UNIVERSITI PUTRA MALAYSIA

ENHANCING NUTRITIVE VALUE OF PALM KERNEL EXPELLER THROUGH PHYSICAL TREATMENTS FOR USE AS POULTRY FEED INGREDIENT

MUHAMAD AKHMAL HAKIM BIN ROSLAN

IPTSM 2019 10

ENHANCING NUTRITIVE VALUE OF PALM KERNEL EXPELLER THROUGH PHYSICAL TREATMENTS FOR USE AS POULTRY FEED INGREDIENT

By

MUHAMAD AKHMAL HAKIM BIN ROSLAN

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

February 2019

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

ENHANCING NUTRITIVE VALUE OF PALM KERNEL EXPELLER THROUGH PHYSICAL TREATMENTS FOR USE AS POULTRY FEED INGREDIENT

By

MUHAMAD AKHMAL HAKIM BIN ROSLAN

February 2019

Chair : Norhani binti Abdullah, PhD
Faculty : Institute of Tropical Agriculture and Food Security

Poultry production in Malaysia is heavily dependent on imported feed ingredients. The palm kernel expeller (PKE) is a potential feed ingredient to sustain the poultry industry. However, PKE had to be treated before it could be incorporated in poultry feed to reduce the anti-nutritive factors like indigestible mannan, lignin and broken kernel shells.. Hence, this study aimed at reducing these factors of PKE by extrusion and static cling-electrostatic separation technique to reduce the mannan and broken shells, respectively, and to produce a poultry feed containing treated PKE with a potential for commercial application. Extrusion was conducted by using a custom made co-rotating twin-screw extruder and static cling–electrostatic separation by using a simple fabricated apparatus. Response surface methodology (RSM) was used to optimize both treatments. Extrusion of PKE at optimized conditions (temperature, 178 ºC; screw speed, 100 rpm; hopper speed, 5 Hz and PKE moisture, 75%), significantly ($P<0.05$) reduced non-starch polysaccharides from 63.3% to 57.6%, and crude fibre from 16.7% to 13.5%, and significantly ($P<0.05$) increased mannose, glucose, fructose, 1,4-β-D-mannobiose; 1,4-β-D-mannotriose; 1,4-β-D-mannohexaose and 1,4-β-D-mannopentaose content. The production rate of extruded PKE (EPKE) was 180 kg/h. The static cling–electrostatic method at optimized conditions (13% PKE moisture; <1.5 mm PKE particle size and 110 g/min feed rate), reduced shells, lignin and fibre of PKE from 8.0% to 1.6%; 15.8% to 8.1% and 17.1% to 10.2%, respectively, and increased crude protein from 16.5% to 18.4%. The production rate of less-shell PKE (LSPKE) was 50 kg/h. The study on the effects of control (0% PKE), UPKE (untreated), EPKE, LSPKE and ELSPKE at 10%, 20% and 30% inclusion rates in finisher diets (d 21-42) showed that growth performance of broilers (Cobb 500) fed 10% PKE (irrespective of treatments), 20% LSPKE and ELSPKE, were comparable to control birds. At 30% PKE inclusion, broilers performance was significantly ($P<0.05$) reduced. Birds fed PKE diets, irrespective of treatments and inclusion levels had lower LDL and total cholesterol, and similar villi height and crypt depth compared to control. At 30% PKE inclusion level, although energy metabolism was enhanced, as indicated by the up-regulation of hexokinase I and phosphofructokinase, but broilers growth performance did not improve. The feeding trial showed that broilers fed 25% or 30% LSPKE (grower feed, d 16-24), followed by 20% LSPKE (finisher feed, d 25-35) containing feed supplements 0.02% commercial enzymes and 0.30% humic acid), had comparable FI, BWG and FCR to broilers fed commercial feeds. Broilers fed 25% or 30% UPKE (grower feed, d 16-24) followed by 20% UPKE (finisher feed, d 25-35) showed significantly higher ($P<0.05$) FCR compared to birds fed commercial feeds. The cost of feeds for production of birds fed LSPKE feeds (2.27-2.29 RM/kg liveweight), was lower than those fed commercial feeds (2.36 RM/kg liveweight). The study showed that physical treatments enhanced the nutritive value of PKE and feeds containing 25-30% and 20% LSPKE as grower and finisher rations, respectively, could attain broilers growth performance comparable to broilers fed commercial feeds. These diets could be potential feeds for commercial poultry production.

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

MENINGKATKAN NILAI PEMAKANAN HAMPAS ISIRUNG KELAPA SAWIT MELALUI RAWATAN FISIKAL UNTUK KEGUNAAN SEBAGAI BAHAN MAKANAN POLTRI

Oleh

MUHAMAD AKHMAL HAKIM BIN ROSLAN

Februari 2019

Pengerusi : Norhani Abdullah, PhD
Fakulti : Institut Pertanian Tropika dan Sekuriti Makanan

Produksi ternakan poltri di Malaysia sangat bergantung kepada bahan makanan import. Hampas isirung kelapa sawit (PKE) berpotensi menjadi makanan alternatif untuk mengekalkan industri poltri. Walaubagaimanapun, PKE perlu dirawat sebelum ia digunakan sebagai bahan dalam makanan poltri untuk mengurangkan bahan anti nutrisi seperti mannan, lignin dan cangkerang. Oleh itu penyelidikan ini bermatlamat untuk meningkatkan nutrisi PKE melalui teknik ekstrusi dan pemisahan statik berpaut – elektrostatik untuk mengurangkan serat dan cangkerang dan menghasilkan makanan poltri yang mengandungi PKE terawat untuk aplikasi komersial. Ekstrusi dijalankan menggunakan mesin ekstrusi skru berkembar dan radas pemisahan statik berpaut – elektrostatik yang dibuat khas. Metodologi permukaan sambutan (RSM) telah digunakan untuk mengoptimumkan kedua-dua jenis rawatan. Ekstrusi PKE pada kondisi optimum (suhu, 178 ºC; kelajuan skru, 100 rpm; kelajuan corong, 5 Hz dan kelembapan PKE, 75%), signifikan menurunkan ($P<0.05$) kandungan polisakarida bukan kanji dari 63.3% kepada 57.6% dan serat mentah daripada 16.7% kepada 13.5%, dan signifikan meningkatkan kandungan mannosa, glukosa, fruktosa dan mannan oligosakarida (1,4-β-D-mannobiosa; 1,4-β-D-mannotriosa; 1,4-β-D-mannoheksaosa and 1,4-β-D-mannopentaosa). Kadar produksi PKE terekstrusi (EPKE) adalah 180 kg/jam. Teknik pemisahan statik berpaut – elektrostatik pada kondisi optimum, menurunkan cangkerang, lignin dan serat dalam PKE masing-masing daripada 8.0% kepada 1.6%; 15.8% kepada 8.1% dan 17.1% kepada 10.2%, dan meningkatkan protin mentah daripada 16.5% to 18.4%. Kadar produksi PKE kurang cangkerang (LSPKE) adalah 50 kg/jam. Kajian terhadap kesan pemakanan kawalan (0% PKE), UPKE (tidak dirawat), EPKE, LSPKE dan ELSPKE pada 10%, 20% dan 30% kadar kemasukan dalam dedak pengakhir (hari 21-42) menunjukkan prestasi tumbesaran ayam pedaging (Cobb 500) diberi makan 10% PKE (tanpa mengira jenis rawatan), 20% LSPKE dan ELSPKE, adalah setanding dengan ayam kawalan. Pada kemasukan 30% PKE, prestasi ayam pedaging ($P<0.05$) menurun dengan signifikan. Ayam diberi makan diet PKE, tanpa mengira jenis rawatan dan kadar tambahan, mempunyai rendah kolesterol lipoprotein densiti rendah (LDL) dan kolesterol keseluruhan dalam serum dan serata tinggi vilus dan kedalaman crypt berbanding ayam

kawalan. Penambahan 30% PKE meningkatkan metabolisma tenaga melalui peningkatan ekspresi heksokinase I dan fosfofruktokinase. Walaubagaimanapun, tumbesaran ayam pedaging tidak bertambah baik. Ujian akhir pemberian makanan terhadap ayam pedaging menunjukkan ayam yang diberi 25% atau 30% LSPKE (dedak pertumbuhan, hari 16-24), diikuti oleh 20% LSPKE (dedak pengakhir, hari 25-35) mengandungi aditif (0.02% enzim komersial dan 0.30% asid humik), mempunyai pemgambilan makanan, kenaikan berat badan dan nisbah penukaran makanan yang setanding ayam diberi makan dedak komersial. Ayam diberi 25% atau 30% UPKE (dedak pertumbuhan hari 16-24), diikuti oleh 20% UPKE (dedak pengakhir, hari 25-35) menunjukkan peningkatan nisbah penukaran makanan yang signifikan berbanding ayam yang diberi makan dedak komersial. Kos dedak bagi produksi ayam yang diberi dedak ini (2.27-2.29 RM/kg berat hidup) adalah lebih rendah berbanding ayam diberi dedak komersial (2.36 RM/kg berat hidup). Kajian ini menunjukkan rawatan fizikal menambah baik nutrisi PKE, dan dedak mengandungi 25% dan 20% LSPKE masing-masing sebagai formula dedak pertumbuhan dan pengakhir, boleh mencapai prestasi tumbesaran ayam yang setanding dengan ayam yang diberi dedak komersial. Dedak ini berpotensi menjadi dedak untuk produksi poltri secara komersial.

ACKNOWLEDGEMENTS

I would like to thank Professor Dr. Norhani Abdullah for giving me the opportunity, trust and responsibility to complete my study under her supervision, it is truly an honor. Her wisdom and teaching on responsibility and integrity, will always be my lifetime inspirations. I would like to thank Professor Dr. Zulkifli Idrus, Professor Dr. Shuhaimi Mustafa and Associate Professor Dr. Mohd Yunus Abd Shukor for all their kind supports during my study. I also acknowledged the cooperation and assistance from my colleagues, Norafilah, Intan, Faridah, Mutaz, Elizabeth, Syikin and Dr. Mohammad, and ITAFoS staffs Mr. Faizol, Ms Azilah, Mr. Farhan, Mr. Eddy, Mr. Zahidi, Mr. Zulhelmi, Mr. Fazmen, Dr. Abdoreza and Dr Suriya.

I would also like to thank the Institute of Tropical Agriculture and Food Security (ITAFoS) and Universiti Putra Malaysia for the facilities provided and to the Ministry of Higher Education of Malaysia for the research grant under the Long Term Research Grant Scheme (LRGS).

To my beloved wife Rawdhah, thank you so much for countless love and support given that helped me to get through the challenging period wonderfully. Lastly, very special thanks to my parents Siti Sara and Roslan for their endless love and strong support throughout my life. This study would have been impossible to complete without their pray and support.

My lord, make what you teach us beneficial, teach us what is beneficial, and increase us in knowledge. Amen.

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:

Norhani binti Abdullah, PhD
Institute of Tropical Agriculture and Food Security
Universiti Putra Malaysia
(Chairman)

Zulkifli bin Idrus, PhD
Professor
Institute of Tropical Agriculture and Food Security
Universiti Putra Malaysia
(Member)

Shuhaimi bin Mustafa, PhD
Professor
Halal Products Research Institute
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: Muhamad Akhmal Hakim Bin Roslan GS34569

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: Dr. Norhani binti Abdullah

Signature: ______________________

Name of Member of Supervisory Committee: Professor Zulkifli bin Idrus

Signature: ______________________

Name of Member of Supervisory Committee: Professor Shuhaimi bin Mustafa

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Adj. R2	Adjusted coefficient of determination
AIDC	Apparent ileal digestibility coefficient
AJDU	Apple juice depectinizing units
AME	Apparent metabolisable energy
AMEN	Nitrogen-corrected apparent metabolizable energy
ANOVA	Analysis of variance
AOAC	Association official agricultural chemists
ASTM	American society for testing and materials
BBD	Box-behnken design
BGU	Beta-glucanase unit
Bil	Billion
BW	Body weight
BWG	Body weight gain
cDNA	Complementary deoxyribonucleic acid
CI	Confidence interval
Cl	Chloride
cm	Centimeter
CMCU	Carboxymethyl cellulase
CP	Crude protein
C (t)	Effluent concentration–time curve
d	day
DCP	Dicalcium phosphate
DM	Dry matter

DNA	Deoxyribonucleic acid
DP	Degree of polymerization
DPKC	Deproteinated palm kernel cake
ECT	Total extrudate collection time
EDTA	Ethylenediaminetetraacetic acid
ELSPKE	Extruded less shell palm kernel Expeller
EPKE	Extruded palm kernel Expeller
Exp	Experiment
FAU	Fungal amylase unit
FCR	Feed conversion ratio
FI	Feed intake
FPRT	Fastest particle residence time
FTIR	Fourier transform infrared spectroscopy
g	Gram
GAPDH	Glyceraldehyde 3-phosphate dehydrogenase
gDNA	Genomic deoxyribonucleic acids
GFSI	Global Food Security Index
h	Hour
HCl	Hydrochloric acid
HDL	High density lipoprotein cholesterol
HK1	Hexokinase I
HPLC	High performance liquid chromatography
HUT	Hemoglobin unit on a tyrosine basis
Hz	Hertz
IVPD	In-vitro protein digestibility
L	Liter

LDL	Low density lipoprotein cholesterol
LSPKE	Less shell palm kernel Expeller
MDCP	Mono dicalcium phosphate
MJ/kg	Megajoules per kilogram
mg	Milligram
min	Minutes
MIU	Milli-international unit
mL	Millilitre
mM	Millimolar
MOS	Mannan oligosaccharide
MUC2	Mucin 2
mRNA	Messenger ribonucleic acid
Na	Sodium
nm	Nanometer
NSP	Non-starch polysaccharide
ºC	Degree celcius
PCR	Polymerase chain reaction
PDI	Pellet Durability Index
PFK	Phosphofructokinase
pH	Hydrogen ion concentration
pKa	Acid dissociation constant
PKC	Palm kernel cake
PKE	Palm kernel expeller
PKM	Palm kernel meal
ppm	Parts per million
Pred	Predicted

R2	Coefficient of determination
rpm	Revolutions per minute
RM	Ringgit Malaysia
RSM	Response surface methodology
RTD	Residence time distribution
SEM	Standard error of mean
s	Seconds
SC	Swelling capacity
SPU	Solid state fermentation phytase unit
T-NSP	Total non-starch polysaccharides
TiO2	Titanium dioxide
Tm	Particle mean residence time
µg	Microgram
µl	Microliter
UPKE	Untreated palm kernel Expeller
WRC	Water retention capacity
XU	Xylanase unit
YCW	Yeast cell wall

CHAPTER 1

INTRODUCTION

Malaysia is currently self-sufficient in poultry meat and eggs, but the industry is not sustainable in the long term due to its heavy dependency on imported feeds such as soybean meal, corn and fish meal. Although some raw materials such as tapioca and fishmeal are produced locally, the amount is not sufficient to meet the requirements of the local feed industry (Raghavan, 2000).

Hence, continued availability of the main conventional feedstuffs is a major concern and this triggers interest by researchers to find alternative feed ingredients available locally. The utilization of agro-industrial wastes as feedstuff is one of the strategies to partially replaced imported feed ingredients in poultry production since it is not competing with human consumption.

Palm kernel cake (PKC) of the oil palm industry is the most suitable by-product to be considered as a source of energy. It is the residue left after the palm kernel is crushed during the oil extraction process (Ab Rahman et al*.,* 2011). Due to the increase in palm oil production in the country, the amount of PKC available is also increased. As one of the world's greatest palm oil producers, the production of PKC in Malaysia, according to the Malaysian Palm Oil Board is about 2 million metric tons per year (MPOB, 2018; Mundi, 2018). Palm kernel cake contains 14 to 21% crude protein, which is adequate for older birds (Sundu et al., 2006; Zahari and Alimon, 2005). However, the high fibre content (about 21%), lignin (14%) and non-starch polysaccharides (60%) (Lawal et al., 2010; Sundu et al., 2006) impose a constraint for it to be utilized as poultry feed at a high inclusion rate.

As the main constraint for PKC to be utilized as poultry feed is the presence of fibre, appropriate strategies should be evaluated to alleviate the high fibre content (Sharmila et al., 2014). Upgrading of low quality agricultural waste into high quality products by microbial treatment has been practiced for a long time. The growth of microbes on agro-wastes is able to furnish almost all the hydrolytic enzymes often added in the preparation of feeds. Hence, many studies have been conducted to improve the nutritive values of PKC through solid-state fermentation (SSF) either by using fungi such as *Trichoderma harzianum* (Ramin et al*.,* 2010), *T. longibrachiatum* and *T. koningii* (Iluyemi et al., 2006), *Rhizopus stolonifer* (Lateef et al., 2008), *Aspergillus niger, T. varidae* and *Mucor mucedo* (Lawal et al., 2010) or bacterial species such as *Paenibacillus polymyxa* and *P. curdlanolyticus* (Alshelmani et al., 2014).

Many feeding trial studies have been conducted to evaluate the growth performance of birds fed fermented PKC. Alshelmani et al. (2016) reported that solid-state fermentation process was able to reduce the fibre content of PKC and their feeding trial with broilers showed that PKC fermented by *P.polymyxa* ATCC 842 could be fed to broiler chickens only up to 15% without any adverse effect on nutrient digestibility.

A feeding trial conducted by Lawal et al. (2010), showed that the apparent digestibility of nutrients of broilers fed the fermented PKC was improved compared to untreated PKC. In addition, the performance of the birds on fermented PKC was also improved significantly. Similarly, other studies reported positive results where broilers fed diets containing 30% fermented PKC showed no adverse effect on performance, carcass yield and blood constituents (Bello et al, 2011).

Although fermented PKC shows promising potential as an alternative feed ingredient for poultry, but until today, there is no commercially available fermented PKC with improved nutritive values in the market. The fermentation technologies, some of which have been filed (Jing, 2016; Madsen and Pettersson, 2015; Young and Gondipon, 2006) are unable to penetrate the feed market at commercial production scale probably due to cost of operation and time-consuming process as well as the inconsistency of results in the growth performance of broilers when fed fermented PKC.

As biological treatments have considerable drawbacks like long fermentation time (5-14 days), possible production of mycotoxin by fungal activity and formation of inhibitors (Lim et al., 2001), physical treatments should be considered as alternative methods to improve the nutritive of PKC. Physical treatments (soaking and boiling) have been shown to reduce crude fibre content and increase the metabolisable energy value of cowpea seed hulls (Adebiyi et al., 2010). Other physical methods like extrusion could be a possible technique to improve PKC as extrusion method is based on a combination of severe shear force and hydrothermal process with the ability to disrupt the structure of the non-starch polysaccharides (Kumar et al., 2018; Colovic et al., 2016; de Vries et al., 2012) within a short period of time. The extrusion treatment can increase accessible surface area and size of pores, decrease crystallinity and degrees of polymerization of cellulose and mannan polymers in PKC. Hence, in modern feed milling operations, extrusion process has been considered as one of the best processing methods not only to enhance the nutritional content of the feed ingredients but also the efficiency of the feed (Rahman et al., 2015).

Another physical treatment to reduce the fibre content of PKC is the electrostatic separation method where, the difference in electrostatic properties of materials allow the materials to be separated into different components, like separation of proteins from biomass-containing polysaccharides, lignin, and polyphenols (Barakat et al., 2015) and separation of proteins and lignin (Basset et al., 2016). Other applications of electrostatic separation include separation of reusable plastic material from plastic mixture, minerals or ash contents from coal powder, removal of tea stalks and foreign objects from product in food industry and coal cleaning (Higashiyama and Asano, 1998). This method triggers considerable interest to separate the broken shells contaminants, fibre and lignin from the PKC residue.

Problem Statement

Developing a sustainable poultry production requires abundant supply of locally available feed ingredients like agricultural by-products that do not compete with human consumption. Utilization of PKE as a major feed ingredient in poultry feed could reduce the dependency on imported feed ingredients. However, PKE had to be treated before it could be incorporated in poultry feed to reduce the indigestible mannan and lignin content that reduce nutrient digestibility.

Hypothesis

Physical treatments like extrusion and static cling-electrostatic separation method could reduce the broken shells, fibre, lignin and NSP content of PKE, and thus enhance the nutritive value of PKE and its level of inclusion in the poultry feed.

Objectives

The general objective of this study was to improve the nutritive value of PKE by physical treatments and to evaluate the performance of broiler chickens fed different levels of treated PKE. The specific objectives were:

i) To enhance the nutritive value of PKE by optimisation of multiple variables of twin screw extrusion process using response surface methodology (RSM).
ii) To remove broken shells contaminants in PKE by optimisation of multiple variables of static cling - electrostatic separation process using RSM.
iii) To evaluate the effects of feeding treated PKE on broiler chickens growth performance, serum biochemistry, intestinal histology and gene expression profiles.
iv) To develop a suitable feed formula based on PKE for broilers with a potential commercial application.

REFERENCES

Abdel-Salam, M., Ahmed, A., & El-Kishky, H. *Seeds sorting by electrostatic separation: an experimental study*. Paper presented at the 17th Annual Meeting of the IEEE Lasers and Electro-Optics Society, Colorado. December 2004.

Abdulrashid, M., & Agwunobi, L. N. (2009). Taro cocoyam (Colocasia esculenta) meal as feed ingredient in poultry. *Pakistan Journal of Nutrition*, ***8***(5), 668-673.

Abdollahi, M. R., Hosking, B., & Ravindran, V. (2015). Nutrient analysis, metabolisable energy and ileal amino acid digestibility of palm kernel meal for broilers. *Animal Feed Science and Technology*, ***206***, 119-125.

Abdollahi, M. R., Hosking, B. J., Ning, D., & Ravindran, V. (2016). Influence of palm kernel meal inclusion and exogenous enzyme supplementation on growth performance, energy utilization, and nutrient digestibility in young broilers. *Asian-Australasian Journal of Animal Sciences*, ***29***(4), 539.

Abdollahi, M. R., Zaefarian, F., Ravindran, V., & Selle, P. H. (2018). The interactive influence of dietary nutrient density and feed form on the performance of broiler chickens. *Animal Feed Science and Technology*, ***239***, 33-43.

Ab Rahman, N. N. N., Nama, M. M. B., Al-Rawi, S. S., Ibrahim, A. H., & Ab Kadir, M. O. (2011). Comparison of nutritional composition between palm kernel fibre and the effect of the supercritical fluid extraction on its quality. *Procedia Food Science*, ***1***, 1940-1945.

Abidah, M. N., & Nooraida, W. W. (2017). Research Article Growth Performance and Carcass Analysis of Broilers Fed with Enhanced Quality Palm Kernel Meal. *International Journal of Poultry Science,* ***16***, 215-220.

Abdurofi, I., Ismail, M. M., Kamal, H. A. W., & Gabdo, B. H. (2017). Economic analysis of broiler production in Peninsular Malaysia. *International Food Research Journal*, ***24***(2).

A'dilah Hj. Md. Makhtar@ Mohd. Zin. (2011). *Improving Nutritive Value of Palm Kernel Cake (PKC) Through Chemical Pre-treatment Followed by Fungal Fermentation*. (Doctoral dissertation). Universiti Putra Malaysia, Malaysia.

Adebiyi, O. A., Ologhobo, A. D., Adu, O. A., & Olasehinde, T. O. (2010). Evaluation of the nutritional potentials of physically treated cowpea seed hulls in poultry feed. *Emirates Journal of Food and Agriculture*, 232-239.

Adesehinwa, A. O. K. (2007). Utilization of palm kernel cake as a replacement for maize in diets of growing pigs: effects on performance, serum metabolites, nutrient digestibility and cost of feed conversion. *Bulgarian Journal of Agricultural Science*, ***13***(5), 591.

Adrizal, A., Yusrizal, Y., Fakhri, S., Haris, W., Ali, E., & Angel, C. R. (2011). Feeding native laying hens diets containing palm kernel meal with or without enzyme supplementations: 1. Feed conversion ratio and egg production. *Journal of Applied Poultry Research*, ***20***(1), 40-49.

Ahmed, A., Zulkifli, I., Farjam, A. S., Abdullah, N., & Liang, J. B. (2014). Extrusion enhances metabolizable energy and ileal amino acids digestibility of canola meal for broiler chickens. *Italian Journal of Animal Science*, ***13***(1), 3032.

Alimon, Abdul. (2004). The Nutritive Value of Palm Kernel Cake for Animal Feed. *Palm Oil Developments*. **40**.

Alsaftli, Z. A., Al-Saadi, M. A., & Subuh, A. M. (2015). Effect of using extruded full-fat soybean on performance and carcass characteristics in female turkeys. *Asian Journal of Animal Sciences*, ***9***(5), 198-207.

Alshelmani, M. I., Loh, T. C., Foo, H. L., Lau, W. H., & Sazili, A. Q. (2014). Biodegradation of palm kernel cake by cellulolytic and hemicellulolytic bacterial cultures through solid state fermentation. *The Scientific World Journal*, *2014*.

Alshelmani, M. I., Loh, T. C., Foo, H. L., Sazili, A. Q., & Lau, W. H. (2016). Effect of feeding different levels of palm kernel cake fermented by Paenibacillus polymyxa ATCC 842 on nutrient digestibility, intestinal morphology, and gut microflora in broiler chickens. *Animal Feed Science and Technology*, ***216***, 216-224.

Alshelmani, M. I., Loh, T. C., Foo, H. L., Sazili, A. Q., & Lau, W. H. (2017). Effect of feeding different levels of palm kernel cake fermented by Paenibacillus polymyxa ATCC 842 on broiler growth performance, blood biochemistry, carcass characteristics, and meat quality. *Animal Production Science*, ***57***(5), 839-848.

American Society for Testing and Materials (ASTM). (2001). *Standard D, ASTM D 1106-96 Standard Test Method for Acid-Insoluble Lignin in Wood*. West Conshohocken, ASTM international.

Amerah, A. M., Ravindran, V., Lentle, R. G., & Thomas, D. G. (2007). Feed particle size: Implications on the digestion and performance of poultry. *World's Poultry Science Journal*, ***63***(3), 439-455.

Andersen, H. J., Oksbjerg, N., Young, J. F., & Therkildsen, M. (2005). Feeding and meat quality–a future approach. *Meat Science*, ***70***(3), 543-554.

Anderson, M. J., & Whitcomb, P. J. (2016). *RSM Simplified: Optimizing Processes Using Response Surface Methods for Design of Experiments*. Boca Raton: Productivity Press.

Anguita, M., Gasa, J., Martín-Orúe, S. M., & Pérez, J. F. (2006). Study of the effect of technological processes on starch hydrolysis, non-starch polysaccharides solubilization and physicochemical properties of different ingredients using a two-step *in vitro* system. *Animal Feed Science and Technology*, ***129***(1-2), 99-115.

Armstrong, H. (1994). Nutritional implications of expanded feed. *Tecnica Molitoria*, ***45***, 385-385.

Atil, O. (2007). *Proceedings of Product Development and Nutrition Conference: PIPOC 2007 International Palm Oil Congress: Palm Oil: Empowering Change*, *Kuala Lumpur, 2007*. Kuala Lumpur, Malaysian Palm Oil Board.

Audet, L. (1995). Emerging feed mill technology: keeping competitive. *Animal Feed Science and Technology*, ***53***(2), 157-170.

Aya, V. E., Ayanwale, B. A., Ijaiya, A. T., & Aremu, A. (2013). Performance and nutrient digestibility in broiler chicks as influenced by multienzyme addition to starter diets containing palm kernel meal. *Biotechnology in Animal Husbandry*, ***29***(1), 93-104.

Ayed, H. B., Attia, H., & Ennouri, M. (2015). Effect of oil supplemented diet on growth performance and meat quality of broiler chickens. *Advanced Techniques in Biology and Medicine*, ***4***(156), 2379-1764.

Awalludin, M. F., Sulaiman, O., Hashim, R., & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, ***50***, 1469-1484.

Azizan, H. (2016). The grain plan. Retrieved from https://www.thestar.com.my/news/nation/2016/07/24/the-rain-plan-feed-grain-farming-is-integral-to-the-countrys-agrofood-s cheme-in-attaining-food-sove/#hJ166DkikhrgQSEM.99

Balnave, D., Hayat, J., & Brake, J. (1999). Dietary arginine: lysine ratio and methionine activity at elevated environmental temperatures. *Journal of Applied Poultry Research*, ***8***(1), 1-9.

Bailey, W. H., & Rob, J. (1944). Studies of the metabolism of mannose. The influence of mannose administration on blood sugar, blood lactic acid, and liver glycogen in the adult rabbit. *Journal of Biological Chemistry*, ***152***, 135-146.

Banerjee, A. (2011). Food, feed, fuel: transforming the competition for grains. *Development and Change*, ***42***(2), 529-557.

Barakat, A., Jérôme, F., & Rouau, X. (2015). A Dry Platform for Separation of Proteins from Biomass-Containing Polysaccharides, Lignin, and Polyphenols. *ChemSusChem*, ***8***(7), 1161-1166.

Barsberg, S., Sanadi, A. R., & Jørgensen, H. (2011). A new density functional theory (DFT) based method for supporting the assignment of vibrational signatures of mannan and cellulose—analysis of palm kernel cake hydrolysis by ATR-FT-IR spectroscopy as a case study. *Carbohydrate Polymers*, ***85***(2), 457-464.

Basset, C., Kedidi, S., & Barakat, A. (2016). Chemical-and Solvent-Free Mechanophysical Fractionation of Biomass Induced by Tribo-Electrostatic Charging: Separation of Proteins and Lignin. *ACS Sustainable Chemistry & Engineering*, ***4***(8), 4166-4173.

Baurhoo, B., Phillip, L., & Ruiz-Feria, C. A. (2007). Effects of purified lignin and mannan oligosaccharides on intestinal integrity and microbial populations in the ceca and litter of broiler chickens. *Poultry Science*, ***86***(6), 1070-1078.

Baurhoo, B., Ruiz-Feria, C. A., & Zhao, X. (2008). Purified lignin: Nutritional and health impacts on farm animals—A review. *Animal Feed Science and Technology*, ***144***(3), 175-184.

Baurhoo, B., Ferket, P. R., & Zhao, X. (2009). Effects of diets containing different concentrations of mannanoligosaccharide or antibiotics on growth performance, intestinal development, cecal and litter microbial populations, and carcass parameters of broilers. *Poultry Science*, ***88***(11), 2262-2272.

Behnke, K. C. (2001). Factors influencing pellet quality. *Feed Tech*, ***5***(4), 19-22.

Bello, K. M., Oyawoye, E. O., Bogoro, S. E., & Dass, U. D. (2011). Performance of broilers fed varying levels of palm kernel cake. *International Journal of Poultry Science*, ***10***(4), 290-294.

Berg, J. M., Tymoczko, J. L., & Stryer, L. (2002). *Glycolysis is an Energy-Conversion Pathway in Many Organisms*. New York: WH Freeman.

Bindelle, J., Leterme, P., & Buldgen, A. (2008). Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. *Biotechnologie, Agronomie, Société et Environnement*, ***12***(1), 69-80.

Bobleter, O. (1994). Hydrothermal degradation of polymers derived from plants. *Progress in Polymer Science*, *19*(5), 797-841.

Bono, A., Ying, P. H., Yan, F. Y., Muei, C. L., Sarbatly, R., & Krishnaiah, D. (2009). Synthesis and characterization of carboxymethyl cellulose from palm kernel cake. *Advances in Natural and Applied Sciences*, ***3***(1), 5-11.

Brachet, M., Arroyo, J., Bannelier, C., Cazals, A., & Fortun-Lamothe, L. (2015). Hydration capacity: a new criterion for feed formulation. *Animal Feed Science and Technology*, ***209***, 174-185.

Brennan, K. M., Paul, M. A., Samuel, R. S., Lumpkins, B., Pierce, J. L., Collett, S. R., & Mathis, G. F. (2014). Comparison of performance and intestinal morphology of broilers using step-down supplementation with a mannan-rich fraction versus bacitracin methylene disalicylate. *Journal of Applied Animal Nutrition*, ***2***, e12.

Briggs, J. L., Maier, D. E., Watkins, B. A., & Behnke, K. C. (1999). Effect of ingredients and processing parameters on pellet quality. *Poultry Science*, ***78***(10), 1464-1471.

Cano, M., Calonge, M. L., Peral, M. J., & Ilundain, A. A. (2001). A Na+-dependent D-mannose transporter in the apical membrane of chicken small intestine epithelial cells. *European Journal of Physiology*, ***441***(5), 686-691.

Caprez, A., Arrigoni, E., Amadò, R., & Neukom, H. (1986). Influence of different types of thermal treatment on the chemical composition and physical properties of wheat bran. *Journal of Cereal Science*, ***4***(3), 233-239.

Căpriţă, R., Căpriţă, A., & Julean, C. (2010). Biochemical aspects of non-starch polysaccharides. *Scientific Papers Animal Science and Biotechnologies*, ***43***(1), 368-374.

Cerveró, J. M., Skovgaard, P. A., Felby, C., Sørensen, H. R., & Jørgensen, H. (2010). Enzymatic hydrolysis and fermentation of palm kernel press cake for production of bioethanol. *Enzyme and Microbial Technology*, ***46***(3-4), 177-184.

Ceylan, N., Çiftçi, İ., & İlhan, Z. (2003). The effects of some alternative feed additives for antibiotic growth promoters on the performance and gut microflora of broiler chicks. *Turkish Journal of Veterinary and Animal Sciences*, ***27***(3), 727-733.

Cowieson, A. J., & Ravindran, V. (2008). Effect of exogenous enzymes in maize-based diets varying in nutrient density for young broilers: growth performance and digestibility of energy, minerals and amino acids. *British Poultry Science*, ***49***(1), 37-44.

Cowieson, A. J., Lu, H., Ajuwon, K. M., Knap, I., & Adeola, O. (2017). Interactive effects of dietary protein source and exogenous protease on growth performance, immune competence and jejunal health of broiler chickens. *Animal Production Science*, ***57***(2), 252-261.

Chamruspollert, M., Pesti, G. M., & Bakalli, R. I. (2002). Dietary interrelationships among arginine, methionine, and lysine in young broiler chicks. *British Journal of Nutrition*, ***88***(06), 655-660.

Chee, S. H., Iji, P. A., Choct, M., Mikkelsen, L. L., & Kocher, A. (2010). Characterisation and response of intestinal microflora and mucins to manno-oligosaccharide and antibiotic supplementation in broiler chickens. *British Poultry Science*, ***51***(3), 368-380.

Chen, W. L., Liang, J. B., Jahromi, M. F., Abdullah, N., Ho, Y. W., & Tufarelli, V. (2014). Enzyme Treatment Enhances Release of Prebiotic Oligosaccharides from Palm Kernel Expeller. *BioResources*, ***10***(1), 196-209.

Chen, W. L., Jahromi, M. F., Candyrine, S. C. L., Liang, J. B., Abdullah, N., & Idrus, Z. (2018). Enzymatic hydrolysis drastically reduces fibre content of palm-kernel expeller, but without enhancing performance in broiler chickens. *Animal Production Science*.

Cheled-Shoval, S. L., Amit-Romach, E., Barbakov, M., & Uni, Z. (2011). The effect of in ovo administration of mannan oligosaccharide on small intestine development during the pre-and posthatch periods in chickens. *Poultry Science*, ***90***(10), 2301-2310.

Choct, M., & Annison, G. (1992a). Anti-nutritive effect of wheat pentosans in broiler chickens: Roles of viscosity and gut microflora. *British Poultry Science*, ***33***(4), 821-834.

Choct, M., & Annison, G. (1992b). The inhibition of nutrient digestion by wheat pentosans. *British Journal of Nutrition*, *67*(01), 123-132.

Choct, M., Hughes, R. J., & Bedford, M. R. (1999). Effects of a xylanase on individual bird variation, starch digestion throughout the intestine, and ileal and caecal volatile fatty acid production in chickens fed wheat. *British Poultry Science*, ***40***(3), 419-422.

Choct, M. (2001). Nutritional constraints to alternative ingredients. *ASA Technical Bulletin*, 1-9.

Chung, H. J., & Liu, Q. (2010). Molecular structure and physicochemical properties of potato and bean starches as affected by gamma-irradiation. *International Journal of Biological Macromolecules*, ***47***(2), 214-222.

Clarke, E., & Wiseman, J. (2005). Effects of variability in trypsin inhibitor content of soya bean meals on true and apparent ileal digestibility of amino acids and pancreas size in broiler chicks. *Animal Feed Science and Technology*, ***121***(1-2), 125-138.

Colovic, D., Colovic, R., Levic, J., Ikonic, B., Vukmirovic, D., & Levic, L. (2016). Linseed-Sunflower Meal Co-extrudate as a Functional Additive for Animal Feed–extrusion Optimization. *Journal of Agricultural Science and Technology*, ***18***, 1761-1772.

Conde-Mejia, C., Jimenez-Gutierrez, A., & El-Halwagi, M. (2012). A comparison of pretreatment methods for bioethanol production from lignocellulosic materials. *Process Safety and Environmental Protection*, ***90***(3), 189-202.

Dascalescu, L., Tilmatine, A., Aman, F., & Mihailescu, M. (2004). Optimization of electrostatic separation processes using response surface modeling. *IEEE Transactions on Industry Applications*, ***40***(1), 53-59.

Dascalescu, L., Dragan, C., Bilici, M., Beleca, R., Hemery, Y., & Rouau, X. (2008). *Industry Applications Society Annual Meeting, Alberta, 2008.* IEEE.

Daud, M. J., & Jarvis, M. C. (1992). Mannan of oil palm kernel. *Phytochemistry*, ***31***(2), 463-464.

De Melo, B. A. G., Motta, F. L., & Santana, M. H. A. (2016). Humic acids: Structural properties and multiple functionalities for novel technological developments. *Materials Science and Engineering: C*, ***62***, 967-974.

Demirbas, A. (2007). Products from lignocellulosic materials via degradation processes. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, ***30***(1), 27-37.

Department of Veterinary Services Malaysia. (2018). Perangkaan Ternakan 2016/2017. Retrieved from http://www.dvs.gov.my /index.php/pages/view/1847

De Vrije, T. D., De Haas, G. G., Tan, G. B., Keijsers, E. R. P., & Claassen, P. A. M. (2002). Pretreatment of Miscanthus for hydrogen production by Thermotoga elfii. *International Journal of Hydrogen Energy*, ***27***(11-12), 1381-1390.

De Vries, S., Pustjens, A. M., Schols, H. A., Hendriks, W. H., & Gerrits, W. J. J. (2012). Improving digestive utilization of fiber-rich feedstuffs in pigs and poultry by processing and enzyme technologies: A review. *Animal Feed Science and Technology*, ***178***(3), 123-138.

Diaz, A. F., & Felix-Navarro, R. M. (2004). A semi-quantitative tribo-electric series for polymeric materials: the influence of chemical structure and properties. *Journal of Electrostatics*, ***62***(4), 277-290.

Disetlhe, A. R. P., Marume, U., & Mlambo, V. (2018). Humic acid and enzymes inclusion in canola-based diets generate different responses in growth performance, protein utilization dynamics, and hemato-biochemical parameters in broiler chickens. *Poultry science*, ***97***(8), 2745-2753.

Dong, J. Q., Zhang, H., Jiang, X. F., Wang, S. Z., Du, Z. Q., Wang, Z. P., ... & Li, H. (2015). Comparison of serum biochemical parameters between two broiler chicken lines divergently selected for abdominal fat content. *Journal of Animal Science*, ***93***(7), 3278-3286.

Durán, J. M., Cano, M., Peral, M. J., & Ilundáin, A. A. (2004). D-mannose transport and metabolism in isolated enterocytes. *Glycobiology*, ***14***(6), 495-500.

Düsterhöft, E. M., Posthumus, M. A., & Voragen, A. G. J. (1992). Non-starch polysaccharides from sunflower (Helianthus annuus) meal and palm-kernel (Elaeis guineensis) meal—investigation of the structure of major polysaccharides. *Journal of the Science of Food and Agriculture*, ***59***(2), 151-160.

Düsterhölt, E. M., Engels, F. M., & Voragen, A. G. (1993). Parameters affecting the enzymic hydrolysis of oil-seed meals, lignocellulosic by-products of the food industry. *Bioresource Technology*, ***44***(1), 39-46.

Dhanasekaran, S., Bhattacharya, T. K., Chatterjee, R. N., Paswan, C., & Dyushanth, K. (2014). Functional genomics in chicken (Gallus gallus)-status and implications in poultry. *World's Poultry Science Journal*, ***70***(01), 45-56.

Elajnaf, A., Carter, P., & Rowley, G. (2006). Electrostatic characterisation of inhaled powders: effect of contact surface and relative humidity. *European Journal of Pharmaceutical Sciences*, ***29***(5), 375-384.

Engberg, R. M., Hedemann, M. S., Leser, T. D., & Jensen, B. B. (2000). Effect of zinc bacitracin and salinomycin on intestinal microflora and performance of broilers. *Poultry Science*, ***79***(9), 1311-1319.

Engisch, W., & Muzzio, F. (2016). Using residence time distributions (RTDs) to address the traceability of raw materials in continuous pharmaceutical manufacturing. *Journal of Pharmaceutical Innovation*, ***11***(1), 64-81.

Englyst, H. N., & Hudson, G. J. (1987). Colorimetric method for routine measurement of dietary fibre as non-starch polysaccharides. A comparison with gas-liquid chromatography. *Food Chemistry*, ***24***(1), 63-76.

Englyst, H. N., Quigley, M. E., & Hudson, G. J. (1994). Determination of dietary fibre as non-starch polysaccharides with gas–liquid chromatographic, high-performance liquid chromatographic or spectrophotometric measurement of constituent sugars. *Analyst*, ***119***(7), 1497-1509.

Ezieshi, E. V., & Olomu, J. M. (2004). Comparative performance of broiler chickens fed varying levels of palm kernel cake and maize offal. *Pakistan Journal of Nutrition*, ***3***(254.257).

Ezieshi, E. V., & Olomu, J. M. (2008). Nutritional evaluation of palm kernel meal types: 2. Effects on live performance and nutrient retention in broiler chicken diets. *African Journal of Biotechnology*, ***7***(8).

Fadel, J. G., Newman, R. K., Newman, C. W., & Graham, H. (1989). Effects of baking hulless barley on the digestibility of dietary components as measured at the ileum and in the feces in pigs. *The Journal of Nutrition*, ***119***(5), 722-726.

Fan, S. P., Jiang, L. Q., Chia, C. H., Fang, Z., Zakaria, S., & Chee, K. L. (2014). High yield production of sugars from deproteinated palm kernel cake under microwave irradiation via dilute sulfuric acid hydrolysis. *Bioresource Technology*, *153*, 69-78.

Farahiyah, I. J., Wong, H. K., & Mardhati, M. (2014). Effect of mannanase-supplemented PKE-based diets on the growth performance, feed efficiency and dressing percentage of broilers. *Journal of Tropical Agriculture and Food Science*, ***42***(2), 125-133.

Fasuyi, A. O., Abiodun, S. O., & Akomolafe, O. T. (2014). Bioconversion and enzymes fortification of palm kernel meal as protein supplement in broiler rations. *American Journal of Experimental Agriculture*, *4*(7), 767.

Fengler, A. I., & Marquardt, R. R. (1988). Water-soluble pentosans from rye: II. Effects on rate of dialysis and on the retention of nutrients by the chick. *Cereal Chemistry*, ***65***(4), 298-302.

Ferreira, S. C., Bruns, R. E., Ferreira, H. S., Matos, G. D., David, J. M., Brandao, G. C., da Silva, E. G. P., Portugal, L. A., dos Reis, P. S., Souza, A. S., & Dos Santos, W. N. L. (2007). Box-Behnken design: An alternative for the optimization of analytical methods. *Analytica Chimica Acta*, ***597***(2), 179-186.

Fogler, H. S., & Brown, L. F. (1986). Distributions of residence times for chemical reactors. *Elements of Chemical Reaction Engineering*, 629-679.

Frikha, M., Valencia, D. G., de Coca-Sinova, A., Lázaro, R., & Mateos, G. G. (2013). Ileal digestibility of amino acids of unheated and autoclaved pea protein concentrate in broilers. *Poultry Science*, ***92***(7), 1848-1857.

Gabdo, B. H., Mansor, M. I., Kamal, H. A. W., & Ilmas, A. M. (2017). Robust Efficiency and Output Elasticity of Broiler Production in Peninsular Malaysia. *Journal of Agricultural Science and Technology*, ***19***(3), 525-539.

Gallaher, C. M., Munion, J., Hesslink Jr, R., Wise, J., & Gallaher, D. D. (2000). Cholesterol reduction by glucomannan and chitosan is mediated by changes in cholesterol absorption and bile acid and fat excretion in rats. *The Journal of nutrition*, ***130***(11), 2753-2759.

Ghasemian, M., & Jahanian, R. (2016). Dietary mannan-oligosaccharides supplementation could affect performance, immunocompetence, serum lipid metabolites, intestinal bacterial populations, and ileal nutrient digestibility in aged laying hens. *Animal Feed Science and Technology*, ***213***, 81-89.

Giesfeldt, J. T. (1988). *U.S. Patent No. 4,738,772*. Washington, DC: U.S. Patent and Trademark Office.

Go, S., Sato, C., Furuhata, K., & Kitajima, K. (2006). Oral ingestion of mannose alters the expression level of deaminoneuraminic acid (KDN) in mouse organs. *Glycoconjugate Journal*, ***23***(5-6), 411-421.

Gobl, B., & Gohl, I. (1977). The effect of viscous substances on the transit time of barley digesta in rats. *Journal of the Science of Food and Agriculture*, ***28***(10), 911-915.

González-Alvarado, J. M., Jiménez-Moreno, E., Lázaro, R., & Mateos, G. G. (2007). Effect of type of cereal, heat processing of the cereal, and inclusion of fiber in the diet on productive performance and digestive traits of broilers. *Poultry Science*, ***86***(8), 1705-1715.

González-Vega, J. C., Kim, B. G., Htoo, J. K., Lemme, A., & Stein, H. H. (2011). Amino acid digestibility in heated soybean meal fed to growing pigs. *Journal of Animal Science*, ***89***(11), 3617-3625.

Guardiola, J., Rojo, V., & Ramos, G. (1996). Influence of particle size, fluidization velocity and relative humidity on fluidized bed electrostatics. *Journal of Electrostatics*, ***37***(1), 1-20.

Haga, K. (1995). *Applications of the Electrostatic Separation Technique*. New York: Marcel Dekker.

Hanafiah, H. A., Zulkifli, I., Soleimani, A. F., & Awad, E. A. (2017). Apparent metabolisable energy and ileal crude protein digestibility of various treated palm kernel cake based diets for heat-stressed broiler chickens. *European Poultry Science*, ***81***.

Hansen, H. B., Østergaard, K., & Knudsen, K. B. (1988). Effect of baking and staling on carbohydrate composition in rye bread and on digestibility of starch and dietary fibre in vivo. *Journal of Cereal Science*, ***7***(2), 135-144.

Hassan, E. G., Alkareem, A. M. A., & Mustafa, A. M. I. (2008). Effect of fermentation and particle size of wheat bran on the antinutritional factors and bread quality.

Pakistan Journal of Nutrition, *7*(4), 521-526.

Hejdysz, M., Kaczmarek, S. A., & Rutkowski, A. (2016a). Effect of extrusion on the nutritional value of peas for broiler chickens. *Archives of Animal Nutrition*, ***70***(5), 364-377.

Hejdysz, M., Kaczmarek, S. A., & Rutkowski, A. (2016b). Extrusion cooking improves the metabolisable energy of faba beans and the amino acid digestibility in broilers. *Animal Feed Science and Technology*, ***212***, 100-111.

Hemery, Y., Rouau, X., Dragan, C., Bilici, M., Beleca, R., & Dascalescu, L. (2009). Electrostatic properties of wheat bran and its constitutive layers: Influence of particle size, composition, and moisture content. *Journal of Food Engineering*, ***93***(1), 114-124.

Hetland, H., Svihus, B., & Olaisen, V. (2002). Effect of feeding whole cereals on performance, starch digestibility and duodenal particle size distribution in broiler chickens. *British poultry science*, ***43***(3), 416-423.

Heuzé, V., Tran, G., & Lebas, F., (2017). *Maize grain*. Retrieved from https://www.feedipedia.org/node/556

Heuzé, V., Tran, G., Baumont, R., Noblet, J., Renaudeau, D., Lessire, M., & Lebas, F. (2015). *Wheat bran*. Retrieved from https://feedipedia.org/node/726

Heuzé, V., Tran, G., Sauvant, D., Noblet, J., Renaudeau, D., Bastianelli, D., & Lebas F. (2016). *Palm kernel meal*. Retrieved from https://www.feedipedia.org/node/43

Heuzé V., & Tran G. (2015). *Rice bran and other rice by-products*. Retrieved from https://feedipedia.org/node/750

Heuzé, V., Tran, G., & Kaushik, S. (2017). *Soybean meal*. Retrieved from https://feedipedia.org/node/674

Higashiyama, Y., & Asano, K. (1998). Recent progress in electrostatic separation technology. *Particulate Science and Technology*, ***16***(1), 77-90.

Hölker, U., Höfer, M., & Lenz, J. (2004). Biotechnological advantages of laboratory-scale solid-state fermentation with fungi. *Applied Microbiology and Biotechnology*, ***64***(2), 175-186.

Holme, I., McIntyre, J. E., & Shen, Z. J. (1998). Electrostatic charging of textiles. *Textile Progress*, ***28***(1), 1-85.

Hooge, D. M., Pierce, J. L., McBride, K. W., & Rigolin, P. J. (2010). Meta-analysis of broiler chicken trials using diets with or without Allzyme® SSF Enzyme Complex®. *International Journal of Poultry Science*, ***9***(9), 819-823.

Horwitz, W., & Latimer, G. W. (2000). *Official methods of analysis of AOAC international*. Gaithersburg: AOAC International.

Ibrahim, N. A. (2013). Characteristics of Malaysian palm kernel and its products. *Journal of Oil Palm Research*, ***25***(2), 245-252.

Ibuki, M., Kovacs-Nolan, J., Fukui, K., Kanatani, H., & Mine, Y. (2010). Analysis of gut immune-modulating activity of β-1, 4-mannobiose using microarray and real-time reverse transcription polymerase chain reaction. *Poultry Science*, ***89***(9), 1894-1904.

Ibuki, M., Kovacs-Nolan, J., Fukui, K., Kanatani, H., & Mine, Y. (2011). β 1-4 mannobiose enhances Salmonella-killing activity and activates innate immune responses in chicken macrophages. *Veterinary Immunology and Immunopathology*, ***139***(2-4), 289-295.

Igbasan, F. A., & Guenter, W. (1996). The enhancement of the nutritive value of peas for broiler chickens: An evaluation of micronization and dehulling processes. *Poultry Science*, ***75***(10), 1243-1252.

Iluyemi, F. B., Hanafi, M. M., Radziah, O., & Kamarudin, M. S. (2006). Fungal solid state culture of palm kernel cake. *Bioresource Technology*, ***97***(3), 477-482.

Iyayi, E. A., & Davies, B. I. (2005). Effect of enzyme supplementation of palm kernel meal and brewer's dried grain on the performance of broilers. *International Journal of Poultry Science*, ***4***(2), 76-80.

Jiménez-Moreno, E., González-Alvarado, J. M., de Coca-Sinova, A., Lázaro, R., & Mateos, G. G. (2009). Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. *Animal Feed Science and Technology*, ***154***(1-2), 93-101.

Jing, B. (2016). China Patent Application No. CN105995044A.

Jørgensen, H., Kristensen, J. B., & Felby, C. (2007). Enzymatic conversion of lignocellulose into fermentable sugars: challenges and opportunities. *Biofuels, Bioproducts and Biorefining*, ***1***(2), 119-134.

Jørgensen, H., Sanadi, A. R., Felby, C., Lange, N. E. K., Fischer, M., & Ernst, S. (2010). Production of ethanol and feed by high dry matter hydrolysis and fermentation of palm kernel press cake. *Applied Biochemistry and Biotechnology*, ***161***(1-8), 318-332.

Juliano, B. O. (1992). Structure, chemistry, and function of the rice grain and its fractions. *Cereal Foods World*, ***37***, 772-772.

Kakade, M. L., Simons, N. R., Liener, I. E., & Lambert, J. W. (1972). Biochemical and nutritional assessment of different varieties of soybeans. *Journal of Agricultural and Food Chemistry*, ***20***(1), 87-90.

Karunanithy, C., & Muthukumarappan, K. (2011). Influence of extruder and feedstock variables on torque requirement during pretreatment of different types of biomass–A response surface analysis. *Biosystems Engineering*, ***109***(1), 37-51.

Karunanithy, C., & Muthukumarappan, K. (2013). Thermo-Mechanical Pretreatment of Feedstocks. In *Green Biomass Pretreatment for Biofuels Production* (pp. 31-65). Springer Netherlands.

Kaur, S., Sharma, S., Dar, B. N., & Singh, B. (2012). Optimization of process for reduction of antinutritional factors in edible cereal brans. *Food Science and Technology International*, ***18***(5), 445-454.

Kim, G. B., Seo, Y. M., Kim, C. H., & Paik, I. K. (2011). Effect of dietary prebiotic supplementation on the performance, intestinal microflora, and immune response of broilers. *Poultry Science*, ***90***(1), 75-82.

Knudsen, K. E. B., Jensen, B. B., & Hansen, I. (1993). Digestion of polysaccharides and other major components in the small and large intestine of pigs fed on diets consisting of oat fractions rich in β-D-glucan. *British Journal of Nutrition*, ***70***(02), 537-556.

Kocabağli, N., Alp, M., Acar, N., & Kahraman, R. (2002). The effects of dietary humate supplementation on broiler growth and carcass yield. *Poultry Science*, ***81***(2), 227-230.

Kohnlechner, R., & Dascalescu, L. (2005). *Fourtieth IAS Annual Meeting. Conference Record of the 2005 Industry Applications Conference*, *Hong Kong, 2005*. IEEE.

Kok, S., Ong-Abdullah, M., Ee, G. C., & Namasivayam, P. (2011). Comparison of nutrient composition in kernel of tenera and clonal materials of oil palm (Elaeis guineensis Jacq.). *Food Chemistry*, ***129***(4), 1343-1347.

Kootstra, A. M. J., Beeftink, H. H., Scott, E. L., & Sanders, J. P. (2009). Optimization of the dilute maleic acid pretreatment of wheat straw. *Biotechnology for Biofuels*, ***2***(31).

Kperegbeyi, J. I., & Ikperite, S. E. (2011). The effectiveness of replacing maze with palm kernel cake in broilers' starter diets. *Journal of Environmental Issues and Agriculture in Developing Countries*, ***3***(1), 145.

Krishnamurthy, K., Khurana, H. K., Soojin, J., Irudayaraj, J., & Demirci, A. (2008). Infrared heating in food processing: an overview. *Comprehensive Reviews in Food Science and Food Safety*, ***7***(1), 2-13.

Kumar, T. V., Sinha, J. P., Samuel, D. V. K., & Jha, S. K. (2018). Twin screw extrusion of sorghum and soya blends: a response surface analysis. *Journal of Agriculture Science and Technology, **17**, 649-662*.

Kupiainen, L., Ahola, J., & Tanskanen, J. (2012). Distinct effect of formic and sulfuric acids on cellulose hydrolysis at high temperature. *Industrial & Engineering Chemistry Research*, ***51***(8), 3295-3300.

Lacks, D. J., & Sankaran, R. M. (2011). Contact electrification of insulating materials. *Journal of Physics D: Applied Physics*, ***44***(45), 453001. Lai, K. C., Lim, S. K., Teh, P. C., & Yeap, K. H. (2016). Modeling electrostatic separation process using artificial neural network (ANN). *Procedia Computer Science*, ***91***, 372-381.

Laguna, O., Barakat, A., Alhamada, H., Durand, E., Baréa, B., Fine, F., ... & Lecomte, J. (2018). Production of proteins and phenolic compounds enriched fractions from rapeseed and sunflower meals by dry fractionation processes. *Industrial Crops and Products*, ***118***, 160-172.

Lala, A. O., Oso, A. O., Okwelum, N., Ajao, A. M., & Adegbenjo, A. (2017). Response of Broiler Chickens to Varying Dosage of Humic Acid in Drinking Water. *Journal of Animal Production Research*, ***29***(1), 288-294.

Lateef, A., Oloke, J. K., Kana, E. G., Oyeniyi, S. O., Onifade, O. R., Oyeleye, A. O., Oladosu, O. C. & Oyelami, A. O. (2008). Improving the quality of agro-wastes by solid-state fermentation: enhanced antioxidant activities and nutritional qualities. *World Journal of Microbiology and Biotechnology*, ***24***(10), 2369-2374.

Laudadio, V., Ceci, E., & Tufarelli, V. (2011). Productive traits and meat fatty acid profile of broiler chickens fed diets containing micronized fava beans (Vicia faba L. var. minor) as the main protein source. *Journal of Applied Poultry Research*, ***20***(1), 12-20.

Law, S. E. (2001). Agricultural electrostatic spray application: a review of significant research and development during the 20th century. *Journal of Electrostatics*, ***51***, 25-42.

Lawal, T. E., Iyayi, E. A., Adeniyi, B. A., & Adaramoye, O. A. (2010). Biodegradation of palm kernel cake with multienzyme complexes from fungi and its feeding value for broilers. *International Journal of Poultry Science*, ***9***(9), 695-701.

Lee, S. Y., & McCarthy, K. L. (1996). Effect of screw configuration and speed on RTD and expansion of rice extrudate. *Journal of Food Process Engineering*,***19***(2), 153-170.

Le Gall, M., Serena, A., Jørgensen, H., Theil, P. K., & Bach Knudsen, K. E. (2009). The role of whole-wheat grain and wheat and rye ingredients on the digestion and fermentation processes in the gut–a model experiment with pigs. *British Journal of Nutrition*, ***102***(11), 1590-1600.

Li, H., Qu, Y., Yang, Y., Chang, S., & Xu, J. (2016). Microwave irradiation–A green and efficient way to pretreat biomass. *Bioresource Technology*, ***199***, 34-41.

Liljeberg, H., Åkerberg, A., & Björck, I. (1996). Resistant starch formation in bread as influenced by choice of ingredients or baking conditions. *Food Chemistry*, ***56***(4), 389-394.

Lim, H. A., Ng, W. K., Lim, S. L., & Ibrahim, C. O. (2001). Contamination of palm kernel meal with Aspergillus flavus affects its nutritive value in pelleted feed for tilapia, Oreochromis mossambicus. *Aquaculture Research*, ***32***(11), 895-905

Lindberg, J. E., Ternrud, I. E., & Theander, O. (1984). Degradation rate and chemical composition of different types of alkali-treated straws during rumen digestion. *Journal of the Science of Food and Agriculture*, ***35***(5), 500-506.

Livak, K. J., & Schmittgen, T. D. (2001). Analysis of relative gene expression data using real-time quantitative PCR and the 2− ΔΔCT method. *Methods*, ***25***(4), 402-408.

Löwe, R. (2005). Judging pellet stability as part of pellet quality. *Feed Technology*, ***9***(2), 15-19.

Loyau, T., Métayer-Coustard, S., Berri, C., Crochet, S., Cailleau-Audouin, E., Sannier, M., ... & Couroussé, N. (2014). Thermal manipulation during embryogenesis has long-term effects on muscle and liver metabolism in fast-growing chickens. *PloS one*, ***9***(9), e105339.

Mack, D. R., Michail, S., Wei, S., McDougall, L., & Hollingsworth, M. A. (1999). Probiotics inhibit enteropathogenic E. coliadherence *in vitro* by inducing intestinal mucin gene expression. *American Journal of Physiology-Gastrointestinal and Liver Physiology*, ***276***(4), G941-G950.

Madsen, U., & Pettersson, D. (2015). *U.S. Patent No. WO2015197623A1*. Washington, DC: U.S. Patent and Trademark Office.

Malaysia Competition Commision. (2014). Review of Domestic Broiler Market: Final Report. Retrieved from www.mycc.gov.my/market-review/final-report-review-of-dom estic -broiler-market

Mardhati, M., Wong, H. K., & Noraini, S. (2011). Growth performance and carcass quality of broilers fed with palm kernel meal-based rations. *Journal of Tropical Agriculture and Food Science,* ***39***(39), 157-166.

Marini, A. M., Daud, M. J., Noraini, S., Jame ah, H., & Azahan, E. E. (2005). Performance of locally isolated microorganism in degrading palm kernel cake (PKC) fibre and improving the nutritional value of fermented PKC. *Journal of Tropical Agriculture and Food Science*, ***33***(2), 311.

Marshall, W. L., & Jones, E. V. (1966). Second dissociation constant of sulfuric acid from 25 to 350 evaluated from solubilities of calcium sulfate in sulfuric acid solutions1, 2. *The Journal of Physical Chemistry*, ***70***(12), 4028-4040.

Marsman, G. J., Gruppen, H., Van der Poel, A. F., Kwakkel, R. P., Verstegen, M. W., & Voragen, A. G. (1997). The effect of thermal processing and enzyme treatments of soybean meal on growth performance, ileal nutrient digestibilities, and chyme characteristics in broiler chicks. *Poultry Science*, ***76***(6), 864-872.

Mazumder, M. K., Sims, R. A., Biris, A. S., Srirama, P. K., Saini, D., Yurteri, C. U., ... & Sharma, R. (2006). Twenty-first century research needs in electrostatic processes applied to industry and medicine. *Chemical Engineering Science*, ***61***(7), 2192-2211.

Medugu, C. I., Saleh, B., Igwebuike, J. U., & Ndirmbita, R. L. (2012). Strategies to improve the utilization of tannin-rich feed materials by poultry. *International*

Journal of Poultry Science, ***11***(6), 417.

Mengesha, M. (2012). The Issue of Feed-Food Competition and Chicken Production for the Demands of Foods of Animal Origin. *Asian Journal of Poultry Science*, ***6***(2), 31-43.

Menon, V., & Rao, M. (2012). Trends in bioconversion of lignocellulose: biofuels, platform chemicals & biorefinery concept. *Progress in Energy and Combustion Science*, ***38***(4), 522-550.

Mercier, C. (1971). Effects of various US grain processes on the alteration and the" in vitro" digestibility of starch granule. *Feedstuffs, Minneapolis*, ***43***(50), 33-47.

Mirnawati, G. C. Ferawati. (2017). The effect of mannanolytic fungi and humic acid dosage to improve the nutrient content and quality of fermented palm kernel cake. *International Journal of ChemTech Research*, ***10***, 56-61.

Mirnawati , Ade Djulardi and Gita Ciptaan. (2018). Utilization of Fermented Palm Kernel Cake with *Sclerotium rolfsii* in Broiler Ration. *International Journal of Poultry Science*, **17**, 342-347.

Mohamed Halim, R., RamLi, R., Che Mat, C. R., Yuen May, C., Abu Bakar, N., & Abdul Hadi, N. M. (2016). Dry Separation of Palm Kernel and Palm Shell Using a Novel Five-Stage Winnowing Column System. *Technologies*, ***4***(2), 13.

MPOB. (2018). Production of palm kernel cake for the month of December 2017 January - June 2016 & 2017 (tonnes). Retrieved from http://bepi.mpob.gov.my/index.php/en/statis -tics/production/177-production-2017/795-production-of-palm-kernel-cak- e-2017.html

Mujahid, A., Ul Haq, I., Asif, M., & Hussain Gilani, A. (2004). Effect of different levels of rice bran processed by various techniques on performance of broiler chicks. *British Poultry Science*, ***45***(3), 395-399.

Mundi, I. (2018). Malaysia Palm Kernel Meal Production by Year. Retrieved from https://www.indexmundi.com/ agriculture/?C ountry=my&commodity=palm-kernel meal&graph=production

Murphy, R. A., & Dawson, K. A. (2008). Nutrigenomics: Evaluating and understanding nutritional effects on intestinal gene expression and function. *ut efficiency; the key ingredien*, 139.

Murtomaa, M., Savolainen, M., Christiansen, L., Rantanen, J., Laine, E., & Yliruusi, J. (2004). Static electrification of powders during spray drying. *Journal of Electrostatics*, ***62***(1), 63-72.

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2009). Response surface methodology, hoboken. *New Jersey: John Wiley & Sons, Inc*, ***20***, 38-44.

Nagaraju, R., Reddy, B. S., Gloridoss, R., Suresh, B. N., & Ramesh, C. (2014). Effect of dietary supplementation of humic acids on performance of broilers. *Indian Journal of Animal Sciences*, ***84***(4), 447-452.

Nalle, C. L., Ravindran, G., & Ravindran, V. (2011). Extrusion of peas (Pisum sativum L.): Effects on the apparent metabolisable energy and ileal nutrient digestibility of broilers. *American Journal of Animal and Veterinary Sciences*, ***6*** (1): 25-30.

Näsi, M. (1992). Effects of grinding, pelleting and expanding on nutritive value of barley in pig diets. *Agricultural and Food Science*, *1*(5), 461-469.

Nattorp, A., Graf, M., Spühler, C., & Renken, A. (1999). Model for random hydrolysis and end degradation of linear polysaccharides: Application to the thermal treatment of mannan in solution. *Industrial & Engineering Chemistry Research*, ***38***(8), 2919-2926.

Navidshad, B., Liang, J. B., Jahromi, M. F., Akhlaghi, A., & Abdullah, N. (2016). Effects of enzymatic treatment and shell content of palm kernel expeller meal on performance, nutrient digestibility, and ileal bacterial population in broiler chickens. *The Journal of Applied Poultry Research*, ***25***(4), 474-482.

Nir, I., Melcion, J. P., & Picard, M. (1990). Effect of particle size of sorghum grains on feed intake and performance of young broilers. *Poultry Science*, ***69***(12), 2177-2184.

Nor'Asyikin Mochamat. (Jan 10, 2018). Personal communication

Nwokolo, E. N., Bragg, D. B., & Kitts, W. D. (1976). The availability of amino acids from palm kernel, soybean, cottonseed and rapeseed meal for the growing chick. *Poultry Science*, ***55***(6), 2300-2304.

Oeste, R.E., Miller, R., Sjoestroem, H. and Noren, O. (1987). Effect of Maillard reaction products on protein digestion. Studies on pure compounds. *Journal of Agricultural and Food Chemistry*. **35** (6), 938–942.

Omar, M. A., & Hamdan, A. M. (1998). *Proceeding 8th World Conference on Animal Production, Seoul, 1998*. Seoul, WCAP.

O'Mara, F. P., Mulligan, F. J., Cronin, E. J., Rath, M., & Caffrey, P. J. (1999). The nutritive value of palm kernel meal measured in vivo and using rumen fluid and enzymatic techniques. *Livestock Production Science*, ***60***(2), 305-316.

Onwudike, O. C. (1986). Palm kernel meal as a feed for poultry. 3. Replacement of groundnut cake by palm kernel meal in broiler diets. *Animal Feed Science and Technology*, ***16***(3), 195-202.

Onu, P. N., & Okongwu, S. N. (2006). Performance characteristics and nutrient utilization of starter broilers fed raw and processed pigeon pea (Cajanus cajan) seed meal. *International Journal of Poultry Science*, ***5***(7), 693-697.

Onuh, S.O., Ortserga, D.D. & Okoh, J.J. (2010). Response of broilers chickens to palm kernel cake and maize offal mixed in different ratios. *Pakistan Journal of Nutrition*. ***9***(6): 516-519.

Panigrahi, S., & Powell, C. J. (1991). Effects of high rates of inclusion of palm kernel meal in broiler chick diets. *Animal Feed Science and Technology*, ***34***(1), 37-47.

Parchure, A. A., & Kulkarni, P. R. (1997). Effect of food processing treatments on generation of resistant starch. *International Journal of Food Sciences and Nutrition*, ***48***(4), 257-260.

Parsons, C. M., Hashimoto, K., Wedekind, K. J., Han, Y., & Baker, D. H. (1992). Effect of overprocessing on availability of amino acids and energy in soybean meal. *Poultry Science*, ***71***(1), 133-140.

Pérez-Bonilla, A., Frikha, M., Lázaro, R. P., & Mateos, G. G. (2014). Type of grinding of the main cereal of the diet affects production of brown egg-laying hens. *Animal Feed Science and Technology*, ***194***, 121-130.

Pfost, H. B. (1963). Testing the durability of pelleted feed. *Feedstuffs*, ***23***, 66-68.

Plavnik, I., & Sklan, D. (1995). Nutritional effects of expansion and short time extrusion on feeds for broilers. *Animal Feed Science and Technology*, ***55***(3-4), 247-251.

Raghavan, V. (2000). *Proceeding of 22nd Malaysian Society of Animal Production Annual Conference, Kota Kinabalu, 2000.* Serdang, Universiti Putra Malaysia.

Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., & Tharanathan, R. N. (2004). Dietary fiber from coconut residue: effects of different treatments and particle size on the hydration properties. *European Food Research and Technology*, ***218***(6), 563-567.

Rahman, M. A., & Mahmood, S. (1996). Antinutritional factors, metabolizable energy and chemical composition of rice bran. *MARDI Research Journal*, ***24***, 135-146.

Rahman, M. A. U., Rehman, A., Chuanqi, X., Long, Z. X., Binghai, C., Linbao, J. H. S., & Huawei, S. (2015). Extrusion of Feed/Feed Ingredients and Its Effect on Digestibility and Performance of Poultry: A Review. *International Journal of Current Microbiology & Applied Sciences*, ***4***(4), 48-61.

Raimbault, M. (1998). General and microbiological aspects of solid substrate fermentation. *Electronic Journal of Biotechnology*, ***1***(3), 26-27.

Ramin, M., Alimon, A. R., & Ivan, M. (2010). Effects of fungal treatment on the *in vitro* digestion of palm kernel cake. *Livestock Research for Rural Development*, ***22***.

Rath, N. C., Huff, W. E., & Huff, G. R. (2006). Effects of humic acid on broiler chickens. *Poultry Science*, ***85***(3), 410-414.

Ravindran, V. (2013). Poultry feed availability and nutrition in developing countries. *Poultry Development Review*, 60-63.

Razuan, R., Finney, K. N., Chen, Q., Sharifi, V. N., & Swithenbank, J. (2011). Pelletised fuel production from palm kernel cake. *Fuel Processing Technology*,***92***(3), 609-615.

Rhule, S. W. A. (1996). Growth rate and carcass characteristics of pigs fed on diets containing palm kernel cake. *Animal feed science and technology*, ***61***(1-4), 167-172.

Riaz, M. N. . (2000). *Extruders in Food Applications*. Boca Raton: CRC Press.

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J. F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *LWT-Food Science & Technology*, ***33***(2), 72-79.

Rokade, J. J., Kagate, M., Bhanja, S. K., Mehra, M., Goel, A., Vispute, M., & Mandal, A. B. (2017). Effect of mannan-oligosaccharides (MOS) supplementation on performance, immunity and HSP70 gene expression in broiler chicken during hot-dry summer. *Indian Journal of Animal Research*, ***52***(6), 868-874.

Rokade, J. J., Bhanja, S. K., Shinde, A. S., Sajad, S., Kapgate, M., & Mandal, A. B. (2018). Evaluation of mannan-oligosaccharides (MOS) in broiler chicken during hot humid summer using zoo technical, molecular and physio-biochemical tools. *The Indian Journal of Animal Sciences*, ***86***(4).

Ronnie., T. (2018). The grain chain: Gauging Malaysia's food security. Retrieved from http://www.theborneopost.com /2018/04/15/the-grain-chain-gauging-malaysias-food-security/

Rowley, G. (2001). Quantifying electrostatic interactions in pharmaceutical solid systems. *International Journal of Pharmaceutics*, ***227***(1-2), 47-55.

Rowley, G., & Mackin, L. A. (2003). The effect of moisture sorption on electrostatic charging of selected pharmaceutical excipient powders. *Powder Technology*, ***135***, 50-58.

Saenphoom, P., Liang, J. B., Ho, Y. W., Loh, T. C., & Rosfarizan, M. (2013). Effects of enzyme treated palm kernel expeller on metabolizable energy, growth performance, villus height and digesta viscosity in broiler chickens. *Asian-Australasian Journal of Animal Sciences*, ***26***(4), 537.

Sagum, R., & Arcot, J. (2000). Effect of domestic processing methods on the starch, non-starch polysaccharides and *in vitro* starch and protein digestibility of three varieties of rice with varying levels of amylose. *Food Chemistry*, ***70***(1), 107-111.

Sajilata, M. G., Singhal, R. S., & Kulkarni, P. R. (2006). Resistant starch–a review. *Comprehensive Reviews in Food Science and Food Safety*, ***5***(1), 1-17.

Sakaguchi, M., Makino, M., Ohura, T., & Iwata, T. (2014). Contact electrification of polymers due to electron transfer among mechano anions, mechano cations and mechano radicals. *Journal of Electrostatics*, ***72***(5), 412-416.

Sales, J., & Janssens, G. P. J. (2003). The use of markers to determine energy metabolizability and nutrient digestibility in avian species. *World's poultry science journal*, ***59***(3), 314-327.

Sarkar, N., Ghosh, S. K., Bannerjee, S., & Aikat, K. (2012). Bioethanol production from agricultural wastes: an overview. *Renewable Energy*, ***37***(1), 19-27.

Saw, H. Y., Janaun, J., Kumaresan, S., & Chu, C. M. (2012). Characterization of the physical properties of palm kernel cake. *International Journal of Food Properties*, ***15***(3), 536-548.

Serrano, X., & Agroturia, S. A. (1997). The extrusion-cooking process in animal feeding. Nutritional implications. *Feed manufacturing in Southern Europe: New challenges*, 107-114.

Sharma, V., & Freeze, H. H. (2011). Mannose Efflux from the Cells A Potential Source Of Mannose In Blood. *Journal of Biological Chemistry*, ***286***(12), 10193-10200.

Sharma, V., Ichikawa, M., He, P., Bravo, Y., Dahl, R., Ng, B. G., ... & Freeze, H. H. (2011). Phosphomannose isomerase inhibitors improve N-glycosylation in selected phosphomannomutase-deficient fibroblasts. *Journal of Biological Chemistry*, ***286***(45), 39431-39438.

Sharma, M., & Kumar, A. (2013). Xylanases: an overview. *British Biotechnology Journal*, ***3***(1), 1.

Sharma, V., Ichikawa, M., & Freeze, H. H. (2014). Mannose metabolism: more than meets the eye. *Biochemical and Biophysical Research Communications*, ***453***(2), 220-228.

Sharmila, A., Alimon, A. R., Azhar, K., Noor, H. M., & Samsudin, A. A. (2014). Improving nutritional values of Palm Kernel Cake (PKC) as poultry feeds: a review. *Malaysian Journal of Animal Science*, ***17***(1), 1-18.

Short, F. J., Gorton, P., Wiseman, J., & Boorman, K. N. (1996). Determination of titanium dioxide added as an inert marker in chicken digestibility studies. *Animal Feed Science and Technology*, ***59***(4), 215-221.

Shuit, S. H., Tan, K. T., Lee, K. T., & Kamaruddin, A. H. (2009). Oil palm biomass as a sustainable energy source: a Malaysian case study. *Energy*, ***34***(9), 1225-1235.

Silva, P. R. L., Freitas Neto, O. C., Laurentiz, A. C., Junqueira, O. M., & Fagliari, J. J. (2007). Blood serum components and serum protein test of Hybro-PG broilers of different ages. *Revista Brasileira de Ciência Avícola*, ***9***(4), 229-232.

Sinurat, A. P., Purwadaria, T., & Pasaribu, T. (2014). Improving nutrient values of palm kernel cake (PKC) by reducing shell contamination and enzymes supplementation. *Indonesian Journal of Animal and Veterinary Sciences*, ***18***(1), 27-33.

Singh, S., Gamlath, S., & Wakeling, L. (2007). Nutritional aspects of food extrusion: a review. *International Journal of Food Science & Technology*, ***42***(8), 916-929.

Sinurat, A. P., Purwadaria, T., & Purba, M. (2015). Effect of enzyme supplementation on nutritive values of fermented palm kernel cake used to substitute soybean meal in broiler diet. *Indonesian Journal of Animal and Veterinary Sciences*, ***20***(3), 184-192.

Siew, W. L. (1989). Characteristics and uses of Malaysian palm kernel cake. *PORIM Technology (Malaysia).* 14.

Sinurat, A. P., Purwadaria, T., & Pasaribu, T. (2013). Improving nutrient values of palm kernel cake (PKC) by reducing shell contamination and enzymes supplementation. *Jurnal Ilmu Ternak dan Veteriner*, ***18***(1), 34-41.

Slein, M. W. (1950). Phosphomannose isomerase. *Journal of Biological Chemistry*, ***186***(2), 753-761.

Slein, M. W., Cori, G. T., & Cori, C. F. (1950). A comparative study of hexokinase from yeast and animal tissues. *Journal of Biological Chemistry*, ***186***(2), 763-779.

Smits, C. H., & Annison, G. (1996). Non-starch plant polysaccharides in broiler nutrition–towards a physiologically valid approach to their determination. *World's Poultry Science Journal*, ***52***(02), 203-221.

Son, J. H., & Ravindran, V. (2012). Influence of extrusion of white lupins (Lupinus albus L.) on the apparent metabolizable energy and ileal nutrient digestibility for broilers. *International Journal of Poultry Science*, ***11***(9), 565-569.

Sundu, B., Kumar, A., & Dingle, J. (2005). *Proceedings of the 17th Australian Poultry Science Symposium, New South Wales, Australia, 2005*. Sydney, Poultry Research Foundation.

Sundu, B., Kumar, A., & Dingle, J. (2006). Palm kernel meal in broiler diets: effect on chicken performance and health. *World's Poultry Science Journal*, ***62***(02), 316-325.

Sundu, B., Kumar, A., & Dingle, J. (2009). Feeding value of copra meal for broilers. *World's Poultry Science Journal*, ***65***(3), 481-492.

Svihus, B. (2011). The gizzard: function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal*, ***67***(2), 207-224.

Svihus, B., Kløvstad, K. H., Perez, V., Zimonja, O., Sahlström, S., Schüller, R. B., & Prestløkken, E. (2004). Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. *Animal Feed Science and Technology*, ***117***(3-4), 281-293.

Tabtabaei, S., Jafari, M., Rajabzadeh, A. R., & Legge, R. L. (2016). Development and optimization of a triboelectrification bioseparation process for dry fractionation of legume flours. *Separation and Purification Technology*, ***163***, 48-58.

Tabtabaei, S., Vitelli, M., Rajabzadeh, A. R., & Legge, R. L. (2017). Analysis of protein enrichment during single-and multi-stage tribo-electrostatic bioseparation processes for dry fractionation of legume flour. *Separation and Purification Technology*, ***176***, 48-58.

Tan, C., Wei, H., Zhao, X., Xu, C., Zhou, Y., & Peng, J. (2016). Soluble fiber with high water-binding capacity, swelling capacity, and fermentability reduces food intake by promoting satiety rather than satiation in rats. *Nutrients*, ***8***(10), 615.

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

Thomas A. C., D'Hombres B., Casubolo C., Saisana M., Kayitakire F. (2017). *The use of the Global Food Security Index to inform the situation in food insecure countries*. Luxembourg: Publications Office of the European Union.

Thongprajukaew, K., Yawang, P., Dudae, L., Bilanglod, H., Dumrongrittamatt, T., Tantikitti, C., & Kovitvadhi, U. (2013). Physical modification of palm kernel meal improved available carbohydrate, physicochemical properties and *in vitro* digestibility in economic freshwater fish. *Journal of the Science of Food and Agriculture*, ***93***(15), 3832-3840.

Thongprajukaew, K., Rodjaroen, S., Yoonram, K., Sornthong, P., Hutcha, N., Tantikitti, C., & Kovitvadhi, U. (2015). Effects of dietary modified palm kernel meal on growth, feed utilization, radical scavenging activity, carcass composition and muscle quality in sex reversed Nile tilapia (Oreochromis niloticus). *Aquaculture*, ***439***, 45-52.

Todd, D. B. (1975). Residence time distribution in twin-screw extruders.*Polymer Engineering & Science*, *15*(6), 437-443.

Trach, N. X. (1998). The need for improved utilisation of rice straw as feed for ruminants in Vietnam: An overview. *Livestock Research for Rural Development*, ***10***(2), 1-14.

Tutt, M., Kikas, T., & Olt, J. (2012). Influence of different pretreatment methods on bioethanol production from wheat straw. *Agronomy Research*, ***10***(1), 209-276.

Uslu, A., Faaij, A. P., & Bergman, P. C. (2008). Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. *Energy*, ***33***(8), 1206-1223.

Uyeda, K. (1979). Phosphofructokinase. *Advances in Enzymology and Related Areas of Molecular Biology*, ***48***, 193-244.

Vagadia, B. H., Vanga, S. K., & Raghavan, V. (2017). Inactivation methods of soybean trypsin inhibitor–A review. *Trends in Food Science and Technology*, ***64***, 115-125.

Valencia, D. G., Serrano, M. P., Lázaro, R., Jiménez-Moreno, E., & Mateos, G. G. (2009). Influence of micronization (fine grinding) of soya bean meal and full-fat soya bean on the ileal digestibility of amino acids for broilers. *Animal Feed Science and Technology*, ***150***(3-4), 238-248.

Van der Klis, J. D., & Van Voorst, A. (1993). The effect of carboxy methyl cellulose (a soluble polysaccharide) on the rate of marker excretion from the gastrointestinal tract of broilers. *Poultry Science*, ***72***(3), 503-512.

Vantress, C. (2012). Cobb broiler management guide. Arkansas: Cobb-Vantress.

Venou, B., Alexis, M. N., Fountoulaki, E., & Haralabous, J. (2006). Effects of extrusion and inclusion level of soybean meal on diet digestibility, performance and nutrient utilization of gilthead sea bream (Sparus aurata). *Aquaculture*, ***261***(1), 343-356.

Wagner, D. D., & Thomas, O. P. (1978). Influence of diets containing rye or pectin on the intestinal flora of chicks. *Poultry Science*, ***57***(4), 971-975.

Waje, S. S., Patel, A. K., Thorat, B. N., & Mujumdar, A. S. (2007). Study of residence time distribution in a pilot-scale screw conveyor dryer. *Drying Technology*, ***25***(1), 249-259.

Wang, Y., McAllister, T. A., Zobell, D. R., Pickard, M. D., Rode, L. M., Mir, Z., & Cheng, K. J. (1997). The effect of micronization of full-fat canola seed on digestion in the rumen and total tract of dairy cows. *Canadian Journal of Animal Science*, ***77***(3), 431-440.

Wang, Y., Li, D., Wang, L. J., Chiu, Y. L., Chen, X. D., Mao, Z. H., & Song, C. F. (2008). Optimization of extrusion of flaxseeds for *in vitro* protein digestibility analysis using response surface methodology. *Journal of Food Engineering*, ***85***(1), 59-64.

Wang, J., Smits, E., Boom, R. M., & Schutyser, M. A. (2015). Arabinoxylans concentrates from wheat bran by electrostatic separation. *Journal of Food Engineering*, ***155***, 29-36.

Wang, J., Zhao, J., De Wit, M., Boom, R. M., & Schutyser, M. A. (2016). Lupine protein enrichment by milling and electrostatic separation. *Innovative Food Science and Emerging Technologies*, ***33***, 596-602.

Watanabe, H., Ghadiri, M., Matsuyama, T., Ding, Y. L., Pitt, K. G., Maruyama, H., ... & Masuda, H. (2007). Triboelectrification of pharmaceutical powders by particle impact. *International Journal of Pharmaceutics*, ***334***(1-2), 149-155.

Wate, A. (2013). *Influence of Feed Bulk on Physicochemical Properties of Digesta in Pigs.* (Doctoral dissertation). University of KwaZulu-Natal, Pietermaritzburg.

Wenk, C. (2001). The role of dietary fibre in the digestive physiology of the pig. *Animal Feed Science & Technology*, ***90***(1-2), 21-33.

Westerlund, E., Andersson, R., Åman, P., & Theander, O. (1990). Effects of baking on water-soluble non-starch polysaccharides in white bread fractions. *Journal of Cereal Science*, ***12***(1), 33-42.

Wong, H. K., & Wan Zahari, M. (1997). Nutritive value of palm kernel cake and cocoa pod husks for growing cattle. *Journal of Tropical Agriculture and Food Science*, ***25***, 125-131.

Wong, Y. P., Saw, H. Y., Janaun, J., Krishnaiah, K., & Prabhakar, A. (2011). Solid-state fermentation of palm kernel cake with aspergillus flavus in laterally aerated moving bed bioreactor. *Applied Biochemistry and Biotechnology*, ***164***(2), 170-182.

Xiao, R., Power, R. F., Mallonee, D., Routt, K., Spangler, L., Pescatore, A. J., ... & Dawson, K. A. (2012). Effects of yeast cell wall-derived mannan-oligosaccharides on jejunal gene expression in young broiler chickens. *Poultry Science*, ***91***(7), 1660-1669.

Xu, J., Zhang, X., & Cheng, J. J. (2012). Pretreatment of corn stover for sugar production with switchgrass-derived black liquor. *Bioresource Technology*, ***111***, 255-260.

Xu, Z., Jin, X., Pan, T., Liu, T., Wan, N., & Li, S. (2017). Antagonistic effects of selenium on cadmium-induced apoptosis by restoring the mitochondrial dynamic equilibrium and energy metabolism in chicken spleens. *Oncotarget*, ***8***(32), 52629.

Yağcı, S., & Göğüş, F. (2008). Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. *Journal of Food Engineering*, ***86***(1), 122-132.

Yemiş, O., & Mazza, G. (2012). Optimization of furfural and 5-hydroxymethylfurfural production from wheat straw by a microwave-assisted process. *Bioresource Technology*, ***109***, 215-223.

Yoshida, T., Tsubaki, S., Teramoto, Y., & Azuma, J. I. (2010). Optimization of microwave-assisted extraction of carbohydrates from industrial waste of corn starch production using response surface methodology. *Bioresource Technology*, ***101***(20), 7820-7826.

Young, C., & Gondipon, R. (2006). *U.S. Patent Application No. US20060292264A1*.

Yu, C. T., Chen, W. H., Men, L. C., & Hwang, W. S. (2009). Microscopic structure features changes of rice straw treated by boiled acid solution. *Industrial Crops and Products*, ***29***(2-3), 308-315.

Yu, L., Meng, Y., Ramaswamy, H. S., & Boye, J. (2014). Residence Time Distribution of Soy Protein Isolate and Corn Flour Feed Mix in a Twin-Screw Extruder. *Journal of Food Processing and Preservation*, ***38***(1), 573-584.

Zahari, M. W., & Alimon, A. R. (2004). Use of palm kernel cake and oil palm by-products in compound feed. *Palm Oil Developments*, (40), 5-9.

Zaini, I. N., Novianti, S., Nurdiawati, A., Irhamna, A. R., Aziz, M., & Yoshikawa, K. (2017). Investigation of the physical characteristics of washed hydrochar pellets made from empty fruit bunch. *Fuel Processing Technology*, ***160***, 109-120.

Zhu, K., Tan, R. B., Chen, F., Ong, K. H., & Heng, P. W. (2007). Influence of particle wall adhesion on particle electrification in mixers. *International Journal of Pharmaceutics*, ***328***(1), 22-34.

Zulkifli, I., Rahayu, H. I., Alimon, A. R., Vidyadaran, M. K., & Babjee, S. A. (2009). Gut micoflora and intestinal morphology of commercial broiler chickens and Red Jungle Fowl fed diets containing palm kernel meal. *Arch Geflugelk*, ***73***(73), 49-55.

BIODATA OF STUDENT

Muhamad Akhmal Hakim bin Roslan is a researcher and technopreneur. He is passionate in helping farmers to reduce costs and increase profits via sustainable farming. He holds a Bachelor of Science Degree in Biochemistry from Faculty of Biotechnology and Biomolecular Science at Universiti Putra Malaysia. Before undertaking his doctoral studies in 2012, Akhmal worked as a consultant at Superior Training & Consultancy; since 2010. He is actively involved with seminars & workshops for science subject among school students. In 2013, he was appointed as the editorial assistant for the scientific journal "Bulletin of Environmental Science and Management" and "Nanobio & Bionano" Hibiscus Publisher. He is a co-founder and managing director of Halways Sdn Bhd, an agriculture technology company that focused on empowering farmers to produce food in a sustainable way. He is currently active doing research with his team on the application of probiotics for aquaculture and poultry industries.

LIST OF PUBLICATIONS

Intellectual Property

An apparatus for removing contaminants from palm kernel cake and a method thereof.
Inventor: Norhani Abdullah, Muhamad Akhmal Hakim Roslan, Mohd. Yunus Abd. Shukor and Faridah Hanim Shakirin
IP type: patent
IP status: Patent pending
Application no.: PI 2014703428
Filing date: 17/11/2014

Journal Publications

Roslan, M. A. H., Abdullah, N., & Mustafa, S. (2015). Removal of shells in palm kernel cake via static cling and electrostatic separation. *Journal of Biochemistry, Microbiology and Biotechnology*, *3*(1), 1-6. (Published)

Roslan, M. A. H., Abdullah, N., Murad, N. Z. A., Halmi, M. I. E., Idrus, Z., & Mustafa, S. (2017). Optimisation of Extrusion for Enhancing the Nutritive Value of Palm Kernel Cake Using Response Surface Methodology. *BioResources*, *12*(3), 6679-6697. (Published)

Conference Proceedings

Roslan, M. A. H., Abdullah, N., Mustafa, S., Halmi, M. I. E. & Shukor, M.Y.A. (2015). *Proceeding of WVPA (Malaysia Branch) and WPSA (Malaysia Branch) Scientific Conference: Enhancing Innovation in Poultry Health and Production, Kuala Lumpur, 2015.* Serdang, Universiti Putra Malaysia

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : Second Semester 2018/2019

TITLE OF THESIS / PROJECT REPORT :

ENHANCING NUTRITIVE VALUE OF PALM KERNEL EXPELLER THROUGH PHYSICAL TREATMENTS FOR USE AS POULTRY FEED INGREDIENT

NAME OF STUDENT : MUHAMAD AKHMAL HAKIM BIN ROSLAN

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.: 901206075525	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.