UNIVERSITI PUTRA MALAYSIA

SEPARATION AND RECOVERY OF PALM MESOCARP AND NUTS USING THE NEWLY-DEVELOPED BATCH DRUPE DEHUSKER MACHINE

CHRISTINE JAMIE ANAK VINCENT EDDY

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By

CHRISTINE JAMIE ANAK VINCENT EDDY

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

December 2021

DEDICATION

Dedicated to my parents,

Vincent Eddy and **Victoria Jessie**,

for their unending love, encouragements and prayers.

2021, Serdang, Selangor, Malaysia

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

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Chairman : Professor Ts. Rosnah binti Shamsudin, PhD
Faculty : Engineering

The disproportionate nut-to-fiber ratio in the different breeds of the palm oil fruitlets allows for inadequate screw-pressing and high oil loss to fiber. Over-pressing causes nut breakage and mixing of the two different oils together (Crude Palm Oil and Kernel Palm Oil) which affects the oil quality. Manual dehusking of oil palm fruitlets in conducted in research centers using hand-crafted knives is very tiring and labor intensive. Due to the restrictions in both of these processes, this study was initiated to simultaneously solve them with the development of a Drupe Dehusker machine to dehusk the fibrous outer layer of a drupe fruitlets from its nut, specifically, the oil palm fruitlets (*Elaeis Guineesensisis*) to improve mesocarp and kernel recovery. The drum-type batch system's main mechanism is through the process of molecular dissociation achieved through centrifugal force combined with frictional action between the fruitlets and blades incur in the system. The angles of the blades are 70 degrees and the effective working volume is at ¼ of the total peeling compartment volume. It was found that fruitlets sterilized at 105˚C / 0.121 MPa for 60 minutes is the most optimum condition prior to dehusking of the fruitlets based on the oil quality analysis done based on the Free Fatty Acid, Deterioration of Bleachability Index (DOBI), Carotene content and Moisture content. The structural studies conducted inferred that the heat treatment was definitely found to assist in the structure alteration of the fruitlet. The dehusking efficiency of the Drupe Dehusker machine at 95% is attainable for the dehusking of ideal weight 4 kg load at speed of 25 Hz for the current radius size of the peeling disc at 0.1575 m. Based on the Finite Element Analysis, the machine must be prevented from operating at 32Hz and 43Hz which are same as the natural frequencies to prevent resonance from happening which could lead to machine failure. Economic analysis of the machine inferred that the current machine would generate a net annual profit of RM 91649.89 with Benefit-Cost-Ratio of 5.45, a Return on Investment of 386% with a Pay-Back Period of 0.18 year. Further study could be done in order to obtain the optimum load for the current size of

machine and operating disc of radius 0.1575m at the reported speed of 28.85 Hz. Future research could also be conducted to design the system to convert current batch system into continuous system that does not require manual unloading process of the nuts which at current is manually collected after every process.

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

MENINGKATKAN PEMISAHAN DAN PEMULIHAN SABUT DAN BIJI KELAPA SAWIT DENGAN MENGGUNAKAN MESIN YANG BARU DIBANGUNKAN ‘PENYAHSABUT DRUP’

Oleh

CHRISTINE JAMIE ANAK VINCENT EDDY

Disember 2021

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

Nisbah biji dan sabut tidak seimbang dalam pelbagai baka buah kelapa sawit akan menyebabkan tekanan skru tidak mencukupi dan kehilangan minyak yang tinggi dalam sabut. Penekanan berlebihan akan menyebabkan biji pecah dan mengakibatkan pencampuran dua minyak berbeza (minyak sawit mentah dan minyak sawit isirong) yang akan menjejaskan kualiti minyak. Proses nyahsabut buah lerai dengan menggunakan pisau dilakukan secara manual di pusat penyelidikan adalah amat memenatkan dan melibatkan ramai tenaga kerja. Disebabkan kekangan dalam kedua-dua proses, maka kajian dimulakan dengan pembinaan mesin penyahsabut pepauh untuk mengasingkan lapisan luar bersabut dari biji, terutamanya buah kelapa sawit lerai (Elaeis Guineesensisis) untuk meningkatkan pemulihan mesokarpa dan isirong. Mekanisma utama dalam kelompok jenis-gelendong dimana akan melalui proses molekul pengasingan secara daya emparan dengan pengabungan dari tindakan geseran antara buah lerai dan bilah yang berlaku dalam sistem. Sudut antara bilah adalah 70 darjah dan efektif isipadu kerja adalah ¼ daripada jumlah isipadu kawasan kupasan. Kajian mendapati bahawa buah lerai yang disterilkan pada 105 oC / 0.121 MPa selama 60 minit adalah yang paling optimum untuk proses nyahsabut buah lerai di mana berdasarkan analisis kualiti minyak yang dilakukan seperti kandungan asid lemak bebas (FFA), penentuan indeks kebolehlunturan (DOBI), kandungan karotena dan kandungan lembapan. Kajian struktur yang dijalankan dapat disimpulkan bahawa rawatan haba membantu dalam perubahan pada struktur buah lerai. Kecekapan mesin nyahsabut pepauh pada 95% dapat dicapai untuk nyahsabut pada beban unggul seberat 4kg dengan kelajuan 25 Hz dan ukuran semasa jejari cakera pengupasan 0.1575 m. Berdasarkan kaedah unsur terhingga, mesin tidak boleh beroperasi pada 32 Hz dan 43 Hz dimana sama dengan frekuensi semulajadi bagi menggelakkan gegaran yang boleh menyebabkan kegagalan mesin. Kajian lanjut perlu dilakukan untuk mendapatkan beban optimum untuk saiz semasa mesin dan

jejari cakera operasi 0.1575 m pada kelajuan yang dilaporkan 28.85 Hz. Kajian masa depan perlu dijalankan untuk merekabentuk dari jenis sistem kelompok kepada sistem berterusan yang tidak memerlukan biji secara manual muatan dimana sekarang memerlukan manual muatan pada setiap kali proses dijalankan.

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

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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.

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LIST OF ABBREVIATIONS

CPO	Crude Palm Oil
PKO	Palm Kernel Oil
FFA	Free fatty acid
OER	Oil extraction rate
MC	Moisture content
DOBI	Deterioration of Bleachability Index
PPF	Palm pressed fiber
FFB	Fresh fruit bunch
EFB	Emtpy fruit bunch
OPEFB	Oil Palm Empty Fruit Bunch
POME	Palm oil mill effluent
PORAM	Palm Oil Refiners Association of Malaysia
TPD	Ton per day
%	Percentage
Ø	Sphericity Index
R_a	Aspect Ratio
ρ	Density
ρ_t	True density
ρ_b	Bulk density
m	meter
r	Radial distance
d	diameter
h	height
t	thickness

l	length
w	width
V	volume
Ve	Efficient Working Volume
mm	millimeter
kg	kilograms
g	gram
ml	milliliter
m^3	meter cube
Dr	Density ratio
Pr	Porosity
Ɵ	Angle of repose
H	Height
D	Diameter
μ	Coefficient of static friction
α	Angle of tilt
F	Force
Fc	Cutting Force
P	Power
T	Torque
N	Newton
v	Velocity/speed
HP	Horsepower
a	acceleration
ac	Radial acceleration

ω	Angular velocity
f	Frequency
w.b	Wet basis
TPA	Texture Profile Analysis
WBSF	Warner-Bratzler Shearing Force
SEM	Scanning Electron Microscopy
RSM	Research Surface Methodology
CCD	Central Composite Design
SS	Sum of Squares
R^2	Coefficient of Regression
ANOVA	Analysis of Variance
2FI	Two-factorial Index
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
SHS	Superheated Steam
OPEFB	Oil Palm Empty Fruit Bunch
MS	Malaysian Standard
PV	Peroxide value
aV	Anisidine value
N	Normality
A_{csap}	Cross-sectional area
A_{sec}	Area of sector
W	Weight
as	Absorbance of the sample

ab	Cuvette error
β	Beta
ppm	Parts-per-million
MPOA	Malaysian Palm Oil Association
MPOB	Malaysian Palm Oil Board
PORIM	Palm Oil Research Institute of Malaysia
ASABE	American Society of Agricultural and Biological Engineers
RBDPO	Refined, bleached and deodorized palm oil
SS 304	Stainless Steel 304
NBR	Nitrile Butadiene Rubber
Kw	Kilo-Watt
Hz	Hertz
RPM	Revolutions per minute
Kv	Kilo-voltage
Dw	Dehusking weight proportion
ηp	Dehusking efficiency
Mpc	Weight of mesocarp collected
Ms	Weight of sample
Twp	total weight of mesocarp collected by manual peeling
λ	Fruitlet damage
Mf	Weight of broken nut
Mc	Weight of completely dehusked fruitlet
Gpa	Giga-Pascal
Mpa	Mega-Pascal
CAD	Computer-aided design

ANSYS	Analysis System
NASTRAN	NASA Structural Analysis
FEA	Finite Element Analysis
FEM	Finite Element Method
PDE	Partial Different Equation
FOS	Factor of Safety
BCR	Benefit-cost ratio
R	Revenue
p	Profit
PBP	Payback Period
ROI	Return on Investment
FC	Fixed cost
VC	Variable Cost
D	Depreciation
I	Interest on investment
STI	Shelter, taxes and insurance
SV	Salvage value
AC	Annual Cost
RM	Ringgit Malaysia
kWh	Kilowatt-hour
SD	Standard Deviation
AV	Average

CHAPTER 1

INTRODUCTION

Drupes are fruits that are made up of three layers: an epicarp, also known as the flesh layers of mesocarp, and an endocarp or a woody nut shell that consists of the white kernel or seed inside the shell. The oil palm fruitlets (*Elaeis Guineesensis*), the olive tree (*Olea Europa*), the Sarawak Olive, Dabai (*Canarium Odontophyllum Miq*), and avocado are all examples of oil-bearing drupes (*Persea Americana*).

The oil palm fruitlets are usually process to palm oil, which is a widely used cooking oil of the vegetable source, especially in Southeast Asia, Africa and parts of Brazil. Palm oil is less expensive than other vegetable oils such as groundnut, corn, or soybean oil and is widely utilised in food processing. It is obtained from the mesocarp of oil palm fruits (Hadi et al., 2009), principally from *Elaeis guineensis*, the African oil palm, and to a lesser amount from the *Elaeis oleifera* (American palm), and the *Attalea maripa (*maripa palm). With a global production record of 11.356 million tonnes in 1989–1991, it accounts for almost a quarter of the vegetable oil production of 61.409 million tonnes, globally (Edem, 2002). In the same period, soybean oil production increased by 26.2% to 16.130 million tonnes (Escobar et al., 1994).

Palm oil has a lot of deep red pigments known as carotenoids usually found in plants and animals. The amount of oxidation in lengthy-stored bruised fruitlets prior to subsequent processes, as well as the oxidation during processing and when in bulk are all factors that influence the colour. The oxidation during processing and when in bulk are usually catalysed by iron.

Palm oil is valued in temperate areas for its viscous semi-solid state and as a solid fat because the saturated fatty acid palmitic makes up the majority of its glycerides, eliminating the requirement for hydrogenation. It's also high in anti-oxidants, carotenes (vitamin A), and tocotrienols (a type of vitamin E). Soybean or rapeseed, on the other hand, must be hydrogenated before being turned into margarine. Hydrogenation has an oxidation tendency, and it also produces significant amounts of trans fatty acids, which have unknown health implications (British Nutrition Foundation, 1987). Hence, it is ideal for frying, allows for the food to last longer before expiring, and agressively increasing the nutritional and health value of meals, particularly in underdeveloped nations. Palm oil, on the other hand, is a far healthier source of solid fats than hydrogenated vegetable oils. Furthermore, palm oil products have a wide range of applications, giving lots of room for additional industrial innovation.

This chapter provides an overview of the manual dehusking of palm mesocarp and the screw- process in mills, as well as the oil palm fruitlets and the proposed Drupe Dehusker machine for enhanced palm mesocarp and palm nut recovery and quality.

1.1 Oil Palm fruitlet

Oil palm fruitlets are drupes that is clustered in a bunch (Fatin et al., 2014). Each bunch normally contains 1000 to 3000 fruitlets. Depending on its size and maturity, the fruit bunch could weigh anywhere from 10 kg to 40 kg, while each fruitlet could weigh about 6 to 20 g (Razali et al., 2012). Crude palm oil (CPO) is produced from the red, fibrous mesocarp layers while palm kernel oil (PKO) is produced from the kernel inside the nut, as it is referred to throughout this thesis. As demonstrated in Figure 1.1, the mesocarp, kernel, and nuts are all marked. Glycerides, the oil's major component, make up over 99 percent of crude palm oil (Alyas et al., 2006). It is also rich in minor components such as carotenoids, tocopherols, tocotrienols, phytosterols and phosphatides (O'Holohan, 1997), that impart unique nutritional properties.

Oil makes up 70-75 percent of the weight of ripe fruits' mesocarps compared to unripe fruits. As a result, accurate ripeness judgement is critical for a healthy yield (Berger, 1983). Furthermore, Berger (1983) stated that a ten percent proportion of loose fruitlets are considered to be the best stage of maturity or ripeness. Quality of oil below the acceptable grade and unsatisfactory mill productivity will result from over-ripeness, bruising, and a long post-harvest delay (Mahidin, 1998). As a result, determining the best processing conditions based on the ripeness of the fruit is critical to ensuring a larger yield of high-quality oil.

At different phases of the milling process, the two oils are separated by careful separation. The two oils are used in quite different ways and have very different markets. The palm oil is usually used globally to produce consummables such as margarine, shortening, ice-creams, chocolate ingredient substitutes or even for frying; while the palm kernel oil is mainly processed to produce oleochemicals, soaps and detergents (Edem, 2002).

Palm kernel oil (PKO) is a minor oil extracted from the kernel of the palm fruit, accounting for around 10% of total palm oil production. It is a firm, light yellow oil with a higher amount of “saturated lauric and myristic acids” than coconut oil (in taste and odour) (Bosu, 2013). The by-product obtained from the extraction process is usually in the form of pressed cakes with containing approximately 19.5% protein and it is usually use as livestock feed.

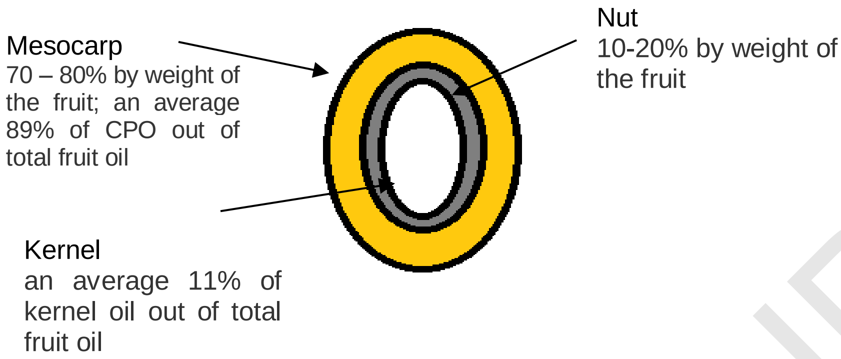

Figure 1.1 : Structure of the oil palm fruitlet

One of the most pressing challenges in the palm oil milling industry is oil quality and Oil Extraction Rate (OER). The primary significant criteria to ensure that the oil is on-par with the global palm oil standard requirements is the oil quality in terms of Free Fatty Acid content (FFA), Moisture Content (MC), Deterioration of Bleachability Index (DOBI), and Carotene Content. The FFA is the most important of these metrics based on numerous reports concerning the high and rapid increment of FFA level in bruised fruitlets (Rajanaidu and Tan, 1983). Free fatty acid (FFA) percentage of the oil in a fresh, ripe, and unbruised fruitlet is usually less than 0.3 percent. As the fruit splits from the bunch, the exocarp becomes brittle and more easily damaged by lipolytic enzymes. Through hydrolysis, the enzymatic action results in a rise in the oil's FFA. As a result, there is a broad variation of content and quality within the bunch depending on how damaged it is.

1.2 Screw pressing process in mills

Crude Palm Oil (CPO) is typically obtained in the palm oil industry through a series of mill processes including mechanical systems. Fruit sterilising, fruit loosening/stripping, fruit digesting, oil extraction, and oil clarifying were the five basic activities involved in oil palm extraction procedure (Owolarafe et al., 2002; Osei-Amponsah et a., 2012). The extracted palm oil generated in palm oil mills is reddish in color and most commonly known as Crude Palm Oil (CPO) before fractioning and refining in palm oil refineries. “Palm olein and super olein” are the fractions of palm oil that are derived after refining, bleaching, and deodorization.

The most common way to extract oil from the mesocarp layer is usually by pressing of the fruitlets in the mill. After the digesting phase, whole oil palm fruitlets are normally pressed using a screw-presser in order to force the oil to expel. As a result, the screw-presser frequently contains a “heterogeneous mixture of nut, fiber, and fluid.” The unbalance portion of nuts and fibers in the various palm oil breeds causes considerable amounts of oil loss to fiber due to insufficient screw-pressing. Screw-pressing is normally done carefully to minimise large amounts of oil being lost due to insufficient pressing. Several studies have found that following screw pressing there is about 4% of oil that remains in the Palm Pressed Fiber (PPF) (Choo et al., 1996). The mill oil loss is exacerbated by the leftover residual oil. To ensure high oil extraction efficiency, the mill had tried upping the pressure limit to an additional 40% from the usual 50 to 60 bar. However, the study also found that this had increase 40% in nut breakage (Owolarafe et al., 2008), allowing for the mixing of two different oils. This has an impact on both the yield and the quality of the oil. Milling machineries and Fresh Fruit Bunch (FFB) conditions are essential factors in producing high-quality oil (Fatin et al., 2014).

Despite the need to improve crude palm oil recovery, current screw-pressing process to obtain oil also discourages the ability for Research Centres to study and work towards the future development of the different oil obtained, which leads to the manual dehusking of the palm mesocarp for this sole purpose. Hence, there is a need for a machine that can address those concerns. An additional process was then proposed in order to yield efficient dehusking process with separation of palm mesocarp from its nuts before it is subjected to screw-pressing process and at the same time eliminate the digestion process that serves the current purpose of encouraging the loosening of the mesocarp from the nuts prior to the screw-pressing process. The introduction of the ‘drupe dehusking’ process allows for the elimination of the digestion process, simplification of screw-pressing process and in turn, has the potential to not only increase yield and quality of oil but allows for a much efficient pressing, thus reducing process time and maintenance cost (no mixture of solids). Faster processing time can also be attained.

1.3 Manual dehusking of palm mesocarp

Generally, in research centres, for the purpose of evaluating and assessing the quality of the oil obtained, the palm fruitlet mesocarp are dehusked manually using a specially-crafted knife as shown in Figure 1.2 and 1.3 to prevent bruising and loss of oil, as compared to when subjected to mechanical means in mills. An approximation of about 8000 fruits are dehusked daily by a group of skilled workers in the Felda Sg Tekam’s oil mill’s research centre. These techniques necessitate expert labour and are exhausting to employ. Attempts to develop dehusking tools have only been somewhat successful and have not been helpful in replacing the traditional process. Unsatisfactory and partial dehusking, oil losses, greater work required than manual approach, bruising of the fruitlets, and other factors have been cited as causes for these machines' failure.

Figure 1.2 : Dehusking of mesocarp by skilled labourers

Figure 1.3 : Knife used to de-husk the mesocarp of palm fruitlets

Therefore, this study focuses on the development of a dehusker machine with the benefits of reducing intensive labor, reduce processing time, ability to separate the mesocarp and nuts and the possibility of screw-pressing process of only the mesocarp in mills to obtain higher recovery and quality of oils from the mesocarp and kernel. This is in accordance to its effects on not only the separation of the mesocarp in terms of its structure, but also for the quality as well as the evaluation on the fully utilization of the palm fruitlets' sustainability.

1.4 Problem Statement

Both the screw-pressing process in mills and the manual dehusking of the oil palm fruitlets are for the same end purpose, which is to obtained quality CPO. Previous studies on the yield of oil through the screw-pressing process carried out in the mills has denoted that recovery is only between 90-95% and over-pressing causes nut breakage and thus mixing of the two different oils together (CPO and PKO). One of the main reasons for this is due to the imbalance portions of the nuts and fiber in the various palm oil fruitlet breeds.

On the other hand, manual dehusking of oil palm fruitlets in research centres are tiring and labor intensive. Due to the restrictions in both of these processes, a need was identified and this study was initiated to simultaneously solve two main issues faced in the Palm Oil Industry, which are the screw-pressing process and the manual dehusking of whole oil palm fruitlets in research centres in the form of a mechanical system or machine.

In palm oil mills, the Fresh Fruit Bunches (FFB) are sterilized prior to subsequent processes that leads to the oil extraction and recovery process to ensure the quality of the oil obtained. High temperature is needed during the sterilization process to ensure that the heat is able to penetrate and encourage loosening of the fruitlets from the bunches in the next step of threshing process. Subsequent digestion process is then done to contribute to the separation of the palm mesocarp from the nuts and to break up the oil bearing cell prior to the screw-pressing process. Digestion process is done at a lower temperature of 95°C compared to the sterilization process.

An attempt to design a system that caters to the use of both the Palm Oil mills and Research Centres that is able to eliminate the current digestion process then requires the need to study on the physical, chemical and mechanical properties of the fruitlets for fresh and sterilized fruitlets. Sterilization in this study is at a shorter time and temperature compared to the existing condition in the mills to obtain the optimum condition of the fruitlets prior to subjecting the fruitlets into the mechanical system designed. This part of the study is required to ensure that the separation process using the machine designed is achieveable for both fresh and sterilized fruitlets at lower temperature and time but also would not disrupt the quality of the oil obtained.

As there is no other related invention that serves the purpose of separating the constituents of a fruit with disproportionate nut-to-fiber ratio, this highlights the second problem statement of this study. There is a need to design, develop and evaluate the concept designs that could achieve the separation of the palm mesocarp and nuts. These concept designs are initially designed as a table top system to cater to the use in the Research Centres.

As this study is to also simultaneously solve the recovery issues in the Palm Oil mills, there is a need to scale-up the effective separator to be able to cater to industrial purposes. As per every machine designed, the strength of the machine is usually studied to prevent breakdown and safety of the machine when in use. This is of crucial importance as it could save a lot of cost in repairing and also prevent unwanted accidents involving the lives of others.

1.5 Study Objectives

Keeping all the above arguments in mind, the study focused on the development of a viable machine that is efficient in enhancing separation and is able to process whole oil palm fruitlets of variable shapes, mass and sizes. The machine must be carefully designed to cater to these differences in properties and with regards to the resulting effects on its oil quality. Consideration of the size and cost is also of utmost importance to prevent high operational and maintenance cost which would then put the whole production system at economic risk.

The specific objectives targeted to achieve the project goals are summarized as follows:

1) to determine physical, mechanical and chemical properties of fresh and sterilized oil palm fruitlets for design consideration of the Drupe Dehusker machine

2) to design, develop, scale-up and evaluate performance and comparison of prototype design concepts of a batch separator machine ('Drupe Dehusker') for the separation of the palm mesocarp and nuts

3) to analyze the Finite Finite Element Analysis (FEA) on the machine components in terms of its Static Structural Analysis and Dynamic/Modal Analysis to obtain the Natural Frequency, Mode shapes and von-Misses Stress

1.6 Scope of Thesis

The research focused on the potential elimination of digestion process and improvements in the current palm oil milling process with the design of a newly-designed batch mechanical system to enhance separation of the palm mesocarp from its nut prior to screw-pressing process. This mechanical system assists in the dehusking process that provides the separation of the two constituents. This mechanical system's main mechanism is achieved through centrifugal force combined with frictional action between the fruitlets and blades incurred in the system, which are placed at their designated positions to ensure maximum detaching effects. The thorough study on the design in terms of its component design, position and material is done to ensure maximum frictional contact between the fruitlets and the blades, thus allowing dehusking of mesocarp to occur. The efficiency study in terms of the successful detachment of the drupe pulp/mesocarp from the nuts, with various adjustable speed and time while ensuring the quality of oil obtained from the dehusked mesocarp using the invention was also looked into. This dehusking process allows for the elimination of the current digestion process as the purpose of the digestion process is now irrelevant with the introduction of the dehusking process. Longer sterilization and higher temperature used during the process is also re-evaluated in this research to obtain the optimum conditions needed if dehusking process is adapted in the mills. The suggested conditions of 95°C,105°C and 120°C at 60, 90 and 120 minutes were studied in this research. This suggested sterilization conditions of the fruitlets were observed based on its effect on the physical, chemical and mechanical properties of the fruitlets. Optimum condition for the sterilization of fresh fruitlets obtained is then used as a suggested condition to pre-treat the fruitlets prior to the dehusking process and the final comparison between the fresh and sterilized fruitlets in terms of its oil quality is tabulated. This is done to prove that the dehusking process allows for the use of both fresh and sterilized fruitlets without affecting the oil quality much. This research also focused on the study of design stability and safety as it is one of the crucial points in introducing a new machine in the industry together with its economic analysis when introduced into the mills as it is a new process.

1.7 Thesis Organization

The introduction in Chapter 1 generally gives an insight on the oil palm fruitlets, which is the subject of study in this research. This insight is important to denote that the fruitlet consist of two constituents that make up the fruit, which is the mesocarp and nut. These two constituents also generate two types of oil: crude palm oil and palm kernel oil, with the screw-pressing technique being the primary method of extraction. The challenges encountered during the oil extraction process in palm oil mills, particularly during the screw-pressing process, are also discussed in Chapter 1, as well as the need of the sterilising process as the first stage in the oil extraction process to ensure efficient extraction. Apart from that, the lack of technology to assist manual slicing of the mesocarp off the nuts of the fruitlets in the Research Centres were also highlighted here. Understanding the current problems faced in the Palm oil industry, they are then converted into main problem statements to be solved through this research. With that, the objective of the research and its significance and contribution of the research are also presented in Chapter 1.

Chapter 2 looks into the palm oil industry in Malaysia, current practice of palm oil extraction in the mills and its significance to this research, previous studies on the physical, chemical and mechanical properties of the oil palm fruitlets, previous studies on palm mesocarp and nut separation, past design studies on peeling of fruits and the mechanism and parameters involved in the machinery design, the significant effect of sterilization process on the subject of matter, previous modelling attempts for machine design related to food and the economic analysis of a new process or machinery in an industry.

Chapter 3 reviews detailed experimental designs and methods in finishing this research. Physical studies of the fruitlets were done as part of the required step in designing a machine effectively. Chemical properties were conducted for the oil obtained from the fresh and sterilized fruitlets at the designated temperature and time. Mechanical properties are also to study on the effect of the sterilization process on the fruitlets. Both the chemical and mechanical properties were investigated to obtain optimum condition to complement the dehusking process through the separator machine. Statistical analysis using one-way annova was used to compare the variation of results obtained and if it is significant at $p<0.05$. Using the physical properties obtained, the development of the machine in terms of its conceptual designs, calculations involved and evaluation process were also discussed in this chapter. The methodologies involved in the study on the machine strength using Finite Element Analysis when operated at the designated conditions were also discussed here. Apart from that, fabrication cost of the machine and the variables required to conduct the economic analysis of the machine were also included in this Chapter.

Chapter 4 presents the findings of the research investigations on the objectives mentioned in Chapter 1. Efficient design concept of the separator machine was invented and named the ‘Drupe Dehusker’. The findings involving the optimum condition of the fruitlets prior to the dehusking process using the ‘Drupe Dehusker’ is also reported in this Chapter. The economic analysis in terms of the Benefit-Cost-Ratio, Return on Investment and Payback Period of the machine if it were adapted in the mill were also discussed here.

Chapter 5 summarizes the significant results obtained throughout the research with recommendations on future research to improve the current scope of study.

1.8 Contribution of Thesis

The present work involved the construction and design of a mechanical system which overcomes the drawbacks of the previously reported implements. The design and developmental stages called for a closer look at the characteristics of the subject matter which is the oil palm fruitlet, the magnitude and direction of the dehusking forces and the required generation mechanism through various concept designs and the analysis of the oil obtained from the prototype.

A Drupe Dehusker machine was invented to dehusk the fibrous outer layer of a fruit from its nut, specifically, the oil palm fruitlets (*Elaeis Guineesensisis*). The system comprised of a drum-type batch system that include a cylindrical drum with its main mechanism through the process of molecular dissociation achieved through centrifugal force combined with frictional action between the fruitlets and blades incurred in the system, which are placed at their designated positions to ensure maximum detaching effects. Operating disc with helix stirrer is situated at ¼ of the peeling compartment volume and is also equipped with its own detachable blades on the disc to encourage the outwards throwing of the fruits to the blade walls which then encourages maximum frictional contact between the fruitlets and the blades, thus allowing dehusking of mesocarp to occur. The detachable steel blades are placed in a cage-like system at an angle of 70 degrees and at the direction opposing the operating disc’s rotation. The blades on the disc are also at 70 degrees and facing outward towards the blade walls. Resulting molecular dissociation with the dehusking of the mesocarp from the nuts, under optimum speed, is achievable with the system. The optimum clearance between the steel blade walls or the ‘peeling basket’ allows for the mesocarp to be collected in the collector at the bottom of the system. On the other hand, the resulting nuts can be found on the operating disc once the process is done. The resulting physical destruction with incipient detachment of the drupe pulp/mesocarp from the nuts, under adjustable speed and time set at its optimum condition to avoid the oxidation mainly of the fruitlet’s natural antioxidants and depending on the type of drupes subjected to the dehusker, is achieved with the device.

No invention of any sort was able to achieve efficient separation of the palm mesocarp from its nuts with minimal oil loss has ever been accomplished before. With that, the details of a simple, sturdy and efficient rotating dehusker unit, financially beneficial to labourers and producers of the Palm Oil Industry, are reported in this study.

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