkan profil biokimia serum (ALT, AST, glukosa, kolesterol, trigliserida, dan kortisol) yang lebih baik dan signifikan ($P < 0.05$) apabila menerima diet yang mengandungi peningkatan dos astaxanthin. Secara jelas, dapat diperhatikan bahawa ikan yang diberikan astaxanthin mempunyai kandungan jumlah protein serum dengan ketaranya lebih tinggi ($P < 0.05$) berbanding kumpulan kawalan. Malah, mekanisme pertahanan tidak spesifik (aktiviti lysozyme, aktiviti fagositik, aktiviti respiratory burst, dan jumlah imunoglobulin serum) bagi ikan yang dicabar juga terangsang secara signifikan ($P < 0.05$) dengan pengambilan astaxanthin. Menariknya lagi, ikan terbabit mengalami pegurangan yang signifikan ($P < 0.05$) dan secara progresif dari segi perubahan histopatologi di dalam organ-organ sasaran (ginjal, hati, dan limpa) dengan bertambahnya dos pengambilan astaxanthin. Keputusan kajian juga mendapati bahawa suplemen astaxanthin membawa kepada kenaikan kadar survival ikan yang mendadak ($P < 0.05$) sepanjang tempoh pasca-jangkitan.

ACKNOWLEDGEMENTS

"Thank you, God, for the blessings and abundance that you have bestowed upon me, in my life"…

I gratefully acknowledge the following individuals for their assistance in striving towards the completion of this dissertation:

I begin first by tendering the warmest and most enthusiastic gratitude to my supervisory committee chairperson, Prof. Dr. Fatimah Md. Yusoff, who accommodated every need, including her invaluable guidelines, motivation, continuous support, immense patience, valuable time, constructive comments, and meticulous suggestions. I very much appreciate her confidence and the freedom she gave me to conduct this research under her auspices. I am deeply indebted to my advisory committee members, Prof. Dato' Dr. Mohamed Shariff Mohamed Din and Prof. Dr. Mohd. Salleh Kamarudin, whose collective support and guidance have made this dissertation a reality. I sincerely thank you all for sharing your expertise, wisdom, and passion with me along this memorable journey.

Above all, I am profoundly grateful to my wonderful wife, Hooi Ching, for her unconditional love, inexhaustible patience, and faith in me over these years. She has been my greatest companion that stood by me through thick and thin. I may never have completed my study without her infinite support (financial, mental, and motivational) and selflessness. Thanks also to my beloved daughter, Ms. Miley Lim Thya, for the joyful moments that gave me the extra strength and motivation to get things done. My success would not have been possible without the kind support, encouragement, confidence, love, concern, and countless blessings from my dearest parents, Mr. Lim Eng Seng and Mrs. Hew Yeat Chen, to whom I owed my heartfelt thanks and appreciation. My undying gratitude also goes to my dear brothers, Mr. Lim Keng Liang and Mr. Lim Keng Lee, for their unlimited love, concern, prayers, and generous support.

I also wish to thank the fellow staff members of the Aquatic Animal Health Unit (AAHU), particularly Dr. Sanjoy Banerjee, who had corresponded sincerely and tolerated my requests, to provide research facilities and equipment as well as to offer suggestions. Thanks for making me feel at home among you, and for your support and encouragement. I am thankful to all my colleagues and friends, with whom I shared moments of anxiety but also of great excitement. Your friendships are life's treasures that will be cherished forever.

This work was financially supported by the Putra Grant, Universiti Putra Malaysia (GP-IPS/2014/9433901) and the SATREPS-COSMOS Matching Fund from the Ministry of Higher Education (MOHE) Malaysia under the Malaysia-Japan SATREPS (JICA-JST) collaboration. I earnestly acknowledge

the MyBrain15 (MyPhD) Postgraduate Scholarship Scheme from the Ministry of Higher Education (MOHE) Malaysia with much gratitude and appreciation.

I am also extremely grateful to the experimental animals for their sacrifices, without which the study would be impossible, and may God rest their souls in peace. And last but not least, I express my sense of gratitude to all my well-wishers who helped me in many ways.

"For your kindness, generosity, and thoughtfulness, for what I have received, may the Lord make me truly thankful"…

Lim Keng Chin
November 2020

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:

Fatimah Md. Yusoff, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Dato' Mohamed Shariff Mohamed Din, PhD
Professor
Faculty of Veterinary Medicine
Universiti Putra Malaysia
(Member)

Mohd. Salleh Kamarudin, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 11 March 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	Percent
‰	Per mille
°C	Degree Celsius
$	Dollar
cm	Centimeter
cm^2	Square centimeter
m^{-2} s^{-1}	Meter squared per second
µg	Microgram
µL	Microliter
µm	Micrometer
µmol	Micromole
ACTH	Adrenocorticotropic hormone
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
ANOVA	One-way analysis of variance
cDNA	Complementary DNA
CFU	Colony-forming unit
DF	Dilution factor
dL	Deciliter
DMF	N, N-dimethyl formamide
DNA	Deoxyribonucleic acid
DW	Dry weight
e.g.	Exempli gratia or 'for example'
FAO	Food and Agricultural Organization
FBW	Final body weight
FCR	Feed conversion ratio
FER	Feed efficiency ratio
g	Gram
g	Relative centrifugal force
GH	Growth hormone
h	Hour
Hb	Hemoglobin
HPLC	High-performance liquid chromatography
Ht	Hematocrit
IACUC	Institutional Animal Care and Use Committee
IBM	International Business Machines
i.e.	Id est or 'that is'
Ig	Immunoglobulin
IGF	Insulin-like growth factor
K	Condition factor
kb	Kilobase
kg	Kilogram
KU	One Keil unit
L	Liter
LD_{50}	Median lethal dose
ln	Natural logarithm

LT	Long-term
M	Molarity
MBBM	Modified Bold's basal medium
mg	Milligram
min	Minute
mL	Milliliter
mM	Millimolar
mm	Millimeter
mmol	Millimole
MS-222	Tricaine methanesulfonate
MT	Medium-term
N	Nitrogen
NADH	Nicotinamide adenine dinucleotide
NBT	Nitroblue tetrazolium
ng	Nanogram
nm	Nanometer
PBS	Phosphate-buffered saline
PCR	Polymerase chain reaction
PER	Protein efficiency ratio
pH	A measure of acidity or alkalinity
PI	Post-infection
ppm	Parts per million
pmol	Picomole
PTFE	Polytetrafluoroethylene
®	Registered trademark
r	Correlation coefficient or effect size
R^2	Coefficient of determination
RBA	Respiratory burst activity
RBC	Red blood cell
ROS	Reactive oxygen species
rpm	Revolutions per minute
rRNA	Ribosomal ribonucleic acid
sec	Second
SEM	Standard error of the mean
SGR	Specific growth rate
Sdn. Bhd.	Sendirian Berhad
SPSS	Statistical Package for the Social Sciences
ST	Short-term
TCBS	Thiosulphate-citrate-bile salts-sucrose
TSB	Tryptic soy broth
U	Enzyme unit or international unit for enzyme
UPM	Universiti Putra Malaysia
US	The United States
UV	Ultraviolet
WG	Weight gain
WBC	White blood cell
v	Volume

CHAPTER 1

INTRODUCTION

1.1 Research background

Aquaculture is the farming of aquatic organisms such as fish, mollusks, crustaceans as well as aquatic plants from fresh, brackish, and salt waters. Global aquaculture has expanded dramatically over the past decades and is anticipated to progress further. From the production of less than a million tonnes in the early 1950s, aquaculture production in 2018 was reported to have risen to 114.5 million tonnes (including aquatic plants) with a first-sale value estimated at US$263.6 billion; portraying an outstanding growth (FAO, 2020). Over-fishing and harvesting of wild populations have reached critical thresholds, and the role of aquaculture in contributing to human nutrition is continually increasing. The introduction of new species and advances in culture techniques have significantly contributed to the rapid growth of the aquaculture industry (Xiang, 2015; Ahmed and Thompson, 2019). Aquaculture continues to grow more rapidly than other livestock industries and plays a vital contribution to human nutrition in relieving nutritional deprivation (Little *et al*., 2016; FAO, 2020).

Asian seabass (*Lates calcarifer* Bloch), or also known as giant sea perch or barramundi, is among the most economically important catadromous fish species in southeastern Asia and Australia. The major producers of both fingerlings and marketable fish for domestic and regional markets include Indonesia, Malaysia, Singapore, Taiwan, and Thailand (Senanan *et al*., 2015; Joerakate *et al*., 2018). Aquaculture production of the Asian seabass is a speedily developing enterprise in the global aquaculture industry, with market expansion growth as a popular seafood item in many European and North American countries (Glencross *et al*., 2014; Harrison *et al*., 2014). According to FAO (2018), the global production of cultured Asian seabass has witnessed a surge over the past decades to 95,385 tonnes in 2016, chiefly ascribable to intensive farming activities that have been predominantly initiated based on hatchery-reared stocks in either brackish, marine, or freshwater ponds. The fish fetches a good market value due to its delicate and mild-flavored white flesh, regularly served as favorite food fish in many cuisines and delicacies.

Astaxanthin (3,3′-dihydroxy-β,β-carotene-4,4′-dione) is a naturally occurring deep red-orange keto-carotenoid pigment primarily present in the flesh of salmonids, the carapace of many crustaceans (e.g., crabs, crayfish, lobsters, and shrimp), and also in several freshwaters and marine microorganisms (e.g., bacteria, fungi, yeast, and microalgae) (Begum *et al*., 2016; Barredo *et al*., 2017; Galasso *et al*., 2018; Lim *et al*., 2018). Fish, as do other animals, lack the capacity to biochemically synthesize astaxanthin de novo, and the pigment must be acquired from their diets to maintain decent colorations. *Haematococcus pluvialis* is acknowledged as one of the most abundant bio-

resources of astaxanthin (3–5% on a dry weight basis) and the exclusive producer of this carotenoid (Panis and Carreon, 2016; Ho *et al*., 2018). Astaxanthin can also be readily derived via chemical synthesis, but there has been heightened interest in natural sources of the pigment (Panis and Carreon, 2016; Shah *et al*., 2016). Nearly all commercially available astaxanthin is produced synthetically from petrochemical sources (Lim *et al*., 2018). Astaxanthin has drawn considerable attention accounted to its super potent antioxidant capacity with multiple biological functions and beneficial applications in animal health and nutrition (Lim *et al*., 2018; 2019a). The continued growth of the aquaculture industry has prompted a massive demand for this pigment.

Nutrition plays an essential part in the profitability and viability of the fish farming industry. The development of feeds with nutritional ingredients that promote satisfactory growth and survival of farmed species is a requisite to minimize production costs. Adequate and proper nutrition has also been recognized as necessary for sustaining animal health and its ability to combat diseases. Astaxanthin has emerged as a fascinating natural source of a new compound with biological activities that can be used as a functional ingredient in feed formulation. In general, the immune response of aquatic animals can be enhanced through specific dietary manipulation, such as the incorporation of immunostimulants. Immunostimulators activate the immune systems of aquatic animals and improve their capability for disease tolerance. There has been heightened interest in the ability of carotenoid pigments, specifically astaxanthin, to act as a promising immunopotentiating agent in aquaculture. As a human dietary supplement, astaxanthin induces the protective effects of anti-aging (Tominaga *et al*., 2017; Eren *et al*., 2018; Nootem *et al*., 2018), anti-atherosclerotic (Kishimoto *et al*., 2016; Visioli and Artaria, 2017), anti-diabetic (Satoh, 2016; Visioli and Artaria, 2017; Mashhadi *et al*., 2018), anti-inflammatory (Miyachi *et al*., 2015; Tominaga *et al*., 2017; Davinelli *et al*., 2018), anti-cancer (Smith, 1998; Palozza *et al*., 2009; Tanaka *et al*., 2012), immune system boosting (Kishimoto *et al*., 2010; Park *et al*., 2010; Yamashita, 2013), sun-proofing (O'Connor and O'Brien, 1998; Suganuma *et al*., 2010), and amongst other diverse health benefits. Hence, dietary astaxanthin has excellent potential to enhance the growth, health, and well-being of aquatic animals (Hansen *et al*., 2016; Cheng *et al*., 2018; Lim *et al*., 2019a; b).

1.2 Problem statement

Culture operations for Asian seabass (*L. calcarifer*) are diverse, which involves various rearing practices. However, the large-scale aquaculture production of Asian seabass under stressful circumstances (high-density culture) has posed several major problems, including sluggish growth rate and poor survivability (Lim *et al*., 2019b). Growth and survival exert the most significant impact on the economic performance of Asian seabass production. The sustainability, success, and profitability of semi-intensive and intensive Asian seabass culture in ponds and cages depend, to a large extent, on good quality supplemented feed (Lim *et al*., 2019b). Thus, a high-performing practical diet for optimum growth performance and survival is indispensable.

In recent decades, the massive development within the aquaculture industry has dramatically increased the interest in the study of fish immunity and defense against deadly infections. Several drawbacks, notably the frequent outbreak of diseases, had raised concern over its management and effective control. Cultured animals are subjected to stress conditions that weaken the immune system of fish, leading to increased vulnerability to pathogens and the emergence of diseases commonly associated with intensive fish rearing. Consequently, these infectious diseases contribute to considerable economic loss, which is one of the significant constraints of intensive fish cultivation (Thompson, 2017; Lim *et al*., 2018). Therefore, substantial effort in fish nutrition research must be directed toward mitigating stress and enhancing the immunity of farmed Asian seabass. Moreover, there is a lack of comprehensive studies on the effect of supplementation with natural astaxanthin as an immunostimulant in the tropical fish species, Asian seabass (*L. calcarifer*), to confer a great benefit to its immune defense.

1.3 Justification

Dietary supplementation of astaxanthin in the diet of Asian seabass could have the potential for maximum output (e.g., growth performance and survival of fish) and a significant impact on its production efficiencies. Growth remains the foremost trait in finfish aquaculture, which is inherently associated with the productivity and profitability of enterprises (Gjedrem and Robinson, 2014; Ye *et al*., 2017). The administration of astaxanthin as an immunostimulant on fish through this study will significantly enhance the immune response of fish, alleviate stress, and confer protection against different pathogens. The pigment can be included as a dietary supplement during stressful aquaculture operations such as transfer, grading, vaccination, or during crucial life stages to help the animal to ward off pathogens and sustain good health. Undeniably, this should generate a general benefit to the fish immune system, which hinders the problem associated with the emergence of diseases in intensive fish farming, globally. Supplementation of naturally derived astaxanthin can prevent the risks associated with the use of chemical products. The use of immunostimulants has drawn great attention as a valuable alternative to immunoprophylactic control in the fight against various infectious diseases that are caused by pathogens in most circumstances (Wang *et al*., 2016a; Subramani and Michael, 2017; Lim *et al*., 2019a). This study aims to provide valuable knowledge regarding the importance of astaxanthin as a growth enhancer with immunomodulatory benefits for the aquaculture industry.

1.4 Research objectives

The main objectives of this study include:

1) To evaluate the impacts of dietary administration with astaxanthin on feed utilization, growth performance, survival, and serum growth hormone (GH) availability of Asian seabass (*L. calcarifer* Bloch)

2) To study the immunomodulatory effects of dietary supplementation with astaxanthin on the immunocompetence and health of Asian seabass (*L. calcarifer* Bloch)

3) To investigate the effects of dietary provisioning with astaxanthin on the disease resistance of Asian seabass (*L. calcarifer* Bloch) challenged with pathogenic *V. alginolyticus*

1.5 Research hypothesis

The main hypotheses of this study include:

Null hypothesis:

1) Dietary administration of astaxanthin does not improve feed utilization, growth performance, survival, and serum growth hormone (GH) availability of Asian seabass (*L. calcarifer* Bloch)

2) Dietary supplementation of astaxanthin is unable to enhance the immunocompetence and health of Asian seabass (*L. calcarifer* Bloch)

3) Dietary provision of astaxanthin is not capable of improving the disease resistance of Asian seabass (*L. calcarifer* Bloch) against *V. alginolyticus* infection

Alternate hypothesis:

1) Dietary administration of astaxanthin improves feed utilization, growth performance, survival, and serum growth hormone (GH) availability of Asian seabass (*L. calcarifer* Bloch)

2) Dietary supplementation of astaxanthin enhances the immunocompetence and health of Asian seabass (*L. calcarifer* Bloch)

3) Dietary provision of astaxanthin improves the disease resistance of Asian seabass (*L. calcarifer* Bloch) against *V. alginolyticus* infection

REFERENCES

Abarike, E.D., Kuebutornye, F.K.A., Jian, J., Tang, J., Lu, Y. and Cai, J. (2018). Influences of immunostimulants on phagocytes in cultured fish. *Reviews in Aquaculture* 11: 1219–1227.

Abolfathi, M., Hajimoradloo, A., Ghorbani, R. and Zamani, A. (2012). Compensatory growth in juvenile roach *Rutilus caspicus*: effect of starvation and re-feeding on growth and digestive surface area. *Journal of Fish Biology* 81: 1880–1890.

Acar, U., Kesbic, O.S., Yilmaz, S., Gultepe, N. and Turker, A. (2015). Evaluation of the effects of essential oil extracted from sweet orange peel (*Citrus sinensis*) on growth rate of tilapia (*Oreochromis mossambicus*) and possible disease resistance against *Streptococcus iniae*. *Aquaculture* 437: 282–286.

Adedeji, O.B., Okerentugba, P.O., Onianwa, O. and Okonko, I.O. (2013). Immune response of fish to bacterial infections. *Researcher* 5: 96–103.

Ahmad, M.T., Shariff, M., Yusoff, F.M., Goh, Y.M. and Banerjee, S. (2020). Applications of microalga *Chlorella vulgaris* in aquaculture. *Reviews in Aquaculture* 12: 328–346.

Ahmed, N. and Thompson, S. (2019). The blue dimensions of aquaculture: a global synthesis. *Science of the Total Environment* 652: 851–861.

Ahmed, I., Reshi, Q.M. and Fazio, F. (2020). The influence of the endogenous and exogenous factors on hematological parameters in different fish species: a review. *Aquaculture International*. https://doi.org/10.1007/s10499-019-00501-3.

Ajayi, B.B., Ogunsola, J.O., Olatoye, O.I., Antia, R.E. and Agbede, S. (2018). Effects of pituitary extract, ovaprim, and bitter leaf (*Vernonia amygdalina*) on the histopathology of African catfish (*Clarias gariepinus*). *Aquaculture and Fisheries* 3: 232–237.

Ali, M., Soltanian, S., Akbary, P. and Gholamhosseini, A. (2018). Growth performance and lysozyme activity of rainbow trout fingerlings fed with vitamin E and selenium, marjoram (*Origanum* spp.), and ajwain (*Trachyspermum ammi*) extracts. *Journal of Applied Animal Research* 46: 650–660.

Alishahi, M., Karamifar, M. and Mesbah, M. (2015). Effects of astaxanthin and *Dunaliella salina* on skin carotenoids, growth performance and immune response of *Astronotus ocellatus*. *Aquaculture International* 23: 1239–1248.

Allsop, Q., De Lestang, P., Griffin, R. and White, G. (2006). Barramundi. *Fishnote*: 27: 1–5.

Alltech(2019).*Globalfeedsurvey*.https://www.alltech.com/sites/default/files/2019 02/GFS_Brochure_2019_English.pdf (accessed 13 May 2019).

Almeida, D.V., Martins, C.D.G., Figueiredo, M.D., Lanes, C.F.C., Bianchini, A. and Marins, L.F. (2013). Growth hormone transgenesis affects osmoregulation and energy metabolism in zebrafish, *Danio rerio*. *Transgenic Research 22*: 75–88.

Alvarez-Pellitero, P. (2008). Fish immunity and parasite infections: from innate immunity to immunoprophylactic prospects.*Veterinary Immunology and Immunopathology* 126: 171–198.

Aly, S.M. and Albutti, A. (2014). Antimicrobials use in aquaculture and their public health impact. *Aquaculture Research and Development* 5: 247. https://doi.org/10.4172/2155-9546.1000247.

Amar, E.C., Kiron, V., Satoh, S., Okamoto, N. and Watanabe, T. (2000). Effects of dietary β-carotene on the immune response of rainbow trout *Oncorhynchus mykiss*. *Fisheries Science* 66: 1068–1075.

Amar E.C., Kiron, V., Akutsu, T., Satoh, S. and Watanabe, T. (2012). Resistance of rainbow trout *Oncorhynchus mykiss* to infectious hematopoietic necrosis virus (IHNV) experimental infection following ingestion of natural and synthetic carotenoids. *Aquaculture* 330–333: 148–155.

Ambati, R.R., Phang, S.M., Ravi, S. and Aswathanarayana, R.G. (2014). Astaxanthin: sources, extraction, stability, biological activities and its commercial application-a review. *Marine Drugs* 12: 128–152.

Ambati, R., Gogisetty, D., Gokare, R., Ravi, S., Bikkina, P., Su, Y. and Lei, B. (2017). *Botryococcus* as an alternative source of carotenoids and its possible applications - an overview. *Critical Reviews in Biotechnology* 38: 1–18.

Anacleto, O., Cabaleiro, S., Villanueva, B., Saura, M., Houston, R.D., Woolliams, J. and Doeschl-Wilson, A.B. (2019). Genetic differences in host infectivity affect disease spread and survival in epidemics. *Scientific Reports* 9: 4924. https://doi.org/10.1038/s41598-019-40567-w.

Anbazahan, S.M., Mari, L.S.S., Yogeshwari, G., Jagruthi, C., Thirumurugan, R., Arockiaraj, J., Velanganni, A.A.J., Krishnamoorthy, P., Balasundaram, C. and Harikrishnan, R. (2014). Immune response and disease resistance of carotenoids supplementation diet in *Cyprinus carpio* against *Aeromonas hydrophila*. *Fish and Shellfish Immunology* 40: 9–13.

Andersen, R.A. and Kawachi, M. (2005). Traditional microalgae isolation techniques. In *Algae Culturing Techniques*, ed. R.A. Andersen, pp. 83–100. United Kingdom: Elsevier Academic Press.

Andersen, L., Holck, S., Kupcinskas, L., Kiudelis, G., Jonaitis, L., Janciauskas, D., Permin, H. and Wadstrom, T. (2007). Gastric inflammatory markers and interleukins in patients with functional dyspepsia treated with astaxanthin. *FEMS Immunology and Medical Microbiology* 50: 244–248.

Anderson, D.P. and Siwicki, A.K. (1995). Basic haematology and serology for fish health programs. In *Diseases in Asian Aquaculture II. Fish Health Section*, ed. M. Shariff, J.R. Arthur and R.P. Subasinghe, pp. 185–202. Manila: Asian Fisheries Society.

Angeles, I.P., Chien, Y.H. and Tayamen, M.M. (2009). Effects of different dosages of astaxanthin on giant freshwater prawn Macrobrachium rosenbergii (De Man) challenged with *Lactococcus garvieae*. *Aquaculture Research* 41: 70–77.

AOAC (2016). *Official methods of analysis*, 20th ed., pp. 1–77. Gaithersburg, MD: AOAC International.

Aoki, T., Takano, T., Santos, M.D. and Kondo, H. (2008). Molecular innate immunity in teleost fish: review and future perspectives. In: *Fisheries for Global Welfare and Environmental*, ed. K. Tsukamoto, T. Kawamura, T.D., Takeuchi, J., Beard and M.J. Kaiser), pp. 263–276. Japan: Terra Publication.

Aquasearch Inc. (1999). *Haematococcus pluvialis* and astaxanthin safety for human consumption. Technical Report TR 3005.001.

Araneda, M., Perez, E.P. and Gasca, L.E. (2008). White shrimp *Penaeus vannamei* culture in freshwater at three densities: condition state based on length and weight. *Aquaculture* 283: 13–18.

Arredondo-Figueroa, J.L., Pedroza-Islas, R., Ponce, J.T. and Vernon-Carter, E.J. (2003). Pigmentation of Pacific white shrimp (*Litopenaeus vannamei*, Boone 1931) with esterified and saponified carotenoids from chilli *Capsicum annum* in comparison to astaxanthin. *Revista Mexicana De Ingenieria Qumica* 3: 101–108.

Ashfaq, H., Soliman, H., Saleh, M. and El-Matbouli, M. (2019). CD4: a vital player in the teleost fish immune system. *Veterinary Research* 50: 1. https://doi.org/10.1186/s13567-018-0620-0.

Assefa, A. and Abunna, F. (2018). Maintenance of fish health in aquaculture: review of epidemiological approaches for prevention and control of infectious disease of fish. *Veterinary Medicine International* 10: 5432497. https://doi.org/10.1155/2018/5432497.

Austin, B. and Austin, D.A. (2016). *Bacterial fish pathogens: Disease of farmed and wild fish, 6th edition*. Switzerland: Springer International Publishing.

Austin, B. (2017). Chapter 10 - Antibiotics and disinfectants. In *Diagnosis and Control of Diseases of Fish and Shellfish*, ed. B. Austin and A. Newaj-Fyzul, pp. 263–278. Hoboken, NJ: Wiley-Blackwell.

Ayoade, A.A. (2011). Length-weight relationship and diet of African carp *Labeo ogunensis* (Boulenger, 1910) in Asejire lake southwestern Nigeria. *Journal of Fisheries and Aquatic Science* 6: 472–478.

Azad, I.S., Thirunavukkarasu, A.R., Kailasam, M. and Rajan, J.J.S. (2004). Virulence and histopathology of *Vibrio anguillarum* like (VAL) bacterium isolated from hatchery produced juveniles of *Lates calcarifer* (Bloch). *Asian Fisheries Science* 17: 101–110.

Azwai, S.M., Alfallani, E.A., Abolghait, S.K., Garbaj, A.M., Naas, H.T., Moawad, A.A., Gammoudi, F.T., Rayes, H.M., Barbieri, I., Eldaghayes, I.M. and Eldaghayes, I.M. (2016). Isolation and molecular identification of *Vibrio* spp. by sequencing of 16S rDNA from seafood, meat and meat products in Libya. *Open Veterinary Journal* 6: 36–43.

Baba, E., Acar, U., Ontas, C., Kesbic, O.S. and Yilmaz, S. (2016). Evaluation of *Citrus limon* peels essential oil on growth performance, immune response of Mozambique tilapia *Oreochromis mossambicus* challenged with *Edwardsiella tarda*. *Aquaculture* 465: 13–18.

Baker, R.T., Pfeiffer, A.M., Schoner, F.J. and Smith-Lemmon, L. (2002). Pigmenting efficacy of astaxanthin and canthaxanthin in freshwater-reared Atlantic salmon, *Salmo salar*. *Animal Feed Science and Technology* 99: 97–106.

Balebona, M.C., Zorilla, I., Morinigo, M.A. and Borrego, J.J. (1998). Survey of bacterial pathologies affecting farmed gilt-head sea bream (*Sparus auratus* L.) in southwestern Spain from 1990 to 1996. *Aquaculture* 166: 19–35.

Banerjee, K., Ghosh, R., Homechaudhuri, S. and Mitra, A. (2009). Biochemical composition of marine macroalgae from Gangetic delta at the apex of Bay of Bengal. *African Journal of Basic and Applied Sciences* 1: 96–104.

Barbosa, M.J., Morais, R. and Choubert, G. (1999). Effect of carotenoid source and dietary lipid content on blood astaxanthin concentration in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* 176: 331–341.

Barredo, J.L., Garcia-Estrada, C., Kosalkova, K. and Barreiro, C. (2017). Biosynthesis of astaxanthin as a main carotenoid in the heterobasidiomycetous yeast *Xanthophyllomyces dendrorhous*. *Journal of Fungi* 3: 44. https://doi.org/10.3390/jof3030044.

Barros, A.I., Goncalves, A.L., Simoes, M. and Pires, J. (2015). Harvesting techniques applied to micoralgae: a review. *Renewable and Sustainable Energy Reviews* 41: 1489–1500.

Barsanti, L. and Gualtieri, P. (2006). *Algae: anatomy, biochemistry and biotechnology*, 301 pp. New York: CRC Press.

Bastos Gomes, G., Jerry, D.R., Miller, T.L. and Hutson, K.S. (2016). Current status of parasitic ciliates *Chilodonella* spp. (Phyllopharyngea: Chilodonellidae) in freshwater fish aquaculture. *Journal of Fish Disease* 40: 703–715.

Bazyar Lakeh, A.A., Ahmadi, M.R., Safi, S., Ytrestoyl, T. and Bjerkeng, B. (2010). Growth performance, mortality and carotenoid pigmentation of fry offspring as affected by dietary supplementation of astaxanthin to female rainbow trout (*Oncorhynchus mykiss*) broodstock. *Journal of Applied Ichthyology* 26: 35–39.

Becker, E.W. (1995). *Microalgae biotechnology and microbiology*, pp. 56–62. Great Britain: Cambridge University Press.

Begum, H., Yusoff, F.M., Banerjee, S., Khatoon, H. and Shariff, M. (2016). Availability and utilization of pigments from microalgae. *Critical Review in Food Science and Nutrition* 56: 2209–2222.

Bendich, A. and Shapiro, S. (1986). Effect of β-carotene and canthaxanthin on the immune response of the rat. *Journal of Nutrition* 116: 2254–2262.

Benedet, S., Andersson, E., Mittelholzer, C., Taranger, G.L. and Bjornsson, B.T. (2010). Pituitary and plasma growth hormone dynamics during sexual maturation of female Atlantic Salmon.*General and Comparative Endocrinology* 167: 77–85.

Bernet, D., Schmidt, H., Meier, W., Burkhardt-Holm, P. and Wahli, T. (1999). Histopathology in fish: proposal for a protocol to assess aquatic pollution. *Journal of Fish Disease* 22: 25–34.

Berra, T.M. (2007). *Freshwater fish distribution*, 2nd edition, 606 pp. California: Academic Press.

Bhuvaneswari, S., Yogalakshmi, B., Sreeja, S. and Anuradha, C.V. (2014). Astaxanthin reduces hepatic endoplasmic reticulum stress and nuclear factor-kB-mediated inflammation in high fructose and high fat diet-fed mice. *Cell Stress and Chaperones* 19: 183–191.

Birceanu, O. and Wilkie, M.P. (2018). Post-exposure effects of the piscicide 3-trifluoromethyl-4-nitrophenol (TFM) on the stress response and liver metabolic capacity in rainbow trout (*Oncorhynchus mykiss*). *PLOS ONE* 13: e0200782. https://doi.org/10.1371/journal.pone.0200782.

Bischoff, H.W. and Bold, H.C. (1963). Phycological studies. IV. Some soil algae from Enchanted Rock and related algal species. *University of Texas Publications* 6318: 1–95.

Bjerkeng, B., Storebakken, T. and Liaaen-Jensen, S. (1992). Pigmentation of rainbow trout from start feeding to sexual maturation. *Aquaculture* 108: 333–346.

Bjornsson, B.T., Stefansson, S.O. and Hansen, T. (1995). Photoperiod regulation of plasma growth hormone levels during parr-smoltt transformation of Atlantic salmon: implications for hypoosmoregulatory ability and growth. *General and Comparative Endocrinology* 100: 73–81.

Bjornsson, B.T., Johansson, V., Benedet, S., Einarsdottir, I.E., Hildahl, J., Agustsson, T. and Jonsson, E. (2002). Growth hormone endocrinology of salmonids: regulatory mechanisms and mode of action. *Fish Physiology and Biochemistry* 27: 227–242.

Blaber, S., Milton, D. and Salini, J. (2008). The biology of barramundi (*Lates calcarifer*) in the Fly River system. *Developments in Earth and Environmental Sciences* 9: 411–426.

Bold, H.C. (1949). The morphology of *Chlamydomonas* sp. *Bulletin of the Torrey Botanical Club* 76: 101–108.

Boltana, S., Roher, N., Goetz, F. and Mackenzie, S. (2011). PAMPs, PRRs and the genomics of Gram negative bacterial recognition in fish. *Developmental and Comparative Immunology* 35: 1195–1203.

Boonyaratpalin, M. and Williams, K. (2002). Asian sea bass, *Lates calcarifer*. In *Nutrient Requirements and Feeding of Finfish for Aquaculture*, ed. C.D. Webster and C.E. Lim, pp. 40–48. New York: Cabi Publishing.

Borgne, Y.L. (1996). Culture of microalgae. In *Aquaculture*, ed. G. Barnabe, pp. 197–206. England: Ellis Horwood Limited.

Borkhanuddin, M.H., Cech, G., Molnar, K., Shaharom-Harrison, F., Khoa, T.N.D., Shamsuri, M.A., Mazelan, S., Atkinson, S.D. and Szekely, C. (2019). Henneguya (Cnidaria: Myxosporea: Myxobolidae) infections of cultured barramundi, *Lates calcarifer* (Perciformes: Latidae) in an estuarine wetlands system of Malaysia: description of *Henneguya setiuensis* n. sp., *Henneguya voronini* n. sp. and *Henneguya calcarifer* n. sp. *Fish Parasitology* 119: 85–96.

Brameld, J.M., Atkinson, J.L., Saunders, J.C., Pell, J.M., Buttery, P.J. and Gilmour, R.S. (1996). Effects of growth hormone administration and dietary protein intake on insulin-like growth factor I and growth hormone receptor mRNA expression in porcine liver, skeletal muscle, and adipose tissue. *Journal of Animal Science* 74: 1832–1841.

Brendler, T. and Williamson, E.M. (2019). Astaxanthin: how much is too much? A safety review. *Phytotherapy Research* 33: 3090–3111.

Brizio, P., Benedetto, A., Righetti, M., Prearo, M., Gasco, L., Squadrone, S. and Abete, M. (2013). Astaxanthin and canthaxanthin (xanthophyll) as supplements in rainbow trout diet: in vivo assessment of residual levels and contributions to human health. *Journal of Agricultural and Food Chemistry* 61: 10954–10959.

Brubaker, S.W., Bonham, K.S., Zanoni, I. and Kagan, J.C. (2015). Innate immune pattern recognition: a cell biological perspective. *Annual Review of Immunology* 33: 257–290.

Buchmann, K. (2015). Impact and control of protozoan parasites in maricultured fish. *Parasitology* 142: 168–177.

Buesen, R., Schulte, S., Strauss, V., Treumann, S., Becker, M., Groters, S., Carvalho, S. and van Ravenzwaay, B. (2015). Safety assessment of [3S,3S']-astaxanthin-subchronic toxicity study in rats. *Food and Chemical Toxicology* 81: 129–136.

Bunpa, S., Sermwittayawong, N. and Vuddhakul, V. (2016). Extracellular enzymes produced by *Vibrio alginolyticus* isolated from environments and diseased aquatic animals. *Procedia Chemistry* 18: 12–17.

Burrells, C., William, P.D., Southage, P.J. and Wadsworth, S.L. (2001). Dietary nucleotides: a novel supplement in fish feeds: 2. Effects on vaccination, salt water transfer, growth rate and physiology of Atlantic salmon (*Salmo salar* L.). *Aquaculture* 199: 171–184.

Caipang, C.M.A., Junior, R.V.P. and Apines-Amar, M.J.S. (2012). Screening of vibriosis in Asian seabass, *Lates calcarifer* using loop-mediated isothermal amplification (LAMP) assay. *Human and Veterinary Medicine (Bioflux)* 4: 52–57.

Campoverde, C., Andree, K.B., Milne, D.J., Estevez, A., Gisbert, E. and Carella, F. (2019). Ontogeny of lymphoid organs and mucosa associated lymphoid tissues in meagre (*Argyrosomus regius*). *Fish and Shellfish Immunology* 84: 509–520.

Canli, E.G., Dogan, A. and Canli, M. (2018). Serum biomarker levels after following nanoparticle (Al_2O_3, CuO, TiO_2) exposures in freshwater fish (*Oreochromis niloticus*). *Environmental Toxicology and Pharmacology* 62: 181–187.

Cao, H., Zhou, R.J., Wei, Q.W., Li, C.J., and Gui, J.F. (2011). Molecular characterization of the growth hormone in Chinese sturgeon and its expression during embryogenesis and early larval stages. *Journal of Applied Ichthyology* 27: 501–504.

Capelli, B., Bagchi, D. and Cysewski, G. (2014). Synthetic astaxanthin is significantly inferior to algal-based astaxanthin as an antioxidant and may not be suitable as a human nutraceutical supplement. *Nutrafoods* 12: 4. https://doi.org/10.1007/s13749-013-0051-5.

Castillo-Vargasmachuca, S., Ponce-Palafox, J., Arambul-Munoz,E., Rodriguez-Dominguez, G. and Aragon-Noriega, E. (2018). The spotted rose snapper (*Lutjanus guttatus* Steindachner 1869) farmed in marine cages: Review of growth models. *Reviews in Aquaculture* 10: 376–384.

Castro, R., Jouneau, L., Tacchi, L., Macqueen, D., Alzaid, A., Secombes, J., Martin, S. and Boudinot, P. (2015). Disparate developmental patterns of immune responses to bacterial and viral infections in fish. *Scientific Reports* 5: 15458. https://doi.org/10.1038/srep15458.

Cerezuela, R., Guardiola, F.A., Gonzalez, P., Meseguer, J. and Esteban, M.A. (2012a). Effects of dietary *Bacillus subtilis*, *Tetraselmis chuii* and *Phaeodactylum tricornutum*, singularly or in combination, on the immune response and disease resistance of sea bream (*Sparus aurata* L.). *Fish and Shellfish Immunology* 33: 342–349.

Cerezuela, R., Guardiola, F.A., Meseguer, J. and Esteban, M.A. (2012b). Enrichment of gilthead seabream (*Sparus aurata* L.) diet with microalgae: effects on the immune system. *Fish Physiology and Biochemistry* 38: 1729-1739.

Chang, J.P. and Wong, A.O.L. (2009). Growth hormone regulation in fish: a multifactorial model with hypothalamic, peripheral and local autocrine/paracrine signals. In *Fish Neuroendocrinology*, ed. N.J. Bernier, G. Van Der Kraak, A.P. Farrell and C.J. Brauner. *Fish Neuroendocrinology* 28: 151–195.

Chen, B.H., Yang, S.H. and Han, L.H. (1991). Characterization of major carotenoids in water convolvulus (*Ipomea aquatica*) by open-column, thin-layer and high-performance liquid chromatography. *Journal of Chromatography A* 543: 147–155.

Chen, Y. and Junger, W.G. (2012). Measurement if oxidative burst in neutrophils. *Methods in Molecular Biology* 844: 115–124.

Chen, C., Chang J. and Lee D. (2015). Dewatering and drying methods for microalgae. *Drying Technology* 33: 443–454.

Chen, X.M., Guo, G.L., Sun, L., Yang, Q.S., Wang, G.Q. and Qin, G.X. (2016). Effects of Ala-Gln feeding strategies on growth, metabolism, and crowding stress resistance of juvenile *Cyprinus carpio* var. Jian. *Fish and Shellfish Immunology* 51: 365–372.

Chen, Y., Cheng, A., Cheng, S. and Chen, J. (2018a). Orange-spotted grouper *Epinephelus coioides* that have encountered low salinity stress have decreased cellular and humoral immune reactions and increased susceptibility to *Vibrio alginolyticus*. *Fish and Shellfish Immunology* 80: 392–396.

Chen, N., Jiang, J., Gao, X., Li, X., Zhang, Y., Liu, X., Yang, H., Bing, X. and Zhang, X. (2018b). Histopathological analysis and the immune related

gene expression profiles of mandarin fish (*Siniperca chuatsi*) infected with *Aeromonas hydrophila*. *Fish and Shellfish Immunology* 83: 410–415.

Chen, F., Sun, J., Han, Z., Yang, X., Xian, J., Lv, A., Hu, X. and Shi, H. (2019). Isolation, identification and characteristics of Aeromonas veronii from diseased crucian carp (*Carassius auratus gibelio*). *Frontiers in Microbiology* 10: 2742. https://doi.org/10.3389/fmicb.2019.02742.

Cheng, C., Guo, Z., Ye, C. and Wang, A. (2018). Effect of dietary astaxanthin on growth performance, non-specific immunity, and antioxidant capacity of pufferfish (*Takifugu obscurus*) under high temperature stress. *Fish Physiology and Biochemistry* 44: 209–218.

Chien, Y.H. and Shiau, W.C. (2005). The effects of dietary supplementation of algae and synthetic astaxanthin on body astaxanthin, survival, growth and low dissolved oxygen stress resistance of kuruma prawn, *Marsupenaeus japonicus* Bate. *Journal of Experimental Marine Biology and Ecology* 318: 201–211.

Chimsung, N., Tantikitti, C., Milley, J.E., Verlhac-Trichet, V. and Lall, S.P. (2014). Effects of various dietary factors on astaxanthin absorption in Atlantic salmon (*Salmo salar*). *Aquaculture Research* 45: 1611–1620.

Cho, S.H. (2012). Effects of dietary nutrient on the biological index and serum chemistry of juvenile olive flounder *Paralichthys olivaceus* achieving compensatory growth. *Fisheries and Aquatic Science* 15: 69–72.

Choi, H. D., Youn, Y. K. and Shin, W.G. (2011). Positive effects of astaxanthin on lipid profiles and oxidative stress in overweight subjects. *Plant Foods for Human Nutrition* 66: 363–369.

Chotnipat, S., Miller, T.L., Knuckey, R.M. and Hutson, K.S. (2015). Molecular and morphological evidence for the widespread distribution of *Laticola paralatesi* infecting wild and farmed *Lates calcarifer* in Australia. *Diseases of Aquatic Organisms* 113: 195–205.

Choubert, G. (2010). Response of rainbow trout (*Oncorhynchus mykiss*) to varying dietary astaxanthin/canthaxanthin ratio: colour and carotenoid retention of the muscle. *Aquaculture Nutrition* 16: 528–535.

Christiansen, R., Lie, O. and Torrissen, O.J. (1994). Effect of astaxanthin and vitamin A on growth and survival during first feeding of Atlantic salmon, *Salmo salar* L. *Aquaculture Research* 25: 903–914.

Christiansen, R., Lie, O. and Torrissen, O.J. (1995a). Growth and survival of Atlantic salmon, *Salmo salar* L., fed different dietary levels of astaxanthin. First-feeding fry. *Aquaculture Nutrition* 1: 189–198.

Christiansen, R., Glette, J., Lie, O., Torrissen, O.J. and Waagbo, R. (1995b). Antioxidant status and immunity in Atlantic salmon, *Salmo salar* L., fed

semi-purified diets with and without astaxanthin supplementation. *Journal of Fish Disease* 18: 317–328.

Christiansen, R. and Torrissen, O.J. (1996). Growth and survival of Atlantic salmon, *Salmo salar* L., fed different dietary levels of astaxanthin. Juveniles. *Aquaculture Nutrition* 2: 55–62.

Conde-Sieira, M., Alvarez, R., Lopez-Patino, M.A., Miguez, J.M., Flik, G. and Soengas, J.L. (2013). ACTH-stimulated cortisol release from head kidney of rainbow trout is modulated by glucose concentration. *Journal of Experimental Biology* 216: 554–567.

Costello, C., Cao, L., Gelcich, S., Cisneros-Mata, M., Free, C., Froehlich, H., Golden, C., Ishimura, G., Maier, J., Macadam-Somer, I., Mangin, T., Melnychuk, M., Miyahara, M., de Moor, C., Naylor, R., Nostbakken, L., Ojea, E., O'Reilly, E., Parma, A., Plantinga, A., Thilsted, S. and Lubchenco, J. (2020). The future of food from the sea. *Nature* 588: 95–100.

Crumlish, M. (2017). Chapter 2 - Bacterial diagnosis and control in fish and shellfish. In *Diagnosis and Control of Diseases of Fish and Shellfish*, ed. B. Austin and A. Newaj-Fyzul, pp. 5–18. Hoboken, NJ: Wiley-Blackwell.

Daet, I. (2019). Study on culture of sea bass (*Lates calcarifer*, Bloch 1790) in hapa-in-pond environment. *International Conference on Green Agro-industry and Bioeconomy* 230: 012115. https://doi.org/10.1088/1755-1315/230/1/012115.

Dai, X., Zhang, W., Zhuo, Z., He, J. and Yin, Z. (2015). Neuroendocrine regulation of somatic growth in fishes. *Science China Life Sciences* 58: 137–147.

Daly, B., Swingle, J. and Eckert, G. (2013). Dietary astaxanthin supplementation for hatchery-cultured red king crab, *Paralithodes camtschaticus*, juveniles. *Aquaculture Nutrition* 19: 312–320.

Datta, S.N., Kaur, V.I., Dhawan, A. and Jassal, G. (2013). Estimation of length-weight relationship and condition factor of spotted snakehead *Channa punctata* (Bloch) under different feeding regimes. *Springerplus* 2: 436. https://doi.org/10.1186/2193-1801-2-436.

Davinelli, S., Nielsen, M.E. and Scapagnini, G. (2018). Astaxanthin in skin health, repair, and disease: a comprehensive review. *Nutrients* 10: 522. http://dx.doi.org/10.3390/nu10040522.

Davis, M. J. (2010). Contrast coding in multiple regression analysis: Strengths, weaknesses, and utility of popular coding structures. *Journal of Data Science* 8: 61–73.

Declercq, A.M., Haesebrouck, F., Van den Broeck, W., Bossier, P. and Decostere, A. (2012). Columnaris disease in fish: a review with emphasis on bacterium-host interactions. *Veterinary Research* 44: 27. https://doi.org/10.1186/1297-9716-44-27.

Defoirdt, T. (2013). Virulence mechanisms of bacterial aquaculture pathogens and antivirulence therapy for aquaculture. *Reviews in Aquaculture* 6: 100–114.

de Jesus-Ayson, E.G. and Ayson, F.G. (2014). Reproductive biology of the Asian seabass, *Lates calcarifer*. In *Biology and Culture of Asian Seabass Lates calcarifer*, ed. D.R. Jerry, pp. 67–76. Boca Raton: *CRC Press*.

de la Fuente, J.L., Rodriguez-Saiz, M., Schleissner, C., Diez, B., Peiro, E. and Barredo, J.L. (2010). High-titer production of astaxanthin by the semi-industrial fermentation of *Xanthophyllomyces dendrorhous*. *Journal of Biotechnology* 148: 144–146.

Deng, S.P., Wu, B., Zhu, C.H. and Li, G.L. (2014). Molecular cloning and dimorphic expression of growth hormone (*gh*) in female and male spotted scat *Scatophagus argus*. *Fisheries Science* 80: 715–723.

Deveney, M.R., Chisholm, L.A. and Whittington, I.D. (2001). First published record of the pathogenic monogenean parasite *Neobenedenia melleni* (Capsalidae) from Australia. *Diseases of Aquatic Organisms* 46: 79–82.

Devlin, R., Sakhrania, D., Tymchuka, W., Rise, M. and Goha, B. (2009). Domestication and growth hormone transgenesis cause similar changes in gene expression in coho salmon (*Oncorhynchus kisutch*). *Proceedings of the National Academy of Sciences of the United States of America* 106: 3047–3052.

Dhasarathan, P., Pugazhenthi, M. and Valivittan, K. (2014). Analysis of humoral immune response of animals exposed to bacterial antigens. *Central European Journal of Immunology* 39: 323–326.

Diaz-Rosales, P., Chabrillon, M., Abdala, R.T., Figueroa, F.L., Balebona, M.C. and Morinigo, M.A. (2008). Effect of dietary administration of *Porphyridium cruentum* on the respiratory burst activity of sole, *Solea senegalensis* (Kaup), phagocytes. *Journal of Fish Disease* 31: 489–495.

Diener, A. and Rohrmann, S. (2016). Associations of serum carotenoid concentrations and fruit or vegetable consumption with serum insulin-like growth factor (IGF)-1 and IGF binding protein-3 concentrations in the Third National Health and Nutrition Examination Survey (NHANES III). *Journal of Nutritional Science* 5: e13. https://doi.org/10.1017/jns.2016.1.

Dong, H.T., Taengphu, S., Sangsuriya, P., Charoensapsri, W., Phiwsaiya, K., Sornwatana, T., Khunrae, P., Rattanarojpong, T. and Senapin, S. (2017). Recovery of *Vibrio harveyi* from scale drop and muscle necrosis disease in farmed barramundi, *Lates calcarifer* in Vietnam. *Aquaculture* 473: 89–96.

Dunkelberger, J. and Song, W. (2010). Complement and its role in innate and adaptive immune responses. *Cell Research* 20: 34–50.

Dursun, D. and Dalgic, A.C. (2016). Optimization of astaxanthin pigment bioprocessing by four different yeast using wheat wastes. *Biocatalysis and Agricultural Biotechnology* 7: 1–6.

Eales, J.G., Higgs, D.A., Uin, L.M., MacLatchy, D.L., Bres, O., McBride, J.R. and Dosanjh, B.S. (1990). Influence of dietary lipid and carbohydrate levels and chronic 3,5,3'-triiodo-L-thyronine treatment on thyroid function in immature rainbow trout, *Oncorhynchus mykiss*. *General and Comparative Endocrinology* 80: 146–154.

Ebeling, J.M. and Timmons, M.B. (2012). Recirculating aquaculture systems. In *Aquaculture Production Systems*, ed. J.H. Tidwell, pp. 245–277. Ames, IA: John Wiley and Sons Inc.

EFSA. (2005). Opinion of the scientific panel on additives and products or substances used in animal feed on the request from the European commission on the safety of use of colouring agents in animal human nutrition. *EFSA Journal* 291: 1–40.

EFSA. (2007a). Safety and efficacy of panaferd-AX (red carotenoid-rich bacterium *Paracoccus carotinifaciens*) as feed additive for salmon and trout. *EFSA Journal* 546: 1–30.

EFSA (2007b). Scientific opinion on the safety and efficacy of CAROPHYLL® Stay-Pink (astaxanthin dimethyldisuccinate) as feed additive for salmon and trout. *EFSA Journal* 574: 1–25.

EFSA (2014). Scientific opinion on the safety and efficacy of astaxanthin (CAROPHYLL® Pink 10% CWS) for salmonids and ornamental fish. *EFSA Journal* 12: 1–35.

EFSA (2020). Safety of astaxanthin for its use as a novel food in food supplements. *EFSA Journal* 18. https://doi.org/10.2903/j.efsa.2020.5993.

Ellis, A.E. (1990). Lysozyme assay. In *Techniques in fish immunology*, ed. J.S. Stolen, D.P. Fletcher, B.S. Anderson and B.S. Robertson, pp. 101–103. New Jersey: SOS Publication.

Eren, B., Tanriverdi, S.K., Kose, F.A. and Ozer, O. (2018). Antioxidant properties evaluation of topical astaxanthin formulations as anti-aging products. *Journal of Cosmetic Dermatology* 18: 242–250.

Espinosa, V. and Rivera, A. (2016). First line of defense: innate cell-mediated control of pulmonary aspergillosis. *Frontiers in Immunology* 7: 272. https://doi.org/10.3389/fmicb.2016.00272.

Esteban, M.A. (2012). An overview of the immunological defenses in fish skin. *ISRN Immunology* 2012: 853470. http://dx.doi.org/10.5402/2012/853470.

Fang, L., Zhang, J., Fei, Z. and Wan, M. (2020). Astaxanthin accumulation difference between non-motile cells and akinetes of *Haematococcus pluvialis* was affected by pyruvate metabolism. *Bioresources and Bioprocessing* 7: 5. https://doi.org/10.1186/s40643-019-0293-1.

FAO (2017). *FAO aquaculture newsletter*. Rome: Food and Agricultural Organization.

FAO (2018). *Fishstat plus version 2.30. Food and Agricultural Organization Fisheries Department, Fishery information, Data and Statistics Unit.* Retrieved from http://www.fao.org/fi/statist/FISOFT/FISHPLUS.

FAO (2020). *The state of world fisheries and aquaculture: Contributing to food security and nutrition for all.* Rome, Italy: Food and Agricultural Organization.

Farruggia, C., Kim, M., Bae, M., Lee, Y., Pham, T.X., Yang, Y., Han, M.J., Park, Y. and Lee, J. (2018). Astaxanthin exerts anti-inflammatory and antioxidant effects in macrophages in NFR2-dependent and independent manners. *The Journal of Nutritional Biochemistry* 62: 202–209.

Faruk, M.A.R. and Anka, I.Z. (2017). An overview of diseases in fish hatcheries and nurseries. *Fundamental and Applied Agriculture* 2: 311–316.

Fassett, R.G. and Coombes, J.S. (2011). Astaxanthin: a potential therapeutic agent in cardiovascular disease. *Marine Drugs* 9: 447–465.

Fawley, M.W. and Fawley, K.P. (2004). A simple and rapid technique for the isolation of DNA from microalgae. *Journal of Phycology* 40: 223–225.

Fazio, F., Filiciotto, F., Marafioti, S., Di Stefano, V., Assenza, A., Placenti, F., Buscaino, G., Piccione, G., and Mazzola, S. (2012). Automatic analysis to assess haematological parameters in farmed gilthead sea bream (*Sparus aurata* Linnaeus, 1758). *Marine and Freshwater Behaviour and Physiology 45*: 63–73.

Fazio, F., Ferrantelli, V., Saoca, C., Giangrosso, G. and Piccione, G. (2017). Stability of hematological parameters in stored blood samples of rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792). *Veterinarni Medicina (Praha)* 62: 401–405.

Feldman, T.A. and Wolfe, D. (2014). Tissue processing and hematoxylin and eosin staining. In: *Histopathology: Methods and Protocols*, ed. C.E. Day, pp. 31–43. USA: Humana Press.

Ferguson, H.W. (2006). Spleen, thymus, Reticulo-Endothelial system, blood. In: *Systemic Pathology of Fish: A Text and Atlas of Normal Tissues in Teleosts and their Responses in Disease*, ed. H.W. Ferguson, pp. 199–214. London (UK): Scotian Press.

Figueroa, J., San Martin, R., Flores, C., Grothusen, H. and Kausel, G. (2005). Seasonal modulation of growth hormone mRNA and protein levels in carp pituitary: evidence for two expressed genes. *Journal of Comparative Physiology B: Biochemical, Systemic and Environmental Physiology* 175: 185–192.

Foo, S.C., Yusoff, F.M., Ismail, M., Basri, M., Yau, S.K., Khong, M.H., Chan, K.W. and Ebrahimi, M. (2017). Antioxidant capacities of fucoxanthin-producing algae as influenced by their carotenoid and phenolic contents. *Journal of Biotechnology* 10: 175–183.

Forn-Cuni, G., Reis, E.S., Dios, S., Posada, D., Lambris, J.D., Figueras, A. and Novoa, B. (2014). The evolution and appearance of C3 duplications in fish originate an exclusive teleost c3 gene form with anti-inflammatory activity. *PLOS ONE* **9**: e99673. https://doi.org/10.1371/journal.pone.0099673.

Frank, J.A., Reich, C.I., Sharma, S., Weisbaum, J.S., Wilson, B.A. and Olsen, G.J. (2008). Critical evaluation of two primers commonly used for amplification of bacterial 16S rRNA genes. *Applied and Environmental Microbiology* 74: 2461–2470.

Franz, A., Faass, O., Kollner, B., Shved, N., Link, K., Casanova, A., Wenger, M., D'Cotta, H., Baroiller, J., Ullrich, O., Reinecke, M. and Eppler, E. (2016). Endocrine and local IGF-I in the bony fish immune system. *Biology* 5: E9. https://doi.org/10.3390/biology5010009.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology* 22: 241–253.

Gabriel, N.N., Qiang, J., He, J., Ma, X.Y., Kpundeh, M.D. and Xu, P. (2014). Dietary *Aloe vera* supplementation on growth performance, some haemato-biochemical parameters and disease resistance against *Streptococcus iniae* in tilapia (GIFT). *Fish and Shellfish Immunology* 44: 504–514.

Galasso, C., Corinaldesi, C. and Sansone, C. (2017). Carotenoids from marine organisms: biological functions and industrial applications. *Antioxidants (Basel)* 6: 96. https://doi.org/10.3390/antiox6040096.

Galasso, C., Orefice, I., Pellone, P., Cirino, P., Miele, R., Ianora, A., Brunet, C. and Sansone, C. (2018). On the neuroprotective role of astaxanthin: new perspective? *Marine Drugs* 16: 247. https://doi.org/10.3390/md16080247.

Galindo-Villegas, J., Fukada, H., Masumoto, T. and Hosokawa, H. (2006). Effect of dietary immunostimulants on some innate immune responses and disease resistance against *Edwardsiella tarda* infection in Japanese flounder (*Paralichthys olivaceus*). *Aquaculture Science* 54: 153–162.

Gao, L., He, C., Liu, X., Su, H., Gao, X., Li, Y. and Liu, W. (2012a). The innate immune-related genes in catfish. *International journal of molecular sciences* 13: 14172–14202.

Gao, Z., Meng, C., Zhang, X., Xu, D., Zhao, Y., Wang, Y., Lv, H., Yang, L., Chen, L. and Ye, N. (2012b). Differential expression of carotenogenic genes, associated changes on astaxanthin production and photosynthesis features induced by JA in *H. pluvialis*. *PLOS ONE* 7: e42243. https://doi.org/10.1371/journal.pone.0042243.

Gao, X., Pi, D., Chen, N., Li, X., Liu, X., Yang, H., Wei, W. and Zhang, X. (2018). Survival, virulent characteristics, and transcriptomic analyses of the pathogenic *Vibrio anguillarum* under starvation stress. *Frontiers in Cellular and Infection Microbiology* 8: 389. https://doi.org/10.3389/fcimb.2018.00389.

Gaylord, T.B. and Gatlin III, D.M. (2001). Dietary protein and energy modifications to maximize compensatory growth of channel catfish (*Ictalurus punctatus*). *Aquaculture* 194: 337–348.

Gervasi, T., Santini, A., Daliu, P., Salem, A., Gervasi , C., Pellizzeri, V., Barrega, L., De Pasquale, P., Dugo, G. and Cicero, N. (2019). Astaxanthin production by *Xanthophyllomyces dendrorhous* growing on a low cost substrate. *Agroforest System*. https://doi.org/10.1007/s10457-018-00344-6.

Gerwich, L., Steinhauer, R., Lapatra, S., Sandell, T., Ortuno, J. and Hajiseyedjavadi, N. (2002). The acute phase response of rainbow trout (*Oncorhynchus mykiss*) plasma protein to viral, bacterial and fungal inflammatory agents. *Fish and Shellfish Immunology* 12: 242–299.

Giannelli, L., Yamada, H., Katsuda, T. and Yamaji, H. (2015). Effects of temperature on the astaxanthin productivity and light harvesting characteristics of the green alga *Haematococcus pluvialis*. *Journal of Bioscience and Bioengineering* 119: 345–350.

Gjedrem, T. and Baranski, M. (2009). Initiating breeding programs. In *Selective Breeding in Aquaculture: An Introduction*, ed. T. Gjedrem and M. Baranski, pp. 63–85. New York: Springer.

Gjedrem, T. and Robinson, N. (2014). Advances by selective breeding for aquatic species: a review. *Agricultural Sciences* 5: 1152–1158.

Glencross, B. (2006). The nutritional management of barramundi, *Lates calcarifer*-a review. *Aquaculture Nutrition* 12: 291–309.

Glencross, B.D., Booth, M. and Allan, G.L. (2007). A feed is only as good as its ingredients – a review of ingredients evaluation strategies of aquaculture feeds. *Aquaculture Nutrition* 13: 17–34.

Glencross, B., Blyth, D., Irvin, S., Bourne, N. and Wade, N. (2014). An analysis of the effects of different dietary macronutrient energy sources on the growth and energy partitioning by juvenile barramundi, *Lates calcarifer*, reveal a preference for protein-derived energy. *Aquaculture Nutrition* 20: 583–594.

Godhe, A., Anderson, D.M. and Rehnstam-Holm, A. (2002). PCR amplification of microalgal DNA for sequencing and species identification: studies on fixatives and algal growth stages. *Harmful Algae* 1: 375–382.

Gomes, E., Dias, J., Silva, P., Valente, L., Empis, J., Gouveia, L., Bowen, J. and Young, A. (2002). Utilization of natural and synthetic sources of carotenoids in the skin pigmentation of gilthead seabream (*Sparus aurata*). *European Journal of Food Research and Technology* 214: 287–293.

Gomez-Leon, J., Villamil, L., Lemos, M.L., Novoa, B. and Figueras, A.(2005). Isolation of *Vibrio alginolyticus* and *Vibrio splendidus* from aquacultured carpet shell clam (*Ruditapes decussatus*) larvae associated with mass mortalities. *Applied and Environmental Microbiology* 71: 98–104.

Gorissen, M. and Flik, G. (2016). The endocrinology of the stress response in fish: an adaptation-physiological view. In *Biology of Stress in Fish: Fish Physiology*, ed. C.B. Schreck, L. Tort, A.P. Farrell and C.J. Brauner, pp. 75–111. Cambridge, MA: Academic Press-Elsevier.

Gou, C., Wang, J., Wang, Y., Dong, W., Shan, X., Lou, Y. and Gao, Y. (2018). *Hericium caputmedusae* (bull.:fr.) pers. polysaccharide enhance innate immune response, immunerelated genes expression and disease resistance against *Aeromonas hydrophila* in grass carp (*Ctenopharyngodon idella*). *Fish and Shellfish Immunology* 72: 604–613.

Gouveia, L., Choubert, G., Gomez, E., Rema, P. and Empis, J. (1998). Use of *Chlorella vulgaris* as a carotenoid source for rainbow trout: effect of dietary lipid content on pigmentation, digestibility and retention in the muscle tissue. *Aquaculture International* 6: 269-279.

Gowda, S., Desai, P.B., Hull, V.V., Math, A.A., Vernekar, S.N. and Kulkarni, S.S. (2009). A review on laboratory liver function tests. *Pan African Medical Journal* 3: 17.

Grayfer, L., Kerimoglu, B., Yaparla, A., Hodgkinson, J.W., Xie, J. and Belosevic, M. (2018). Mechanisms of fish macrophage antimicrobial immunity. *Frontiers in Immunology* 9: 1105. https://doi.org/10.3389/fimmu.2018.01105.

Grung, M., Metzger, P. and Liaaen-Jensen, S. (1994). Algal carotenoids 53: secondary carotenoids of algae 4. Secondary carotenoids in the green alga *Botryococcus braunii*, race L, new strain. *Biochemical Systematic and Ecology* 22: 25–29.

Gu, W., Xie, X., Gao, S., Zhou, W. and Pan, G. (2013). Comparison of different cells of *Haematococcus pluvialis* reveals an extensive acclimation mechanism during its aging process: from a perspective of photosynthesis. *PLOS ONE* 8: e67028. https://doi.org/10.1371/journal.pone.0067028.

Gunerken, E., D'Hondt, E., Eppink, M., Elst, K. and Wijffels, R. (2016). Influence of nitrogen depletion in the growth of *N. oleoabundans* on the release of cellular components after beadmilling. *Bioresource Technology* 214: 89–95.

Gupta, S.K., Pal, A.K., Sahu, N.P., Dalvi, R., Kumar, V. and Mukherjee, S.C. (2008). Microbial levan in the diet of *Labeo rohita* Hamilton juveniles: effect of non-specific immunity and histopathological changes after challenge with *Aeromonas hydrophila*. *Journal of Fish Diseases* 31: 649–657.

Haddad, N.F., Teodoro, A.J., de Oliveira, F.L., Soares, N., de Mattos, R.M., Hecht, F., Dezonne, R.S., Vairo, L., Goldenberg, R., Gomes, F., de Carvalho, D.P., Gadelha, M.R., Nasciutti, L.E. and Miranda-Alves, L. (2013). Lycopene and beta-carotene induce growth inhibition and proapoptotic effects on ACTH-secreting pituitary adenoma cells. *PLOS ONE* 11: e0149157. https://doi.org/10.1371/journal.pone.0062773.

Haenen, O.L.M., Evans, J.J. and Berthe, F. (2013). Bacterial infections from aquatic species: potential for and prevention of contact zoonoses. *Revue Scientifique et Technique (International Office of Epizootics)* 32: 497–507.

Hallerman, E.M., McLean, E. and Fleming, I.A. (2007). Effect of growth hormone transgenes on the behavior and welfare of aquacultured fishes: a review identifying research needs. *Applied Animal Behaviour Science* 104: 265–294.

Halliwell, B. (2008). Are polyphenols antioxidants or pro-oxidants? What do we learn from cell culture and in vivo studies? *Archives of Biochemistry and Biophysics* 476: 107–112.

Halver, J.E. and Hardy, R.W. (2002). Nutrient flow and retention. In *Fish Nutrition*, ed. J.E. Halver and R.W. Hardy, pp 756–769. San Diego, CA: Academic Press.

Hamid, R., Ahmad, A. and Usup, G. (2016). Pathogenicity of Aeromonas hydrophila isolated from the Malaysia sea against coral (*Turbinaria* sp.) and sea bass (*Lates calcarifer*). *Environmental Science and Pollution Research* 23: 17269–17276.

Han, D., Li, Y. and Hu, Q. (2013). Astaxanthin in microalgae: pathway, functions and biotechnological implications. *Algae* 28: 131–147.

Handeland, S.O., Imsland, A.K., Bjornsson, B.T. and Stefansson, S.O. (2013). Long-term effects of photoperiod, temperature and their interaction on growth, gill NA^+, K^+-ATPase activity, seawater tolerance and plasma growth-hormone levels in Atlantic salmon *Salmo salar*. *Journal of Fish Biology* 83: 1197–1209.

Hansen, O.J., Puvanendran, V. and Bangera, R. (2016). Broodstock diet with water and astaxanthin improve condition and egg output of brood fish and larval survival in Atlantic cod, *Gadus morhua* L. *Aquaculture Research* 47: 819–829.

Harrison, P., Calogeras, C. and Phillips, M. (2014). Farming of barramundi/Asian seabass: an Australian industry perspective. In *Biology and culture of Asian Seabass Lates calcarifer*, ed. D.R. Jerry, pp. 258–272. Boca Raton, FL: CRC Press.

Hashish, E., Merwad, A., Elgaml, S., Amer, A., Kamal, H., Elsadek, A., Marei, A. and Sitohy, M. (2018). *Mycobacterium marinum* infection in fish and man: epidemiology, pathophysiology and management; a review. *Veterinary Quarterly* 38: 35–46.

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

Henryon, M., Jokumsen, A., Berg, P., Lund, I., Pedersen, P.B., Olesen, N.J. and Slierendrecht, W.J. (2002). Genetic variation for growth rate, feed conversion efficiency and disease resistance exists within a farmed population of rainbow trout. *Aquaculture* 209: 59–76.

Hiyoshi, H., Kodama, T., Iida, T. and Honda, T. (2010). Contribution of *Vibrio parahaemolyticus* virulence factors to cytotoxicity, enterotoxicity, and lethality in mice. *Infection and Immunity* 78: 1772–1780.

Ho, Y.H., Leung, H.M., Yuen, S.Y., Ng, K.S., Li, T.S., Yuen, L.M. and Wong, Y.K. (2018). Maximization of astaxanthin production from green microalga *Haematococcus pluvialis* using internally-illuminated photobioreactor. *Advance in Bioscience and Bioengineering* 6: 10–22.

Hoai, T.D. and Hutson, K.S. (2014). Reproductive strategies of the insidious fish ectoparasite, *Neobenedenia* sp. (Capsalidae: Monogenea). *PLOS ONE* 10: e0117881.https://doi.org/10.1371/journal.pone.011781.

Hossain, M.Y., Ahmed, Z.F., Leunda, P.M., Jasmine, S., Oscoz, J., Miranda, R. and Ohtomi, J. (2006). Condition, length-weight and length-length relationships of the Asian striped catfish *Mystus vittatus* (Bloch, 1794) (Siluriformes: Bagridae) in the Mathabhanga River, southwestern Bangladesh. *Journal of Applied Ichthyology* 22: 304–307.

Hu, I. (2019). Chapter 14 - Production of potential coproducts from microalgae. In *Biofuels from Algae*, ed. A. Pandey, J. Chang, C.S. Soccol, D. Lee and Y. Chisti, pp. 345–358. Cambridge, MA: Elsevier.

Hussein, G., Nakagawa, T., Goto, H., Shimada, Y., Matsumoto, K., Sankawa, U. and Watanabe, H. (2007). Astaxanthin ameliorates features of metabolic syndrome in SHR/NDmcr-cp. *Life Sciences* 80: 522–529.

Hutson, K.S. (2014). Infectious diseases of Asian seabass and health management. In *Biology and Culture of Asian Seabass Lates calcarifer*, ed. D.R. Jerry, pp. 102–136. Boca Raton, USA: CRC Press.

Imamoglu, E., Dalay, M.C. and Sukan, F.V. (2009). Influences of different stress media and high light intensities on accumulation of astaxanthin in the green algae *Haematococcus pluvialis*. *New Biotechnology* 26: 199–204.

Ina-Salwany, M.Y., Al-Saari, N., Mohamad, A., Mursidi, F.A., Mohd-Aris, A., Amal, M.N.A., Kasai, H., Mino, S., Sawabe, T. and Zamri-Saad, M. (2019). Vibriosis in fish: a review on disease development and prevention. *Journal of Aquatic Animal Health* 31: 3–22.

Inbaraj, B.S., Chien, J. T. and Chen, B.H. (2006). Improved high performance liquid chromatographic method for determination of carotenoids in the microalga *Chlorella pyrenoidosa*. *Journal of Chromatography A* 1102: 193–199.

Ip, P.F. and Chen, F. (2005). Employment of reactive oxygen species to enhance astaxanthin formation in *Chlorella zofingiensis* in heterotrophic culture. *Process Biochemistry* 40: 3491–3496.

Ivanova, I.P., Trofimova, S.V. and Piskarev, I.M. (2013). Evaluation of prooxidant properties of ascorbic acid. *Biofizika* 58: 582–586.

Iwabayashi, M., Fujioka, N., Nomoto, K., Miyazaki, R., Takahashi, H., Hibino, S., Takahashi, Y., Nishikawa, K., Nishida, M. and Yonei, Y. (2009). Efficacy and safety of eight-week treatment with astaxanthin in individuals screened for increased oxidative stress burden. *Journal of Anti-Aging Medicine* 6: 15–21.

Jabeen, G., Manzoor, F., Javid, A., Azmat, H., Arshad, M. and Fatima, S. (2018). Evaluation of fish health status and histopathology in gills and liver due to metal contaminated sediments exposure. *Bulletin of Environmental Contamination and Toxicology* 100: 492–501.

Jagruthi, C., Yogeshwari, G., Anbazahan, S.M., Mari, L., Arockiaraj, J., Mariappan, P., Sudhakar, G.R., Balasundaram, C. and Harikrishnan, R. (2014). Effect of dietary astaxanthin against *Aeromonas hydrophila* infection in common carp *Cyprinus carpio*. *Fish Shellfish Immunology* 41: 674–680.

Jain, A.K., Kumar, G. and Mukherjee, S.C. (2006). Survival and growth of early juveniles of barramundi, *Lates calcarifer* (Bloch, 1790) in inland saline groundwater. *Journal of Biological Research* 5: 93–97.

James, R., Sampath, K., Thangarathinam, R. and Vasudevan, I. (2006) Effect of dietary spirulina level on growth, fertility, coloration and leucocyte count in red swordtail, *Xiphophorus helleri*. *The Israeli Journal of Aquaculture* 58: 97–104.

Jannel, S., Caro, Y., Bermudes, M. and Petit, T. (2020). Novel insights into the biotechnological production of *Haematococcus pluvialis*-derived astaxanthin: advances and key challenges to allow its industrial use as novel food ingredient. *Journal of Marine Science and Engineering* 8: 10. https://doi.org/10.3390/jmse8100789.

Javed, M., Ahmad, I., Ahmad, A., Usmani, N. and Ahmad, M. (2016). Studies on the alteration in haematological indices, micronuclei induction and pathological marker enzyme activities in *Channa punctatus* (spotted snakehead) perciformes, channidae exposed to thermal power plant effluent. *Springerplus* 5: 761. https://doi.org/10.1186/s40064-016-2478 9.

Jiang, Y., Feng, S., Zhang, S., Liu, H., Feng, J., Mu, X., Sun, X. and Xu, P. (2016). Transcriptome signatures in common carp spleen in response to *Aeromonas hydrophila* infection. *Fish and Shellfish Immunology* 57: 41–48.

Jin, J., Yao, M., Gu, X., Li, B., Liu, H., Ding, M., Xiao, W. and Yuan, Y. (2018). Astaxanthin overproduction in yeast by strain engineering and new gene target covering. *Biotechnology for Biofuels* 11: 230. https://d oi.org/10.1186/s13068-018-1227-4.

Joerakate, W., Yenmak, S., Senanan, W., Tunkijjanukij, S., Koonawootrittriron, S. and Poompuang, S. (2018). Growth performance and genetic diversity in four strains of Asian sea bass, *Lates calcarifer* (Bloch, 1790) cultivated in Thailand. *Agriculture and Natural Resources* 52: 93–98.

Jorgensen, J.B. (2014). The innate immune response in fish. In *Fish Vaccination*, ed. R. Gudding, A. Lillehaug and O. Evensen, pp. 85–103. New Jersey: John Wiley and Sons.

Jovanovic, B., Whitley, E.M. and Palic, D. (2014). Histopathology of fathead minnow (*Pimephales promelas*) exposed to hydroxylated fullerenes. *Nanotoxicology* 8: 755–762.

Jyonouchi, H., Zhang, L. and Tomita, Y. (1993). Studies of immunomodulating actions of carotenoids II. Astaxanthin enhances in vitro antibody production to T dependent antigens without facilitating polyclonal B-cell activation. *Nutrition and Cancer* 19: 269–280.

Jyonouchi, H., Zhang, L., Gross, M. and Tomita, Y. (1994). Immunomodulating actions of carotenoids: enhancement of in vivo and in vitro antibody production to T-dependent antigens. *Nutrition and Cancer* 21: 47–58.

Jyonouchi, H., Sun, S. and Gross, M. (1995). Effect of carotenoids on in vitro immunoglobulin production by human peripheral blood mononuclear cells: astaxanthin, a carotenoid without vitamin A activity, enhances in vitro immunoglobulin production in response to a T-dependent stimulant and antigen. *Nutrition and Cancer* 23: 171–183.

Kailasam, M., Thirunavukkarasu, A.R., Abraham, M., Chandra, P.K. and Subburaj, R. (2002). Influence of size variation and feeding on cannibalism of Asian sea bass *Lates calcarifer* (Bloch) during hatchery rearing. *Indian Journal of Fisheries* 49: 107–111.

Kalinowski, C.T., Robaina, L.E., Fernandez-Palacios, H., Schuchardt, D. and Izquierdo, M.S. (2005). Effect of different carotenoid sources and their dietary levels on red porgy (*Pagrus pagrus*) growth and skin colour. *Aquaculture* 244: 223–231.

Kalinowski, C.T., Robaina, L.E. and Izquierdo, M.S. (2011). Effect of dietary astaxanthin on the growth performance, lipid composition and post-mortem skin colouration of red porgy *Pagrus pagrus*. *Aquaculture International* 19: 811–823.

Kattappagari, K.K., Ravi Teja, C.S., Kommalapati, R.K., Poosarla, C., Gontu, S.R. and Reddy, B.V. (2015). Role of antioxidants in facilitating the body functions: a review. *Journal of Orofacial Sciences* 7: 71–75.

Katersky, R.S. and Carter, C.G. (2005). Growth efficiency of juvenile barramundi, *Lates calcarifer*, at high temperatures. *Aquaculture* 250: 775–780.

Katsumata, T., Ishibashi, T. and Kyle, D. (2014). A sub-chronic toxicity evaluation of a natural astaxanthin-rich carotenoid extract of *Paracoccus carotinifaciens* in rats. *Toxicology Reports* 1: 582–588.

Kaur, G., Khattar, J., Singh, D., Singh, Y. and Jeevesh, N. (2009). Microalgae: a source of natural colours. In: *Algal Biology and Biotechnology*, ed. J. Khattar, D. Singh, D. and G. Kaur, pp. 129–149. New Delhi: I.K. International Publishing House Pvt. Ltd.

Kayansamruaj, P., Dong, H.T., Nguyen, V.V., Le, H.D., Pirarat, N. and Rodkhum, C. (2017). Susceptibility of freshwater rearing Asian seabass (*Lates calcarifer*) to pathogenic *Streptococcus iniae*. *Aquaculture Research* 48: 711–718.

Khalil, N.A. and Mousa, M.A. (2013). Experimental study on the activation of growth hormone secreting cells during larval development of Nile tilapia, *Oreochromis niloticus*. *The Egyptian Journal of Aquatic Research* 39: 67–74.

Khang, P.V., Phuong, T.H., Dat, N.K., Knibb, W. and Nguyen, N.H. (2018). An 8-year breeding program for Asian seabass *Lates calcarifer*: genetic evaluation, experiences, and challenges. *Frontiers in Genetics* 9: 191. https://doi.org/10.3389/fgene.2018.00191.

Khang, P.V., Nha, V.V. and Nguyen, N.H. (2019). Resistance to *Streptococcus iniae* and its genetic associations with traits of economic importance in Asian seabass (*Lates calcarifer*). *Journal of Fish Disease* 42:1657–1666.

Khoa, T.N.D., Mazelan, S., Muda, S. and Shaharom-Harrison, F. (2019). Use of neem oil (*Azadirachta indica*) to control caligid copepod infestation on Asian seabass (*Lates calcarifer*). *Aquaculture Research* 50: 1885–1892.

Khouadja, S., Lamari, F. and Bakhrouf, A. (2013). Characterization of *Vibrio parahaemolyticus* isolated from farmed seabass (*Dicentrarchus labrax*) during disease outbreaks. *International Aquatic Research* 5: 13.https:// doi.org/10.1186/2008-6970-5-13.

Kim, Y.K. and Chyun, J.H. (2004). The effects of astaxanthin supplements on lipid peroxidation and antioxidant status in postmenopausal women. *Journal of Nutritional Science* 7: 41–46.

Kim, J.H., Chang, M.J., Choi, H.D., Youn, Y.K., Kim, J.T., Oh, J.M. and Shin, W.G. (2011). Protective effects of *Haematococcus* astaxanthin on oxidative stress in healthy smokers. *Journal of Medicinal Food* 14: 1469–1475.

Kim, D., Vijayan, D., Ramasamy, P. and Oh, Y. (2016). Cell-wall disruption and lipid/astaxanthin extraction from microalgae: *Chlorella* and *Haematococcus*. *Bioresource Technology* 199: 300–310.

Kim, J., Lee, C., Jeon, M., Park, J. and Choi, Y. (2018). Enhancement of microalga *Haematococcus pluvialis* growth and astaxanthin production by electrical treatment. *Bioresource Technology* 268: 815–819.

Kiron, V. (2012). Fish immune system and its nutritional modulation for preventive health care. *Animal Feed Science and Technology* 173: 111–133.

Kishimoto, Y., Tani, M., Uto-Kondo, H., Iizuka, M., Saita, E., Sone, H., Kurata, H. and Kondo, K. (2010). Astaxanthin suppresses scavenger receptor expression and matrix metalloproteinase activity in macrophages. *European Journal of Nutrition* 49: 119–126.

Kishimoto, Y., Yoshida, H. and Kondo, K. (2016). Potential anti-atherosclerotic properties of astaxanthin. *Marine Drugs* 14: 35.https://doi.org/10.3390/md14020035.

Klochkova, T.A., Kwak, M.S., Han, J.W., Motomura, T., Nagasato, C. and Kim, G.H. (2013). Cold-tolerant strain of *Haematococcus pluvialis* (Haematococcaceae,Chlorophyta) from Blomstrandhalvoya (Svalbard). *Algae* 28: 185–192.

Kobayashi, M., Kurimura, Y. and Tsuji, Y. (1997). Light-independent, astaxanthin production by the green microalga *Haeamatococcus pluvialis* under salt stress. *Biotechnology Letters* 19: 507–509.

Kobayashi, S.I., Alimuddin, Morita, T., Miwa, M., Lu, J., Endo, M., Takeuchi, T. and Yoshizaki, G. (2007). Transgenic Nile tilapia *Oreochromis niloticus* over-expressing growth hormone show reduced ammonia excretion. *Aquaculture* 270: 427–435.

Koller, M., Muhr, A. and Braunegg, G. (2014). Microalgae as versatile cellular factories for valued products. *Algal Research* 6: 52–63.

Kordon, A.O., Karsi, A. and Pinchuk, L. (2018). Innate immune responses in fish: antigen presenting cells and professional phagocytes. *Turkish Journal of Fisheries and Aquatic Sciences* 18: 1129–1139.

Kothari, R., Pandey, A., Ahmad, S., Kumar, A., Pathak, V.V. and Tyagi, V.V. (2017). Microalgal cultivation for value-added products: a critical enviro-economical assessment. *3 Biotech* 7: 243. https://doi.org/10.1007/s13205-017-0812-8.

Kuhn, R. and Soerensen, N.A. (1938). The coloring matters of the lobster (*Astacus gammarus* L). *Zeitschrift Fur Angewandte Chemie* 51: 465–466.

Kumar, S.R., Parameswaran, V., Ahmed, V.P., Musthaq, S. and Hameed, A.S. (2007). Protective efficiency of DNA vaccination in Asian seabass (*Lates calcarifer*) against *Vibrio anguillarum*. *Fish and Shellfish Immunology* 23: 316–326.

Kumar, V., Pillai, B.R., Sahoo, P.K., Mohanty, J. and Mohanty, S. (2009). Effect of dietary astaxanthin on growth and immune response of giant freshwater prawn *Macrobrachium rosenbergii* (De Man). *Asian Fisheries Science Journal* 22: 61–69.

Kumar, R., Salwe, K.J. and Kumarappan, M. (2017). Evaluation of antioxidant, hypolipidemic, and antiatherogenic property of leucopene and astaxanthin in atherosclerosis-induced rats. *Pharmacognosy Research* 9: 161–167.

Kumaran, S., Deivasigamani, B., Alagappan, K.M. and Sakthivel, M. (2010). Infection and immunization trials of Asian sea bass (*Lates calcarifer*)

against fish pathogen *Vibrio anguillarum*. *Journal of Environmental Biology* 31: 539–541.

Kupcinskas, L., Lafolie, P., Lignell, A., Kiudelis, G., Jonaitis, L., Adamonis, K., Andersen, L.P. and Wadstrom, T. (2008). Efficacy of the natural antioxidant astaxanthin in the treatment of functional dyspepsia in patients with or without *Helicobacter pylori* infection: a prospective, randomized,double blind, and placebo-controlled study. *Phytomedicine* 15: 391–399.

Kurdianto, Alimuddin, Faridah, N., Yoshizaki, G., Nuryati, S. and Setiawati, M. (2016). Growth, survival, and body composition of transgenic common carp *Cyprinus caprio* 3rd generation expressing tilapia growth hormone cDNA. HAYATI *Journal of Biosciences* 23: 150–154.

Laith, A.A., Mazlan, A.G., Effendy, A.W., Ambak, M.A., Nurhafizah, W.W.I., Alia, A.S., Jabar, A. and Najiah, M. (2017). Effect of *Excoecaria agallocha* on non-specific immune responses and disease resistance of *Oreochromis niloticus* against *Streptococcus agalactiae*. *Research in Veterinary Science* 112: 192–200.

Laleye, P.A. (2006). Length weight and length-length relationship of fishes from the Oueme river in Benin (West Africa). *Journal of Applied Ichthyology*, 22: 330–333.

Lau, L., Hatai, K., Fukano, H. and Kurata, O. (2018). First report of *Achlya oblongata* infection in freshwater-reared Asian Seabass *Lates calcarifer*. *Journal of Aquatic Animal Health* 30: 239–244.

Lee, Y.K. and Shen, H. (2004). Basic culturing techniques for microalgae. In *Handbook of microalgal Culture, Biotechnology and Applied Phycology*, ed. A. Richmond, pp. 40–56. USA: Blackwell Publishing Limited.

Lee, M.S. and Kim, Y.J. (2007). Signaling pathways downstream of pattern-recognition receptors and their cross talk. *Annual Review of Biochemistry*, 76: 447–480.

Leite, M.F., de Lima, A.M., Kang, S.J.S., dos Santos, M.T.B.R. and Otton, R. (2014). Effect of astaxanthin and fish oil on enzymatic antioxidant system and α-amylase activity of salivary glands from rats. *Brazilian Journal of Oral Sciences* 13: 1. https://doi.org/10.1590/16773225v13n1a12.

Lemoine, Y. and Schoefs, B. (2010). Secondary ketocarotenoid astaxanthin biosynthesis in algae: a multifunctional response to stress. *Photosynthesis Research* 106: 155–177.

Leonardi, M., Sandino, A.M. and Klempau, A. (2003). Effect of a nucleotide-enriched diet on the immune system, plasma cortisol levels and resistance to infectious pancreatic necrosis (IPN) in juvenile rainbow

trout (*Oncorhynchus mykiss*). *Bulletin of the European Association of Fish Pathologists* 23: 52–59.

Leong, T.S. and Wong, S.Y. (1990). Parasites of Healthy and Diseased Juvenile Grouper (*Epinephelus malabaricus* (Bloch and Schneider)) and Seabass (*Lates calcarifer* (Bloch)) in Floating Cages in Penang, Malaysia. *Asian Fisheries Science* 3: 319–327.

Leung, T.L.F. and Bates, A.E. (2013). More rapid and severe disease outbreaks for aquaculture at the tropics: implications for food security. *Journal of Applied Ecology* 50: 215–222.

Li, Y., Huang, J., Sandmann, G. and Chen, F. (2008). Glucose sensing and the mitochondrial alternative pathway are involved in the regulation of astaxanthin biosynthesis in the dark-grown *Chlorella zofingiensis* (Chlorophyceae). *Planta* 228: 735–743.

Li, J., Zhu, D., Niu, J., Shen, S. and Wang, G. (2011). An economic assessment of astaxanthin production by large scale cultivation of *Haematococcus pluvialis*. *Biotechnology Advances* 29: 568–574.

Li, Y.H., Liu, Y.J., Xu, X.L., Jin, M., An, L.Z., Zhang, H. (2012). Effect of 2,4-epibrassinolide on drought stress-induced changes in *Chorispora bungeana*. *Biologia Plantarum* 56: 192–196.

Li, M., Wu, W., Zhou, P., Xie, F., Zhou, Q. and Mai, K. (2014). Comparison effect of dietary astaxanthin and *Haematococcus pluvialis* on growth performance, antioxidant status and immune response of large yellow croaker *Pseudosciaena crocea*. *Aquaculture* 434: 227–232.

Li, Y., Cui, D., Zhuo, P., Zhang, L., Sun, X. and Xu, N. (2018). A new approach to promote astaxanthin accumulation via Na_2WO_4 in *Haematococcus pluvialis*. *Journal of Oceanography and Limnology* 37: 176–185.

Li, B., Li, Z., Sun, Y., Wang, S., Huang, B. and Wang, J. (2019a). Effects of dietary lysolecithin (LPC) on growth, apparent digestibility of nutrient and lipid metabolism in juvenile turbot *Scophthalmus maximus* L. *Aquaculture and Fisheries* 4: 61–66.

Li, M., Zhu, X., Tian, J., Liu, M. and Wang, G. (2019b). Dietary flavonoids from *Allium mongolicum* Regel promotes growth, improves immune, antioxidant status, immune-related signaling molecules and disease resistance in juvenile northern snakehead fish (*Channa argus*). *Aquaculture* 501: 473–481.

Li, F., Cai, M., Lin, M., Huang, X., Wang, J., Zheng, X., Wu, S. and An, Y. (2019c). Accumulation of astaxanthin was improved by the nonmotile cells of *Haematococcus pluvialis*. *BioMed Research International* 2019: 8101762. https://doi.org/10.1155/2019/8101762.

Lin, K., Lin, K., Lu, W., Thomas, P., Jayakumar, T. and Sheu, J. (2016). Astaxanthin, a carotenoid, stimulate immune responses by enhancing IFN-ɣ and IL-2 secretion in primary cultured lymphocytes in vitro and ex vivo. *International Journal of Molecular Sciences* 17: 44. https://doi.org/1010.3390/ijms17010044.

Lin, Y.J., Lin, J.Y., Wang, D.S., Chen, C.H. and Chiou, M.H. (2017). Safety assessment of astaxanthin derived from engineered *Escherichia coli* K-12 using a 13-week repeated dose oral toxicity study and a prenatal developmental toxicity study in rats. *Regulatory Toxicology and Pharmacology* 87: 95–105.

Liu, F., Shi, H.Z., Guo, Q.S., Yu, Y.B., Wang, A.M., Lv, F. and Shen, W.B. (2016). Effects of astaxanthin and emodin on the growth, stress resistance and disease resistance of yellow catfish (*Pelteobagrus fulvidraco*). *Fish and Shellfish Immunology* 51: 125–135.

Lieschke, G.J. and Trede, N.S. (2009). Fish Immunology. *Current Biology (Primer)* 19: 678–682.

Lim, K.C., Yusoff, F.M., Shariff, M. and Kamarudin, M.S. (2018). Astaxanthin as feed supplement in aquatic animals. *Reviews in Aquaculture* 10: 738–773.

Lim, K.C., Yusoff, F.M., Shariff, M., Kamarudin, M.S. and Nagao, N. (2019a). Dietary supplementation of astaxanthin enhances hemato-biochemistry and innate immunity of Asian seabass, *Lates calcarifer* (Bloch, 1790). *Aquaculture* 512: 734339. https://doi.org/10.1016/j.aquaculture.2019.734339.

Lim, K.C., Yusoff, F.M., Shariff, M. and Kamarudin, M.S. (2019b). Dietary administration of astaxanthin improves feed utilization, growth performance and survival of Asian seabass, *Lates calcarifer* (Bloch, 1790). *Aquaculture Nutrition* 25: 1410–1421.

Liu, F., Shi, H.Z., Guo, Q.S., Yu, Y.B., Wang, A.M., Lv, F. and Shen, W.B. (2016). Effects of astaxanthin and emodin on the growth, stress resistance and disease resistance of yellow catfish (*Pelteobagrus fulvidraco*). *Fish and Shellfish Immunology* 51: 125–135.

Little, D.C., Newton, R. and Beveridge, M. (2016). Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proceedings of the Nutrition Society* 75: 274–286.

Loughnan, S.R., Domingos, J.A., Smith-Keune, C., Forrester, J.P., Jerry, D.R., Beheregaray, L.B. and Robinson, N.A. (2013). Broodstock contribution after mass spawning and size grading in barramundi (*Lates calcarifer*, Bloch). *Aquaculture* 404–405:139–149.

Lorenz, M., Friedl, T. and Day, J.G. (2005). Perpetual maintenance and actively metabolizing microalgal cultures. In *Algae Culturing*

Techniques, ed. R. Andersen, 578 pp. California: Elsevier Academic Press.

Ludwig, K., Grabhorn, E., Bitzan, M., Bobrowski, C., Kemper, M.J., Sobottka, I., Laufs, R., Karch, H. and Muller-Wiefel, D.E. (2002). Saliva IgM and IgA are a sensitive indicator of the humoral immune response to *Escherichia coli* O157 lipopolysaccharide in children with enteropathic hemolytic uremic syndrome. *Pediatric Research* 52: 32–48.

Lugert, V., Thaller, G., Tetens, J., Schulz, C. and Krieter, J. (2016). A review on fish growth calculation: Multiple functions in fish production and their specific application. *Reviews in Aquaculture* 8: 30–42.

Luo, Q., Bian, C., Tao, M., Huang, Y., Zheng, Y., Lv, Y., Li, J., Wang, C., You, X., Jia, B., Xu, J., Li, J., Li, Z., Shi, Q. and Hu, Z. (2019). Genome and transcriptome sequencing of the astaxanthin-producing green microalga, *Haematococcus pluvialis.Genome Biology and Evolution* 11: 166–173.

Lynn, S.G., Powell, K.A., Westneat, D.F. and Shepherd, B.S. (2009). Seasonal and sex-specific mRNA levels of key endocrine genes in adult yellow perch (*Perca flavescens*) from Lake Erie. *Marine Biotechnology* 11: 210–222.

Ma, R. and Chen, F. (2001). Induction of astaxanthin formation in the green microalga *Chlorococcum* sp. by reactive oxygen species (ROS) under mixotrophic conditions of growth. In *Algae and their Biotechnological Potential*, ed. F. Chen and Y. Jiang, pp. 121–126. Dordrecht: Springer.

Ma, X.L., Zhang, Y., Liu, X.C. and Lin, H.R. (2009). Developmental changes of two hepatic growth hormone receptors mRNA expression in male Nile tilapia (*Oreochromis niloticus*). *Journal of Fisheries Sciences of China* 16: 1–7.

Macedo, R.C., Bolin, A.P., Marin, D.P. and Otton, R. (2010). Astaxanthin addition improves human neutrophils function: in vitro study. *European Journal of Nutrition* 49: 447–457.

Magadan, S., Sunyer, O.J. and Boudinot, P. (2015). Unique features of fish immune repertoires: particularities of adaptive immunity within the largest group of vertebrates. *Results and Problems in Cell Differentiation* 57: 235–264.

Magnadottir, B., Lange, S., Gudmunsdottir, S., Bogwald, J. and Dalmo, R.A. (2005). Ontogeny of humoral immune parameters in fish. *Fish and Shellfish Immunology* 19: 429–423.

Magnadottir, B. (2006). Innate immunity of fish (overview). *Fish and Shellfish Immunology* 20: 137–151.

Magnadottir, B. (2010). Immunological control of fish diseases. *Journal of Marine Biotechnology* 12: 361–379.

Martinez-Porchas, M., Martinez-Cordova, L.R. and Ramos-Enriquez, R. (2009). Cortisol and glucose: Reliable indicators of fish stress? *Pan-American Journal of Aquatic Sciences* 4: 158–178.

Marti-Palanca, H., Martinez-Barbera, J.P., Pendon, C., Valdivia, M.M., Perez-Sanchez, J. and Kaushik, S. (1996). Growth hormone as a function of age and dietary protein: energy ratio in a marine teleost, the gilthead sea bream (*Sparus aurata*). *Growth Regulation* 6: 253–259.

Mascia, F., Girolomoni, L., Alcocer, M., Bargigia, I., Perozeni, F., Cazzaniga, S., Cerullo, G., D' Andrea, C. and Ballotari, M. (2017). Functional analysis of photosynthetic pigment binding complexes in the green alga *Haematococcus pluvialis* reveals distribution of astaxanthin in Photosystems. *Scientific Report* 7: 16319. https://doi.org/10.1038/s41598-017-16641-6.

Mashhadi, N.S., Zakerkish, M., Mohammadiasl, J., Zarei, M., Mohammadshahi, M. and Haghighizadeh, M.H. (2018). Astaxanthin improves glucose metabolism and reduces blood pressure in patients with type 2 diabetes mellitus. *Asia Pacific Journal of Clinical Nutrition* 27: 341–346.

Mashoof, S. and Criscitiello, M.F. (2016). Fish immunoglobulins.*Biology* (Basel) 5: 45. https://doi.org/10.3390/biology5040045.

Mateus, A.P., Power, D.M. and Canario, A.V.M. (2017). Chapter 8 - Stress and disease in fish. In *Fish Diseases*, ed. G. Jeney, pp. 187–220. Cambridge, MA: Academic Press-Elsevier.

Mathew, G. (2009). Taxonomy, identification and biology of sea bass (*Lates calcarifer*). In *Course Manual: National training on cage culture of sea bass*, ed. J. Imelda, V.E. Joseph and V. Susmitha, pp. 38–43. Kochi: CMFRI and NFDB.

Matsuno, T. (2001). Aquatic animal carotenoids. *Fishery Science* 67: 771–783.

Mbokane, E.M. and Moyo, N.A.G. (2018). A preliminary investigation into the potential effect of *Artemisia afra* on growth and disease resistance in sub-adults of *Oreochromis mossambicus*. *Aquaculture* 482:197–202.

Meilisza, N., Suprayudi, M.A., Jusadi, D., Jr, M.A., Artika, I.M. and Utomo, N.B.P. (2018). Effect of type and dosage of carotenoid in feed on plasma cortisol and glucose of Kurumoi rainbowfish (*Melanotaenia parv*a Allen) due to transportation stress. *International Journal of Fisheries and Aquatic Sciences* 6: 272–277.

Merchie, G., Kontara, E., Lavens, P., Robles, R., Kurmaly, K. and Sorgeloos, P. (1998). Effect of vitamin C and astaxanthin on stress and disease

resistance of postlarval tiger shrimp, *Penaeus monodon* (Fabricius). *Aquaculture Research* 29: 579–585.

Mieiro, C.L., Martins, M., da Silva, M., Coelho, J.P., Lopes, C.B., da Silva, A.A., Alves, J., Pereira, E., Pardal., M., Costa, M.H. and Pacheco, M. (2019). Advances on assessing nanotoxicity in marine fish - the pros and cons of combining an ex vivo approach and histopathological analysis in gills. *Aquatic Toxicology* 217: 105322. https://doi.org/10.1016/j.aquatox .2019.105322.

Milla, S., Mathieu, C., Wang, N., Lambert, S., Nadzialek, S., Massart, S., Henrotte, E., Douxfils, J., Melard, C., Mandiki, S.N. and Kestemont, P. (2010). Spleen immune status is affected after acute handling stress but not regulated by cortisol in Eurasian perch, *Perca fluviatilis*. *Fish and Shellfish Immunology* 28: 931–941.

Misganaw, K. and Getu, A. (2016). Review on major parasitic crustacean in fish. *Fisheries and Aquaculture Journal* 7: 3. https://doi.org/10.4172/21 150-3508.1000175.

Mitiku, M.A. (2018). A review on columnaris disease in freshwater farmed fish. *International Journal of Advanced Research in Biological Sciences* 5: 79–90.

Miyachi, M., Matsuno, T., Asano, K. and Mataga, I. (2015). Anti-inflammatory effects of astaxanthin in the human gingival keratinocyte line NDUSD-1. *Journal of Clinical Biochemistry and Nutrition* 56: 171–178.

Miyawaki, H., Takahashi, J., Tsukahara, H. and Takehara, I. (2008). Effects of astaxanthin on human blood rheology. *Journal of Clinical Biochemistry Nutrition* 43: 69–74.

Mohamad, N., Amal, M.N.A., Yasin, I.S.M., Saad, M.Z., Nasruddin, N.S., Al-saari, N., Mino, S. and Sawabe, T. (2019). Vibriosis in cultured marine fishes:areview.*Aquaculture*512:734289.https://doi.org/10.1016/j.aquacu lture.2019.734289.

Molino, A., Rimauro, J., Casella, P., Cerbone, A., Larocca, V., Chianese, S., Karatza, D., Mehariya, S., Ferraro, A., Hristoforou, E. and Musmarra, D. (2018). Extraction of astaxanthin from microalga *Haematococcus pluvialis* in red phase by using generally recognized as safe solvents and accelerated extraction. *Journal of Biotechnology* 283: 51–61.

Montero, D., Terova, G., Rimoldi, S., Tort, L., Negrin, D., Zamorano, M.J. and Izquierdo, M. (2015). Modulation of adenocorticotrophin hormone (ACTH)-induced expression of stress-related genes by PUFA in inter-renal cells from European sea bass (*Dicentrarchus labrax*). *Journal of Nutritional Science* 4: e16. https://doi.org/10.1017/jns.2015.6.

Moran, J.D.W., Whitaker, D.J., Kent, M.L. (1999). A review of the myxosporean genus *Kudoa* Meglitsch, 1947, and its impact on the international

aquaculture industry and commercial fisheries. *Aquaculture* 172: 163–196.

Moretti, A., Pedini Fernandez-Criado, M., Cittolin, G. and Guidastri, R. (1999). *Manual on hatchery production of seabass and gilthead seabream*. Rome: FAO, 194 pp.

Moustafa, E.M., Dawood, M.A.O., Assar, D.H., Omar, A.A., Elbialy, Z.I., Farrag, F.A., Shukry, M. and Zayed, M.M. (2019). Modulatory effects of fenugreek seeds powder on the histopathology, oxidative status, and immune related gene expression in Nile tilapia (*Oreochromis niloticus*) infected with *Aeromonas hydrophila*. *Aquaculture*: 734589. https://doi.org/10.1016/j.aquaculture.2019.734589.

Mugetti, D., Varello, K., Gustinelli, A., Pastorino, P., Menconi, V., Florio, D., Fioravanti, M.L., Bozzetta, E., Zoppi, S., Dondo, A. and Prearo, M. (2020). *Mycobacterium pseudoshottsii* in Mediterranean fish farms: new trouble for European aquaculture? *Pathogens* 9: 610.https://doi.org/doi:10.3390/pathogens9080610.

Muhd-Faizul, H.A.H., Kua, B.C. and Leaw, Y.Y. (2011). Caligidae infestation in Asian sea bass, *Lates calcarifer*, Bloch 1970 cultured at different salinity in Malaysia. *Veterinary Parasitology* 184: 68–72.

Muller-Feuga, A., Moal, J. and Kaas, R. (2003). The microalgae of aquaculture. In *Live Feeds in Marine Aquaculture*, ed. J.G. Stottrup and L.A. Mcevoy, pp. 206–252. USA: Blackwell Publishing Limited.

Mushahida-Al-Noor, S., Kamruzzaman, S. and Hossain, D. (2012). Seasonal variation of food composition and feeding activity of small adult barramundi (*Lates calcarifer*, Bloch) in the south west coastal water near Khulna, Bangladesh. *Journal of Fisheries International* 7: 77–82.

Naghili, H., Tajik, H., Mardani, K., Razavi Rouhani, S.M., Ehsani A and Zare, P. (2013). Validation of drop plate technique for bacterial enumeration by parametric and nonparametric tests. *Veterinary Research Forum* 4: 179–183.

Najdegerami, E.H., Bakhshi, F. and Lakani, F.B. (2016). Effects of biofloc on growth performance, digestive enzyme activities and liver histology of common carp (*Cyprinus carpio* L.) fingerlings in zero-water exchange system. *Fish Physiology and Biochemistry* 42: 457–465.

Nakai, T., Mori, K., Sugaya, T., Nishioka, T., Mushiake, K. and Yamashita, H. (2009). Current knowledge on viral nervous necrosis (VNN) and its causative betanodaviruses. *The Israeli Journal of Aquaculture* 6: 198–207.

Nakanishi, T., Shibasaki, Y. and Matsuura, Y. (2015). T cells in fish. *Biology (Basel)* 4: 640–663.

Nardocci, G., Navarro, C., Cortes, P.P., Imarai, M., Montoya, M., Valenzuela, B., Jara, P., Acuna-Castillo, C. and Fernandez, R. (2014). Neuroendocrine mechanisms for immune system regulation during stress in fish. *Fish and Shellfish Immunology* 40: 531–538.

Nelson, J.S. (2006). Fishes of the world, 4th edition, 601 pp. USA: John Wiley and Sons Inc.

Newton, J.R., Smith-Keune, C. and Jerry, D.R. (2010). Thermal tolerance varies in tropical and sub-tropical populations of barramundi (*Lates calcarifer*) consistent with local adaptation. *Aquaculture* 308: 128–132.

Netea, M.G., Schlitzer, A., Placek, K., Joosten, L. and Schultze, J.L. (2019). Innate and adaptive immune memory: an evolutionary continuum in the host's response to pathogens. *Cell Host and Microbe* 25: 13–26.

Nguyen, G.T., Green, E.R. and Mecsas, J. (2017). Neutrophils to the ROScue: mechanisms of NADPH oxidase activation and bacterial resistance. *Frontiers in Cellular and Infection Microbiology* 7: 373. https://doi.org/10.3389/fcimb.2017.00373.

Nichols, H. W. (1973). Growth media-freshwater. In *Handbook of Phycological Methods, Culture Methods and Growth Measurements*, ed. J. Stein, pp. 7–24. Cambridge, MA: Cambridge University Press.

Niu, J., Tian, L.X., Liu, Y.J., Yang, H.J., Ye, C.X. and Gao, W. (2009). Effect of dietary astaxanthin on growth, survival, and stress tolerance of postlarval shrimp, *Litopenaeus vannamei*. *Journal of the World Aquaculture Society* 40: 795–802.

Niu, J., Li, C.H., Liu, Y.J., Tian, L.X., Chen, X., Huang, Z. and Lin, H.Z. (2011). Dietary values of astaxanthin and canthaxanthin in *Penaeus monodon* in the presence and absence of cholesterol supplementation: effect on growth, nutrient digestibility and tissue carotenoid composition. *British Journal of Nutrition* 6: 1–12.

Niu, J., Wen, H., Li, C.H., Liu, Y.J., Tian, L.X. and Chen, X. (2014). Comparison effect of dietary astaxanthin and b-carotene in the presence and absence of cholesterol supplementation on growth performance, antioxidant capacity and gene expression of *Penaeus monodon* under normoxia and hypoxia condition. *Aquaculture* 422–423: 8–17.

Noga, J.E. (2010). *Fish disease: diagnosis and treatment,* 2nd edition, 519 pp. USA: Willey-Blackwell Publishing Limited.

Nogami, S., Ohnuki, S. and Ohya, Y. (2014). Hyperspectral imaging techniques for the characterization of *Haematococcus pluvialis* (Chlorophyceae). *Journal of Phycol*ogy 50: 939–947.

Nombela, I. and Ortega-Villaizan, M.d.M. (2018). Nucleated red blood cells: immune cell mediators of the antiviral response. *PLOS Pathogen* 14: e1006910. https://doi.org/10.1371/journal.ppat.1006910.

Nootem, J., Chalorak, P., Meemon, K., Mingvanish, W., Pratumyot, K., Ruckthong, L., Srisuwannaket, C. and Niamnont, N. (2018). Electrospun cellulose acetate doped with astaxanthin derivatives from *Haematococcus pluvialis* for in vivo anti-aging activity. *RSC Advances* 8: 37151-37158.

Norbeck, L.A., Kittilson, J.D. and Sheridan, M.A. (2007). Resolving the growth-promoting and metabolic effects of growth hormone: differential regulation of GH-IGF-I system components. *General and Comparative Endocrinology* 151: 332–341.

Nowak, B.F., Martin, M.B. and Boltana, F. (2020). Paraisitic cructaceans. In *Fisheries amd Aquaculture*, ed. G. Lowrich and M. Thiel, pp. 401–434. London (UK): Oxford University Press.

O'Connor, I. and O'Brien, N. (1998). Modulation of UVA lightinduced oxidative stress by β-carotene, lutein and astaxanthin in cultured fibroblasts. *Journal of Dermatological Science* 16: 226–230.

Oh, W.T., Jun, J.W., Kim, H.J., Giri, S.S., Yun, S., Kim, S.G., Kim, S.W., Kang, J.W., Han, S.J., Kwon, J. and Park, S.C. (2020). Characterization and pathological analysis of a virulent *Edwardsiella anguillarum* strain isolated from Nile tilapia (*Oreochromis niloticus*) in Korea. *Frontiers in Veterinary Science* 7: 14. https://doi.org/10.3389/fvets.2020.00014.

Ohimain, E.I., Angaye, T. and Okpeku, M. (2014). The challenge of non-infectious diseases in catfish farming. *The Journal of Veterinary Science* (*Photon*) 115: 344–349.

Orosa, M., Torres, E., Fidalgo, P. and Abalde, J. (2000). Production and analysis of secondary carotenoids in green algae. *Journal of Applied Phycology* 12: 553–556.

Orosa, M., Valero, J.F. and Abalde, J. (2001). Comparison of the accumulation of astaxanthin in *Haematococcus pluvialis* and other green microalgae under N-starvation and high light conditions. *Biotechnology Letters* 23: 1079–1085.

Ota, S., Morita, A., Ohnuki, S., Hirata, A., Sekida, S., Okuda, K., Ohya, Y. and Kawano, S. (2018). Carotenoid dynamics and lipid droplet containing astaxanthin in response to light in the green alga *Haematococcus pluvialis*. *Scientific Reports* 8. https://doi.org/10.1038/s41598-018-23854-w.

Owatari, M.S., Alves Jesus, G.F., Brum, A., Pereira, S.A., Lehmann, N.B., de Padua Pereira, U., Martins, M.L. and Pedreira Mourino, J.L. (2018). Sylimarin as hepatic protector and immunomodulator in Nile tilapia

during *Streptococcus agalactiae* infection. *Fish and Shellfish Immunology* 82: 565–572.

Palma, J., Andrade, J. and Bureau, D. (2016). The impact of dietary supplementation with astaxanthin on egg quality and growth of long snout seahorse (*Hippocampus guttulatus*) juveniles. *Aquaculture Nutrition* 23: 304–312.

Palozza, P., Torelli, C., Boninsegna, A., Simone, R., Catalano, A., Mele, M. and Picci, N. (2009). Growth-inhibitory effects of the astaxanthin rich alga *Haematococcus pluvialis* in human colon cancer cells. *Cancer Letters* 283: 108–117.

Pan, C.H., Chien, Y.H. and Cheng, J.H. (2001). Effects of light regime, algae in the water, and dietary astaxanthin on pigmentation, growth, and survival of black tiger prawn *Penaeus monodon* post-larvae. *Zoological Studies* 40: 371–382.

Pan, C.H., Chien, Y.H. and Wang, Y.J. (2011). Antioxidant defence to ammonia stress of characins (*Hyphessobrycon eques* Steindachner) fed diets supplemented with carotenoids. *Aquaculture Nutrition* 17: 258–266.

Panase, P., Saenphet, S. and Saenphet, K. (2017). Visceral and serum lysozyme activities in some freshwater fish (three catfish and two carps). *Comparative Clinical Pathology* 26: 169–173.

Panis, G. and Carreon, J. (2016). Commercial astaxanthin production derived by green alga *Haematococcus pluvialis*: a microalgae process model and a techno-economic assessment all through production line. *Algal Research* 18: 175–190.

Parameswaran, V., Kumar, S.R., Ahmed, I. and Hameed, A.S.S. (2008). A fish nodavirus associated with mass mortality in hatchery-reared Asian sea bass, *Lates calcarifer*. *Aquaculture* 275: 366-369.

Park, J.S., Chyun, J.H., Kim, Y.K., Line, L.L. and Chew, B.P. (2010). Astaxanthin decreased oxidative stress and inflammation and enhanced immune response in humans. *Nutrition and Metabolism* 7: 18. https://doi.org/10.1186/1743-7075-7-18.

Park, S.B., Aoki, T. and Jung, T.S. (2012). Pathogenesis of and strategies for preventing *Edwardsiella tarda* infection in fish. *Veterinary Research* 43: 67. https://doi.org/10.1186/1297-9716-43-67.

Parrino, V., Cappello, T., Costa, G., Cannava, C., Sanfilippo, M., Fazio, F. and Fasulo, S. (2018). Comparative study of haematology of two teleost fish (*Mugil cephalus* and *Carassius auratus*) from different environments and feeding habitats. *European Zoological Journal* 85: 193–199.

Partridge, G.J. and Lymbery, A.J. (2008). The effect of salinity on the requirement of potassium by barramundi (*Lates calcarifer*) in saline groundwater. *Aquaculture* 278: 164–170.

Patel, A., Mikes, F. and Matsakas, L. (2018). An overview of current pretreatment methods used to improve lipid extraction from oleaginous microorganisms.*Molecules*23:1562.https://doi.org/10.3390/molecules23071562.

Percin, F. and Akyol, O. (2009). Length–weight and length–length relationships of the bluefin tuna, *Thunnus thynnus* L., in the Turkish part of the eastern Mediterranean Sea. *Journal of Applied Ichthyology* 25: 782–784.

Perez-Lopez, P., Gonzalez-Garcia, S., Jeffryes, C., Agathos, S. N., McHugh, E., Walsh, D., Murray, P., Moane, S., Feijoo, G. and Moreira, M.T. (2014). Life cycle assessment of the production of the red antioxidant carotenoid astaxanthin by microalgae: from lab to pilot scale. *Journal of Cleaner Production* 64: 332–344.

Perez-Sanchez, J., Marti-Palanca, H. and Le Bail, P.Y. (1994). Seasonal changes in growth hormone (GH), hepatic GH-binding and plasma insulin-like growth factor-I immunoreactivity in a marine fish, gilthead sea bream, *Sparus aurata*. *Fish Physiology and Biochemistry* 13: 199–208.

Pethiyagoda, R. and Gill, A.C. (2014). Taxonomy and distribution of Indo-Pacific *Lates*. In *Biology and Culture of Asian Seabass Lates calcarifer*, ed. D.R. Jerry, pp. 1–15. Boca Raton: CRC Press.

Peyghan, R., Rahnama, R., Dezfuly, Z.T. and Shokoohmand, M. (2019). Achlya infection in an Oscar (*Astronotus ocellatus*) with typical symptoms of saprolegniosis. *Veterinary Research Forum* 10: 89–92.

Pham, M.A., Byun, H., Kim, K. and Lee, S. (2014). Effects of dietary carotenoid source and level on growth, skin pigmentation, antioxidant activity and chemical composition of juvenile olive flounder *Paralichthys olivaceus*. *Aquaculture* 431: 65–72.

Picha, M.E., Turano, M.J., Beckman, B.R. and Borski, R.R. (2008). Endocrine biomarkers of growth and applications to aquaculture: a mini review of growth hormone, insulin-like growth factor (IGF)-I, and IGF-binding proteins and potential growth indicators in fish. *North American Journal of Aquaculture* 70:196–211.

Postma, P.R., Miron, T.L., Olivieri, G., Barbosa, M.J., Wijffels, R.H., Eppink, M.H. (2015). Mild disintegration of the green microalgae *Chlorella vulgaris* using bead milling. *Bioresource Technology* 184: 297–304.

Postma, P.R., Suarez-Garcia, E., Safi, C., Yonathan, K., Olivieri, G., Barbosa, M.J., Wijffels, R.H. and Eppink, M.H.M (2017). Energy efficient bead

milling of microalgae: effect of bead size on disintegration and release of proteins and carbohydrates. *Bioresource Technology* 224: 670–679.

Preena, P., Arathi, D., Raj, N., Arun Kumar, T., Arun Raja, S., Reshma, R. and Raja Swaminathan, T. (2019). Diversity of antimicrobial-resistant pathogens from a freshwater ornamental fish farm. *Letters in Applied Microbiology*. https://doi.org/10.1111/lam.13231.

Puente-Marin, S., Nombela, I., Chico, V., Ciordia, S., Mena, M.C., Coll, J., Mercado, L. and Ortega-Villaizan, M.d.M. (2018). Rainbow trout erythrocytes ex vivo transfection with a DNA vaccine encoding glycoprotein G induces an antiviral immune response. *Frontiers in Immunology* 9: 2477. https://doi.org/10.3389/fimmu.2018.02477.

Pulkkinen, K., Suomalainen, L.R., Read, A.F., Ebert, D., Rintamaki, P. and Valtonen, E.T. (2010). Intensive fish farming and the evolution of pathogen virulence: the case of columnaris disease in Finland. *Proceedings of the Royal Society B: Biological Sciences* 277: 593–600.

Qiang, J., Yang, H., Wang, H., Xu, P., Le, Y.R. and He, J. (2012). Temperature and dietary protein level affect growth and serum growth hormone level in GIFT Nile tilapia juvenile (*Oreochromis niloticus*). *Chinese Journal of Animal Nutrition* 24: 1589–1601.

Qin, S., Liu, G.X. and Hu, Z.Y. (2008). The accumulation and metabolism of astaxanthin in *Scenedesmus obliquus* (Chlorophyceae). *Process Biochemistry* 43: 795–802.

Ragap, H.M., Khalil, R.H. and Mutawie, H.H. (2012). Immunostimulant effects of dietary *Spirulina platensis* on tilapia *Oreochromis niloticus*. *Journal of Applied Pharmaceutical Science* 2: 26–31.

Ragland, S.A. and Criss, A.K. (2017). From bacterial killing to immune modulation: Recent insights into the functions of lysozyme. *PLOS Pathogens*13:e1006512. https://doi.org/10.1371/journal.ppat.1006512.

Ragland, S.A., Schaub, R.E., Hackett, K.T., Dillard, J.T. and Criss, A.K. (2017). Two lytic transglycosylases in *Neisseria gonorrhoeae* impart resistance to killing by lysozyme and human neutrophils.*Cellular Microbiology* 19: e12662. https://doi.org/10.1111/cmi.12662.

Rahimikia, E. (2016). Analysis of antioxidants and serum biochemical responses in goldfish under nickel exposure by sub-chronic test. *Journal of Applied Animal Research* 45: 320–325.

Rahman, M.M., Khosravi, S., Chang, K.H. and Lee, S. (2016). Effects of dietary inclusion of astaxanthin on growth, muscle pigmentation and antioxidant capacity of juvenile rainbow trout (*Oncorhynchus mykiss*). *Preventive Nutrition and Food Science* 21: 281–288.

Rajan, P.R., Lin, J.H., Ho, M.S. and Yang, H.L. (2003). Simple and rapid detection of *Photobacterium damselae* ssp. *piscicida* by a PCR technique and plating method. *Journal of Applied Microbiology* 95: 1375–1380.

Rajvanshi, M., Sagaram, U.S., Subhash, G.V., Kumar, G., Kumar, C., Govindachary, S. and Dasgupta, S. (2019). Biomolecules from microalgae for commercial applications. In *Sustainable Downstream Processing of Microalgae for Industrial Application*, ed. K. Gayen, T.K. Bhowmick and S.K. Maity, pp. 3–38. Florida: CRC Press.

Raman, R. and Mohamad, S.E. (2012). Astaxanthin production by freshwater microalgae *Chlorella sorokiniana* and marine microalgae *Tetraselmis* sp. *Pakistan Journal of Biological Sciences* 15: 1182–1186.

Ranga Rao, A.R., Raghunath Reddy, R.L., Sarada, R., Baskaran, V. and Ravishankar, G.A. (2010). Characterization of microalgal carotenoids by mass spectrometry and their bioavailability and antioxidant properties in rat model. *Journal of Agricultural and Food Chemistry* 58: 8553–8559.

Ransangan, J. and Mustafa, S. (2009). Identification of *Vibrio harveyi* isolated from diseased Asian seabass (*Lates calcarifer*) by use of 16S ribosomal DNA sequencing. *Journal of Aquatic Animal Health* 21: 150–155.

Ransangan, J. and Manin, B.O. (2010). Mass mortality of hatchery-produced larvae of Asian sea bass, *Lates calcarifer* (Bloch), associated with viral nervous necrosis in Sabah, Malaysia. *Veterinary Microbiology* 145: 153–157.

Ransangan, J. and Manin, B.O. (2012). Genome analysis of Betanodavirus from cultured marine fish species in Malaysia. *Veterinary Microbiology* 156: 16–44.

Ransangan, J., Lal, T.M. and Al-Harbi, A.H. (2012). Characterization and experimental infection of *Vibrio harveyi* isolated from diseased Asian seabass (*Lates calcarifer*). *Malaysian Journal of Microbiology* 8: 104–115.

Rastiannasab, A., Afsharmanesh, S., Rahimi, R. and Sharifian, I. (2016). Alternations in the liver enzymatic activity of common carp, *Cyprinus carpio* in response to parasites, *Dactylogyrus* spp. and *Gyrodactylus* spp. *Journal of Parasitic Diseases* 40: 1146–1149.

Rauta, P.R., Nayak, B. and Das, S. (2012). Immune system and immune responses in fish and their role in comparative immunity study: a model for higher organisms. *Immunological Letters* 148: 23–33.

Rebl, A. and Goldammer, T. (2018). Under control: The innate immunity of fish from inhibitors' perspective. *Fish and Shellfish Immunology* 77: 328–349.

Recht, L., Topfer, N., Batushansky, A., Sikron, N., Gibon, Y., Fait, A., Nikoloski, Z., Boussiba, S. and Zarka, A. (2014). Metabolite profiling and integrative modeling reveal metabolic constraints for carbon partitioning under nitrogen-starvation in the green algae *Haematococcus pluvialis*. *The Journal of Biological Chemistry* 289: 30387–30403.

Reed L.L. and Muench, H. (1938). A simple method of estimating fifty percent end points. *American Journal of Epidemiology* 27: 493–497.

Reindl, K.M. and Sheridan, M.A. (2012). Peripheral regulation of the growth hormone-insulin-like growth factor system in fish and other vertebrates. *Comparative Biochemistry and Physiology. A, Molecular and Integrative Physiology* 163: 231–245.

Reinecke, M. (2010). Influences of the environment on the endocrine and paracrine fish growth hormone-insulin-like growth factor-I system. *Journal of Fish Biology* 76: 1233–1254.

Reno, P.W. (2011). Factors involved in the dissemination of disease in fish populations. *Journal of Aquatic Animal Health* 10: 160–171.

Reyes-Lopez, F.E., Aerts, J., Vallejos-Vidal, E., Ampe, B., Dierckens, K., Tort, L. and Bossier, P. (2018). Modulation of innate immune-related genes and glucocorticoid synthesis in gnotobiotic full-sibling European sea bass (*Dicentrarchus labrax*) larvae challenged with *Vibrio anguillarum*. *Frontiers in Immunology* 9: 914. https://doi.org/10.3389/fimmu.2018.00914.

Ribet, D. and Cossart, P. (2015). How bacterial pathogens colonize their hosts and invade deeper tissues. *Microbes and Infection* 17: 173–183.

Riccioni, G., Speranza, L., Pesce, M., Cusenza, S., D'Orazio, N. and Glade, M. (2012). Novel phytonutrient contributors to antioxidant protection against cardiovascular disease. *Nutrition* 28: 605–610.

Richlen, M.L. and Barber, P.H. (2005). A technique for the rapid extraction of microalgal DNA from single live and preserved cells. *Molecular Ecology Notes* 5: 688–691.

Robinson, E.H. and Li, M.H. (2010). Channel catfish, *Ictalurus punctatus*, size and feed conversion ratio. *Journal of the World Aquaculture Society* 41: 829–833.

Rodriguez-Saiz, M., de la Fuente, J.L. and Barredo, J.L. (2010). *Xanthophyllomyces dendrorhous* for the industrial production of astaxanthin. *Applied Microbiology and Biotechnology* 88: 645–658.

Romo, M.R., Perez-Martinez, D. and Ferrer, C.C. (2016). Innate immunity in vertebrates: an overview. *Immunology* 148: 125–139.

Ronneseth, A., Castillo, D., D'Alvise, P., Tonnesen, O., Haugland, G., Grotkjaer, T., Engell-Sorensen, K., Norremark, L., Bergh, O., Wergeland, H.I. and Gram, L. (2017). Comparative assessment of *Vibrio* virulence in marine fish larvae. *Journal of Fish Disease* 40: 1373–1385.

Ruckert, S., Palm, H.W. and Klimpel, S. (2008). Parasite fauna of seabass (*Lates calcarifer*) under mariculture conditions in Lampung Bay, Indonesia. *Journal of Applied Ichthyology* 24: 321–327.

Ruwandeepika, H.A.D., Jayaweera, T.S.P., Bhowmick, P.P., Karunasagar, I., Bossier, P. and Defoirdt, T. (2012). Pathogenesis, virulence factors and virulence regulation of vibrios belonging to the *Harveyi* clade. *Reviews in Aquaculture* 4: 59–74.

Ryu, S.K., King, T.J., Fujioka, K., Pattison, J., Pashkow, F.J. and Tsimikas, S., (2012). Effect of an oral astaxanthin prodrug (CDX-085) on lipoprotein levels and progression of atherosclerosis in LDLR(–/–) and ApoE(–/–) mice. *Atherosclerosis* 222: 99–105.

Sadhu, N., Sharma, S., Dube, P.N., Joseph, S. and Philipose, K.K. (2015). First results of culture of Asian seabass (*Lates calcarifer*, Bloch) in open sea floating net cages in India: effect of stocking density on survival and growth. *Indian Journal of Geo-Marine Sciences* 44: 1540–1544.

Saha, S.K. and Murray, P. (2018). Exploitation of microalgae species for nutraceutical purposes: cultivation aspects. *Fermentation* 4: 46. https://doi.org/10.3390/fermentation4020046.

Sakakura, Y., Tagawa, M. and Tsukamoto, K. (1998). Whole-body cortisol concentration and ontogeny of aggressive behavior in yellowtail (*Seriola quinqueradiata* Temminck Schlegel; Carangidae). *General and Comparative Endocrinology* 109: 286–292.

Sakamoto, T. and McCormick, S.D. (2006). Prolactin and growth hormone in fish osmoregulation. *General and Comparative Endocrinology* 147: 24–30.

Salama, N. and Rabe, B. (2013). Developing models for investigating the environmental transmission of disease-causing agents within open-cage salmon aquaculture. *Aquaculture Environment Interactions* 4: 91–115.

Saleh, N.E., Wassef, E.A. and Shalaby, S.M. (2018). The role of dietary astaxanthin in European seabass (*Dicentrarchus labrax*) growth, immunity, antioxidant competence and stress tolerance. *Egyptian Journal of Aquatic Biology and Fisheries* 22: 189–200.

Salinas, I., Zhang, Y. and Sunyer, J.O. (2019). Mucosal immunoglobulins and B cells of teleost fish. *Developmental and Comparative Immunology* 35: 1346–1365.

Samaras, A., Papandroulakis, N., Lika, K. and Pavlidis, M. (2018). Water temperature modifies the acute stress response of European sea bass, *Dicentrarchus labrax* L. (1758). *Journal of Thermal Biology* 78: 84–91.

Samori, C., Pezzolesi, L., Galetti, P., Semeraro, M. and Tagliavini, E. (2019). Extraction and milking of astaxanthin from *Haematococcus pluvialis*. *Green Chemistry* 21: 3621–3628.

Sankar, G.P., Saravanan, J., Krishnamurthy, P., Chandrakala, N. and Rajendran, K. (2012). Isolation and identification of *Vibrio* spp. in diseased *Channa punctatus* from aquaculture fish farm. *Indian Journal of Geo-Marine Sciences* 41: 159–163.

Santos, L. and Ramos, F. (2018). Antimicrobial resistance in aquaculture: current knowledge and alternatives to tackle the problem. *International Journal of Antimicrobial Agents* 52: 135–143.

Sarada, R., Tripathi, U. and Ravishankar, G.A. (2002). Influence of stress on astaxanthin production in *Haematococcus pluvialis* grown under different culture conditions. *Process Biochemistry* 37: 623–627.

Satheeshkumar, P., Ananthan, G., Senthil Kumar, D. and Jagadeesan, L. (2011). Haematology and biochemical parameters of different feeding behaviour of teleost fishes from Vellar estuary, India. *Comparative Clinical Pathology* 21: 1–5.

Satoh, A., Tsuji, S., Okada, Y., Murakami, N., Urami, M., Nakagawa, K., Ishikura, M., Katagiri, M., Koga, Y. and Shirasawa, T. (2009). Preliminary clinical evaluation of toxicity and efficacy of a new astaxanthin-rich *Haematococcus pluvialis* extract. *Journal of Clinical Biochemistry and Nutrition* 44: 280–284.

Satoh, T. (2016). Astaxanthin: health benefits and toxicity. In *Neutraceuticals: efficacy, safety and toxicity*, ed. R.C. Gupta, pp. 531–539. Cambridge, MA: Academic Press.

Saura, M., Carabano, M.J., Fernandez, A., Cabaleiro, S., Doeschl-Wilson, A.B., Anacleto, O., Maroso, F., Millan, A., Hermida, M., Fernandez, C., Martinez, P. and Villanueva, B. (2019). Disentangling genetic variation for resistance and endurance to Scuticociliatosis in turbot using pedigree and genomic information. *Frontiers in Genetics* 10: 539. https://doi.org/10.3389/fgene.2019.00539.

Sawanboonchun, J., Roy, W., Robertson, D. and Bell, J. (2008). The impact of dietary supplementation with astaxanthin on egg quality in Atlantic cod broodstock (*Gadus morhua* L.). *Aquaculture* 283: 97–101.

Scapigliati, G., Fausto, A.M. and Picchietti, S. (2018). Fish lymphocytes: an evolutionary equivalent of mammalian innate-like lymphocytes? *Frontiers in Immunology* 9: 971. https://doi.org/10.3389/fimmu.2018.00971.

Schipp, G., Bosmans, J. and Humphrey, J. (2007). Northern territory barramundi farming handbook, 80 pp. Darwin: Department of Primary Industry, Fisheries and Mines.

Scholthof, K.G. (2007). The disease triangle: pathogens, the environment and society. *Nature Reviews Microbiology* 5: 152–156.

Schumann, G., Bonora, R., Ceriotti, F., Ferard, G., Ferrero, C., Franck, P., Gella, F., Hoelzel, W., Jorgensen, P., Kanno, T., Kessner, A., Klauke, R., Kristiansen, N., Lessinger, J., Linsinger, T., Misaki, H., Panteghini, M., Pauwels, J., Schiele, F., Schimmel, H., Weidemann, G. and Siekmann, L. (2002a). IFCC primary reference procedures for the measurement of catalytic activity concentrations of enzymes at 37°C. International Federation of Clinical Chemistry and Laboratory Medicine. Part 4: Reference procedure for the measurement of catalytic concentration of alanine aminotransferase. *Clinical Chemistry and Laboratory Medicine* 40: 718–724.

Schumann, G., Bonora, R., Ceriotti, F., Ferard, G., Ferrero, C., Franck, P., Gella, F., Hoelzel, W., Jorgensen, P., Kanno, T., Kessner, A., Klauke, R., Kristiansen, N., Lessinger, J., Linsinger, T., Misaki, H., Panteghini, M., Pauwels, J., Schiele, F., Schimmel, H., Weidemann, G. and Siekmann, L. (2002b). IFCC primary reference procedures for the measurement of catalytic activity concentrations of enzymes at 37 degrees C. International Federation of Clinical Chemistry and Laboratory Medicine. Part 5: Reference procedure for the measurement of catalytic concentration of aspartate aminotransferase. *Clinical Chemistry and Laboratory Medicine* 40: 725–733.

Segner, H., Arend, P., Von Poeppinghausen, K. and Schmidt, H. (1989). The effect of feeding astaxanthin to *Oreochromis niloticus* and *Colisa labiosa* on the histology of the liver. *Aquaculture* 79: 381–390.

Senanan, W., Pechsiri, J., Sonkaew, S., Na-Nakorn, U., Sean-In, N. and Yashiro, R. (2015). Genetic relatedness and differentiation of hatchery populations of Asian seabass (*Lates calcarifer*) (Bloch, 1790) broodstock in Thailand inferred from microsatellite genetic markers. *Aquaculture Research* 46: 2897–2912.

Serebruany, V., Malinin, A., Goodin, T. and Pashkow, F. (2010). The in vitro effects of Xancor, a synthetic astaxanthine derivative, on hemostatic biomarkers in aspirin-naive and aspirin-treated subjects with multiple risk factors for vascular disease. *American Journal of Therapeutics* 17: 125–132.

Shah, M., Liang, Y., Cheng, J. and Daroch, M. (2016). Astaxanthin-producing green microalga *Haematococcus pluvialis*: from single cell to high value commercial products. *Frontiers in Plant Science* 7: 531. https://doi.org/10.3389/fpls.2016.00531.

Shaheen, A.A., Eissa, N., Abou-ElGheit, E.N., Yao, H. and Wang, H.P. (2014). Effect of probiotic on growth performance and growth-regulated genes in yellow perch (*Perca flavescens*). *Global Journal of Fisheries and Aquaculture Researches* 1: 1–15.

Shang, M., Ding, W., Zhao, Y., Xu, J., Zhao, P., Li, T., Ma, H. and Yu, X. (2016).Enhanced astaxanthin production from *Haematococcus pluvialis* using butylated hydroxyanisole. *Journal of Biotechnology* 236:199–207.

Sharif, S., Shoae, A., Amiri, B.M. and Farahmand, H. (2015). The effects of brackish water on growth hormone/insulin-like growth factor-1gene expression of the Caspian trout, *Salmo trutta caspius* (Kessler, 1877), during the early stage of smoltification. *Journal of the World Aquaculture Society* 46: 201–209.

Sharma, S.R.K., Rathore, G., Verma, D.K., Sadhu, N. and Philipose, K.K. (2012). *Vibrio alginolyticus* infection in Asian seabass (*Lates calcarifer*, Bloch) reared in open sea floating cages in India. *Aquaculture Research* 44: 86–92.

Sharma, S.R.K., Pradeep, M.A., Sadu, N., Dube, P.N. and Vijayan, K.K. (2017). First report of isolation and characterization of *Photobacterium damselae* subsp. *damselae* from cage-farmed cobia (*Rachycentron canadum*). *Journal of Fish Disease* 40: 953–958.

Sharma, S.R., Pradeep, M.A., Dube, P.N., Kumar, T.V., Kumar, R. and Swaminathan, T.R. (2019). Betanodavirus-associated mortality in Asian seabass (*Lates calcarifer*, Bloch) cultured in indoor tanks and sea cages. *Aquaculture International* 27: 279–286.

Sheikhzadeh, N., Tayefi-Nasrabadi, H., Oushani, A.K. and Enferadi, M.H.M. (2012). Effects of *Haematococcus pluvialis* supplementation on antioxidant system and metabolism in rainbow trout (*Oncorhynchus mykiss*). *Fish Physiology and Biochemistry* 38: 413–419.

Shen, Y., Wang, D., Zhao, J. and Chen, X. (2018). Fish red blood cells express immune genes and responses. *Aquaculture and Fisheries* 3: 14–21.

Shiu, Y.L., Chiu, K.H., Huynh, T.G., Liu, P.C. and Liu, C.H. (2017). Plasma immune protein analysis in the orange-spotted grouper *Epinephelus coioides*: evidence for altered expressions of immune factors associated with a choline-supplemented diet. *Fish and Shellfish Immunology* 65: 235–243.

Simonelli, P., Troedsson, C., Nejstgaard, J., Zech, K., Larsen, J. and Frischer, M. (2009). Evaluation of DNA extraction and handling procedures for

PCR-based copepod feeding studies. *Journal of Plankton Research* 31: 1465–1474.

Singh, G. and Patidar, S.K. (2018). Microalgae harvesting techniques: a review. *Journal of Environmental Management* 217: 499–508.

Siwicki, A.K. and Anderson, D.P. (1993). An easy spectrophotometric assay for determining total protein and immunoglobulin levels in fish sera: correlation to fish health. *Techniques in Fish Immunology* 3: 23–30.

Smith, T. (1998). Carotenoids and cancer: prevention and potential therapy. *British Journal of Biomedical Science* 55: 268–275.

Smith, C., Gomez, L. and Cortes, R. (2013). Astaxanthin effect on reactive oxygen species and leucocytes count in rainbow trout (*Oncorhynchus mykiss*). *Global Virtual Conference* 14: 451–454.

Smith, N.C., Rise, M.L. and Christian, S.L. (2019). A comparison of the innate and adaptive immune systems in cartilaginous fish, ray-finned fish, and lobe-finned fish. *Frontiers in Immunology*. https://doi.org/10.3389/fimmu .2019.02292.

Snieszko, S.F. (1974). The effects of environmental stress on outbreaks of infectious diseases of fishes. *Journal of Fisheries Biology* 6: 197–208.

Sookoian, S. and Pirola, C.J. (2015). Liver enzymes, metabolomics and genom-wide association studies: From systems biology to personalized medicine. *World Journal of Gastroenterology* 21: 711–725.

Spiller, G.A. and Dewell, A. (2003). Safety of an astaxanthin-rich *Haematococcus pluvialis* algal extract: a randomized clinical trial. *Journal of Medicinal Food* 6: 51–56.

Stefansson, S.O., Bjornsson, B.T., Hansen, T., Haux, C., Taranger, G.L. and Saunders, R.L. (1999). Growth, parr-smolt transformation, and changes in growth hormone of Atlantic salmon (*Salmo salar*) reared under different photoperiods. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2100–2108.

Stein, J.R. (1973). *Handbook of phycological methods*, 448 pp. Cambridge, MA: Cambridge University Press.

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K.S. and Lima, M. (2002). Ecological effects of climate fluctuations. *Science* 297: 1292–1296.

Stewart, J., Lignell, A., Pettersson, A., Elfving, E. and Soni, M. (2008). Safety assessment of astaxanthin-rich microalgae biomass: acute and subchronic toxicity studies in rats. *Food and Chemical Toxicology* 46: 3030–3036.

Suanyuk, N., Sukkasame, N., Tanmark, N., Yoshida, T., Itami, T., Thune, R.L., Tantikitti, C. and Supamattaya, K. (2010). *Streptococcus iniae* infection in cultured Asian seabass (*Lates calcarifer*) and red tilapia (*Oreochromis* sp.) in southern Thailand. *Songklanakarin Journal of Science and Technology* 32: 341–348.

Subramani, P.A. and Michael, R.D. (2017). Prophylactic and prevention methods against diseases in aquaculture. In *Fish Diseases: Prevention and Control Strategies*, ed. G. Jeney, pp. 81–117. Cambridge, MA: Academic Press.

Suganuma, K., Nakajima, H., Ohtsuki, M. and Imokawa, G. (2010). Astaxanthin attenuates the UVA-induced up-regulation of matrixmetalloproteinase-1 and skin fibroblast elastase in human dermal fibroblasts. *Journal of Dermatological Science* 58: 136–142.

Sun, P., Yin, F. and Tang, B. (2016a). Effects of acute handling stress on expression of growth-related genes in *Pampus argenteus*. *Journal of the World of Aquaculture Society* 48: 166–179.

Sun, H., Kong, Q., Geng, Z. and Wang, N. (2016b). Repeated cultivation: non-cell disruption extraction of astaxanthin for *Haematococcus pluvialis*. *ScientificReports*6: 20578. https://doi.org/10.1038/srep20578.

Sun, W., Xing, L., Lin, H., Leng, K., Zhai, Y. and Liu, X. (2016c). Assessment and comparison of in vitro immunoregulatory activity of three astaxanthin stereoisomers. *Journal of Ocean University of China* 15: 283–287.

Szentes, K., Meszaros, E., Szabo, T., Csorbai, B., Borbely, G., Bernath, G. and Horvath, A. (2012). Gonad development and gametogenesis in the Asian sea bass (*Lates calcarifer*) grown in an intensive aquaculture system. *Journal of Applied Ichthyology* 28: 883–885.

Taddese, F., Huh, M.D., Bai, S.C. and Vijverberg, J. (2014). Histological changes of liver in overfed young Nile tilapia. *Journal of Fisheries and Aquatic Sciences* 9: 63–74.

Tago, Y., Fujii, T., Wada, J., Kato, M., Wei, M., Wanibuchi, H. and Kitano, M. (2014). Genotoxicity and subacute toxicity studies of a new astaxanthin containing *Phaffia rhodozyma* extract. *Journal of Toxicological Sciences* 39: 373–382.

Tahmasebi-Kohyani, A., Keyvanshokooh, S., Nematollahi, A., Mahmoudi, N. and Pasha-Zanoosi, H. (2013). Effects of dietary nucleotides supplementation on rainbow trout (*Oncorhynchus mykiss*) performance and acute stress response. *Fish Physiology and Biochemistry* 38: 431–440.

Talpur, A.D. and Ikhwanuddin, M. (2012). Dietary effects of garlic (*Allium sativum*) on haemato-immunological parameters, survival, growth, and

disease resistance against *Vibrio harveyi* infection in Asian sea bass, *Lates calcarifer* (Bloch). *Aquaculture* 364–365: 6–12.

Talpur, A.D. and Ikhwanuddin, M. (2013). *Azadirachta indica* (neem) leaf dietary effects on the immunity response and disease resistance of Asian seabass, *Lates calcarifer* challenged with *Vibrio harveyi*. *Fish and Shellfish Immunology* 34: 254–264.

Talpur, A.D., Ikhwanuddin, M. and Bolong, A.A. (2013). Nutritional effects of ginger (*Zingiber officinale* Roscoe) on immune response of Asian sea bass, *Lates calcarifer* (Bloch) and disease resistance against *Vibrio harveyi*. *Aquaculture* 400–401: 46–52.

Tanaka, T., Shnimizu, M. and Moriwaki, H. (2012). Cancer chemoprevention by carotenoids. *Molecules* 17: 3202–3242.

Tang, F., Zhan, W., Sheng, X. and Chi, H. (2010). Immune response of Japanese flounder *Paralichthys olivaceus* to outer membrane protein of *Edwardsiella tarda*. *Fish and Shellfish Immunology* 28: 333–343.

Tang, M., Xu, X., Li, S., Wu, T., Yan, Y., Gu, W., Wang, W., Jiang, Y. and Meng, Q. (2019). The metabolic responses of crucian carp blood to Cyprinid herpesvirus 2 infection. *Aquaculture* 498: 72–82.

Taucher, J., Baer, S., Schwerna, P., Hofmann, D., Hummer, M., Buchholz, R. and Becker, A. (2016). Cell disruption and pressurized liquid extraction of carotenoids from microalgae. *Journal of Thermodynamics and Catalysis* 7: 1. https://doi.org/10.4172/2158-7544.1000158.

Tavares-Dias, M. and Martins, M.L. (2017). An overall estimation of losses caused by diseases in the Brazilian fish farms. *Journal of Parasitic Diseases* 41: 913–918.

Tejera, N., Cejas, J.R., Rodriguez, C., Bjerkeng, B., Jerez, S., Bolanos, A. and Lorenzo, A. (2007). Pigmentation, carotenoids, lipid peroxides and lipid composition of skin of red porgy (*Pagrus pagrus*) fed diets supplemented with different astaxanthin sources. *Aquaculture* 270: 218–230.

Tendencia, E.A. (2002). *Vibrio harveyi* isolated from cage-cultured seabass *Lates calcarifer* Bloch in the Philippines. *Aquaculture Research* 33: 455–458.

Terech-Majewska, E. (2016). Improving disease prevention and treatment in controlled fish culture. *Archives of Polish Fisheries* 24: 115-116.

Thapa, B.R. and Walia, A. (2007). Liver function tests and their interpretation. *Indian Journal of Pediatrics* 74: 663–671.

Thompson, I., Fletcher, T.C., Houlihan, D.F. and Secombes, C.J. (1994). Effect of dietary vitamin A intake on the immunocompetence of Atlantic

salmon (*Salmo salar* L.). Fish *Physiology and Biochemistry* 12: 513–523.

Thompson, I., Choubert, G., Houlihan, D.F. and Secombes, C.J. (1995). The effect of dietary vitamin A and astaxanthin on the immunocompetence of rainbow trout. *Aquaculture* 133: 91–102.

Thompson, K.D. (2017). Immunology: improvement of innate and adaptive immunity. In *Fish Diseases: Prevention and Control Strategies*, ed. G. Jeney, pp. 1–17. Cambridge, MA: Academic Press.

Tkachenko, H., Kurhaluk, N., Andriichuk, A., Gasiuk, E. and Beschasniu, S. (2014). Oxidative stress biomarkers in liver of sea trout (*Salmo trutta* m. *trutta* L.) affected by ulcerative dermal necrosis syndrome. *Turkish Journal Fisheries and Aquatic Sciences* 14: 391–402.

Toffan, A., Pascoli, F., Pretto, T., Panzarin, V., Abbadi, M., Buratin, A., Quartesan, R., Gijon, D. and Padros, F. (2017). Viral nervous necrosis in gilthead sea bream (*Sparus aurata*) caused by reassortant betanodavirus RGNNV/SJNNV: an emerging threat for Mediterranean aquaculture. *Scientific Reports* 7: 46755. https://doi.org/10.1038/srep46755.

Tominaga, K., Hongo, N., Fujishita, M., Takahashi, Y. and Adachi, Y. (2017). Protective effects of astaxanthin on skin deterioration. *Journal of Clinical Biochemistry and Nutrition* 61: 33–39.

Tort, L. (2011). Stress and immune modulation in fish. *Developmental and Comparative Immunology* 35: 1366–1375.

Tsubakio-Yamamoto, K., Matsuura, F., Koseki, M., Oku, H., Sandoval, J.C., Inagaki, M., Nakatani, K., Nakaoka, H., Kawase, R., Yuasa-Kawase, M., Masuda, D., Ohama, T., Maeda, N., Nakagawa-Toyama, Y., Ishigami, M., Nishida, M., Kihara, S. and Yamashita, S. (2008). Adiponectin prevents atherosclerosis by increasing cholesterol efflux from macrophages. *Biochemical and Biophysical Research Communications* 375: 390–394.

Uchiyama, K., Naito, Y., Hasegawa, G., Nakamura, N., Takahashi, J. and Yoshikawa, T. (2002). Astaxanthin protects β-cells against glucose toxicity in diabetic db/db mice. *Redox Report* 7: 290–293.

Uduman, N., Qi, Y., Danquah, M.K., Forde, G.M. and Hoadley, A. (2010). Dewatering of microalgal cultures: a major bottleneck to algae-based fuels. *Journal of Renewable and Sustainable Energy* 2: 127–142.

Uribe, C., Folch, H., Enrique, R. and Moran, G. (2011). Innate and adaptive immunity in teleost fish: a review. *Veterinarni Medicina* 56: 486–503.

Valiente-Moro, C., Crouzet, O., Rasconi, S., Thouvenot, A., Coffe, G., Batisson, I. and Bohatier, J. (2009). New design strategy for development of

specific primer sets for PCR-based detection of Chlorophyceae and Bacillariophyceae in environmental samples. *Applied and Environmental Microbiology* 75: 5729–5733.

Vartak, V.R., Makesh, M., Rajendran, K.V., Sivakumar, N., Kumar, K. and Singh, R. (2012). Investigation on the mortality in semi-fry sea bass *Lates calcarifer* (Bloch). *Indian Journal of Fisheries* 59: 157–160.

Varsamos, S., Nebel, C. and Charmantier, G. (2005). Ontogeny of osmoregulation in postembryonic fish: a review. *Comparative Biochemistry and Physiology. A, Molecular and Integrative Physiology* 141: 401–429.

Vasemagi, A., Visse, M. and Kisand, V. (2017). Effect of environmental factors and an emerging parasitic disease on gut microbiome of wild salmonid fish. *mSphere* 2: e00418-17. https://doi.org/10.1128/mSphere.00418-17.

Venkatachalam, S., Kandasamy, K., Krishnamoorthy, I. and Narayanasamy, R. (2018). Survival and growth of fish (*Lates calcarifer*) under intergrated mangrove-aquaculture and open-aquaculture systems. *Aquaculture Reports* 9: 18–24.

Visioli, F. and Artaria, C. (2017). Astaxanthin in cardiovascular health and disease: mechanism of action, therapeutic merits, and knowledge gaps. *Food and Function* 8: 39–63.

Volkoff, H. (2016). The neuroendocrine regulation of food intake in fish: a review of current knowledge. *Frontiers in Neuroscience* 10: 1–31.

Wade, N.M., Cheers, S., Bourne, N., Irvin, S., Blyth, D. and Glencross, B.D. (2015). Dietary astaxanthin levels affect colour, growth, carotenoid digestibility and the accumulation of specific carotenoid esters in the Giant Tiger Shrimp, *Penaeus monodon*. *Aquaculture Research* 48: 395–406.

Wan, M., Zhang, J., Hou, D., Fan, J., Li, Y., Huang, J. and Wang, J. (2014). The effect of temperature on cell growth and astaxanthin accumulation of *Haematococcus pluvialis* during a light–dark cyclic cultivation. *Bioresource Technology* 167: 276–283.

Wang, Y.J., Chien, Y.H. and Pan, C.H. (2006). Effects of dietary supplementation of carotenoids on survival, growth, pigmentation, and antioxidant capacity of characins, *Hyphessobrycon callistus*. *Aquaculture* 261: 641–648.

Wang, Y. and Peng, J. (2008). Growth associated biosynthesis of astaxanthin in heterotrophic *Chlorella zofingiensis* (Chlorophyta). *World Journal of Microbiology and Biotechnology* 24: 1915–1922.

Wang, W., Sun, J., Liu, C. and Xue, Z. (2016a). Application of immunostimulants in aquaculture: current knowledge and future perspectives. *Aquaculture Research* 48: 1–23.

Wang, N., Guan, B., Kong, Q., Sun, H., Geng, Z. and Duan, L. (2016b). Enhancement of astaxanthin production from *Haematococcus pluvialis* mutants by three-stage mutagenesis breeding. *Journal of Biotechnology* 236: 71–77.

Wang, X.M., Gao, J.W., Xu, M., Mo, B.L., Dai, W. and Chen, C. (2017). Responses of growth rates and growth hormone levels of African catfish (*Clarias gariepinus*) to stocking density. *Iranian Journal of Fisheries Sciences* 16: 698–710.

Wang, W., Song, X., Wang, L. and Song, L. (2018a). Pathogen-derived carbohydrate recognition in molluscs immune defense. *International Journal of Molecular Science* 19: 721. https://doi.org/10.3390/ijms1903 07 21.

Wang, R., Sun, L., Wang, Y., Deng, Y., Fang, Z., Liu, Y., Deng, Q., Sun, D. and Gooneratne, R. (2018b). Influence of food matrix type on extracellular products of *Vibrio parahaemolyticus*. *BMC Microbiology* 18: 65. https:// doi.org/10.1186/s12866-018-1207-7.

Wang, P., Geng, J., Gao, J., Zhao, H., Li, J., Shi, Y., Yang, B., Xiao, C., Linghu, Y., Sun, X., Chen, X., Hong, L., Qin, F., Li, X., Yu, J., You, H., Yuan, Z., Zhou, D., Johnson, R. and Chen, L. (2019). Macrophage achieves self-protection against oxidative stress-induced ageing through the Mst-Nrf2 axis. *Nature Communications* 10: 755. https://doi.org/10.1038/s41 467-019-08680-6.

Wargelius, A., Fjelldal, P.G., Benedet, S., Hansen, T., Bjornsson, B.T. and Nordgarden,U. (2005). A peak in gh-receptor expression is associated with growth activation in Atlantic salmon vertebrae, while upregulation of igf-I receptor expression is related to increased bone density. *General and Comparative Endocrinology* 142: 163–168.

Watts, J.E.M., Schreier, H.J., Lanska, L. and Hale, M.S. (2017). The rising tide of antimicrobial resistance in aquaculture: sources, sinks and solutions. *Marine Drugs* 15: 158. https://doi.org/10.3390/md15060158.

Webb, R.O. and O'Donoghue, P. (2015). An epizootic of chilodonelliasis in farmed barramundi *Lates calcarifer* (Bloch), a case report. *Journal of Fish Diseases* 38: 931–936.

Weber, G.M., Davidson, J.W., Kenney, P.B., Good, C.M., Manor, M.L., Welsh, C., Aussanasuwannakul, A. and Summerfelt, ST. (2015). Changes in sex steroids, growth hormone, and insulin-like growth factor-I during ovarian development in rainbow trout cultured in a water recirculating system with continuous light. *North American Journal of Aquaculture* 77: 186–194.

Whyte, S.K. (2007). The innate immune responses of finfish-a review of current knowledge. *Fish and Shellfish Immunology* 23: 1127–1151.

Wolf, J.C., Baumgartner, W.A., Blazer, V.S., Camus, C.A., Engelhardt, J.A., Fournie, J.W., Jr, S.F., Groman, D.B., Kent, M.L., Khoo, L.H., Law, J.M., Lombardini, E.D., Ruehl-Fehlert, C., Segner, H.E., Smith, S.A., Spitsbergen, J.M., Weber, K. and Wolfe, M.J. (2015). Nonlesions, misdiagnoses, missed diagnoses, and other interpretive challenges in fish histopathology studies: a guide for investigators, authors, reviewers, and readers. *Toxicologic Pathology* 43: 297–325.

Wolf, J.C. and Wheeler, J.R. (2018). A critical review of histopathological findings associated with endocrine and non-endocrine hepatic toxicity in fish models. *Aquatic Toxicology* 197: 60–78.

Wong, Y.K., Ho, Y.H., Ho, K.C., Lai, Y.T., Tsang, P.M., Chow, K.P., Yau, Y.H., Choi, M.C. and Ho, R.S.C. (2016). Effects of light intensity, illumination cycles on microalgae *Haematococcus pluvialis* for production of astaxanthin. *Journal of Marine Biology and Aquaculture* 2: 1–6.

Xi, T., Kim, D.G., Roh, S.W., Choi, J.S. and Choi, Y.E. (2016). Enhancement of astaxanthin production using *Haematococcus pluvialis* with novel LED wavelength shif strategy. *Applied Microbiology and Biotechnology* 100: 6231–6238.

Xiang, J. (2015). Recent major advances of biotechnology and sustainable aquaculture in China. *Current Biotechnology* 4: 296–310.

Xie, J., Chen, X., Niu, J., Wang, J., Wang, Y. and Liu, Q. (2017). Effects of astaxanthin on antioxidant capacity of golden pompano *(Trachinotus ovatus)* in vivo and in vitro*. Fisheries and Aquatic Sciences* 20: 1–8.

Yada, T. (2007). Growth hormone and fish immune system. *General and Comparative Endocrinology* 152: 353–358.

Yamashita, E. (2013). Astaxanthin as a medical food. *Functional Foods in Health and Disease* 3: 254–258.

Yamashita, E. (2015). Let astaxanthin be thy medicine. *PharmaNutrition* 3: 115–122.

Yamaoka, Y. (2008). *Microorganism and production of carotenoid compounds.* U.S. Patent 20040253724A1.

Yanez, J.M., Houston, R.D., and Newman, S. (2014). Genetics and genomics of disease resistance in salmonid species. *Frontiers in Genetics* 5: 415. https://doi.org/10.3389/fgene.2014.00415.

Yang, H., Lee, Y.M., Lee, J., Noh, J.K., Kim, H.C., Park, C., Park, J., Hwang, I. and Kim, S.Y. (2013). Expression of perforin gene for early

development of nephrons in olive flounder (*Paralichthys olivaceus*). *Development and reproduction* 17: 321–327.

Ye, B., Wan, Z., Wang, L., Pang, H., Wen, Y., Liu, H., Liang, B., Lim, H., Jiang, J. and Yue, G. (2017). Heritability of growth traits in the *Asian seabass* (*Lates calcarifer*). *Aquaculture and Fisheries* 2: 112–118.

Yi, X., Xu, W., Zhou, H., Zhang, Y., Luo, Y., Zhang, W. and Mai, K. (2014). Effects of dietary astaxanthin and xanthophylls on the growth and skin pigmentation of large yellow croaker *Larimichthys croceus*. *Aquaculture* 433: 377–383.

Yokoyama, A., Adachi, K. and Shizuri, Y. (1995). New carotenoid glucosides, astaxanthin glucoside and adonixanthin glucoside, isolated from the astaxanthin producing marine bacterium, *Agrobacterium aurantiacum*. *Journal of Natural Products* 58: 1929–1933.

Yoshida, H., Yanai, H., Ito, K., Tomono, Y., Koikeda, T., Tsukahara, H. and Tada, N. (2010). Administration of natural astaxanthin increases serum HDL-cholesterol and adinopectin in subjects with mild hyperlipidemia. *Atherosclerosis* 209: 520–523.

Yossa, R. and Verdegem, M. (2015). Misuse of multiple comparison tests and underuse of contrast procedures in aquaculture publications. *Aquaculture* 437: 344–350.

Young, A.J. and Lowe, G.M. (2001). Antioxidant and prooxidant properties of carotenoids. *Archives of Biochemistry and Biophysics* 385: 20–27.

Young, G., Bjornsson, B.T., Prunet, P., Lin, R.J. and Bern, H.A. (1989). Smoltification and seawater adaptation in coho salmon (*Oncorhynchus kisutch*): plasma prolactin, growth hormone, thyroid hormones, and cortisol. *General and Comparative Endocrinology* 74: 346–354.

Young, A.J., Pritchard, J., White, D.A. and Davies, S. (2017). Processing of astaxanthin-rich Haematococcus cells for dietary inclusion and optimal pigmentation in rainbow trout, *Oncorhynchus mykiss* L. *Aquaculture Nutrition* 23: 6. https://doi.org/10.1111/anu.12505.

Ytrestoyl, T., Struksnaes, G., Koppe, W. and Bjerkeng, B. (2005). Effects of temperature and feed intake on astaxanthin digestibility and metabolism in Atlantic salmon, *Salmo salar*. *Comparative Biochemistry and Physiology. B, Biochemistry and Molecular Biology* 142: 445–455.

Yuan, J., Peng, J., Yin, K. and Wang, J. (2011). Potential health-promoting effects of astaxanthin: a high value carotenoid mostly from microalgae. *Molecular Nutrition and Food Research* 55: 150–165.

Yue, G.H., Zhu, Z.Y., Lo, L.C., Wang, C.M., Lin, G., Feng, F. and Orban, L. (2009). Genetic variation and population structure of Asian seabass (*Lates calcarifer*) in the Asia-Pacific region. *Aquaculture* 293: 22–28.

Zanuzzo, F.S., Sabioni, R.E., Montoya, L.N.F., Favero, G. and Urbinati, E.C. (2017). *Aloe vera* enhances the innate response of pacu (*Piaractus mesopotamicus*) after transport stress and combined heat killed *Aeromonas hydrophila* infection. *Fish and Shellfish Immunology* 65: 198–205.

Zhang, D.H., Ng, M.L. and Phang, S.M. (1997). Composition and accumulation of secondary carotenoids in *Chlorococcum* sp. *Journal of Applied Phycology* 9: 147–155.

Zhang, J., Liu, Y.J., Tian, L.X., Yang, H.J., Liang, G.Y. and Yue, Y.R. (2013). Effects of dietary astaxanthin on growth, antioxidant capacity and gene expression in Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition* 19: 917–927.

Zhang, X., Li, Y.W., Mo, Z.Q., Luo, X.C., Sun, H.Y., Liu, P., Li, A.X., Zhou, S.M. and Dan, X.M. (2014). Outbreak of a novel disease associated with *Vibrio mimicus* infection in fresh water cultured yellow catfish, *Pelteobagrus fulvidraco*. *Aquaculture* 432: 119–124.

Zhang, Z., Wang, B., Hu, Q., Sommerfeld, M., Li, Y. and Han, D. (2016). A new paradigm for producing astaxanthin from the unicellular green alga *Haematococcus pluvialis*. *Biotechnology and Bioengineering* 113: 2088–2099.

Zhang, C., Liu, J. and Zhang, L. (2017). Cell cycles and proliferation patterns of *Haematococcus pluvialis*. *Chinese Journal of Oceanography and Limnology* 35: 1205–1211.

Zhang, W., Zhou, X., Zhang, Y., Cheng, P., Ma, R., Cheng, W. and Chu, H. (2018). Enhancing astaxanthin accumulation in *Haematococcus pluvialis* by coupled light intensity and nitrogen starvation in column photobioreactors. *Journal of Microbiology and Biotechnology* 28: 2019–2028.

Zhang, Z., Chi, H. and Dalmo, R.A. (2019). Trained innate immunity of fish is a viable approach in larval aquaculture. *Frontiers in Immunology* 10: 42. https://doi.org/10.3389/fimmu.2019.00042.

Zhang, C., Chen, X. and Too, H. (2020). Microbial astaxanthin biosynthesis: recent achievements, challenges, and commercialization outlook. *Applied Microbiology and Biotechnology* 104: 5725–5737.

Zhao, Y., Jiang, X., Kong, X., Di, G., Nie, G. and Li, X. (2015). Effects of hypoxia on lysozyme activity and antioxidant defences in the kidney and spleen of *Carassius auratus*. *Aquaculture Research* 48: 223–235.

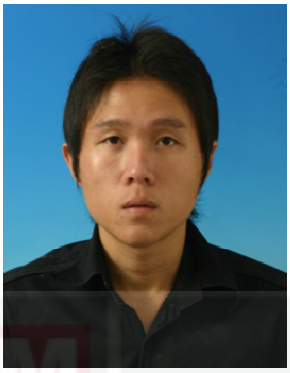
Zhou, C., Ge, X., Liu, B., Xie, J., Chen, R. and Ren, M. (2015). Effect of high dietary carbohydrate on the growth performance, blood chemistry, hepatic enzyme activities and growth hormone gene expression of

Wuchang bream (*Megalobrama amblycephala*) at two temperatures. *Asian-Australasian Journal of Animal Sciences* 28: 207–214.

Zhu, Z.Y., Lin, G., Lo, L.C., Xu, Y.X., Renee, C. and Yue, G.H. (2006). Genetic analyses of Asian seabass stocks using novel polymorphic microsatellites. *Aquaculture* 256: 167–173.

Zhu, L., Nie, L., Zhu, G., Xiang, L. and Shao, J. (2013). Advances in research of fish immune-relevant genes: A comparative overview of innate and adaptive immunity in teleosts. *Developmental and Comparative Immunology* 39: 39–62.

BIODATA OF STUDENT



The student, Mr. Lim Keng Chin, was born on the 28th of May 1985 in Penang to the proud parents of Mr. Lim Eng Seng and Mrs. Hew Yeat Chen. He is the second oldest of the three siblings and was raised in Georgetown, Penang. The author can be described as independent, ambitious, and dedicated while having passionate interests within the fields of aquaculture and marine biology. From an early education at the primary school of SK Pykett Methodist, the author went to the most remarkable secondary school in Penang, SMK Methodist Boys' School, upon completing the Primary School Achievement Test (UPSR). After completion of the Lower Secondary Assessment (PMR) and Malaysian Certificate of Education (SPM) exams, he had another two more years of post-secondary education and sat for the Malaysian Higher School Certificate (STPM) pre-university examination in the same institution. Afterward, he continued his journey swiftly into Universiti Malaysia Terengganu (UMT), where he earned both a Bachelor of Science (Marine Biology) and Master of Science (Marine Science) degrees. With his newfound enthusiasm, he then decided to pursue his doctoral degree in the field of aquaculture and marine biotechnology at Universiti Putra Malaysia (UPM). Fortunately enough, he was awarded the MyBrain15 (MyPhD) Postgraduate Scholarship from the Ministry of Higher Education (MOHE) Malaysia. He has published several scientific articles in national and international journals. The subsequent chapter of his life has yet to be ascertained.

LIST OF PUBLICATIONS

Lim, K.C., Yusoff, F.M., Shariff, M. and Kamarudin, M.S. (2018). Astaxanthin as feed supplement in aquatic animals. *Reviews in Aquaculture* 10: 738–773.

Lim, K.C., Yusoff, F.M., Shariff, M. and Kamarudin, M.S. (2019). Dietary administration of astaxanthin improves feed utilization, growth performance and survival of Asian seabass, *Lates calcarifer* (Bloch, 1790). *Aquaculture Nutrition* 25: 1410–1421.

Lim, K.C., Yusoff, F.M., Shariff, M., Kamarudin, M.S. and Nagao, N. (2019). Dietary supplementation of astaxanthin enhances hemato-biochemistry and innate immunity of Asian seabass, *Lates calcarifer* (Bloch, 1790). *Aquaculture* 512: 734339. https://doi.org/10.1016/j.aquaculture.2019.734339.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _____

TITLE OF THESIS / PROJECT REPORT :

_____

_____

_____

NAME OF STUDENT : _____

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☑	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from_____ until _____ (date) (date)

Approved by:

_____ _____

(Signature of Student) (Signature of Chairman of Supervisory Committee)

New IC No/ Passport No.: Name:

Date : Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]