UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF SEMI-CONTINUOUS MESOCARP AND NUT SEPARATOR IN ENHANCING THE RECOVERY OF CRUDE PALM OIL

MOHD HAFIZZ BIN WONDI

FK 2021 20

DEVELOPMENT OF SEMI-CONTINUOUS MESOCARP AND NUT SEPARATOR IN ENHANCING THE RECOVERY OF CRUDE PALM OIL

By

MOHD HAFIZZ BIN WONDI

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

December 2020

DEDICATION

To Al-Quran, the greatest source of knowledge

Bring me sheets of iron" - until, when he had leveled [them] between the two mountain walls, he said, "Blow [with bellows]," until when he had made it [like] fire, he said, "Bring me, that I may pour over it molten copper." (Al-Kahf:Verse 96)

&

To my beloved father and mother for their invaluable sacrifices, encouragements and support throughout my life

&

To my awesome 2 siblings

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

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December 2020

Chair : Professor Ts. Rosnah Shamsudin, PhD
Faculty : Engineering

Current palm oil milling process involves digestion and pressing of the whole oil palm fruitlets. However, the coexistence of mesocarp fiber and nut during pressing could lead to inevitable oil loss in fiber and nut breakage. Separation of palm mesocarp fiber from nut prior to digestion and pressing is foreseen as a potential solution to solve the problem. Therefore, a Semi-continuous Palm Mesocarp and Nut Separator machine to enhance the recovery of crude palm oil has been developed. The first part of the study was to determine the physical (mass, dimension and density) and mechanical properties (rupture force, deformation, hardness and rupture energy) of the fruitlets (whole fruit, nut and kernel). The results were used to determine the design parameters for the separator machine. The machine consists of two steps process for every cycle. The first step was to cut and remove the mesocarp fiber from its nut (seed) as well as to remove all the mesocarp produced from the process whereas the second step was to discharge the nut. A performance evaluation was conducted on the developed machine under different conditions; speed (700, 900, 1100, 1300 and 1500 rpm) and processing time (20, 30 and 40 s). The best condition, which was at 1500 rpm of speed and 40 s of separation time, was tested further under different loadings (2.50, 3.75 and 5.00 kg). Further, Response Surface Methodology (RSM) optimization was carried out to obtain the optimum process parameters to achieve maximum separation efficiency and minimum percentage of broken nut. The results showed that the ideal separation was obtained at a separation speed of 1100 rpm, 30 s of time and 2.50 g of loading mass. Under this processing condition, the machine could achieve 94.89 % of separation efficiency and 4.29 % of broken nut. Furthermore, the oil content and oil quality (FFA, DOBI, carotene content and colour) of the extracted oil from the separated mesocarp were also evaluated. The results revealed that the oil complies with the Malaysian Palm Oil Board (MPOB) standard. Increasing the digestion time from 0 to 60 minutes reduced the mesocarp oil content significantly from 100 % to 72.19

%. Overall, this study has successfully developed an effective mesocarp and nut separator machine to obtain high oil recovery with minimal nut breakage. The results from this study are valuable to the palm oil industry. If the system is successfully implemented in the industry, some processes in kernel processing plant, such as winnowing and nut polishing, can be skipped since the nut is already isolated from the mesocarp.

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

PEMBANGUNAN MESIN PEMISAH SABUT MESOKARPA DAN BIJI UNTUK MENINGKATKAN PEMULIHAN MINYAK KELAPA SAWIT

Oleh

MOHD HAFIZZ BIN WONDI

Disember 2020

Pengerusi : Profesor Ts. Rosnah Shamsudin, PhD
Fakulti : Kejuruteraan

Kaedah pemprosesan buah kelapa sawit pada masa ini melibatkan proses pencernaan dan pemerahan biji buah kelapa sawit secara bersama. Namun, kewujudan serat mesokarpa dan biji sawit semasa proses pemerahan minyak akan menyebabkan kehilangan minyak dan kecenderungan untuk biji sawit pecah. Pemisahan mesokarpa sawit dari biji sebelum pencernaan dan pemerahan minyak mampu menyelesaikan masalah ini. Oleh itu, sebuah mesin (Semi-continuous Palm Mesocarp and Nut Separator) telah dibangunkan untuk meningkatkan perolehan minyak sawit mentah. Bahagian pertama kajian ini adalah untuk menentukan sifat fizikal (berat, dimensi, ketumpatan) dan mekanikal (daya pecah, perubahan bentuk, kekerasan dan tenaga untuk pecah) dari bahan input buah, kacang dan biji. Hasilnya digunakan untuk menentukan parameter reka bentuk mesin. Mesin terdiri daripada dua langkah proses untuk setiap kitaran. Langkah pertama adalah memotong dan mengeluarkan serat mesokarpa dari isirung (biji) serta membuang semua mesokarpa yang dihasilkan dari proses tersebut. Kajian mengenai penilaian prestasi dilakukan pada mesin yang diuji pada kelajuan yang berbeza (700, 900, 1100, 1300 dan 1500 rpm) dan masa pemisahan (20, 30 dan 40 s). Keadaan terbaik, iaitu 1100 rpm dan 30 s, diuji sekali lagi pada berat muatan yang berbeza (2.50, 3.75 dan 5.00 kg). Selanjutnya, penelitian ini telah diuji menggunakan Response Surface Methodology (RSM) untuk mendapatkan parameter optimum untuk proses pemisahan, di mana kecekapan pemisahan dan peratusan biji pecah turut dinilai sebagai tindak balas kajian ini. Hasilnya menunjukkan bahawa proses pemisahan yang optimum diperoleh pada kelajuan pemisahan 1100 rpm, 30 s dan 2.50 kg muatan. Pada keadaan pemprosesan ini, mesin ini dapat memisahkan mesokarpa dengan kecekapan pemisahan sehingga 94.89% dan 4.29% biji yang pecah. Selanjutnya, kualiti minyak dari mesokarpa yang dipisahkan dari mesin ini dinilai. Hasil kajian menunjukkan bahawa kualiti minyak (FFA, DOBI, karotena, warna) yang diperolehi memenuhi standard yang

dikeluarkan Lembaga Minyak Sawit Malaysia (MPOB). Meningkatkan masa pencernaan dari 0 hingga 60 minit dapat mengurangkan kandungan minyak dalam mesokarpa dengan ketara dari 100% menjadi 72.19%. Keseluruhannya, penyelidikan ini telah berjaya membangunkan mesin pemisah mesokarp dan biji yang cekap untuk perolehan minyak yang tinggi dengan pecahan biji sawit yang lebih rendah. Hasil kajian ini bermanfaat untuk industri minyak sawit. Selain itu, jika mesin ini diimplementasikan di industri, beberapa proses dapat dilangkau seperti proses pemisahan sabut dan penggilap biji karena mesokarpa sudah terpisah dari biji.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious, the Most Merciful

Alhamdulillah, Allah is the best of planners. Finally, I have successfully completed this thesis. First and foremost, I would like to express my most profound appreciation to my supervisor, Professor Ts. Dr. Rosnah Shamsudin for her guidance and supervision throughout my study. She taught me to be an excellent researcher that contributes and gives back to the community. Next, also my deepest appreciation to my co-supervisor, Professor Dr. Robiah Yunus. She taught me to be a dedicated researcher who ensures everything is perfectly done, even with a tight schedule. Both of these prestigious lecturers are the ones who made me who I am today.

I owe a special thanks to my mother, Jamaliah Binti Pawakai and my father, Wondi Bin Kanda, for their unconditional love and sacrifice throughout my journey. To my beloved brother, Mohd. Taufik and sister, Nurul Hidayah, thank you for all the support and always being there for me when I need help.

I am thankful to all the staff in the Faculty of Engineering for their help and guidance. Last but not least, my thanks goes to Geng Lab Havoc especially Izzah Momoi, Bernard, Izzah, Sarah, Fatimah. Fana, Nabila, Amanina, Azida and Puteri. I will never forget our “havoc” moments together.

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

Rosnah Shamsudin, PhD
Professor, Ts.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Robiah Yunus, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

Date: 06 May 2021

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LIST OF ABBREVIATIONS

CPO	Crude palm oil
FFB	Fresh fruit bunch
EFB	Empty fruit bunch
USB	Unstripped bunch
FFA	Free fatty acid
DOBI	Deterioration of bleachability index
MRS	Minimum ripeness standard
MPOB	Malaysian Palm Oil Board
RSM	Response surface methodology
CCD	Central composite design
GC-FID	Gas Chromatography–Flame Ionization Detector
MC	Moisture content
M_w	Initial mass of sample
M_c	Dried mass of sample
D_a	Arithmetic mean diameter
D_g	Geometric mean diameter
$\emptyset$	Sphericity
ρ_b	Bulk density of fruits
m_b	Bulk mass of fruitlets
V_b	Volume of the container
ρ_t	True density of fruit
m_w	Mass of water displaced
ρ_w	Density of water
ε	Porosity

ρ_b	Bulk density of fruits
ρ_t	True density of fruits
S	Fruits surface area
θ	Angle of repose
H	Height of fruits cone
D	Diameter of fruits cone
μ	Coefficient of friction
α	Angle of tilt in degrees
W_{oil}	Mass of extracted oil
W_s	Mass of sample used
N	Normality of NaOH solution
V	Volume of the sample
W	Mass of sample used for analysis
Abs_{446}	Absorbance at 446 nm
ΔE	Total color difference

CHAPTER 1

INTRODUCTION

This chapter presents a general background of the palm oil industries in Malaysia and the current problem on the milling operation especially in the oil extraction process at the palm oil mill. Some of the suggestion to address the problem on the current palm oil milling process are discussed. The main research objectives and scope of the study also being discussed in this chapter.

1.1 Background

Edible oils such as coconut oil, corn oil, palm oil, canola oil and soybean oil have been widely used for many applications such as cooking, food ingredient, cosmetics and fuel. However, unstable supply and demand as well as fluctuation in market oil price are affecting the economy of exporting country. Statistics has shown that the price of sunflower oil and palm oil are decreasing to around 48% in 2018 which is the lowest for the past 10 years (Mielke, 2019). Further, the selling price for palm oil in June 2019 was below the production cost for many of the smallholders in Malaysia and Indonesia due to the weaker demand and decline in export earnings (Din et al., 2019). On the other hand, the consumption of the edible oil was reported to be more than 50% of total world oil production by 2020. Increase in world biodiesel production from edible oil in the past 11 years will be a driving force in increasing edible oil demand at a competitive price. The future demand may lead to a huge world demand-supply gap, hence it is crucial to enhance the production and productivity of edible oil.

Palm oil and palm kernel oil account for almost one-third (80.33 million tonnes) of world total oils production in 2018. It is estimated that palm oil contributes 31.41% of world oil production in 2018 followed by soybean (24.37%), others oil (11.77%), rapeseed oil (11.09%), animal fats (8.52%), sunflower oil (8.25%), palm kernel oil (3.34%) and coconut oil (1.25%) (Din, 2017; Malaysia Palm Oil Council, 2019). Malaysia is the second largest palm oil producer in the world after Indonesia and followed by other countries namely Guatamela, Colombia, Papua New Guinea and Thailand. Oil palm industry plays an important role in the agricultural and economic development in Malaysia. It also contributes in providing a sustainable employment among Malaysians besides enhancing the foreign exchange.

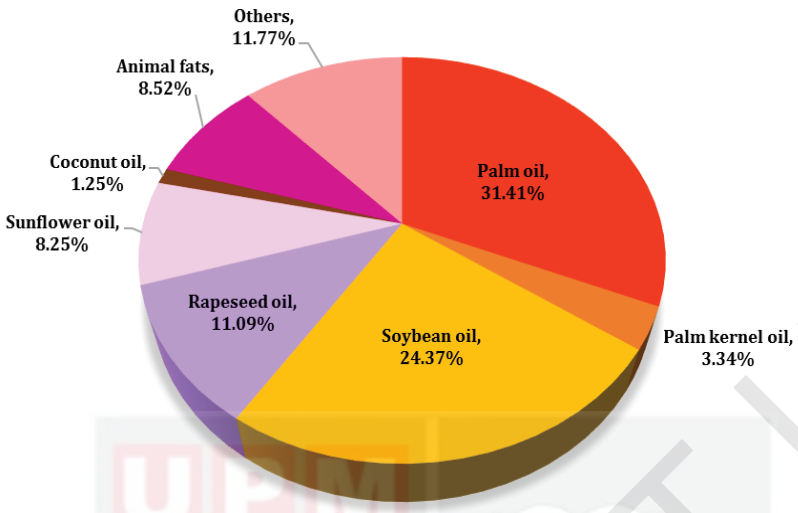

Figure 1.1: World oils and fats production in 2018 (Malaysia Palm Oil Council, 2019)

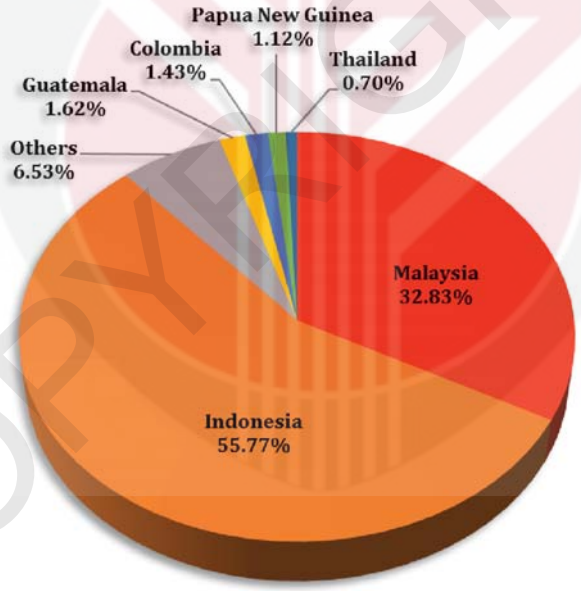

Figure 1.2: World palm oil exports by country in 2018 (Malaysia Palm Oil Council, 2019)

The oil palm (*Elaeis guineensis Jacq*) originated from Africa is now widely cultivated in Asia. Palm oil is extracted from the mesocarp/fiber of oil palm fruitlet while palm kernel oil is extracted from its kernel that is surrounded by hard shell (Abbas et al., 2006; C. Tan et al., 2009). Palm oil is consumed as refined products such as cooking oil, margarine, ghee and shortening. The demand of palm oil is rising due to the public awareness of its rich nutritional-content of vitamin A (carotene) and vitamin E (tocopherols and tocotrienols), which have antioxidant property and is believed to be able to inhibit several types of cancer development (Choo et al., 1996; Han and Choo, 2015; Kushairi et al., 2018; Lau et al., 2006a; Nagendran et al., 2000; C. Tan et al., 2009). Palm oil is also used in worldwide food industries due to its competitive price, proven oxidative stability and long shelf life (Kushairi et al., 2018; Rosnani et al., 2017).

Conventionally, palm oil extraction (milling) process involves five basic operations; fruit sterilization, fruit loosening/stripping, fruit digestion, oil extraction and oil clarification (Osei-Amponsah et al., 2012; Owolarafe et al., 2008, 2002). After the palm fruitlets have been stripped from the bunches, the sterilized fruitlets together with accompanying calyx leaves are reheated and reconditioned inside a digester to loosen the mesocarp before entering screw press for oil extraction (Sivasothy et al., 1993; Stork Amsterdam, 1960; Vincent et al., 2014). Most of these processes are crucial for obtaining high oil yield and high kernel recovery at acceptable oil quality. The values of these parameters in particular the oil yield reflect the mill performance. The oil yield is technically measured as oil extraction rate (OER) which indicate the percentage of the weight of crude palm oil (CPO) produced from a known weight of fresh fruit bunches (FFB) being processed.

The average OER performance for Malaysia in 2017 recorded a decline of 0.5% from 20.2% to 19.7%. The decline was reported to be due to the lower quality of FFB being received and processed by the palm oil mills (Kushairi et al., 2018). The extreme environmental stress such as prolong heavy rainfall and drought also had brought a significant impact on the oil yield. Chang *et al.* (2003) mentioned that machinery and equipment operation at the palm oil mill also became a dominant factor affecting the OER. The conditions and operation settings for every machinery involved in the oil production can possibly contribute to the oil gain or oil loss. Therefore, the improvement of machine operation is foreseen to be a possible way to increase the oil extraction rate for palm oil mill.

Recently, many researchers have introduced various new/improved techniques of oil extraction from palm mesocarp fiber that proved to increase crude palm oil yield or OER compared to the current palm oil mill extraction such as enzyme-assisted aqueous extraction, solvent extraction, microwave pretreatment and supercritical fluid extraction (Baharin et al., 2001; Cheng et al., 2011; Jesus et al., 2013; Mustapa et al., 2011; Noorshamsiana et al., 2017; Sharizan et al., 2016; Sukaribin and Khalid, 2009). However, due to

health issue and economical sustainability, most of these techniques are limited to small scale production and mostly end up at the research level.

1.2 Problem Statement

The purpose of a digester in palm oil mill is to loosen the mesocarp from the nut at the same time to break up the oil bearing cell for the oil extraction. Loosening the mesocarp during digestion will enhance the oil release due to the breakup of the oil bearing cell. After digestion, the digested mash (a mixture of mesocarp fiber and nut) undergoes oil extraction process at the screw press using helical screw. However, the exceeded pressure exerted by the screw press will result in higher nut breakage, estimated to reach as high as 40% which also lead to high the kernel loss (Owolarafe et al., 2008). Since the fruit digested mash is a heterogeneous mixture of nut, fiber and fluid (oil and water), 50 bar is set as the maximum allowable of pressure in the press without causing nut breakage (Stork Amsterdam, 1960).

In additions, about 4% to 5% residual oil still remain in palm pressed fiber (PPF) after oil extraction by using conventional method screw press (Choo et al., 1996; Nur Sulihatimarsyila et al., 2019). The residual oil contributes to oil loss in palm oil mill processing. Since Malaysia is currently producing around 19 million tons of CPO in 2019, the oil loss at 1% will contribute to the loss of income estimated at RM 2.3 billion if the market price of CPO is at RM 2,309/ tons. Thus, numerous approaches have been implemented to overcome this problem either by research institute or by the industry itself.

Besides, the quality of crude palm oil is also dependent on the milling parameters. In fact, the excess extraction pressure tend to crack the kernel during extraction process. The cracked kernel will deliberate certain amount of kernel oil and contaminate the crude palm oil as well as affecting the commercial value of the final palm oil product. This cracked kernel will reduce the kernel oil extraction rate of which eventually will affect the company profits. In fact, kernels are valuable and the kernel oil fetches higher price compared to the crude palm oil. In addition, extraction of oil from mesocarp without nuts will require less solvent usage if we plan to use solvent extraction in future palm oil milling method.

Consequently, disintegration and separation of palm mesocarp fiber from nuts method prior screw pressing is a potential technology that can improve the oil extraction yield. Palm mesocarp and nut separator has been getting a great deal of attention from numerous researchers for its potential in reducing nut breakage while maximizing oil yield. A number of studies regarding the separation of mesocarp from nuts using other methods were already published. Researchers from West Africa have explored the potential of horizontal palm nut-pulp separators installed after fruit digestion; these separators eliminated nut breakage and reduced excessive oil loss from

pressed fibres (Nduka et al., 2012; Vincent et al., 2016). It has been proven that separating mesocarp from nuts before screw press extraction can reduce nut breakage.

However, the removal of mesocarp fiber prior screw pressing do not have any available commercial technology on the large basis. On the other hand, a small palm fruitlets dehusker used to dehusk the mesocarp from nuts was developed in Malaysia (Vincent et al., 2016). The dehusking of palm mesocarp by using perforated sharp edges has been studied, and sharp edge orientation and time to complete dehusking have been considered. This approach was able to successfully dehusk the mesocarp but the equipment is a batch process and manually operated to remove dehusked nut which is not suitable for large scale production. Moreover, lack of studies dealt with the effect of separation process parameters towards oil yield and oil quality. These are important parameters which cannot be ignored since it will contribute to the profit and production efficiency.

Separating palm mesocarp fibres from nuts prior to screw pressing using a centrifugal separator in this study is an emerging potential approach for improving oil extraction yield. By removing nuts from the mesh (fiber) prior digestion and oil extraction process, the issue of nut breakage will be completely omitted, and thus the pressure can be further increased to maximize oil yield. An in-house fabricated continuous palm oil mesocarp and nut separator, which utilizes centrifugal force mechanism with 97% reduction of digestion time, was developed. The findings are expected to contribute to palm oil milling process development and design especially to the Malaysian oil palm oil industry. Since Malaysia contributes to almost 40% to the palm oil production in the world, the improvement of oil extraction yield will increase country gross income. Notably, this work supports the Sustainable Development Goals 9 (SDG 9), 'Responsible consumption and production', by minimizing oil loss during the production process that usually generates effluent waste.

1.3 Objectives

The main objective of this study is to develop an effective machine to separate the mesocarp fiber and nut from oil palm fruitlets for a better oil yield and quality. To achieve this, a semi-continuous centrifugal separation concept design (with rotating cutting blade) and equipped with the intermittent nut removal has been developed. However, to ensure the design of the machine are suitable, the physical and mechanical properties of raw materials (palm fruitlets) must be assessed. In addition, the designed machine must also be cost effective and low maintenance.

The objectives of this study are:

1. To develop a new conceptual design of semi-continuous mesocarp and nut separator machine complete with automatic nut discharge system.
2. To evaluate the separator machine performance and optimize the process conditions including separation speed (700 to 1500 rpm), separation time (20 to 40 s) and loading capacity (2.50 to 5.00 kg) for separation efficiency (%) and broken nut percentage.
3. To analyze the effect of separation speed and digestion condition on the oil yield and quality.

1.4 Significance of study

In summary, the project main goal was to develop a Semi-continuous Mesocarp and Nut Separator Machine which is capable of separating the mesocarp directly from the whole oil palm fruitlets so that the higher oil yield and lower broken kernel with better oil quality can be achieved. In addition, the findings from the current study are expected to enrich the knowledge in separation of palm mesocarp from its nut. Furthermore, the development of a new separator machine is expected to aid in addressing the nut breakage issue and oil loss in palm oil processing. On top of that, the study covered an optimization on the separation process and the findings can be implemented in the design of the pilot plant separator machine. Lastly, this research has potential in improving the economics viability of the overall oil palm industry in Malaysia.

1.5 Scope of study

This study focuses on developing a semi-continuous palm mesocarp and nut separator machine. This study report consist of five chapters. Chapter 1 encompasses the background of study, the problem statement, objectives of the study, significance of the study and scopes of study. Chapter 2 which is attributed to the literature review delivers detailed reviews and results on previous studies related to crude oil extraction technology and recent prior art of the mesocarp and nut separator concept. These previous data and results are base for this study to further investigate each aspect of separation process. Chapter 3 explains the research methodology covering the equipment, materials, design and methods employed in this study. Further on, Chapter 4 presents the results on the design performance tests and analysis based on both the experimental and hypothesis. At the end, Chapter 5 closes with conclusion and recommendation.

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BIODATA OF STUDENT

Mohd Hafizz Wondi was born in Kunak, Sabah on 5th August 1993. He attended a primary school at Sekolah Kebangsaan Ladang Binuang, Sabah and his secondary education at Sekolah Menengah Sains Lahad Datu, Sabah. In 2011, he enrolled his foundation at Agricultural Science Foundation Centre, Universiti Putra Malaysia (UPM), Serdang. In 2016, he graduated with a Bachelor degree in Agricultural and Biosystem Engineering from the Faculty of Engineering, UPM. Immediately after graduation, he started working as an Assistant Mill Manager at the Sime Darby Plantation Sdn. Bhd. in Selangor and Sabah regions from 2016 to 2018. Currently, he was working as Production Engineer at oil refinery division for Wilmar International.

LIST OF PUBLICATIONS

Journals:

Wondi, Mohd Hafizz., Shamsudin, Rosnah., Yunus, Robiah., Alsultan, G.Abdulkareem., Iswardi, Aditya Hutama. (2020). Centrifugal separation-assisted and extraction of crude palm oil from separated mesocarp fiber : Central composite design optimization. Journal of Food Process Engineering, 3(7), 1-13. https://doi.org/10.1111/jfpe.13426. (Published: Q3 ISI, IF 1.703)

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Proceeding:

Wondi, Mohd Hafizz., Shamsudin, Rosnah., Yunus, Robiah., (2019). A review of palm mesocarp maceration and separator machine. *Malaysian Society Of Agricultural Engineers (MSAE) Conference, Wisma Tani, Kementerian Pertanian & Industri Asas Tani, Putrajaya.* 21 March 2019.

Patent:

A device and method to separate a mesocarp from a nut of a drupe. Patent number: PI2019001154