UNIVERSITI PUTRA MALAYSIA

DETECTION OF LARD IN FISH FEED AND OPTIMIZING THE PROCESSING CONDITIONS FOR PELLETED FISH FEED PRODUCTION USING CHEMOMETRIC AND RESPONSE SURFACE METHODOLOGY

MOHAMED HANIFF HANAFY BIN IDRIS

IPPH 2022 2

DETECTION OF LARD IN FISH FEED AND OPTIMIZING THE PROCESSING CONDITIONS FOR PELLETED FISH FEED PRODUCTION USING CHEMOMETRIC AND RESPONSE SURFACE METHODOLOGY

By

MOHAMED HANIFF HANAFY BIN IDRIS

Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement of the Degree of Master of Science

February 2022

DEDICATIONS

Bismillahirrahmanirrahim

Especially for:

Emak and Ayah,

My siblings,

My lectures,

My friends,

Thank you so much for the unwavering support, advice, and encouragement throughout this journey. May Allah bless you and reward you a thousand-fold.

Ameen.

Alhamdulillah.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DETECTION OF LARD IN FISH FEED AND OPTIMIZING THE PROCESSING CONDITIONS FOR PELLETED FISH FEED PRODUCTION USING CHEMOMETRIC AND RESPONSE SURFACE METHODOLOGY

By

MOHAMED HANIFF HANAFY BIN IDRIS

February 2022

Chairman : Shuhaimi bin Mustafa, PhD
Institute : Halal Products Research

In order to save the cost of fish production, some small-scale farmers prefer to produce fish feed using inexpensive pelleting methods and ingredients. However, due to a lack of knowledge and expertise, the processing conditions of fish feed production are often neglected, and the basic ingredient such as oil is deliberately replaced with cheaper material such as lard. From a religious perspective, lard in any product is strictly prohibited, especially for the Muslim community. This research thus intends to optimize the processing conditions of the pelleting method using response surface methodology (RSM) and also to detect lard as an adulterant in fish feed using fatty acid (FA) and triacylglycerol (TAG)-based analyses separately, which are then integrated with chemometrics. The optimum processing conditions were determined based on the desired properties of bulk density, floatability, water absorption and water solubility indices of the fish feed produced. For lard detection, *sn*-2 FA composition was coupled with total FA composition to enhance the FA-based analysis by gas chromatography-mass spectrometry (GC-MS). Meanwhile, to improve the TAG-based analysis, thermal analysis by differential scanning calorimetry (DSC) was combined with TAG composition analysis by high-performance liquid chromatography (HPLC). These two types of analysis (FA and TAG-based) were then incorporated with chemometric techniques, namely principal component analysis (PCA), orthogonal partial least square-discriminant analysis (OPLS-DA), and orthogonal partial least square-regression (OPLS-R). Results of RSM revealed that the combination of water temperature at 70 ºC, mixing speed at 75 rpm, and mixing time of 5 min were the optimal processing conditions in producing pelleted fish feed with the best quality. For lard detection, the enhanced-PCA model exhibited a preferable distribution pattern of fish feed by differentiating them into separate clusters without overlap. The OPLS-based prediction models constructed from the most discriminating variables pre-defined by the enhanced-PCA also showed good performances. The OPLS-DA model provided significant class discrimination between lard adulterated and non-adulterated fish feed; meanwhile, the OPLS-R model revealed a stronger relationship between the observed and predicted value of lard percentage with the increasing value of the coefficient of determination (R^2). The

optimized processing conditions determined by RSM showed it was possible to produce relatively good quality pelleted fish feed comparable to extruded fish feed. In addition, the involvement of complementary analysis with chemometrics indicated that lard in fish feed could be detected and quantified more effectively, and its relevant biomarkers could also be discovered.

Keywords : Chemometrics, Fatty Acid, Fish feed, Lard, Triacylglycerol.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah sarjana Master Sains

PENGESANAN LEMAK BABI DALAM MAKANAN IKAN DAN PENGOPTIMUMAN KEADAAN PEMPROSESAN BAGI PENGHASILAN MAKANAN IKAN PEMPELETAN MENGGUNAKAN KEMOMETRIK DAN METODOLOGI PERMUKAAN RANGSANGAN

Oleh

MOHAMED HANIFF HANAFY BIN IDRIS

Februari 2022

Pengerusi : Shuhaimi bin Mustafa, PhD
Institut : Penyelidikan Produk Halal

Bagi menjimatkan kos pengeluaran makanan ikan, beberapa penternak berskala kecil cenderung menghasilkan makanan ikan menggunakan kaedah pempeletan dan ramuan yang murah. Namun, disebabkan kekurangan ilmu dan kepakaran, keadaan pemprosesan penghasilan makanan ikan sering diabaikan, dan ramuan asas seperti minyak sengaja digantikan dengan bahan yang lebih murah seperti lemak babi. Dari sudut keagamaan, kehadiran lemak babi dalam sesuatu produk adalah dilarang terutama bagi umat Islam. Oleh itu, kajian ini bertujuan mengoptimumkan keadaan pemprosesan kaedah pelet menggunakan metodologi permukaan rangsangan (RSM) dan juga untuk mengesan lemak babi sebagai pencemar dalam makanan ikan menerusi analisis berasakan asid lemak (FA) dan triasilgliserol (TAG) secara berasingan, yang kemudiannya digabungkan bersama kemometrik. Keadaan pemprosesan optimum ditentukan berdasarkan sifat-sifat seperti kepadatan pukal, kebolehapungan, indeks penyerapan air dan kelarutan air makanan ikan yang dihasilkan. Bagi pengesanan lemak babi, komposisi asid lemak *sn*-2 digabungkan bersama komposisi keseluruhan asid lemak untuk menambahbaik analisis berasaskan asid lemak oleh kromatografi gas-spektrometri jisim (GC-MS). Manakala, untuk menambahbaik analisis berasaskan triasilgliserol, analisis termal oleh kalorimeter pengimbasan pembezaan (DSC) digabungkan bersama analisis komposisi triasilgliserol oleh kromatografi cecair berprestasi tinggi (HPLC). Kedua-dua analisis ini kemudiannya digabungkan bersama teknik-teknik kemometrik seperti analisis komponen utama (PCA), analisis diskriminan-kuasa dua terkecil separa ortogonal (OPLS-DA), dan regresi-kuasa dua terkecil separa ortogonal (OPLS-R). Keputusan RSM menunjukkan bahawa gabungan suhu air: 70 ºC, kelajuan pencampuran: 75 rpm dan masa pencampuran: 5 minit merupakan keadaan pemprosesan optimum bagi menghasilkan makanan ikan pempeletan dengan kualiti terbaik. Bagi pengesanan lemak babi, model PCA-yang-ditambahbaik menunjukkan corak taburan makanan ikan yang lebih dikehendaki dengan membezakan mereka kepada kluster tersendiri tanpa pertindihan. Model ramalan OPLS yang dibina daripada pembolehubah yang ditetapkan oleh PCA-yang-ditambahbaik juga menunjukkan prestasi yang baik. Model OPLS-DA menghasilkan diskriminasi kelas

yang signifikan antara makanan ikan yang dicemari lemak babi dan yang tidak tercemar, manakala OPLS-R memberikan hubungan baik antara peratusan lemak babi diperhatikan dan diramalkan dengan peningkatan nilai pekali penentuan (R^2). Keadaan pemprosesan optimum yang ditentukan oleh RSM membuktikan adalah mungkin untuk menghasilkan makanan ikan pempeletan yang berkualiti setara dengan makanan ikan ekstrusi. Selain itu, penyertaan analisis pelengkap bersama kemometrik membuktikan bahawa lemak babi dalam makanan ikan boleh dikesan dan diukur dengan lebih berkesan, dan penanda-bio yang relevan juga dapat ditemukan.

Kata kunci: Kemometrik, Asid lemak, Makanan ikan, Lemak babi, Triasilgliserol,

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Beneficent, the Most Merciful. Foremost, I would like to express my deepest appreciation to my supervisor, Prof. Dr. Shuhaimi bin Mustafa, and my co-supervisors, Dr. Amalia binti Mohd Hashim and Assoc. Prof. Dr. Mohd Nasir bin Mohd Desa, for their kindness guidance, suggestion, advice, assistance, knowledge, and supervision.

I also would like to extend my gratitude to my team members, Dr. Muhammad Shirwan bin Abdullah Sani, Dr. Yanty Norozianna binti Abdul Manaf, Dr. Mohd Hafiz bin Yuswan, Mrs. Nor Nadiha binti Mohd Zaki, for their assistance and cooperation in this research.

I would also like to thank my family and friends for their inspiration and moral support throughout my master's journey. Thank you for being there.

To all Halal Products Research Institute staff, especially Mrs. Siti Nur Zaffan binti Arifin and Mrs. Roszaimah binti Muhammad Sapah, your contributions are deeply appreciated.

Lastly, I acknowledge Universiti Putra Malaysia and Konsortium Institut Halal IPT Malaysia, Ministry of Higher Education Malaysia, for providing funding support (research grant no. 63900911-10205) to this research.

Thank you so much.

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

Shuhaimi bin Mustafa, PhD
Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Chairman)

Amalia Binti Mohd Hashim, PhD
Senior Lecturer
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Mohd Nasir bin Mohd Desa, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

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

Date: 14th April 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature : _____
Name of Chairman of
Supervisory Committee : Prof. Dr. Shuhaimi bin Mustafa

Signature : _____
Name of Member of
Supervisory Committee : Dr. Amalia binti Mohd Hashim

Signature : _____
Name of Member of
Supervisory Committee : Assoc. Prof. Mohd Nasir bin Mohd Desa

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2-MAG	2-monoacylglycerol
BD	Bulk density
BTS	Bartlett's Test of Sphericity
CV-ANOVA	Analysis of variance testing of cross-validated predictive residuals
DSC	Differential scanning calorimetry
FA	Fatty acid
FAME	Fatty acid methyl ester
FT	Floatability
GC-MS	Gas chromatography-mass spectrometry
HPLC	High-performance liquid chromatography
KMO	Kaiser-Mayer-Olkin
LD	Lard
LFF	Lard-containing fish feed
MLP-ANN	Multilayer perceptron-artificial neural network
OPLS-DA	Orthogonal partial least square-discriminant analysis
OPLS-R	Orthogonal partial least square-regression
PCA	Principal component Analysis
PO	Palm oil
POFF	Palm oil-containing fish feed
RF	Random forest
RMSECV	Root mean square error of cross-validation
RMSEE	Root mean square error of estimation
RMSEP	Root mean square error of prediction
RSM	Response surface methodology

SFA	Saturated fatty acids
sn-2	second stereospecific position
SSS	Trisaturated
SSU	Disaturated-monounsaturated
SUU	Monosaturated-diunsaturated
SVM	Support vector machine
TAG	Triacylglycerol
USFA	Unsaturated fatty acids
UUU	Triunsaturated
VIP	Variable importance of projection
WAI	Water absorption index
WSI	Water solubility index

CHAPTER 1

GENERAL INTRODUCTION

1.1 Research background

Catfish (*Clarias spp.*) is one of the freshwater fish species that contributes significantly to aquaculture production in Malaysia (Dauda et al., 2018). This species is well known for its high resistance to disease and ease to breed (Shourbela & Tohamy, 2020). Year after year, the evolutionary progress in the catfish industry has led to the introduction of hybrid catfish through cross-breeding between male *Clarias gariepinus* and female *Clarias macrocephalus* (Koolboon et al., 2014).

The improved features, particularly in terms of delicacy, have caused the market demand for this hybrid catfish species to increase rapidly. (Amang, 2020). However, there are several problems that farmers often encounter to meet market demand and maintain the sustainability of catfish farming. The main challenge is the cost of feed supply which is greatly influenced by two critical factors: processing techniques and ingredients used to produce fish feed. For savings purposes, these factors should be carefully considered as they represent more than 50% of the total cost of fish production (Rana et al., 2009).

In fish feed production, there are two main processing techniques commonly practiced by manufacturers, either by pelleting or extrusion process (Zhenhua, 2011). The pelleting process entails the compression phase of small particles to produce larger particles in the presence of appropriate water content, temperature, and pressure. Meanwhile, the extrusion process involves not only compression but also cooking and expansion phase of the feed, which requires a higher water content, temperature, and pressure than the pelleting process (Anonymous, 2019c).

In general, extruded feed is preferred by most farmers because its buoyancy and water stability are better than pelleted feed (Welker et al., 2018). The good physical properties of extruded feed make it easy for farmers to observe and manage fish feeding activities, which can indirectly prevent wastage and water contamination (Verdegem, 2013). However, the high operating costs and market prices of extruded feed have forced small-scale farmers to produce their fish feed using cheaper pelleting methods to save costs (Agrimag, 2019).

Even so, due to lack of expertise and experience, the fish feed produced is sometimes easily immersed and disintegrated when exposed to water. To address this issue, in addition to using good binding and floating agents, the processing conditions of the pelleting method need to be studied in more detail. Therefore, the optimum level of each processing condition could be well determined to produce high-quality pelleted fish feed comparable to the extruded feed. One of the suggested ways is to apply a well-used optimization approach namely Response Surface Methodology (RSM) (Irungu et al.,

2019). It is suitable for use in situations where two or more influence factors need to be optimized to obtain the desired responses (H. Wang et al., 2021; M. Kumari & Gupta, 2019)

Apart from the physical properties, the nutrient content is also one of the important factors in the production of fish feed related to the selection of the ingredients. The ingredients used are based on the nutrient requirements of the species and the age of the fish raised (Robinson et al., 2001). Fish feeds are composed of various ingredients such as fishmeal, soybean meal, cornmeal, starch, fish oil, vitamin, mineral, and so on. They can be divided into six major compound categories: moisture, protein, fat, ash, crude fibre, and nitrogen-free extract (Anonymous, 2019b). Protein and fats are the most important compounds in producing fish feed (Petricorena, 2014). The main function of protein is to enhance growth and health performance, while fat is important to supply energy to the fish (Craig & Helfrich, 2009).

Traditionally, fish oil is commonly used as a source of fat in fish feed production (Harlıoğlu, 2012). However, due to its high price, sometimes this oil is deliberately replaced by suppliers with cheaper fat sources to reduce production costs. Among the fats often used as a substitute are vegetable oil, chicken fat, and lard. However, as is well known, the presence of lard in the human food chain is a serious religious issue among the Muslim and Jewish communities (Dahimi et al., 2013). In addition, the consumption of swine and its derivatives is perspicuously haram and strictly prohibited (Department of Standard Malaysia, 2009). It is clearly stated in the Al-Quran (chapter 2, verse 173) where Allah has forbidden Muslims to eat only carrion, blood, and swine flesh and slaughtered animals, not for Allah's sake.

Many analytical methods have been used for the analysis of lard adulteration, such as gas chromatography-mass spectrometry (GC-MS) (Guntarti et al., 2020), differential scanning calorimetry (DSC) (Dahimi et al., 2014), high-performance liquid chromatography (HPLC) (Marikkar et al., 2003), fourier transform infrared spectroscopy (FTIR) (Man et al., 2014), nuclear magnetic resonance (NMR) (Fadzillah et al., 2015), and isotope-ratio mass spectrometry (IRMS) (Naquiah et al., 2015). However, the detection of lard was reported to be more difficult when the chemical composition of lard is almost similar to other fats such as chicken and palm oil (Yanty et al., 2018). Furthermore, the existence of lard as a minor component in a complex mixture makes lard detection more complicated (Al-Kahtani. et al., 2014).

In such a situation, one of the possible ways to improve the capabilities of lard detection is by applying chemometric techniques to the data obtained from analytical methods. These chemometric techniques use a combination of knowledge related to mathematics, statistics, and logic-based methods to manage, explore and interpret data better and more effectively (Haswell, 1992). Worley & Powers (2016) have proved that the use of principal component analysis (PCA) with orthogonal partial least square-discriminant analysis (OPLS-DA) are powerful chemometric techniques for qualitative analysis. Meanwhile, Nitta et al. (2017) have shown that the application of principal component analysis with orthogonal partial least square-regression (OPLS-R) are excellent chemometric techniques for quantitative analysis.

At present, there is no specific method that has been published for detecting lard as an adulterant in fish feed. Hence, in addition to proposing optimal processing conditions for the pelleting method, this study also suggests the use of two fundamentally different analytical methods (fatty acid and triacylglycerol-based) along with their respective complementary method and combined with chemometric techniques in developing more reliable detection methods for lard in fish feed.

1.2 Hypothesis

In this study, it is hypothesized that:

1. The use of RSM will provide a good description of the effects of each processing condition of pelleted fish feed production as well as their interactive and quadratic effects on fish feed quality, thereby facilitating the determination of optimal processing conditions.

2. Based on fatty acid analysis, the incorporation of *sn*-2 fatty acid composition with overall fatty acid composition coupled with chemometric techniques will increase the effectiveness of lard detection and quantification processes in fish feed.

3. Based on triacylglycerol analysis, the integration of triacylglycerol thermal properties with triacylglycerol composition combined with chemometric techniques will improve the capabilities of lard detection and quantification methods in fish feed.

1.3 Objectives

Thus, the present study embarks on the following objectives:

1. To optimize the processing conditions of pelleted fish feed production using RSM.

2. To enhance the effectiveness of lard detection and quantification methods in fish feed by incorporating *sn*-2 fatty acid composition with overall fatty acid composition using GC-MS coupled with chemometric techniques.

3. To improve the detection and quantification processes of lard in fish feed by integrating DSC with HPLC data combined with chemometric techniques.

REFERENCES

Abbas, O., Lecler, B., Dardenne, P., & Baeten, V. (2013). Detection of melamine and cyanuric acid in feed ingredients by near infrared spectroscopy and chemometrics. *Journal of Near Infrared Spectroscopy*, *2013*(21), 183–194. https://doi.org/10.1255/jnirs.1047

Abubakar, M. Y., Momoh, A. T., & Ipinjolu, J. K. (2016). Effect of pelletizing machines on floatation and water stability of farm-made fish feeds. *International Journal of Fisheries and Aquatic Studies*, *4*(3), 98–103.

Adebayo, I. A., Akin-Obasola, B. J., & Abe, B. A. (2020). Growth and hematological responses of Clarias gariepinus juveniles fed diets containing varying digestible lipids of plant origin. *International Journal of Fisheries and Aquaculture Research*, *6*(1), 10–23. https://www.eajournals.org/wp-content/uploads/Growth-and-Haematological-Responses-of-*Clarias-gariepinus-Juvenile*s-fed-diets-containing-varying-digestible-lipids-of-Plant-origin.pdf

Adekunle, H. L., Sadiku, S. O. E., & Orire, A. M. (2012). Development of Farm Made Floating Feed for Aquaculture Species. *International Journal of Advance Biological Research*, *2*(4), 579–583. https://pdf4pro.com/cdn/development-of-farm-made-floating-feed-for-3309ec.pdf

Agil, H. M., Jaafar, M. Z., Jamil, M. S., & Lazim, A. M. (2014). Utilization of Chemometric Technique to Determine the Quality of Fresh and Used Palm , Corn and Coconut Oil. *The Malaysian Journal of Analytical Sciences*, *18*(2), 234–244.

Agrimag. (2019). *Cost-benefit advantages of using extruded feeds*. Agriculture Monthly. https://www.agriculture.com.ph/2019/06/03/cost-benefit-advantages-of-using-extruded-feeds/

Ahda, M., Guntarti, A. N. Y., & Kusbandari, A. (2016). Application of High-Pressure Liquid Chromatography for Analysis of Lard in the Meatball Product combied with Principal Component Analysis. *Asian Journal of Pharmaceutical and Clinical Research*, *9*(6), 6–9. https://doi.org/10.22159/ajpcr.2016.v9i6.13831

Ahda, M., & Safitri, A. (2016). Development of lard detection in crude palm oil (Cpo) using ftir combined with chemometrics analysis. *International Journal of Pharmacy and Pharmaceutical Sciences*, *8*(12), 307–309. https://doi.org/10.22159/ijpps.2016v8i12.14743

Ahern, K., Rajagopal, I., & Tan, T. (2018). Structure & Function : Carbohydrates. In *Biochemistry: Free For All* (pp. 189–219). Oregon State University. https://open.umn.edu/opentextbooks/formats/1517

Aishah, Y. (2014). Status of Resource Management and Aquaculture in Malaysia. In M. R. R. Romana-Eguia, F. D. Parado-Estepa, N. D. Salayo, & M. J. H. Lebata-Ramos (Eds.), *Proceedings of the International Workshop on Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia 2014* (pp. 53–65). Tigbauan,

Iloilo, Philippines: Aquaculture Dept., Southeast Asian Fisheries Development Center.

Ajiboye, A. O., Ajani, F., & Folarinwa, O. R. (2015). Nutrient utilization and growth of Clarias gariepinus fed four different commercial feeds. *International Journal of Fisheries and Aquaculture*, *7*(7), 107–110. https://doi.org/10.5897/ijfa15.0486

Aksenov, A. A., Schivo, M., Bardaweel, H., Zrodnikov, Y., Kwan, A. M., Zamuruyev, K., Cheung, W. H. K., Peirano, D. J., & Davis, C. E. (2013). Volatile Organic Compounds in Human Breath: Biogenic Origin and Point-of-Care Analysis Approaches. In *Volatile Biomarkers* (pp. 129–154). Elsevier B.V. https://doi.org/10.1016/B978-0-44-462613-4.00008-8

Akunne, T. C., Okafor, S. N., Okechukwu, D. C., Nwankwor, S. S., Emene, J. O., & Okoro, B. N. (2016). Catfish (*Clarias gariepinus*) Slime Coat Possesses Antimicrobial and Wound Healing Activities. *UK Journal of Pharmaceutical Biosciences*, *4*(3), 81. https://doi.org/10.20510/ukjpb/4/i3/108393

Al-Kahtani., H. A., Arab., A. A. A., & Asif., M. (2014). Detection of Lard in Binary Animal Fats and Vegetable Oils Mixtures and in Some Commercial Processed Foods. *World Academy of Science, Engineering and Technology, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, *8*(11), 1244–1252. https://doi.org/https://doi.org/10.5281/zenodo.1326830

Alahira, J. (2017). *Fish Feed Production in Nigeria : Investment Opportunity*. Agriculture Nigeria. https://www.agriculturenigeria.com/manuals/research/articles/fish-feed-production-in-nigeria-investment-opportunity/

Alali, W. Q., & Ricke, S. C. (2012). The ecology and control of bacterial pathogens in animal feed. In J. Fink-Gremmels (Ed.), *Animal Feed Contamination : Effects on Livestock and Food Safety*. Woodhead Publishing Limited. https://doi.org/10.1533/9780857093615.1.35

Alofa, C. S., Oke, V., & Abou, Y. (2016). Effect of replacement of fish meal with broiler chicken viscera on growth , feed utilization and production of African catfish Clarias gariepinus (Burchell , 1822). *International Journal of Fisheries and Aquatic Studies*, *4*(7), 182–186.

Amang. (2020). *Kenali Ikan Keli*. Umpan. https://www.umpan.com.my/kenali-ikan-keli/

Andersen, S. M., Waagbø, R., & Espe, M. (2016). Functional amino acids in fish health and welfare. *Frontiers in Bioscience - Elite*, *8*(1), 143–169. https://doi.org/10.2741/757

Anonymous. (2019a). *Extruded Aqua Feeds vs Pelleted Aqua Feeds*. Henan Sunwit Industry Co., Ltd. https://www.sinofeedextruder.com/extruded-aqua-feeds-vs-pelleted-aqua-feeds/

Anonymous. (2019b). *Ingredients and Manufacturing Process for Fish Feed*. Henan Sunwit Industry Co. Ltd. https://www.sinofeedextruder.com/ingredients-and-manufacturing-process-for-fish-feed-formulation/

Anonymous. (2019c). *Pellets versus extruded feed*. Derwent Group. https://derwent.es/en/pellets-versus-extruded-feed/

Anonymous. (2021). *Kurangkan kos makanan ikan*. Sarawakvoice. https://sarawakvoice.com/2020/09/20/kurangkan-kos-makanan-ikan/

AOAC. (2019). Official Methods of Analysis of the Association of Official Analytical Chemists : Official Method 960.39. In G. W. Latimer (Ed.), *Association of Official Analytical Chemists* (21st ed.). AOAC International, Gaithersburg, MD, USA.

AOAC (Association of Official Analytical Chemists). (2000). Association of Official Analytical Chemists (AOAC). In *Official Methods of Analysis: Vol. 17th ed*.

AOAC (Association of Official Analytical Chemists). (2005). Association of Official Analytical Chemists (AOAC). In *Official Methods of Analysis*. https://doi.org/10.1371/journal.pone.0092941

Ariff, M. R. B. M., Sharir, M., Ali, I., Majid, M., & Hussin, H. (2011). The development of fishing industry in Peninsula Malaysia: Issues and Questions. *Jati*, *16*(December), 265–299.

Aryal, S. (2020). *High-Performance Liquid Chromatography (HPLC) Principle of High-Performance Liquid Chromatography (HPLC)*. Online Microbiology and Biology Notes. https://microbenotes.com/high-performance-liquid-chromatography-hplc/

Aziz, R. K., Mustapha, N. H. N., Azlina Abd. Aziz, & Muhamad, S. (2012). Transformasi Industri Akuakultur Pantai Timur ke arah Kecekapan Teknikal. *Prosiding Perkem VII*, *1*, 260–268.

Bahurmiz, O. M., & Ng, W.-K. (2007). Effects of dietary palm oil source on growth , tissue fatty acid composition and nutrient digestibility of red hybrid tilapia , Oreochromis sp ., raised from stocking to marketable size. *Aquaculture*, *262*(2–4), 382–392. https://doi.org/10.1016/j.aquaculture.2006.11.023

Barlow, S. (2000). Fishmeal and fish oil: sustainable feed ingredients for aquafeeds. *Global Aquaculture Advocate*, *4*, 85 – 88. https://ci.nii.ac.jp/naid/10019156911/en/

Batu, A., & Regenstein, J. M. (2014). Halal food certification challenges and their implications for Muslim societies worldwide. *International Periodical For The Languange, Literature and History of Turkish or Turkic*, *9*(11), 111–130.

Begdache, L., Kianmehr, H., Sabounchi, N., Marszalek, A., & Dolma, N. (2019). Principal component regression of academic performance, substance use and sleep quality in relation to risk of anxiety and depression in young adults. *Trends in Neuroscience and Education*, *15*(2019), 29–37.

https://doi.org/10.1016/j.tine.2019.03.002

Belão, T. C., Leite, C. A. C., Florindo, L. H., Kalinin, A. L., & Rantin, F. T. (2011). Cardiorespiratory responses to hypoxia in the African catfish, *Clarias gariepinus (Burchell 1822)*, an air-breathing fish. *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology*, *181*(7), 905–916. https://doi.org/10.1007/s00360-011-0577-z

Bernaerts, T. M. M., Verstreken, H., Dejonghe, C., Gheysen, L., Foubert, I., Grauwet, T., & Loey, A. M. Van. (2020). Cell disruption of *Nannochloropsis sp.* improves in vitro bioaccessibility of carotenoids and ω 3-LC-PUFA. *Journal of Functional Foods*, *65*(August 2019), 103770. https://doi.org/10.1016/j.jff.2019.103770

Bernama. (2020). *Tahap kecukupan sumber ikan tinggi pada 92 peratus*. Utusan Borneo Online. https://www.utusanborneo.com.my/2020/07/28/tahap-kecukupan-sumber-ikan-tinggi-pada-92-peratus

Blasco, H., Błaszczyński, J., Billaut, J. C., Nadal-Desbarats, L., Pradat, P. F., Devos, D., Moreau, C., Andres, C. R., Emond, P., Corcia, P., & Słowiński, R. (2015). Comparative analysis of targeted metabolomics: Dominance-based rough set approach versus orthogonal partial least square-discriminant analysis. *Journal of Biomedical Informatics*, *53*, 291–299. https://doi.org/10.1016/j.jbi.2014.12.001

Ble, C. M., Etchian, O. A., Otchoumou, A. K., Yapi, J. N., & Yao, L. A. (2018). Effects of Dietary Palm Oil on the Whole-Body Mineral Composition of African Catfish , *Heterobranchus longifilis (Teleostei , Clariidae)*. In V. Waisundara (Ed.), *Palm Oil* (pp. 171–182). IntechOpen. https://doi.org/http://dx.doi.org/10.5772/intechopen.76615

Borg, F. (2017). *Caring for People and the Planet: Preschool Children's Knowledge and Practices of Sustainability*. [Doctoral dissertation, Dalarna University]. https://www.researchgate.net/publication/319617776

Borota, A., Crisan, L., Bora, A., & Funar-Timofei, S. (2019). PLS Structure-Insecticidal Activity Relationships of Nitromethylene, Pyrrole- and Dihydropyrrole-Fused Neonicotinoids. *Proceedings*, *41*(1), 41. https://doi.org/10.3390/ecsoc-23-06593

Bouvier, J., & Brisset, A. (2006). Aquafeed twin screw extrusion processing. *Asian Aquafeeds: Current Developments in the Aquaculture Feed Industry. Malaysian Fisheries Society Occasional Publication No. 13*, 76–104.

Brereton, R. G. (2015). Pattern recognition in chemometrics. *Chemometrics and Intelligent Laboratory Systems*, *149*(2015), 90–96. https://doi.org/10.1016/j.chemolab.2015.06.012

Brondi, A. M., Torres, C., Garcia, J. S., & Trevisan, M. G. (2017). Differential scanning calorimetry and infrared spectroscopy combined with chemometric analysis to the determination of coffee adulteration by corn. *Journal of the Brazilian Chemical Society*, *28*(7), 1308–1314. https://doi.org/10.21577/0103-5053.20160296

Bureau, D. P. (2006). Rendered products in fish auaculture feeds. In Meeker D. L. (Ed.), *Essential Rendering*. Alexandria, Virginia, USA.

Caballero, M. J., Obach, A., Rosenlund, G., Montero, D., Gisvold, M., & Izquierdo, M. S. (2002). Impact of different dietary lipid sources on growth, lipid digestibility, tissue fatty acid composition and histology of rainbow trout, Oncorhynchus mykiss. *Aquaculture*, *214*(1–4), 253–271. https://doi.org/10.1016/S0044-8486(01)00852-3

Casimir, C. A., & David, B. M. (2008). *Food Lipids* (3rd ed.). CRC Press. https://doi.org/10.1201/9781420046649

Chai, L. L. (2006, January 18). Officials: Fish Fed Feces, Dead Pigs at Malaysian Catfish Farm. *The Star*. https://www.underwatertimes.com/news.php?article_id=94321876100

Cheong, L., Zhang, H., Nersting, L., Jensen, K., Anders, J., Haagensen, J., & Xu, X. (2010). Physical and sensory characteristics of pork sausages from enzymatically modified blends of lard and rapeseed oil during storage. *Meat Science*, *85*(4), 691–699. https://doi.org/10.1016/j.meatsci.2010.03.026

Cho, C. Y., & Kaushik, S. J. (1990). Nutritional energetics in fish: energy and protein utilization in rainbow trout *(Salmo gairdneri)*. *World Review of Nutrition and Dietetics*, *61*, 132–172. https://doi.org/10.1159/000417529

Chou, B., & Shiau, S. (1999). Both n-6 and n-3 Fatty Acids Are Required for Maximal Growth of Juvenile Hybrid Tilapia. *North American Journal of Aquaculture*, *61*(1), 13–20. https://doi.org/10.1577/1548-8454(1999)061<0013:BNANFA>2.0.CO;2

Christie, W. W. (1986). The positional distributions of fatty acids in triglycerides. In R. J. Hamilton & J. B. Rossell (Eds.), *Analysis of oils and fats* (pp. 313–339). Elsevier Applied Science.

Clifford, J., & Curely, J. (2019). Water-Soluble Vitamins: B-Complex and Vitamin C. *Fact Sheet (Colorado State University Extension). Food and Nutrition Series; No. 9.312.* https://extension.colostate.edu/docs/pubs/foodnut/09312.pdf

Colombo, S. M., Foroutani, M. B., & Parrish, C. C. (2020). Fats and Oils in Aquafeed Formulations. *Bailey's Industrial Oil and Fat Products*, 1–28. https://doi.org/10.1002/047167849x.bio095

Constantin, C. (2014). Principal component analysis - A powerful tool in computing marketing information. *Bulletin of the Transilvania University of Braşov Series V: Economic Sciences*, *7*(56), 27.

Craig, S., & Helfrich, L. A. (2002). Understanding Fish Nutrition, Feeds, and Feeding. *Cooperative Extension Service, Publication 420-256, Virginia State University, USA*, 1–4.

Craig, S., & Helfrich, L. A. (2009). Understanding Fish Nutrition, Feeds, and Feeding. *Virginia Cooperative Extension*, 420–256.

Dahimi, O., Hassan, M. S., Rahimm, A. A., Abdulkarim, S. M., & Mashitoh, A. S. (2013). Differentiation of Lard from Other Edible Fats by Gas Chromatography-Flame Ionisation Detector (GC-FID) and Chemometrics. *Journal of Food Pharmaceutical Science*, *2*(2), 27–31. https://doi.org/http://dx.doi.org/10.14499/jfps

Dahimi, O., Rahim, A. A., Abdulkarim, S. M., Hassan, M. S., Hashari, S. B. T. Z., Siti Mashitoh, A., & Saadi, S. (2014). Multivariate statistical analysis treatment of DSC thermal properties for animal fat adulteration. *Food Chemistry*, *158*(2014), 132–138. https://doi.org/10.1016/j.foodchem.2014.02.087

Dan. (2019). How many types of catfish are there in the world? In *Fishing & camping*. https://360digitour.com/fishing/types-of-catfish/

Darias, M. J., Castro-Ruiz, D., Estivals, G., Quazuguel, P., Fernandez-Mendez, C., Nunez-Rodrıguez, J., Clota, F., Gilles, S., Garcıa-Davila, C., Gisbert, E., & Cahu, C. (2015). Influence of dietary protein and lipid levels on growth performance and the incidence of cannibalism in Pseudoplatystoma punctifer *(Castelnau, 1855)* larvae and early juveniles By. *Journal of Applied Ichthyology*, *31*(4), 74–82. https://doi.org/10.1111/jai.12978

Das, H. K., Hattula, M. T., Myllymäki, O. M., & Mälkki, Y. (1993). Effects of formulation and processing variables on dry fish feed pellets containing fish waste. *Journal of the Science of Food and Agriculture*, *61*(2), 181–187. https://doi.org/10.1002/jsfa.2740610208

Dauda, A. B., Natrah, I., Karim, M., Kamarudin, M. S., & Bichi, H. (2018). African Catfish Aquaculture in Malaysia and Nigeria : Status , Trends and Prospects. *Fisheries and Aquaculture Journal Dauda*, *9*(1), 1–5. https://doi.org/10.4172/2150-3508.1000237

Department of Islamic Development Malaysia. (2006). *Status Kesucian Ikan yang Diberi Makanan Tidak Halal*. http://e-smaf.islam.gov.my/e-smaf/

Department of Standard Malaysia. (2009). *Malaysia Standard MS 1500:2009, General Guidelines : HalalFood - Production, preparation, handling and storage (Second Revision)*. Putrajaya, Malaysia. https://law.resource.org/pub/my/ibr/ms.1500.2009.pdf

Diogo, R., & Chardon, M. (2009). The Structures Associated With Catfish *(Teleostei: Siluriformes)* Mandibular Barbels: Origin, Anatomy, Function, Taxonomic Distribution, Nomenclature and Synonymy. *Netherlands Journal of Zoology*, *50*(4), 455–478. https://doi.org/10.1163/156854200x00207

DOF. (2017). Strategic Plan of Department of Fisheries 2016-2020. In *Department of Fisheries Malaysia* (Issue April). http://www.fisheries.gov.bn/SiteCollectionDocuments/Strategic Plan/DOF Strategic Plan - 070617.pdf

DOF. (2018). National Fish Health Strategy Malaysia 2018 - 2022. In *Department of*

Fisheries Malaysia (Issue January 2016). https://doi.org/10.13140/RG.2.2.20022.45128

Dubey, A. (2018). *The Mathematics Behind Principal Component Analysis*. Toward Data Science. https://towardsdatascience.com/the-mathematics-behind-principal-component-analysis-fff2d7f4b643

Efenberger-szmechtyk, M., Nowak, A., & Kregiel, D. (2018). Implementation of chemometrics in quality evaluation of food and beverages. *Critical Reviews in Food Science and Nutrition*, *58*(10), 1747–1766. https://doi.org/10.1080/10408398.2016.1276883

Effiong, M. U., & Yaro, C. A. (2020). Fatty Acid Composition of Fillets of African Catfish , *Clarias gariepinus* Fed with Various Oil-Based Diets. *Aquaculture Studies*, *20*(1), 29–35. http://www.aquast.org/pdf.php?&id=493

Endo, Y., Ohta, A., Kido, H., Kuriyama, M., Sakaguchi, Y., Takebayashi, S., Hirai, H., Murakami, C., & Wada, S. (2011). Determination of triacylglycerol composition in vegetable oils using high-performance liquid chromatography: A collaborative study. *Journal of Oleo Science*, *60*(9), 451–456. https://doi.org/10.5650/jos.60.451

Fadzillah., N. A., Rohman., A., Ismail., A., Manaf., Y. N. A., Rosman., A. S., Khatib., A., Hassan., N. M., & Othman., R. (2019). Chemometrics analysis combined with GC-MS and NMR spectroscopy analysis of fatty acids as a means of discriminating butterfat adulteration. *Journal of Pharmacy and Nutrition Sciences*, *9*, 87–94. https://doi.org/doi.org/10.29169/1927-5951.2019.09.02.5

Fadzillah, N. A., Man, C., Rohman, A., Rosman, A. S., Ismail, A., & Mustafa, S. (2015). Detection of Butter Adulteration with Lard by Employing 1 H-NMR Spectroscopy and Multivariate Data Analysis. *Journal of Oleo Science*, *64*(7), 697–703. https://doi.org/10.5650/jos.ess14255

Fang, G., Goh, J. Y., Tay, M., Lau, H. F., & Li, S. F. Y. (2013). Characterization of oils and fats by 1H NMR and GC/MS fingerprinting: Classification, prediction and detection of adulteration. *Food Chemistry*, *138*(2–3), 1461–1469. https://doi.org/10.1016/j.foodchem.2012.09.136

FAO. (2010). Cultured Aquatic Species Information Programme. In *FAO Fisheries Division*. http://www.fao.org/fishery/culturedspecies/Clarias_gariepinus/en

FAO. (2018). The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. In *FAO Fisheries Division*. http://www.fao.org/3/i9540en/i9540en.pdf

FAO, & IFIF. (2010). Good practices for the feed industry – Implementing the Codex Alimentarius Code of Practice on Good Animal Feeding. In *FAO Animal Production and Health Manual No. 9* (p. 106). Food and Agriculture Organization of United Nations.

Farrés, M., Platikanov, S., Tsakovski, S., & Tauler, R. (2015). Comparison of the variable

importance in projection (VIP) and of the selectivity ratio (SR) methods for variable selection and interpretation. *Journal of Chemometrics*, *29*(10), 528–536. https://doi.org/10.1002/cem.2736

Fashina, A. B., Oyewole, O. A., Iyalabani, K. A., Oniya, O. O., & Olaniran, J. A. (2019). Effects of Fish Feed Carbohydrate Sources on the Floatation and Water Stability of Fish Feed Pellets. *Journal of Biology, Agriculture and Healthcare*, *9*(18), 29–32. https://doi.org/10.7176/JBAH/9-18-06

Fausto Rivero-Cruz, J., Rodríguez de San Miguel, E., Robles-Obregón, S., Hernández-Espino, C. C., Rivero-Cruz, B. E., Pedraza-Chaverri, J., & Esturau-Escofet, N. (2017). Prediction of antimicrobial and antioxidant activities of Mexican propolis by 1 H-NMR spectroscopy and chemometrics data analysis. *Molecules*, *22*(7), 1–17. https://doi.org/10.3390/molecules22071184

Fayza, E. A. (2007). Fisheries and Aquatic Science. *Journal of Fisheries and Aquatic Science*, *2*(2), 140–148. https://doi.org/10.3923/jfas.2007.140.148

Felipe, A. dos S., Ingrid, P. S., Furtadoa, N. A. J. C., & Fernando, B. D. C. (2018). Combined OPLS-DA and decision tree as a strategy to identify antimicrobial biomarkers of volatile oils analyzed by gas chromatography–mass spectrometry. *Brazilian Journal of Pharmacognosy*, *28*(6), 647–653. https://doi.org/10.1016/j.bjp.2018.08.006

Fracalossi, D. M., & Love, R. T. (1994). Dietary lipid sources influence responses of channel catfish *(Ictalurus punctatus)* to challenge with the pathogen *Edwardsiella ictaluri. Aquaculture*, *119*(2–3), 287–298. https://doi.org/doi:10.1016/0044-8486(94)90183-x

Francis, D. S., Turchini, G. M., Jones, P. L., & De Silva, S. S. (2007). Dietary lipid source modulates in vivo fatty acid metabolism in the freshwater fish, murray cod (maccullochella peelii peelii). *Journal of Agricultural and Food Chemistry*, *55*(4), 1582–1591. https://doi.org/10.1021/jf062153x

Galindo-Prieto, B. (2017). *Novel variable influence on projection (VIP) methods in OPLS , O2PLS , and OnPLS models for single- and multi- block variable selection*. Umeå University.

Garrido-novell, C., Garrido-varo, A., Pérez-marín, D., Guerrero-ginel, J. E., & Kim, M. (2015). Quantification and spatial characterization of moisture and NaCl content of Iberian dry-cured ham slices using NIR hyperspectral imaging. *Journal of Food Engineering*, *153*(2015), 117–123. https://doi.org/10.1016/j.jfoodeng.2014.09.035

Giannakis, E., Hadjioannou, L., Jimenez, C., Papageorgiou, M., Karonias, A., & Petrou, A. (2020). Economic consequences of coronavirus disease (COVID-19) on fisheries in the eastern mediterranean (Cyprus). *Sustainability (Switzerland)*, *12*(22), 1–11. https://doi.org/10.3390/su12229406

Glencross, B., Hawkins, W., & Curnow, J. (2003). Evaluation of canola oils as alternative lipid resources in diets for juvenile red seabream , *Pagrus auratus. Aquaculture*

Nutrition, *9*(5), 305–315. https://doi.org/10.1046/j.1365-2095.2003.00257.x

Granato, D., Putnik, P., Bursa, D., Rocha, R. S., Gomes, A., Cruz, D., Jarvis, B., Rodionova, O. Y., & Pomerantsev, A. (2018). Trends in Chemometrics : Food Authentication , Microbiology , and Effects of Processing. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 663–677. https://doi.org/10.1111/1541-4337.12341

Guillocheau, E. (2020). *OPLS vs PCA: Explaining differences or grouping data?* Sartorius Stedim Data Analytics. https://blog.umetrics.com/explaining-differences-or-grouping-data-opls-da-vs-pca-data-analysis

Guntarti, A., Ahda, M., & Kusbandari, A. (2020). Determining fatty acids and halal authentication of sausage. *Food Research*, *4*(2), 495–499. https://doi.org/10.26656/fr.2017.4(2).261

Hafizee, M. A. (2017, March 9). Kolam ikan makan bangkai babi diserbu. *Harian Metro*. https://www.hmetro.com.my/node/212218

Hailu, F. A., Getahun, A., & Wakjira, M. (2019). The Process of Tilapia Feed Formulation and Implementation in pond aquaculture : Low Cost and Locally Available Ingredients option for small-scale farmers. *Journal of Agriculture and Aquaculture*, *1*(1–14).

Hamid, S. N. I. N., Yusof, S. J. H. M., Zakaria, Z., & Abdullah, R. (2014). Review on potential alternative protein and amino acids sources for fish feed: A Malaysian perspective. *Advances in Environmental Biology*, *8*(22), 69–72.

Han, J., Kamber, M., & Pei, J. (2012). Introduction. In *Data Mining* (Third, pp. 1–38). https://doi.org/10.1016/b978-0-12-381479-1.00001-0

Hancz, C. (2011). *Fish Nutrition and Feeding*. Kaposvar University. https://regi.tankonyvtar.hu/en/tartalom/tamop425/0059_fish_nutrition_and_feeding/ch01s04.html

Harlıoğlu, A. G. (2012). Impact of fish meal replacement with full-fat soya on the muscle and liver fatty acid composition in rainbow trout. *Journal of FisheriesSciences.Com*, *7*(2), 99–113. https://doi.org/10.3153/jfscom.2013011

Haswell, S. J. (1992). Introduction to chemometrics. In *Practical guide to chemometrics* (pp. 1–3). New York: Marcel Dekker Inc., USA.

He, W., & Hu, H. (2013). Rapid prediction of different wood species extractives and lignin content using near infrared spectroscopy. *Journal of Wood Chemistry and Technology*, *33*(1), 52–64. https://doi.org/10.1080/02773813.2012.731463

Henderson, R. J. (1996). Fatty acid metabolism in freshwater fish with particular reference to polyunsaturated fatty acids. *Archives of Animal Nutrition*, *49*(1), 5–22. https://doi.org/10.1080/17450399609381859

Hoffman, L. C., & Prinsloo, J. F. (1995). The Influence Of Different Dietary Lipids On The Growth And Body-Composition Of The African Sharptooth Catfish, Clarias-Gariepinus (Burchell). *Outh African Journal of Science*, *91*(6), 1995. https://espace.library.uq.edu.au/view/UQ:1d4732f

Husni, M. N. (2019). *Pemantauan hala ikan, hasil ikan dilakukan berkala*. Harian Metro. https://www.hmetro.com.my/mutakhir/2019/02/426479/pemantauan-halal-ikan-hasil-ikan- dilakukan-berkala%0AJABATAN

Irungu, F. G., Mutungi, C., Faraj, A., Affognon, H., Ekesi, S., Nakimbugwe, D., & Fiaboe, K. K. M. (2019). Optimization of extruder cooking conditions for the manufacture of fish feeds using response surface methodology. *Journal of Food Process Engineering*, *42*(2), 1–12. https://doi.org/10.1111/jfpe.12980

Ismail, A. M., Sani, M. S. A., Azid, A., Zaki, N. N. M., Arshad, S., Tukiran, N. A., Abidin, S. A. S. Z., Samsudin, M. S., & Ismail, A. (2021). Food forensics on gelatine source via ultra-high-performance liquid chromatography diode-array detector and principal component analysis. *Springer Nature Applied Sciences*, *3*(1), 79. https://doi.org/10.1007/s42452-020-04061-7

IUPAC. (1987). International Union of Pure and Applied Chemistry : Standard Method 2.210. In C. Paquot & A. Hautfenne (Eds.), *Standard methods for the analysis of oils, fats and derivatives* (7th ed.). Blackwell, Oxford.

Ivon, E. A., Etangetuk, N. A., Ubi, G. M., Anyanwu, C. O., Nkang, A. N., & Ekanem, A. P. (2020). Assessment of Histopathological Damages in African Catfish *(Clarias garienpinus)* as Influenced by Nittol Detergent Aquatic Pollution in Nigeria. *Annual Research & Review in Biology*, *35*(4), 1–11. https://doi.org/10.9734/arrb/2020/v35i430206

Jain, A. K., Duin, R. P. W., & Mao, J. (2000). Statistical pattern recognition: A review. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *22*(1), 4–37. https://doi.org/10.1109/34.824819

James K. Jackson, Martin A. Weiss, Schwarzenberg, A. B., Nelson, R. M., Sutter, K. M., & Sutherland, M. D. (2021). Global Economic Effects of COVID-19. In *Congressional Research Service* (Issue R46270). https://crsreports.congress.gov

Jollife, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *374*(2065), 1–16. https://doi.org/10.1098/rsta.2015.0202

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, *39*(1), 31–36.

Kanmani, N., Romano, N., Ebrahimi, M., Amin, S. M. N., Salleh, M., Karami, A., & Kumar, V. (2018). Improvement of feed pellet characteristics by dietary pre-gelatinized starch and their subsequent effects on growth and physiology in tilapia. *Food Chemistry*, *239*, 1037–1046. https://doi.org/10.1016/j.foodchem.2017.07.061

Karim, M. M. A. (2020). *Apa kesan COVID-19 kepada industri akuakultur di Malaysia?* Astro Awani. http://www.astroawani.com/berita-malaysia/apa-kesan-covid-19-kepada-industri-akuakultur-di-malaysia-235864

Khatib, M. A. B. M. (2015). A Mini Review on the Present Status of the Marine Fisheries in Sabah, Malaysia. *Journal of Aquaculture & Marine Biology*, *2*(4), 2–7. https://doi.org/10.15406/jamb.2015.02.00033

Khoshooei, M. A., Fazlollahi, F., & Maham, Y. (2019). A review on the application of differential scanning calorimetry (DSC) to petroleum products Characterization and kinetic study. *Journal of Thermal Analysis and Calorimetry*, *2*(138), 3455–3484. https://doi.org/10.1007/s10973-019-08244-2

Kim, H. H., Jeong, I. H., Hyun, J. S., Kong, B. S., Kim, H. J., & Park, S. J. (2017). Metabolomic profiling of CSF in multiple sclerosis and neuromyelitis optica spectrum disorder by nuclear magnetic resonance. *PLoS ONE*, *12*(7), 1–21. https://doi.org/10.1371/journal.pone.0181758

Kimberly, C. (2020). *Impact of COVID-19 on people's livelihoods, their health and our food systems*. World Health Organization. https://www.who.int/news/item/13-10-2020-impact-of-covid-19-on-people's-livelihoods-their-health-and-our-food-systems

Koolboon, U., Skorn Koonawootrittriron, W. K., & Uthairat Na-Nakorn. (2014). Effects of parental strains and heterosis of the hybrid between *Clarias macrocephalus* and *Clarias gariepinus*. *Aquaculture*, *424–425*(2014), 131–139. https://doi.org/10.1016/j.aquaculture.2013.12.023

Koster, W. M., Dawson, D. R., Clunie, P., Hames, F., Mckenzie, J., Moloney, P. D., & Crook, D. A. (2015). Movement and habitat use of the freshwater catfish *(Tandanus tandanus)* in a remnant floodplain wetland. *Ecology of Freshwater Fish*, *24*(3), 443–455. https://doi.org/10.1111/eff.12159

Kozłowska, M., Kowalska, M., & Wo, M. (2020). Physicochemical Characterization and Evaluation of Emulsions Containing Chemically Modified Fats and Different Hydrocolloids. *Biomolecules*, *10*(115), 1–17. https://doi.org/10.3390/biom10010115

Kumar, S. (2020). *Forms of fish feed*. Bihar Animal Sciences University. https://www.basu.org.in/wp-content/uploads/2020/04/FORMS-OF-FISH-FEED.pdf

Kumar, S., Sahu, N. P., & Ranjan, A. (2018). Feeding de-oiled rice bran (DORB) to Rohu, Labeo rohita : Effect of varying dietary protein and lipid level on growth, body composition, and insulin like growth factor (IGF) expression. *Aquaculture*, *492*(2017), 59–66. https://doi.org/10.1016/j.aquaculture.2018.04.001

Kumara, S. (2009, May 20). "Kita hanya jual di luar Perak" - Ternak ikan keli untuk 'membersihkan' air kumbahan dari ladang babi. *Kosmo*. http://www.kosmo.com.my/kosmo/content.asp?y=2009&dt=0518&pub=Kosmo

&sec=Negara&pg=n e_04.htm%0AIPOH

Kumari, B., Ahsan, J., & Kumar, V. (2012). Toxicological & Environmental Chemistry Comparative studies of liver and brain glycogen content of male and female *Clarias batrachus (L .)* after exposure of different doses of arsenic. *Toxicological & Environmental Chemistry*, *94*(9), 1758–1767. https://doi.org/10.1080/02772248.2012.726823

Kumari, M., & Gupta, S. K. (2019). Response surface methodological (RSM) approach for optimizing the removal of trihalomethanes (THMs) and its precursor's by surfactant modified magnetic nanoadsorbents (sMNP) - An endeavor to diminish probable cancer risk. *Scientific Reports*, *9*(1), 1–11. https://doi.org/10.1038/s41598-019-54902-8

Kürşat, B., & Bayır, A. (2012). The Effect of the Replacement of Fish oil with Animal Fats on the Growth Performance, Survival and Fatty Acid Profile of Rainbow Trout Juveniles, *Oncorhynchus mykiss. Turkish Journal of Fisheries and Aquatic Sciences*, *12*, 661–666. https://doi.org/10.4194/1303-2712-v12

Kusumowardani, N., & Tjahjono, B. (2020). Circular economy adoption in the aquafeed manufacturing industry. *Procedia CIRP*, *90*, 43–48. https://doi.org/10.1016/j.procir.2020.01.088

Lajis, N., Maulidiani, M., Abas, F., & Ismail, I. S. (2017). Metabolomics Approach in Pharmacognosy. In *Pharmacognosy* (pp. 597–616). Elsevier Inc. https://doi.org/10.1016/B978-0-12-802104-0.00030-5

Lali, S. P., & Dumas, A. (2015). Nutritional requirements of cultured fish: formulating nutritionally adequate feeds. In D. A. Davis (Ed.), *Feed and Feeding Practices in Aquaculture* (pp. 53–109). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100506-4.00003-9

Lall, S., & Tibbetts, S. M. (2009). Nutrition , Feeding , and Behavior of Fish. *Veterinary Clinics of North America Exotic Animal Practice*, *12*(2). https://doi.org/10.1016/j.cvex.2009.01.005

Latief, M., Khorsidtalab, A., Saputra, I., Akmeliawati, R., Nurashikin, A., Jaswir, I., & Witjaksono, G. (2017). Rapid lard identification with portable electronic nose. *IOP Conference Series: Materials Science and Engineering*, *260*(1), 012043. https://doi.org/10.1088/1757-899X/260/1/012043

Lavine, B. K., Moores, A., & Helfend, L. K. (1999). Genetic algorithm for pattern recognition analysis of pyrolysis gas chromatographic data. *Journal of Analytical and Applied Pyrolysis*, *50*(1), 47–62. https://doi.org/10.1016/S0165-2370(99)00002-9

Legendre, M., Kerdchuen, N., Corraze, G., & Bergot, P. (1995). Larval rearing of an African catfish Heterobranchus longiflis *(Teleostei , Clariidae)*: effect of dietary lipids on growth , survival and fatty acid composition of fry. *Aquatic Living Resources*, *8*(4), 355–363. https://doi.org/10.1051/alr:1995040

Leyva-porras, C., Cruz-alcantar, P., Espinosa-sol, V., & Saavedra-leos, M. Z. (2019). polymers Application of Di ff erential Scanning Calorimetry (DSC) and Modulated Differential Scanning. *Polymers*, *12*(5), 1–21. https://doi.org/10.3390/polym12010005

Li, Y., Shen, Y., Yao, C., & Guo, D. (2020). Quality assessment of herbal medicines based on chemical fingerprints combined with chemometrics approach: A review. *Journal of Pharmaceutical and Biomedical Analysis*, *185*(2020), 113215. https://doi.org/10.1016/j.jpba.2020.113215

Majumdar, R. K., & Singh, R. K. R. (2012). The effect of extrusion conditions on the physicochemical properties and sensory characteristic of fish-based expanded snacks. *Journal of Food Processing and Preservation*, *38*(2014), 864–879. https://doi.org/10.1111/jfpp.12041

Man, Y. B. C., Marina, A. M., Rohman, A., Norazura, O., Man, Y. B. C., Marina, A. M., Rohman, A., Norazura, O., & Norazura, O. (2014). A Fourier Transform Infrared Spectroscopy Method for Analysis of Palm Oil Adulterated with Lard in Pre-Fried French fries. *International Journal of Food Properties*, *17*(2), 354–362. https://doi.org/10.1080/10942912.2011.631254

Mansor, T. S. T., Man, Y. B. C., & Shuhaimi, M. (2012). Employment of Differential Scanning Calorimetry in Detecting Lard Adulteration in Virgin Coconut Oil. *Journal of the American Oil Chemists' Society*, *89*(2012), 485–496. https://doi.org/10.1007/s11746-011-1936-3

Marenkov, O., & Fedonenko, O. (2016). Ways of optimization of breeding conditions of fish by using artificial spawning grounds. *World Scientifc News*, *49*(1), 1–58.

Marikkar, J. M. N., Dzulkifly, M. H., Nadiha, M. Z. N., & Man, Y. B. C. (2012). Detection of animal fat contaminations in sunflower oil by differential scanning calorimetry. *International Journal of Food Properties*, *15*(3), 683–690. https://doi.org/10.1080/10942912.2010.498544

Marikkar, J. M. N., Ghazali, H. M., Che Man, Y. B., & Lai, O. M. (2002). The use of cooling and heating thermograms for monitoring of tallow, lard and chicken fat adulterations in canola oil. *Food Research International*, *35*(10), 1007–1014. https://doi.org/10.1016/S0963-9969(02)00162-X

Marikkar, J. M. N., Ghazali, H. M., Che Man, Y. B., Peiris, T. S. G., & Lai, O. M. (2005). Distinguishing lard from other animal fats in admixtures of some vegetable oils using liquid chromatographic data coupled with multivariate data analysis. *Food Chemistry*, *91*(1), 5–14. https://doi.org/10.1016/j.foodchem.2004.01.080

Marikkar, J. M. N., Ghazali, H. M., Long, K., & Lai, O. M. (2003). Lard uptake and its detection in selected food products deep-fried in lard. *Food Research International*. https://doi.org/10.1016/j.foodres.2003.08.003

Marikkar, J. M. N., & Lai, O. M. (2004). Detection of adulteration in lauric oils: use of different analytical techniques. In Peiris T. S. G. & Ranasinghe C. S. (Eds.),

Proceedings II (pp. 270–284). International Conference of the Coconut Research Institute of Sri Lanka, Lunuwila, Sri Lanka.

Marikkar, J. M. N., Lai, O. M., Ghazali, H. M., & Che Man, Y. B. (2001). Detection of lard and randomized lard as adulterants in refined-bleached-deodorized palm oil by differential scanning calorimetry. *Journal of the American Oil Chemists' Society*, *78*(11), 1113–1119. https://doi.org/10.1007/s11746-001-0398-5

Marikkar, J. M. N., Lai, O. M., Ghazali, H. M., & Che Man, Y. B. (2002). Compositional and thermal analysis of RBD palm oil adulterated with lipase-catalyzed interesterified lard. *Food Chemistry*, *76*(2), 249–258. https://doi.org/10.1016/S0308-8146(01)00257-6

Marikkar, J. M. N., & Yanty, N. A. M. (2014). Effect of chemical and enzymatic modifications on the identity characteristics of lard: A review. *International Journal of Food Properties*, *17*(2), 321–330. https://doi.org/10.1080/10942912.2011.631251

Marikkar, J. M. N., Yanty, N. A. M., Paciulli, M., Miskandar, M. S., & Chiavaro, E. (2018). Composition and thermal properties of quaternary mixtures of palm oil:palm stearin:soybean oil:cocoa butter. *Italian Journal of Food Science*, *30*(4), 740–751. https://doi.org/10.14674/IJFS-1242

Marina, A. M., Man, Y. B. C., & Amin, I. (2010). Use of the SAW sensor electronic nose for detecting the adulteration of virgin coconut oil with RBD palm kernel olein. *JAOCS, Journal of the American Oil Chemists' Society*, *87*(3), 263–270. https://doi.org/10.1007/s11746-009-1492-2

Marliana., A., Sahar., A., Tengku., I. T. A., Yanty., N. A. M., Awis., Q. S., & Shuhaimi., M. (2017). Detection of Lard in Cocoa Butter—Its Fatty Acid Composition, Triacylglycerol Profiles, and Thermal Characteristics. *Foods*, *6*(11), 98. https://doi.org/10.3390/foods6110098

Martins, D. A., Rocha, F., Martínez-Rodríguez, G., Bell, G., Morais, S., Castanheira, F., Bandarra, N., Coutinho, J., Yúfera, M., & Conceição, L. E. C. (2012). Teleost fish larvae adapt to dietary arachidonic acid supply through modulation of the expression of lipid metabolism and stress response genes. *British Journal of Nutrition*, *108*(5), 864–874. https://doi.org/10.1017/S0007114511006143

Mbeledogu, N. N., Odoh, M., & Umeh, M. N. (2012). Stock Feature Extraction Using Principal Component Analysis. *2012 International Conference on Computer Technology and Science*, *47*, 236–241. https://doi.org/10.7763/IPCSIT.2012.V47.44

Mishra, S. P., Sarkar, U., Taraphder, S., Datta, S., Swain, D. P., Saikhom, R., Panda, S., & Laishram, M. (2017). Principal Component Analysis. *International Journal of Livestock Research*, *7*(5), 60–78. https://doi.org/10.5455/ijlr.20170415115235

MOA. (2011). National Agrofood Policy 2011-2020. In *Ministry of Agriculture and Agrobased Industry*. http://www.moa.gov.my/web/guest/dasar-agromakanan-

negara-2011-2020-dan

Mohsin, Z. (2021). *10 Khasiat ikan keli yang perlu anda tahu*. The Diagnosa. https://thediagnosa.com/khasiat-ikan-keli-yang-anda-perlu-tahu/

Momoh, A. T., Abubakar, M. Y., & Ipinjolu, J. K. (2016). Effect of ingredients substitution on binding, water stability and floatation of farm-made fish feed. *International Journal of Fisheries and Aquatic Studies*, *4*(3), 92–97.

Moneim, A., Sadek, A., Yones, M., Eissa, I. A. M., Abd, M., Ali, E.-F., & Marzok, S. S. (2019). Effects of Different Dietary Carbohydrate Sources on Growth Performance and Liver Histology of Nile Tilapia *(Oreochromis Niloticus)* Fingerlings. *The Eqyption Journal of Histology*, *42*(3), 599–607. https://doi.org/10.21608/ejh.2019.12234.1115

Montero, D., & Izquierdo, M. (2010). Welfare and Health of Fish Fed Vegetable Oils as Alternative Lipid Sources to Fish Oil. In G. M. Turchini, W.-K. Ng, & D. R. Tocher (Eds.), *Fish Oil Replacement and Alternative Lipid Sources in Aquaculture Feeds* (pp. 439–485). CRS Press. https://doi.org/10.1201/9781439808634-c14

Muflih, B. K., Ahmad, N. S., Jamaludin, M. A., & Nordin, N. F. H. (2017). The concept and component of contaminated animals (Al-jallalah animals). *International Food Research Journal*, *24*(12), 436–440.

Naquiah, A. N. N., Marikkar, J. M. N., & Shuhaimi, M. (2015). Differentiation of partial acylglycerols derived from different animal fats by EA-IRMS and GCMS techniques. *Grasas y Aceites*, *67*(2), 1–8. https://doi.org/10.3989/gya.0757152

Nasopoulou, C., & Zabetakis, I. (2012). Benefits of fish oil replacement by plant originated oils in compounded fish feeds. A review. *LWT - Food Science and Technology*, *47*(2), 217–224. https://doi.org/10.1016/j.lwt.2012.01.018

Nates, B. S. (2017). *Considerations for alternative ingredients in aquafeeds*. Global Aquaculture Advocate. https://www.aquaculturealliance.org/advocate/considerations-for-alternative-ingredients-in-aquafeeds/

Nazli, I. (2013). *Usus babi jadi makanan ikan sebelum dijual*. Selangor Kini. https://selangorkini.my/2013/11/usus-babi-jadi-makanan-ikan-sebelum-dijual/

Nitta, K., Laviña, W. A., Pontrelli, S., Liao, J. C., Putri, S. P., & Fukusaki, E. (2017). Orthogonal partial least squares/projections to latent structures regression-based metabolomics approach for identification of gene targets for improvement of 1-butanol production in Escherichia coli. *Journal of Bioscience and Bioengineering*, *124*(5), 498–505. https://doi.org/10.1016/j.jbiosc.2017.05.015

Nizar, N. N. A., Marikkar, J. M. N., & Hashim, D. M. (2013). Differentiation of lard, chicken fat, beef fat and mutton fat by GCMS and EA-IRMS techniques. *Journal of Oleo Science*, *62*(7), 459–464. https://doi.org/10.5650/jos.62.459

Njoroge, D. M., Kinyanjui, P. K., Christiaens, S., Shpigelman, A., Makokha, A. O., Sila, D. N., & Hendrickx, M. E. (2015). Effect of storage conditions on pectic polysaccharides in common beans *(Phaseolus vulgaris)* in relation to the hard-to-cook defect. *Food Research International*, *76*, 105–113. https://doi.org/10.1016/j.foodres.2015.03.005

Nkubana, A., Dusabumuremyi, J. C., & Yadufashije, C. (2020). Optimization of extrusion conditions for development of fish-maize based extruded snacks by response surface methodology. *African Journal of Biological Sciences*, *02*(02), 88. https://doi.org/10.33472/afjbs.2.2.2020.88-99

NOAA. (2021). *What is Aquaculture ?* National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/facts/aquaculture.html

Nurhidayah, S., Shirwan, M., Sani, A., Azwan, M., Yuswan, H., Kartinee, N., Noorzianna, Y., Wasoh, H., Nadiha, N., Zaki, M., & Mohd, A. (2020). Discrimination of Malaysian stingless bee honey from different entomological origins based on physicochemical properties and volatile compound profiles using chemometrics and machine learning. *Food Chemistry*, *346*(6), 128654. https://doi.org/10.1016/j.foodchem.2020.128654

Nurrulhidayah, A. F., Arieff, S. R., Rohman, A., Amin, I., Shuhaimi, M., & Khatib, A. (2015). Detection of butter adulteration with lard using differential scanning calorimetry. *International Food Research Journal*, *22*(2), 832–839.

Nyunja, C., Maina, J., Amimo, J., Kibegwa, F., Harper, D., & Jung a, J. (2017). Stock Structure Delineation of the African Catfish *(Clarius gariepinus)* in Selected Populations in Kenya Using Mitochondrial DNA (Dloop) Variability. *Journal of Aquaculture Research & Development*, *8*(5). https://doi.org/10.4172/2155-9546.1000485

Nzoughet, J. K., Guehlouz, K., Leruez, S., Gohier, P., Bocca, C., Muller, J., Blanchet, O., Bonneau, D., Simard, G., Milea, D., Procaccio, V., Lenaers, G., de la Barca, J. M. C., & Reynier, P. (2020). A data mining metabolomics exploration of glaucoma. *Metabolites*, *10*(2). https://doi.org/10.3390/metabo10020049

Oboh, A., Betancor, M. B., Tocher, D. R., & Monroig, O. (2016). Biosynthesis of long-chain polyunsaturated fatty acids in the African catfish *Clarias gariepinus*: Molecular cloning and functional characterisation of fatty acyl desaturase (fads2) and elongase (elovl2) cDNAs. *Aquaculture*, *462*(2016), 70–79. https://doi.org/10.1016/j.aquaculture.2016.05.018

Oke, I. O., Adeparusi, E. O., Dada, A. A., & Famurewa, J. A. V. (2017). Effects of Different Levels of Yeast *(Saccharomyces cerevisiae)* on Binding Property Okra *(Abelmoschus esculentus)* in Fish Feed. *Nigerian Journal of Agriculture, Food and Environment*, *13*(2), 18–22. https://www.researchgate.net/publication/341151857

Oladipupo, T. M., & Salami, S. R. (2020). on growth and haematologic ... Effect of dietary inclusion levels of watermelon *(Citrullus lanatus)* peel meal on growth and haematological parameters of *Clarias gariepinus* Juveniles. *International Journal*

of Fisheries and Aquatic Studies, *8*(3), 537–541.

Omar, S., & Zahrain, M. (2012). Positioning the Halal Food Industry : The Case of Malaysia. *NIDA Case Research Journal*, *4*(8), 157–174.

Omprakash, S., & Gokila, S. (2018). Principal Component Analysis - A Survey. *International Journal of Advanced Research in Computer and Communication Engineering*, *7*(8), 63–66. https://doi.org/10.17148/ijarcce.2018.7814

Opalyn, M. (2019, February 20). Consumer group claims fish may be non-halal. *Malay Mail*. https://www.malaymail.com/news/malaysia/2019/02/20/consumer-group-claims-fish-may-be-non-halal/1724971

Orire, A. M., & Emine, G. I. (2019). Effects of Crude Protein Levels and Binders on Feed Buoyancy. *Journal of Agriculture Research and Development*, *10*(2), 1–5. https://doi.org/10.4172/2155-9546.1000565

Orire, A. M., Fache, P. O., & Sadiku, S. O. E. (2015). The Effects of Varying Inclusion Levels of *Saccharomyces Cerevisiae* and Incubation Periods on Aqua-feed Bouyancy. *Nigerian Journal of Fisheries*, *12*(1), 864–870.

Orire, A. M., & Sadiku, S. O. E. (2014). Development of Farm Made Floating Feed for Aquaculture Species. *Journal of International Scientific Publications: Agriculture and Food*, *2*(1), 521–523.

Otto, M. (2017). *Chemometrics: Statistics and Computer Application in Analytical Chemistry* (Third). Wiley-VCH.

Oyakhilome, G. I., & Ajiwe, V. I. E. (2019). Transfer Factor and Bioaccumulation of Heavy metals in Fishes from Rivers Owan and Evbiobe , Edo State , Nigeria. *Journal of Aquaculture, Fisheries & Fish Science*, *2*(2), 165–173. https://doi.org/10.25177/JAFFS.2.2.RA.603

Pallant, J. (2020). *SPSS Survival Manual : A Step By Step Guide to Data Analysis Using IBM SPSS* (7th ed.). Routledge.

Paolucci, U., Vigneau-Callahan, K. E., Shi, H., Matson, W. R., & Kristal, B. S. (2004). Development of biomarkers based on diet-dependent metabolic serotypes: Characteristics of component-based models of metabolic serotypes. *OMICS A Journal of Integrative Biology*, *8*(3), 221–238. https://doi.org/10.1089/omi.2004.8.221

Petricorena, Z. C. (2014). Chemical Composition of Fish and Fishery Products. In *Handbook of Food Chemistry* (pp. 1–28). Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-41609-5

PMD. (2013). Economic Transformation Program Annual Report. In *Prime Minister's Department*. https://www.pmo.gov.my/dokumenattached/NTP-Report-2013/ETP_2013_ENG.pdf

PMD. (2015). Eleventh Malaysia Plan 2016-2020. In *Prime Minister's Department*. https://www.epu.gov.my/sites/default/files/2020-02/Buku RMKe-11.pdf

Polakof, S., Panserat, S., Soengas, L., & Moon, T. W. (2012). Glucose metabolism in fish: A review. *Journal of Comparative Physiology B*, *182*(8), 1015–1045. https://doi.org/10.1007/s00360-012-0658-7

Potyrailo, R. A. (2001). On-line Measurement. In K. H. J. Buschow, R. W. Cahn, M. C. Flemings, B. Ilschner, E. J. Kramer, S. Mahajan, & Patrick Veyssière (Eds.), *Encyclopedia of Materials: Science and Technology* (2nd ed., pp. 6401–6411). Elsevier. https://doi.org/https://doi.org/10.1016/B0-08-043152-6/01133-5

Prabu, E., Felix, S., Felix, N., Ahilan, B., & Ruby, P. (2017). An overview on significance of fish nutrition in aquaculture industry. *International Journal of Fisheries and Aquatic Studies*, *5*(6), 349–355.

Puspitasari, A. Y., Pranowo, H. D., Swasono, R. T., & Nuringtyas, T. R. (2018). 1 H NMR Fingerprinting of Medicinal Herbs Contain Chemical Drug Material Allopurinol. *Traditional Medicine Journal*, *23*(3), 6–11.

Rajewski, J., & Dobrzyńska-Inger, A. (2021). Application of response surface methodology (Rsm) for the optimization of chromium(iii) synergistic extraction by supported liquid membrane. *Membranes*, *11*(11). https://doi.org/10.3390/membranes11110854

Rana, K. J., Siriwardena, S., & Hasan, M. R. (2009). Impact of rising feed ingredient prices on aquafeeds and aquaculture production. In *Fisheries and Aquaculture Technical Paper: Vol. No. 541*. FAO.

Raso, S., & Anderson, T. A. (2003). Effects of dietary fish oil replacement on growth and carcass proximate composition of juvenile barramundi *(Lates calcarifer)*. *Aquaculture Research*, *34*(10), 813–819. https://doi.org/10.1046/j.1365-2109.2003.00885.x

Renaud, S. C., Ruf, J. C., & Petithory, D. (1995). The positional distribution of fatty acids in palm oil and lard influences their biologic effects in rats. *The Journal of Nutrition*, *125*(2), 229–237. https://doi.org/doi.org/10.1093/jn/125.2.229

Richard, N., Mourente, G., Kaushik, S., & Corraze, G. (2006). Replacement of a large portion of fish oil by vegetable oils does not affect lipogenesis , lipid transport and tissue lipid uptake in European seabass *(Dicentrarchus labrax L.)*. *Aquaculture*, *261*(3), 1077–1087. https://doi.org/10.1016/j.aquaculture.2006.07.021

Robinson, E. H., Li., M. H., & Manning., B. B. (2001). A Practical Guide to Nutrition, Feeds, and Feeding of Catfish. In *Mississippi Agricultural & Forestry Experiment Station Technical Bulletin* (Second Rev, Issue 1113). http://agrilife.org/fisheries2/files/2013/09/A-Practical-Guide-to-Nutrition-Feeds-and-Feeding-of-Catfish.pdf

Robinson, E. H., & Li, M. H. (2015). A Brief Overview of Catfish Nutrition. *Mississippi*

Agricultural and Forestry Experiment Station Research Report, *24*(16), 1–6. https://extension.msstate.edu/sites/default/files/pdf//rr24-16.pdf

Rohman, A., Triyana, K., Sismindari, & Erwanto, Y. (2012). Differentiation of lard and other animal fats based on triacylglycerols composition and principal component analysis. *International Food Research Journal*, *19*(2), 475–479. https://www.researchgate.net/publication/279587520

Rongai, D., Sabatini, N., Del Coco, L., Perri, E., Del Re, P., Simone, N., Marchegiani, D., & Fanizzi, F. (2017). 1H NMR and Multivariate Analysis for Geographic Characterization of Commercial Extra Virgin Olive Oil: A Possible Correlation with Climate Data. *Foods*, *6*(11), 96. https://doi.org/10.3390/foods6110096

Roslan, N. I. M., Marikkar, J. M. N., Manaf, Y. N., Mustafa, S., & Miskandar, M. S. (2019). Effect of enzymatic transesterification using Mucor miehei lipase on physicochemical properties of engkabang *(Shorea macrophylla)* fat-canola oil blends. *International Food Research Journal*, *26*(5), 1427–1435.

Roudi, A. M., Salem, S., Abedini, M., Maslahati, A., & Imran, M. (2021). Response Surface Methodology (RSM)-Based Prediction and Optimization of the Fenton Process in Landfill Leachate Decolorization. *Processes*, *9*(12), 2284. https://doi.org/10.3390/pr9122284

Said, R. E., Hasieb, H. E., Moustafa, M. A., Soliman, S. M. E., Kloas, W., & Osman, A. G. M. (2019). Haematological, Serological and Genotoxic Findings in the African Catfish *Clarias gariepinus* after the Administration of Copper Nanoparticles and Penconazole. *EC Veterinary Science*, *4*(10), 1–14.

Saifullah, A., & Muhammad, A. T. (2014, July 9). Lambakan tulang babi jadi topik hangat. *Sinar Harian*. http://www.sinarharian.com.my/hiburan/lambakan-tulang-babi-jadi-topi k-hangat-1.297815

Salimon, J., Omar, T. A., & Salih, N. (2014). Comparison of Two Derivatization Methods for the Analysis of Fatty Acids and Trans Fatty Acids in Bakery Products Using Gas Chromatography. *The Scientific World Journal*, *2014*. http://dx.doi.org/10.1155/2014/906407

Salwani.. Mansor, T., Che Man, Y. Bin, & Rohman, A. (2011). Application of Fast Gas Chromatography and Fourier Transform Infrared Spectroscopy for Analysis of Lard Adulteration in Virgin Coconut Oil. *Food Analytical Methods*, *4*(3), 365–372. https://doi.org/10.1007/s12161-010-9176-y

Samah, R. (2020). Increasing the Fish Production With Good. *International Journal of Business and Technology Management*, *2*(1), 27–33.

Sargent, J. R., Tocher, D. R., & Bell, J. G. (2002). The Lipids. In J. E. Halver & R. W. Hardy (Eds.), *Fish Nutrition* (3rd ed., pp. 181–257). Elsevier (Academic Press). https://doi.org/https://doi.org/10.1016/B978-012319652-1/50005-7

Sarker, S. D., & Nahar, L. (2015). Applications of High Performance Liquid

Chromatography in the Analysis of Herbal Products. In *Evidence-Based Validation of Herbal Medicine*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-800874-4.00019-2

Sathya, R., & Abraham, A. (2013). Comparison of Supervised and Unsupervised Learning Algorithms for Pattern Classification. *International Journal of Advanced Research in Artificial Intelligence*, *2*(2), 34–38. https://doi.org/10.14569/IJARAI.2013.020206

Schick, C. (2009). Differential scanning calorimetry (DSC) of semicrystalline polymers. *Analytical and Bioanalytical Chemistry*, *395*(6), 1589–1611. https://doi.org/10.1007/s00216-009-3169-y

Schwarz, F. J., Kirchgessner, M., Steinhart, H., & Runge, G. (1988). Influence of different fats with varying additions of α-tocopheryl acetate on growth and body composition of carp *(Cyprinus carpio L.)*. *Aquaculture*, *69*(1–2), 57–67. https://doi.org/10.1016/0044-8486(88)90186-X

Sen, G. A. (2016). Application of full factorial experimental design and response surface methodology for chromite beneficiation by Knelson concentrator. *Minerals*, *6*(1). https://doi.org/10.3390/min6010005

Shahidi, F., & Wanasundara, P. K. J. P. D. (2008). Extraction and Analysis of Lipids. In C. A. Casimir & B. M. David (Eds.), *Food Lipids* (3rd ed., pp. 126–149). CRC Press. https://doi.org/10.1201/9781420046649.ch5

Shourbela, R. M., & Tohamy, H. G. (2020). Induced spawning of African catfish (Clarias gariepinus Burchell , 1822) after pre-spawning prophylactic disinfection ; the breeding performance and tissue histopathological alterations are under scope. *Iranian Journal of Fisheries Sciences*, *19*(1), 309–324. https://doi.org/10.22092/IJFS.2018.115523

Silva, S. S. De, Francis, D. S., & Tacon, A. G. J. (2010). Fish Oils in Aquaculture. In G. M. Turchini, W.-K. Ng, & D. R. Tocher (Eds.), *Fish Oil Replacement and Alternative Lipid Sources in Aquaculture Feeds* (pp. 1–20). CRS Press. https://doi.org/doi.org/10.1201/9781439808634

Simopoulos, A. P. (2016). An increase in the Omega-6/Omega-3 fatty acid ratio increases the risk for obesity. *Nutrients*, *8*(3), 1–17. https://doi.org/10.3390/nu8030128

Sindhu, R., Binod, P., & Pandey, A. (2015). Microbial Poly-3-Hydroxybutyrate and Related Copolymers. In *Industrial Biorefineries and White Biotechnology*. Elsevier B.V. https://doi.org/10.1016/B978-0-444-63453-5.00019-7

Singh, I., Juneja, P., Kaur, B., & Kumar, P. (2013). Pharmaceutical Applications of Chemometric Techniques. *ISRN Analytical Chemistry*, *2013*, 1–13. https://doi.org/10.1155/2013/795178

Singh, S. K., & Muthukumarappan, K. (2014). Effect of Different Extrusion Processing Parameters on Physical Properties of Soy White Flakes and High Protein Distillers

Dried Grains-Based Extruded Aquafeeds. *Journal of Food Research*, *3*(6), 107–123. https://doi.org/10.5539/jfr.v3n6p107

Singh, S. K., & Muthukumarappan, K. (2015). *Effect of feed moisture , extrusion temperature and screw speed on properties of soy white flakes based aquafeed : a response surface analysis*. *July*. https://doi.org/10.1002/jsfa.7339

Solomon, S. G., Ataguba, G. A., & Abeje, A. (2011). Water Stability and Floatation Test of Fish Pellets using Local Starch Sources and Yeast *(Saccahromyces cerevisae)*. *International Journal of Latest Trends in Agriculture and Food Sciences*, *1*(1), 1–5.

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Fish in aquaponics. In *Small-scale aquaponic food production : Integrated fish and plant farming* (pp. 103–121). Food and Agriculture Organization of United Nations. http://www.fao.org/3/a-i4021e.pdf

Sonu, B. (2018). Fish-Oil Finishing Diets: A strategy to recover long-chain polyunsaturated fatty acids in Fish previously fed alternative dietary lipids. *International Journal of Life Sciences*, *6*(2), 466–472.

Sparkman, O. D., Penton, Z. E., & Kitson, F. G. (2011). Gas Chromatography. In *Gas Chromatography and Mass Spectrometry : a practical guide* (pp. 15–83). https://doi.org/10.1016/B978-0-12-373628-4.00002-2

Sriherwanto, C., Suja'i, I., & Soraya. (2017). Utilisation of the Fungus *Rhizopus sp.* as Bio-Floating Agent in Fish Feed (Pemanfaatan Kapang *Rhizopus sp.* sebagai Agen Hayati Pengapung Pakan Ikan). *Journal Mikologi Indonesia*, *1*(2), 70–81. https://www.researchgate.net/publication/322356675

Sun, L. W., Zhang, H. Y., Wu, L., Shu, S., Xia, C., Xu, C., & Zheng, J. S. (2014). 1H-Nuclear magnetic resonance-based plasma metabolic profiling of dairy cows with clinical and subclinical ketosis. *Journal of Dairy Science*, *97*(3), 1552–1562. https://doi.org/10.3168/jds.2013-6757

Takeuchi, T., Watanabe, T., & Ogino, C. (1978). Use of Hydrogenated Fish Oil and Beef Tallow as a Dietary Energy Source for Carp and Rainbow Trout. *Nippon Suisan Gakkaishi*, *44*(8), 875–881. https://doi.org/10.2331/suisan.44.875

Tan, C. P., & Che Man, Y. B. (1999). Quantitative differential scanning calorimetric analysis for determining total polar compounds in heated oils. *Journal of the American Oil Chemists' Society*, *76*(9), 1047–1057. https://doi.org/10.1007/s11746-999-0203-3

Teh, S. S., Voon, P. T., Teng, N. Y., Ong, S.-H., Ong, A. S. H., & Choo, Y. M. (2016). Effects of Fatty Acids at Different Positions in the Triglycerides on Cholesterol Levels. *Journal of Oil Palm Research*, *28*(2), 211–221. https://doi.org/10.21894/jopr.2016.2802.09

Teles, A. O., & Couto, A. (2019). Dietary protein requirements of fish – a meta-analysis.

Reviews in Aquaculture, 1–33. https://doi.org/10.1111/raq.12391

Tesfahun, A. (2018). Feeding biology of the African catfish Clarias gariepinus *(Burchell)* in some of Ethiopian Lakes: A review Feeding biology of the African catfish *Clarias gariepinus (Burchell)* in some of Ethiopian Lakes: A review Agumassie Tesfahun. *International Journal of Fauna and Biological Studies*, *5*(1), 19–23. https://www.researchgate.net/publication/322675358

Teugels, G. G., & Adriaens, D. (2003). Taxonomy and phylogeny of Clariidae - An overview. *Catfishes*, *1*, 465–487.

Thysell, E., Chorell, E., Svensson, M. B., Jonsson, P., & Antti, H. (2012). Validated and predictive processing of gas chromatography- mass spectrometry based metabolomics data for large scale screening studies, diagnostics and metabolite pattern verification. *Metabolites*, *2*(4), 796–817. https://doi.org/10.3390/metabo2040796

Tim, J., & Ibrahim, J. (2013). *Current status of aquaculture in Malaysia*. Department of Fisheries Malaysia. http://www.aquaculture.asia/files/soyabean/pdfs/09. Status of Aquaculture in Malaysia Summary.pdf

Tolstorebrov, I., Eikevik, T. M., & Bantle, M. (2014). A DSC determination of phase transitions and liquid fraction in fish oils and mixtures of triacylglycerides. *Food Research International*, *58*(2014), 132–140. https://doi.org/10.1016/j.foodres.2014.01.064

Tres, A., Veer, G. van der, Perez-Marin, M. D., Ruth, S. M. van, & Garrido-Varo, A. (2012). Authentication of Organic Feed by Near-Infrared Spectroscopy Combined with Chemometrics: A Feasibility Study. *Agricultural and Food Chemistry*, *2012*(60), 8129–8133. https://doi.org/dx.doi.org/10.1021/jf302309t

Triba, M. N., Le Moyec, L., Amathieu, R., Goossens, C., Bouchemal, N., Nahon, P., Rutledge, D. N., & Savarin, P. (2015). PLS/OPLS models in metabolomics: The impact of permutation of dataset rows on the K-fold cross-validation quality parameters. *Molecular BioSystems*, *11*(1), 13–19. https://doi.org/10.1039/c4mb00414k

Trushenski, J. T., & Lochmann, R. T. (2009). Potential, Implications and Solutions Regarding the Use of Rendered Animal Fats in Aquafeeds. *American Journal of Animal and Veterinary Sciences*, *4*(4), 108–128. https://doi.org/10.3844/ajavsp.2009.108.128

Turchini, G. M., Mentasti, T., Frøyland, L., Orban, E., Caprino, F., Moretti, V. M., & Valfre, F. (2003). Effects of alternative dietary lipid sources on performance , tissue chemical composition , mitochondrial fatty acid oxidation capabilities and sensory characteristics in brown trout *(Salmo trutta L.)*. *Aquaculture*, *225*, 251–267. https://doi.org/10.1016/S0044-8486(03)00294-1

Umar, S., & Kamarudin, M. S. (2013). Physical properties of extruded aquafeed with a combination of sago and tapioca starches at different moisture contents. *Animal*

Feed Science and Technology, *183*(1–2), 51–55. https://doi.org/10.1016/j.anifeedsci.2013.03.009

Umetrics, A. B. (2005). *User's guide to SIMCA-P and SIMCA-P+ version 11.0*. Umetrics A. B.: Umeå, Sweden.

Vajargah., K. F., Sadeghi-Bazargani., H., Mehdizadeh-Esfanjani., R., Savadi-Oskouei, D., & Farhoudi., M. (2012). OPLS statistical model versus linear regression to assess sonographic predictors of stroke prognosis. *Neuropsychiatric Disease and Treatment*, *8*, 387–392. https://doi.org/10.2147/NDT.S33991

Van Den Berg, R. A., Hoefsloot, H. C. J., Westerhuis, J. A., Smilde, A. K., & van der Werf, M. J. (2006). Centering, scaling, and transformations: Improving the biological information content of metabolomics data. *BioMed Central Genomics*, *7*(142), 1–15. https://doi.org/10.1186/1471-2164-7-142

Verdegem, M. C. J. (2013). Nutrient discharge from aquaculture operations in function of system design and production environment. *Reviews in Aquaculture*, *5*(3), 158–171. https://doi.org/10.1111/raq.12011

Vessman, J., Stefan, R. I., Staden, J. F. van, Danzer, K., Lindner, W., Burns, D. T., Fajgelj, A., & Müller, H. (2001). Selectivity in Analytical Chemistry (IUPAC Recommendations 2001). *Pure and Applied Chemistry*, *73*(8), 1381–1386. https://doi.org/http://dx.doi.org/10.1351/pac200173081381

Victor, O. E., Edem, T. E., & Felix, E. (2019). Water stability of aquafeed pellets using binder from selected root and tuber crops. *International Journal of Maritime and Interdisciplinary Research*, *1*(1), 354–360. https://www.researchgate.net/publication/344233087

Wang, F., Li, W., Wang, G., Yu, M., Zhong, J., Xu, C., Li, D., & Zhou, Y. (2019). Gas chromatography-mass spectrometry based serum metabolic analysis for premature infants and the relationship with necrotizing enterocolitis: A cross-sectional study. *Italian Journal of Pediatrics*, *45*(1), 1–8. https://doi.org/10.1186/s13052-019-0646-6

Wang, H., Ma, S., Yang, J., Qin, Y., Cheng, H., Xue, M., Li, J., & Li, J. (2021). Optimization of the process parameters for extruded commercial sinking fish feed with mixed plant protein sources. *Journal of Food Process Engineering*, *44*(1), 1–11. https://doi.org/10.1111/jfpe.13599

Wang, X., Wang, P., Zhang, A., & Sun, H. (2013). Metabolic Profiling and Potential Biomarkers of ShenYinXu Syndrome and the Therapeutic Effect of Liuweidihuang Wan. In *Chinmedomics*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-803117-9/00011-1

Welker, T. L., Overturf, K., Snyder, S., Liu, K., Abernathy, J., Frost, J., & Barrows, F. T. (2018). Effects of feed processing method (extrusion and expansion-compression pelleting) on water quality and growth of rainbow trout in a commercial setting. *Journal of Applied Aquaculture*, *30*(2), 97–124.

https://doi.org/10.1080/10454438.2018.1433095

Westerhuis, J. A., Hoefsloot, H. C. J., Smit, S., Vis, D. J., Smilde, A. K., Velzen, E. J. J., Duijnhoven, J. P. M., & Dorsten, F. A. (2008). Assessment of PLSDA cross validation. *Metabolomics*, *4*(1), 81–89. https://doi.org/10.1007/s11306-007-0099-6

Wheelock, Å. M., & Wheelock, C. E. (2013). Trials and tribulations of 'omics data analysis: Assessing quality of SIMCA-based multivariate models using examples from pulmonary medicine. *Molecular BioSystems*, *9*(11), 2589–2596. https://doi.org/10.1039/c3mb70194h

Wilkund, S. (2008). *Multivariate Data Analysis for Omics*. Umetrics: Umeå, Sweden.

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Journal of Emergency Primary Health Care*, *8*(3), 1–13. https://doi.org/10.33151/ajp.8.3.93

Wing-Keong, N. (2019). Clarias gariepinus. In *Invasive Species Compendium*. https://www.cabi.org/isc/datasheet/88683#tosummaryOfInvasiveness

Worley, B., & Powers, R. (2016). PCA as a predictor of OPLS-DA model reliability. *Current Metabolomics*, *4*(2), 97–103. https://doi.org/10.2174/2213235X04666160613122429.PCA

Wu, S., Liu, R., & Li, H. (2012). Comparison of composition and structure of palm oil with lard. *Advanced Materials Research*, *554–556*, 905–908. https://doi.org/10.4028/www.scientific.net/AMR.554-556.905

Yan, S., Li, X., Zhang, L., Zeng, Y., Liu, S., Liu, X., Zhou, H., Wen, L., & Wang, J. (2020). Moderate quantity of lard mixed with sunflower oil attenuate lipid accumulation in mice. *Oil Crop Science*, *In Press*. https://doi.org/10.1016/j.ocsci.2020.06.001

Yang, C., Garrido-novell, C., Pérez-marín, D., Guerrero-ginel, J. E., Garrido-varo, A., Cho, H., & Kim, M. S. (2015). Differentiation of Beef and Fish Meals in Animal Feeds Using Chemometric Analytic Models. *Journal of Biosystems Engineering*, *40*(2), 153–158. https://doi.org/dx.doi.org/10.5307/JBE.2015.40.2.153

Yanty, N. A. M., Dollah, S., Marikkar, J. M. N., Miskandar, M. S., Desa, M. N. M., & Nusantoro, B. P. (2018). Physicochemical Properties and Thermal Behavior of Binary Blends of Madhuca longifolia Seed Fat and Palm Oil as a Lard Substitute. *Journal of Advanced Agricultural Technologies*, *5*(3), 202–208. https://doi.org/10.18178/joaat.5.3.202-208

Yanty, N. A. M., Marikkar, J. M. N., & Abdulkarim, S. M. (2014). Determination of types of fat ingredient in some commercial biscuit formulations. *International Food Research Journal*, *21*(1), 277–282. https://www.researchgate.net/publication/288092573

Yanty, N. A. M., Marikkar, J. M. N., Che Man, Y. B., & Long, K. (2011). Composition and thermal analysis of lard stearin and lard olein. *Journal of Oleo Science*, *60*(7), 333–338. https://doi.org/10.5650/jos.60.333

Yanty, N. A. M., Marikkar, J. M. N., & Miskandar, M. S. (2012). Comparing the thermo-physical characteristics of lard and selected plant fats. *Grasas y Aceites*, *63*(3), 328–334. https://doi.org/10.3989/gya.023712

Yanty, N. A. M., Marikkar, J. M. N., Suhaimi, M., & Miskandar, M. S. (2017). Composition and thermal analysis of ternary mixtures of avocado fat:palm stearin:cocoa butter (Avo:PS:CB). *International Journal of Food Properties*, *20*(2), 465–474. https://doi.org/10.1080/10942912.2016.1166130

Yildirim-Aksoy, M., Lim, C., Davis, D. A., Shelby, R., & Klesius, P. H. (2007). Influence of Dietary Lipid Sources on the Growth Performance, Immune Response and Resistance of Nile Tilapia, *Oreochromis niloticus*, to *Streptococcus iniae* Challenge. *Journal of Applied Aquaculture*, *19*(2), 29–49. https://doi.org/10.1300/J028v19n02

Yousf, N., Nazir, F., Salim, R., Ahsan, H., & Sirwal, A. (2017). Water solubility index and water absorption index of extruded product from rice and carrot blend. *Journal of Pharmacognosy and Phytochemistry*, *6*(66), 2165–2168.

Yuswan, M. H., Aizat, W. M., Lokman, A. A., Desa, M. N. M., Mustafa, S., Junoh, N. M., Yusof, Z. N. B., Mohamed, R., Mohmad, Z., & Lamasudin, D. U. (2018). Chemometrics-Assisted Shotgun Proteomics for Establishment of Potential Peptide Markers of Non-Halal Pork *(Sus scrofa)* among Halal Beef and Chicken. *Food Analytical Methods*, *11*(12), 3505–3515. https://doi.org/10.1007/s12161-018-1327-6

Zailina, M. N. (2019). *Stok ikan makin kurang , saiz makin kecil - Pensyarah UMT*. Malaysia Kini. https://www.malaysiakini.com/news/496378

Zhang, L., Li, M., Zhan, L., Lu, X., Liang, L., Su, B., Sui, H., Gao, Z., Li, Y., Liu, Y., Wu, B., & Liu, Q. (2015). Plasma metabolomic profiling of patients with diabetes-associated cognitive decline. *PLoS ONE*, *10*(5). https://doi.org/10.1371/journal.pone.0126952

Zhang, X., Tong, Q., Zhu, W., & Ren, F. (2013). Pasting , rheological properties and gelatinization kinetics of tapioca starch with sucrose or glucose. *Journal of Food Engineering*, *114*(2), 255–261. https://doi.org/10.1016/j.jfoodeng.2012.08.002

Zhenhua, Z. (2011). *Aquafeed extrusion: production process explained*. Feedmachinery.Com. https://www.feedmachinery.com/articles/feed_technology/aquafeed-extrusion-production-process-explained/

Zhou, L., Han, D., Zhu, X., Yang, Y., Jin, J., & Xie, S. (2016). Effects of total replacement of fish oil by pork lard or rapeseed oil and recovery by a fish oil finishing diet on growth, health and fish quality of gibel carp *(Carassius auratus gibelio)*.

Aquaculture Research, *47*(9), 2961–2975. https://doi.org/10.1111/are.12748

Zhou, Q., Li, C., Liu, C., Chi, S., & Yang, Q. (2007). Effects of dietary lipid sources on growth and fatty acid composition of juvenile shrimp , *Litopenaeus vannamei. Aquaculture Nutrition*, *13*(3), 222–229. https://doi.org/doi:10.1111/j.1365-2095.2007.00470.x