CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Department of Mechanical Engineering

MASTER'S THESIS

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Processing of desiccated coconut medium under uniaxial compression loading

Supervisor

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Processing of desiccated coconut medium under uniaxial compression loading

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Objectives of thesis

The objectives of the thesis are to:
(i) determine the mechanical properties of coconut desiccated samples under cold and hot pressing processes.
(ii) describe the force-deformation curves of coconut desiccated samples under cold and hot pressing processes.
(iii) calculate the oil extraction yield and energy demand of coconut desiccated samples under cold and hot pressing processes.
(iv) discuss the conventional and modern methods of coconut oil extraction, and identify their advantages and disadvantages.

Methodology

To achieve objectives (i), (ii) and (iii), the experimental research will be conducted at the Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences Prague. A universal compression testing machine (ZDM 50, Czech Republic) and a pressing vessel diameter of 60 mm with a plunger (under cold and hot pressing conditions) will be used for the compression test. The cold pressing condition will deal with the laboratory temperature of the pressing vessel and plunger as well as the sample without any heat treatment. The hot pressing condition will subject the pressing vessel and plunger and the sample to heating temperatures of 40, 60 and 80 °C throughout the oil extraction process. The coconut-desiccated samples will be measured at an initial pressing height of 100 mm. A preset load of 400 kN and a speed of 5 mm/min will be applied. The data will be analyzed statistically using Statistica 13 software. Objective (iv), however, will be achieved through a detailed literature review.

Code for compiling the MSc. Thesis

1. Introduction

1.1 Research problem statement

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The proposed extent of the thesis

60–70 pages

Keywords

Coconut medium, oil processing, extraction techniques, utilization, quality characteristics

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Recommended information sources

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Qian, Y. and Rudzinska, M. Chapter 28 – Factors affecting the quality of produced unconventional seeds oil. Multiple Biological Activities of Unconventional Seed Oils, 2022, 345–361.

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ABSTRACT

The study aimed at exploring the effects of different pre-treatment temperatures on desiccated coconut medium under uniaxial compression test under cold and hot pressing. A general overview of the coconut plant was investigated to better understand the background. There were some typical techniques for extracting oil from oil-bearing plants, along with descriptions of their optimization principles. Additionally, a review of the physical and mechanical characteristics of coconut plant was conducted. The experimental data were statistically analyzed by employing descriptive statistics, correlation and regression techniques using STATISTICA 13 software. The initial pressing height of the samples was measured at 100 mm using a pressing vessel of diameter 60 mm with a plunger. The samples were pre-treated at temperatures from 40 to 120, all at a constant time of 30 minutes. Sample laboratory temperature of 20 ℃ served as the control. The dependencies between the force and deformation curves were recorded at a maximum force of 200 kN and a speed of 5 mm min^{-1}. Parameters calculated were mass of oil 76.26 ± 0.57 (g), oil yield 58.56 ± 0.43 (%), oil expression efficiency 94.64 ± 0.70 (%), energy 1.20± 0.00 (kJ), and hardness 2.26 ± 0.05 (kN/mm). The ANOVA results showed that deformation, energy, hardness and oil yield were significant (P-value < 0.05) with high coefficients of determination (R^2) between 92 and 99 %.

Keywords: Coconut medium, oil processing, extraction techniques, utilization, quality characteristics

DECLARATION

I hereby declare that this Master's Thesis "*Processing of desiccated coconut medium under uniaxial compression loading"* is the result of my own work and that it has not been submitted to this University or any institution for a degree. All references, however, used in the development of the work have been dully acknowledged in the text and provided in the list of references.

In Prague Date: 28.3.2024

…… ……

Amarsanaa Tsogoo

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1 INTRODUCTION

Coconut tree crops, primarily cultivated in Asia and the Pacific region, are increasingly recognized as one of the most abundant natural resources globally. Coconut has been used as a food source for 4000 years and is now grown in large plantations throughout the tropics (DebMandal and Mandal 2011). In particular, the coconut industry plays a significant role in the exporting movement in some Southeast Asian nations (Marina et al., 2009). People have been interested in the coconut plant for years because the seeds and fruits contain essential lipids. As a result, they have become a significant economic factor. Producing good and high-quality coconut products and solving the problems faced by the existing coconut industry will be the best thing to develop in the future. Everything in a coconut is beneficial, including the roots, stems, midribs, leaves/sticks, spadix, coir, shells, coconut water, coconut meat, coconut oil (Barlina et al., 2022). Coconut oil is richness in medium chain fatty acids (MCFAs) with a good digestibility (Marina et al., 2009). The coconut produces two types of oil called virgin coconut oil (VCO) and refined, bleached, deodorized coconut oil (RBD). Virgin coconut oil is colorless, free of sediment with natural fresh coconut scent. It is free from rancid odor or taste (Agarwal and Bosco 2017).

Oil extraction from oilseeds is a crucial processing step. In essence, few techniques are employed for this. The methods directly affect the quality and quantity of oil extracted from oilseeds. One is the solvent extraction technique, in which an oil present in the preconditioned oilseed is dissolved by a solvent when it comes into contact with it. The separated mixture is then heated to evaporate the solvent and extract the oil. The technique is extremely effective (oil recovery is over 98%) and is most widely used in North America (Lavenburg et al., 2021).

One of the other common techniques are hydraulic and screw press. In this procedure, the preconditioned oilseed is put through a screw press, which releases the oil using a combination of high temperature and force. Depending on the oilseed and pressure used, the method is relatively less efficient as it only recovers 70-80% of the oil that is readily available. Pretreatments and operating circumstances determine the effectiveness of the screw press. Oilseed pressing is relatively free of any polluting or fire-hazardous materials and has much lower initial and ongoing costs than solvent extraction. For oil quality and cost of production, the mechanical pressing and the traditional method are preferrable. Most importantly, the mechanical pressing involving screw presses or expellers can obliterate the traditional kernel

oil extraction process, which is mostly done by the local people as subsistence (Demirel et al., 2022). Uniaxial or unidirectional process provides one of the practical solutions for improving the mechanical pressing of vegetable oils (Kabutey et al., 2021; Demirel et al., 2022). It also requires proper speed and pressure to extract the oil well. Uniaxial and screw press are commonly used methods for oil expression in a small-medium scale production compared to large scale production, where advanced techniques and green solvents, such as microwave-assisted and pressurized liquid extractions are used (Ng et al., 2020).

The present study considered the uniaxial approach, where the bulk oilseeds are placed in a pressing vessel of a known diameter that contains holes at the bottom that allow the oil to escape while retaining the seedcake (Kabutey et al., 2021). In this process, mechanical properties such as force, speed, heating temperature, and pressing vessel diameter need to be described, in terms of mechanical behavior, oil yield, oil expression efficiency, and energy demand (Ng et al., 2020; Correa and Resende 2008; Gupta and Das 2000).

This thesis explored a Description of the coconut plant and its utilization. Processing of coconut oil, Conventional and modern extraction methods, and the extraction principles of those methods were described. Advantages and disadvantages were discussed. Also, the quality characteristics and composition of coconut oil were reviewed. Some of the detection of adulteration were described.

1.1 Research and problem statement

With global population growth and market demand, the demand for coconut, coconut oil products has increased. With a large amount of coconut plantations worldwide, more research is needed on coconuts to make coconut-based products a lifestyle change. More research into coconuts could lead to economic and environmental advancements. Also, one of the primary reasons for growing coconut is for energy. As a result, for a large amount of oil production, energy consumption in the coconut compression process should be minimized. However, it should be done most appropriately and optimally without adversely affecting the environment.

Similiar study, Ng et al., (2020) studied the deformation, oil expression efficiency, energy, and energy volume of oil to compress bulk soybeans under different pre-treatment temperatures. Mpagalile et al., (2005) studied the compression efficiency of coconut with a range of variables was used. These variables included pressing time, pressure, temperature, and moisture content. Kabutey et al., (2013) studied the pressing force, seed hardness, deformation energy, and volume of the seed of Jatropha curcas L. seeds under different pressing vessel diameters and seed pressing heights. Mejeh and Nwadiboni (2023) studied oil weight and oil yield of coconut oil under different size and different moisture content of coconut sample. Also, Adekola (2014) studied the compression efficiency of coconut with a range of variables was used. These variables included heating time, heating temperature, and moisture content.

In this study, coconut oil production from desiccated coconut medium under uniaxial compression loading under cold and hot pressing conditions to measure deformation, percentage oil yield, oil expression efficiency, and energy of coconut. In order to obtain enough oil with the least amount of energy, the ideal temperature for pressing the seeds can be found in the oil production process.

1.2 Objectives

(i) To determine the mechanical properties of coconut desiccated samples under cold and hot pressing processes.

(ii) To describe the force-deformation curves of coconut desiccated samples under cold and hot pressing processes.

(iii) Calculate the oil extraction yield and energy demand of coconut desiccated samples under cold and hot pressing processes.

(iv) Discuss the conventional and modern methods of coconut oil extraction, and identify their advantages and disadvantages.

2 LITERATURE REVIEW

2.1 Description of coconut plant and utilization

2.1.1 Origin, Biology/Botany

The coconut (Cocos nucifera L.) is a monocot belonging to the family Arecaceae and to the subfamily Cocoidae. Subfamily Cocoidae includes 27 genera and 600 species, and coconut is currently the sole species of the genus Cocos (Perera, 2013). The word "coconut" (or the archaic "cocoanut") can refer to the entire coconut palm, seed, and fruit, which is a drupe, not a nut, according to botanical terms. The name comes from the old Portuguese and Spanish word coco, meaning head or skull, after the three indentations on the coconut shell that resemble facial features (Ahuja et al., 2014). They are a cultural icon of the tropics and are common in coastal tropical regions. In addition to being called the "Tree of Life" in the Philippines, all parts of the coconut palm are useful and economically important (Kappally et al., 2015).

Coconuts are theorized to have been domesticated for the first time by the Austronesian peoples of Island Southeast Asia, and they expanded throughout the Neolithic era by sea through their seaborne migrations as far east as the Pacific Islands and as far west as Madagascar and the Comoros. By the provision of a transportable source of food and water as well as the raw materials needed to construct Austronesian outrigger boats, they were essential to the lengthy sea trips of the people of Austronesia. In the past, South Asian, Arab, and European seafarers spread coconuts around the Atlantic and Indian Ocean coasts. The populations of coconuts can still be separated into the Pacific and Indo-Atlantic subspecies based on these independent introductions.

As of 2021, Indonesia, the Philippines, and India are leading the world in coconut production. In 2021, the world's coconut production was about 58 million tons, of which Indonesia produced 17.16 million tons (29.5%), the Philippines 14.72 million tons (25.4%), and India 14.3 million tons (24.6%). These 3 countries account for 79.5 percent of the total coconut production in the world (Shahbandeh 2023). The Figure 1 below shows the global distribution

of coconut production.

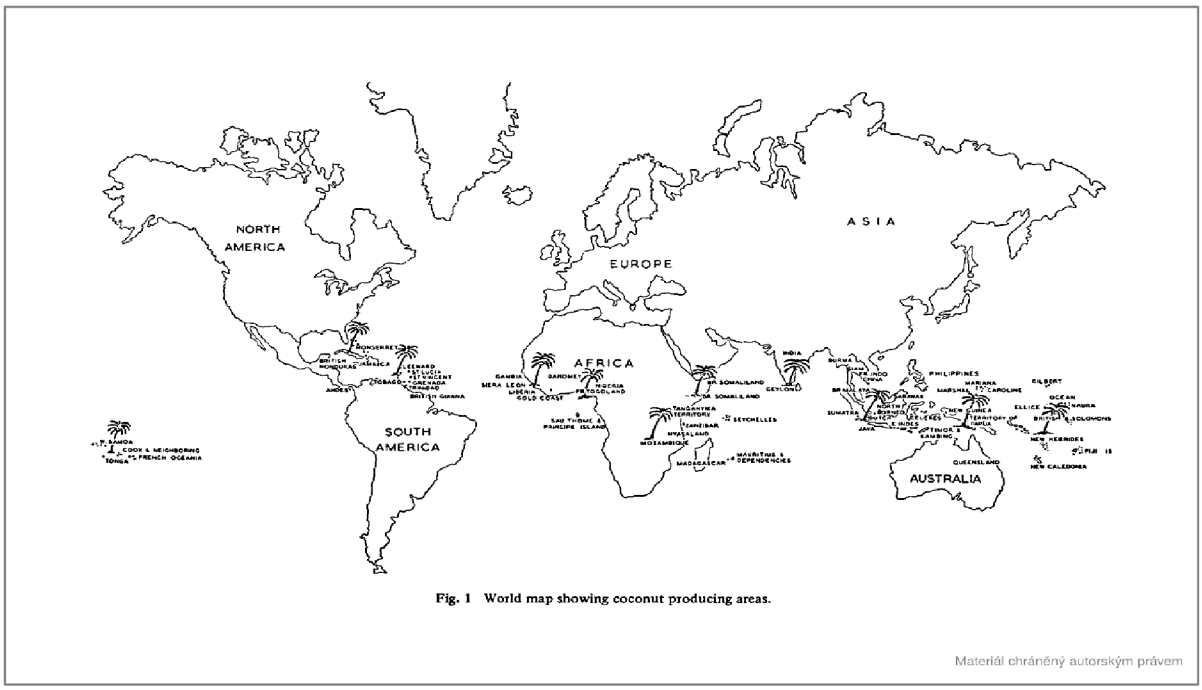

Figure 1. World map showing coconut producing areas

2.1.2 Description of coconut plant

Cocos nucifera is a large palm, growing up to 30 metres tall, with pinnate leaves 4-6 m long, and pinnae 60–90 centimetres long; old leaves break away cleanly, leaving the trunk smooth. A tall coconut palm tree in fertile soil can produce up to 75 fruits per year, but it usually produces less than 30. Coconut palms produce their first fruit in five to eight years if properly cared for and grown, and it takes 15 to 20 years to reach peak production.

2.1.2.1 Fruit

The fruit is a fibrous drupe. It consists of, from the outside in, a thin hard skin (exocarp), a thicker layer of fibrous mesocarp (husk), the hard endocarp (shell), the white endosperm (kernel), and a large cavity filled with liquid (water). When immature, the exocarp is usually green, sometimes bronze. Wide variation in fruit shape and size exist within types and populations. The fruit is a fibrous drupe. It consists of, from the outside in, a thin hard skin (exocarp), a thicker layer of fibrous mesocarp (husk), the hard endocarp (shell), the white endosperm (kernel), and a large cavity filled with liquid (water). When immature, the exocarp is usually green, sometimes bronze. Wide variation in fruit shape and size exist within types and populations. Fruit shapes vary from elongated to almost spherical and weigh between 850

and 2000 g when mature (Chan and Elevitch 2006).

Mature fruits have a thick fibrous husk covering the well-known single-seeded nut of trade, which are ovoid or ellipsoid in shape and 300–450 mm in length and 150–200 mm in diameter. The tiny embryo's copious endosperm, which is made up of both liquid and meat, is enclosed in a hard shell. Coconut fruits float readily and have been dispersed widely by ocean currents and by humans throughout the tropics (Britannica, Encyclopaedia., 2023).

2.1.2.2 Genetics

There are two distinct types according to size and stature of the palm - Talls and Dwarfs. Talls are by far the more commonly grown variety around the world. Tall is wild type and characterized by elongated, triangular-shaped fruits with very small elongated nuts and a high husk-to-nut ratio. Talls was much valued by the early Polynesians for its long fibers used in making braided cordage known as “sennit.”

Dwarfs are smaller in size and stature than the Talls. Dwarfs are flower significantly earlier than the Talls and produce smaller nuts but in greater numbers. Dwarfs come into bearing at 3 years compared to 5 years for the Talls. Their smaller size allows for higher density plantings, but dwarfs do not adapt to varying conditions as well as the Talls (Chan and Elevitch 2006). Dwarf palm varieties typically have a shorter productive lifespan, typically lasting around 30 to 40 years. During this time, they yield an average of 100 to 151 nuts per palm annually.

Table 1. Difference between Talls and Dwarfs palm

Trait	Tall	Dwarf
Palm height	20-30 m	10-15 m
Lifespan	60-100	30-40
Time taken to flower	5-8 years	3-5 years
Nuts/palm/year	40-70	100-150
Whole fruit size	Very small to large	Very small to medium
Copra amount and quality	200 g/nut, good	80-100 g/nut, inferior
Leaves per year	12-18 per year	20-22 per year

2.1.2.3 Leaves

Until about the age of 1 year, leaves remain entire. Thereafter the leaves (called “fronds”) are progressively more pinnate. Fronds range in length from 4.5 to 5.5 m, with the petiole accounting for one-fourth of that length. Leaflets are 50–150 cm long by 1.5–5 cm broad. The frond is firmly attached to the stem by the petiole's enlarged base. The color of the fruit is indicated by the petiole and rachis, which can be green or bronze. Talls in their prime produce about 12–18 leaves per year, and Dwarfs produce 20–22 leaves per year (Chan and Elevitch 2006).

2.1.3 Environmental requirement

In order to grow well, coconut plants need a warm, humid climate, but they cannot withstand extreme cold. A mean annual temperature of 27°C, an evenly distributed rainfall of 1500–2500 mm (60–100 in) per annum, and relative humidity above 60% provide the ideal climatic conditions for vigorous growth and yield. Coconut plant has remarkable adaptability to a wide range of soils, including light, medium, and heavy soils. However, medium textures and well-draining soil are the best for them. It tolerates alkaline soils up to pH 8 and acidic soils of pH 4.5 and above, but grows best in soils with an ideal pH of 5.5-7 (Chan and Elevitch 2006).

2.1.4 Utilization of coconut plant

2.1.4.1 Uses of coconut wood

High-density coconut wood is used to construct posts, power and telecommunication poles,

trusses, floor tiles, railings, and other load-bearing structures. Medium-density coconut wood is used to construct walls, horizontal studs, ceiling joists, and door/window frames. Low-density coconut wood is used for internal parts of a building as ceiling and wall lining in the form of boards and Shingles.

2.1.4.2 Use in construction

One of the most common applications of coconut wood is construction. Coconut wood is appropriate for housing components such as trusses, purlins, walls, joists, doors, window frames, and jalousies. Low-density coconut wood (from the center of the stem) should be used only for non-load structures like walls and panels, whereas high-density coconut wood can be used for load-bearing structures like trusses and joints. The small diameter of the coconut stem limits the size of sawn lumber; thus, the optimum width and thickness of boards that are typically recovered are 25 and 50 mm. High-density coconut wood could also be used as floor tiles (parquet), girts, balustrades and railings, posts, power and telecommunication poles, floor joists, purlins, trusses, and other load-bearing structures (Nzdl.org 1997). Coconut logs must be appropriately treated if they are to be used in ground contact under open circumstances (such as posts or poles for electrical wires). Walling, horizontal studs, ceiling joists, and door/window frames can all be built with medium-density boards. Coconut wood with a density of less than 400 kg/m3 should not be used as a structural framing material. They can, however, be used as ceiling and wall lining in the interior of a building in the form of boards and shingles. The difficulty of nailing high-density wood finishes and the subsequent splitting of those finishes pose a problem for coco wood's structural application.

2.1.4.3 Use in furniture and high-value products

Coconut wood has the potential to be a promising material for the creation of furniture, novelty items, and other handicrafts due to its lovely grain and alluring natural appearance. In terms of appearance, high-value coconut wood products such as parquet floors, furniture, decorative interior walls, and various novelties and curio items such as walking sticks, ashtrays, hammer handles, egg cups, plates, bowls, vases, and so on are equally, if not more, comparable to traditional wood species commonly used in the furniture industry. As a result, effective product promotion, quality furniture, and other high-value coconut wood products can gain a potential share in domestic and global markets. Coconut wood has the potential to be used to produce

high-value, export-quality finished products. However, untreated freshly-cut lumber, like many other conventional wood species, is easily attacked by mold and staining fungi, especially if the material needs to be correctly stacked and exposed to a humid environment during air drying. Degradation of fungi and pinhole borers can also contribute to further degradation during air drying. As a result, prophylactic treatment is required if it is used in the production of high-value products for export. Therefore, kiln drying should be done to bring its moisture content to the level most appropriate for equilibrium with its location in service. Kiln drying should be done because improperly dried coconut wood will show checks and cracks on the surface or as a result of changes in relative humidity.

a. Charcoal

Coconut trunks and other sawmill byproducts can be used right away to make charcoal and generate energy. In terms of fuel properties, coconut wood is similar to other woods, though the density range within the stem causes variation in energy potential. According to studies using the 2-cord double-walled masonry block kiln, good quality charcoal for household use can be produced with an average yield of 25% based on oven-dry weight. The heating value of charcoal and charcoal briquettes is higher. Compared to wood, they produce less smoke and are simple to handle. Briquettes must be made of coconut trunk charcoal to improve their strength, density, and shipping characteristics before they can be used as fuel. There is already a method for briquetting coconut trunk charcoal. At a rate of 500 Lb/h, a briquetting facility in the Philippines makes 1.5 oz ovoid-shaped briquettes. The briquettes' crushing and burning qualities are both excellent. Coconut trunk charcoal briquettes can be effectively bound together using sorghum grain.

2.1.4.4 Chemicals

Coconut trunk charcoal can also be used to make activated carbon. Carbon disulphide, moulding resins, black powder, electrodes, calcium carbide, silicon carbide, carbon monoxide, paint pigments, pharmaceuticals, catalyst reactors, brake linings, and gas cylinder absorbents can all be made from this product. Coconut waste products can also be used to make ethanol.

a. Pulp and paper

Trials in the Philippines and New Zealand have shown that coconut stem wood can be used for

making pulp and paper with qualities similar to those made from most hardwoods. However, the high proportion of fines (from parenchyma tissue) significantly reduces overall yields. These small parenchyma cells also cause problems in the manufacture of particle boards.

2.2 Processing of coconut oil

In principle, the process of coconut oil is divided into two groups, which is the wet and dry method. The dry process, also known as copra, presses coconut oil from the dried coconut flesh using a pressing machine. With the wet method, fresh coconuts are pressed to extract both coconut milk and oil, which are then separated.

a. Wet process

Wet oil processing through the coconut milk production stage, with gradual heating at controlled temperatures, has been carried out by the ICOPRI. Coconut oil has a water content of 0.02%-0.03%, a free fatty acid content of 0.02%, is colorless, and smells good. Then in coconut oil processing where the testa is not removed, the moisture content and free fatty acid content up to 2 months of storage are still around 0.03%. According to a previous study, oil conditions are categorized as a natural or clear oil. In further development, the coconut oil produced is called VCO. VCO is a coconut oil product that is naturally processed from fresh coconut kernel or its derivatives (coconut milk and fresh residue), which have not gone through further processing such as refining.

i. Raw material preparation

Old coconuts, which is 11 to 12 months old and have brown coir skin, are the ones that will be used to make coconut oil. High oil output is produced by mature coconut fruit.

ii. Processing of milk

Crushed fruit kernel added with water in a ratio of 1: 2. Then the extract is shaken and then squeezed and filtered until coconut milk is obtained. We recommend that grate and squeeze the coconut milk using a coconut grater and a coconut press

iii. Separation cream (rich in oil)

The coconut milk is poured into a clear plastic bucket and set aside for 3 hours. During this

time, coconut milk will be separated into three layers: the top layer (rich in oil), the middle layer (rich in protein), and the bottom layer (seasonal). Based on the findings of 30 MTT fruits, 16 kg of kernel were obtained (average kernel weight 500 g/fruit). Coconut milk yielded approximately 48 L after production. Furthermore, during the three hours of incubation, the cream in the middle layer is suctioned out with a plastic tube. The cream yielded is approximately 10 L.

iv. Heating milk

The cream is heated in a frying pan until it boils, at a temperature ranging from 100C to 110C. After the oil has been slightly cooked, it is separated into "blondo" and oil (the blondo remains white), cooled, and then filtered to obtain the oil. The results showed that using 3 L of kerosene fuel, the duration from 10 L of cream heated obtained 3,750 mL oil was around 3 hours. Additionally, the "blondo" is separated through filtering. Blondo, despite being a byproduct, still contains 10%-15% oil.

b. Dry process

The dry method of processing coconut oil begins with the kernel being processed into copra, either by smoking and drying in an oven or by direct heating in the sun. In general, copra that is processed at the farmer level is smoked, so to obtain coconut oil that is ready for consumption, additional processes such as Refined, Bleaching, and Deodorization (RBD) are required. The RBD process has an effect on oil quality, including the destruction of health-supporting micro-constituents. When making coconut oil from white copra, the copra must be dried for 27 hours. Currently, developing oil processing technology with the Direct Micro Expelling-Oven Dried (DME-OD) system at 40°C requires 4 hours of oven time once the process is obtained with a moisture content of 0.10% and Direct Micro Expelling-Sun Dry (DME-SD) with a moisture content of 0.17%.

Direct Micro Expelling-Fluid Bed Dried (DME-FBD) is a method of processing coconut oil that uses a flat bed drying system. Dan Etherington (2016) created the DME method in Vanuatu, Solomon Islands, Fiji, and Asia Pacific. The advantage of this method is that it is hygienic, and the energy is derived from biomass waste such as shells, coir, and wood waste, making it environmentally friendly and inexpensive. Since 2018, the Indonesian Palm Crops Research Institute (IPCRI) has been using Direct Micro Expelling-Fluid Bed Dried (DME-

FBD) technology. The study using Coconut In Mapanget (DMT) coconuts produced a VCO yield of 18.39% from 16 coconuts and Quick Salak (GSK) coconuts produced a VCO yield of 16.38% from 26 coconuts.

2.2.1 Conventional and modern extraction methods

Extraction is the process of obtaining a valuable product from a raw material. The two primary categories are conventional and non-conventional (modern). Traditional methods include maceration, decoction, and Soxhlet extraction. The majority of solvents used in large-scale extraction equipment, including hexane, are byproducts of the petrochemical industry. High energy consumption and the widespread use of such solvents have negative environmental consequences. Non-traditional methods thus concentrate on using various physical or enzymatic means to improve extraction (ultrasonic, pressure, microwaves, etc.) while using fewer solvents or specialized "green" solvents (supercritical fluids).

2.2.1.1 Soxhlet extraction method

A Soxhlet extractor is a piece of laboratory equipment invented in 1879 by Franz von Soxhlet that has been a standard technique for over a century. Soxhlet extraction is a model extraction technique, used to extract compounds, typically lipids, from solid or semi-solid matrices. Soxhlet extraction involves transferring partially soluble components from a solid to the liquid phase using a device called a Soxhlet extractor. A percolator (boiler and reflux), a thimble (typically made of thick filter paper), and a siphon mechanism are the three major components of a Soxhlet extractor. The solid substance is placed within the primary chamber of the Soxhlet extractor, contained within a filter paper thimble. The heated-to-reflux solvent enters the main chamber and slowly transfers the partially soluble components to the solvent (Rsc.org, 2019).

i. Extraction process of Soxhlet extraction

Heat is initially applied to the still pot (solvent volume in the still pot should be three to four times that of the Soxhlet chamber, and the still pot should not be overfilled.). Following the evaporation of the solvent in the still pot, the condenser receives the solvent by way of distillation. Any solvent vapor is made to cool and drip back down into the chamber containing the solid substance by the condenser. Warm solvent progressively fills the compartment containing the solid substance. In the heated solvent, some of the desired chemical dissolve.

When the Soxhlet chamber is nearly empty, the Siphon transfers it back to the distillation flask.

2.2.1.2 Maceration

Maceration is old table-top extraction method commonly used for the extraction of medicinal plants. This is a very simple and cheapest extraction method with the disadvantage of long extraction time and low extraction efficiency (Hidayat and Wulandari 2021). It may be used to extract thermolabile components. The solvent is poured to cover the crushed source completely and is allowed to stand for 3 days with frequent agitation until the soluble matter is dissolved (Pai et al., 2022). To complete the extraction process, the mixture is strained and decanted. However, this extraction process is time-consuming (Zhao et al., 2019).

2.2.1.3 Percolation

Percolation is more efficient than maceration because it is a continuous process in which the saturated solvent is constantly being replaced by fresh solvent (Hidayat and Wulandari 2021).

2.2.1.4 Decoction

The extract from decoction contains a large number of water-soluble impurities. A decoction cannot be used for the extraction of thermolabile or volatile components (Hidayat and Wulandari 2021). Hard materials like roots, bark, and seeds are typical sources; they are pulverized and boiled with water in a closed vessel. The extract is then cooled and filtered from the insoluble residue (Perera et al., 2017). The extraction times of a decoction are relatively short, typically 5 to 10 minutes. However, if the bioactive compounds that must be extracted are not water soluble, this could be a disadvantage. Moreover, a large solvent to solid ratio is also involved.

2.2.1.5 Microwave assisted extraction

In the technique known as microwave-assisted extraction (MAE), solvents that are in contact with a sample are heated using microwave energy in order to separate analytes from the sample matrix into the solvent. The primary benefit of this method, which is intrinsic to MAE, is its capacity to heat the sample solvent mixture rapidly. This technique is used for the extraction of organic compounds from solid samples. Previously microwave ovens are used for the digestion of samples for metal analysis.

Microwave irradiation uses an electromagnetic field with a specific frequency close to a photochemically activated reaction; the frequency ranges between 300 MHz and 300 GHz. Nevertheless, only a few frequencies are permitted for medical, scientific, and industrial use; these range between 0.915 and 2.45 GHz globally. MAE dielectric heating is suitable for heat-sensitive bioactive compounds.

Rapid heating is generated in MAE when ionic species or polar molecules are used, and this heating generates collisions with molecules from the surrounding, which do not require higher pressure. In most cases, the extraction time and microwave power fall between 30 s to 10 min and 25 to 750 W, respectively (Kaufmann and Christen 2002).

i. Extraction process of Microwave assisted extraction

Microwave-assisted extraction works is different from other types of extraction methods. Because the extraction occurs as a result of changes in the cell structure caused by electromagnetic waves (Azwanida 2015). As provided in Figure 1, this process of extraction involves a synergistic combination of mass and heat transfers working in the same direction whereas the mass transfer in conventional methods occurs from inside to outside of the substrates and heat transfer occurs from the outside to inside of the substrate (Deo et al., 2015). The series of phenomenological steps that occur during the microwave-assisted extraction (MAE) are as follows:

a. The irradiation heat from a microwave is transferred to the solid through the microwave-transparent solvent without absorption;

b. The intense heating of the (a) above results in residual microwave-absorbing in the solid being heated up;

c. The heated moisture evaporates and creates a high vapor pressure;

d. The high vapor pressure breaks the cell of the substrate;

e. Cell wall breakage enhances the releases of the extract from the samples (Deo et al., 2015).

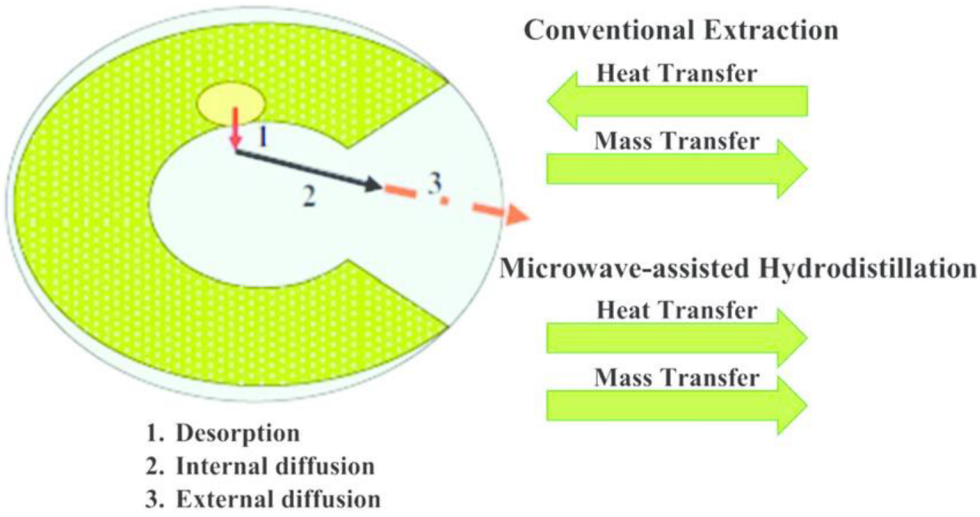

Figure 2. Heat and mass transfer mechanisms in conventional and microwave extraction

Additionally, the extracting solvent is absorbed into the plant sample through diffusion, causing the dissolution of solutes into the solvent until saturation. This solution diffuses to the plant surface through effective diffusion and then transfers to the bulk solution.

The closed vessel and the opened vessel are the two different types of MAE systems. When high temperatures and pressures are required for the extraction process, closed vessel systems are used. And open vessel systems are used when atmospheric pressure conditions are required in the extraction process (Kaufmann and Christen 2002). The operation of open and closed MAE is described below.

a. Open MAE system

In the open MAE system, the sample is located in an open vessel to which an appropriate organic solvent is added. The microwave generated from the magnetron is directed by the waveguide onto the sample/solvent system, thus causing the solvent to boil and rise up within the vessel. The hot solvent then comes into contact with a water-cooled reflux condenser. This causes the solvent to condense and return to the vessel. This process is repeated for a short period of time so enabling organic compounds to be desorbed from the sample matrix into the organic solvent. Typical operating conditions for atmospheric MAE are as temperature up to the boiling point of the solvent, extraction times, 5-20 min and power setting of 100% at 300 W. As the extraction vessels are open to the atmosphere, minimal cooling time is required post-extraction prior to handling the vessels.

b. Closed MAE system

In the closed MAE system, microwaves enter the cavity (the oven), and are dispersed by a mode stirrer. The mode stirrer allows an even distribution of microwaves within the cavity. The other significant difference in the pressurized MAE system is that the sample and solvent are located within the sealed vessel, which is usually made of microwave-transparent materials such as poly (ether imide) or trifluoromethoxy polymers. Operating conditions for pressured MAE are pressure < 200 psi, the temperature is within the range of 110-145^{o} C and power setting of 100% at 900 W.

2.2.1.6 Ultrasound assisted extraction

Ultrasonic-assisted Extraction (UAE) is a quick and efficient extraction technique that uses ultrasound to create rapid movement of solvents, resulting in a faster mass transfer speed and faster extraction. Ultrasound are the mechanical waves having frequency (> 20 kHz) higher than audible frequency range of human hearing (20 Hz to 20 kHz) (Teng et al., 2016). Compared to other advanced extraction techniques, UAE is more economic, eco-friendly, and convenient (Teng et al., 2016). The statements were supported by (Ofori-Boateng and Lee 2013) where it is reported that UAE is a simple and fast technique, which consumes less energy, time and materials, thus producing more pure products at higher yields (Ofori-Boateng and Lee 2013). UAE can be performed under low operation temperature where it can prevent thermal damage to the extracts and preserves the bioactive compounds' properties in term of its structure and molecule, thus UAE is seen as an ideal option for the edible oil industry (Tian et al., 2013). UAE also no prevent the thermal damage on bioactive compounds but it also avoid the damage in plant materials (Yang et al., 2017). There are two ways of ultrasonic irradiation which are direct or indirect contact with sample. Indirect contact means the contact happens through the walls of the sample such as ultrasonic bath system. Ultrasonic bath which was equipped with a temperature-controlled device which helped the recovery of thermo-sensitive compounds including essential oils (Fuad and Don 2016). Direct contact system is more effective in extraction process as it can power up to 100 times better than indirect contact or ultrasonic bath (Medina-Torres et al., 2017).

i. Extraction process of Ultrasonic assisted extraction

In sonication processes, longitudinal waves are created as a sonic wave encounters a liquid medium, which creates regions of alternating compression and rarefaction (expansion) among medium molecules. In these regions of changing pressure, cavitation of formed gas bubbles occurs. During the rarefaction cycle, the surface area of these bubbles increases, which results in increased gas diffusion and an expansion of the bubble. In the compression cycle (i.e., when insufficient ultrasonic energy is provided), these vapor phases cannot remain expanded state, which results in rapid condensation and the release of large amounts of energy (Chemat et al., 2011; Soria and Villamiel 2010). The shock waves created with high temperatures (550◦C) and pressures (50 MPa) (Chemat et al., 2011; Soria and Villamiel 2010) are a consequence of the condensation process. Both high temperatures and pressures generate microjets directed toward solid surfaces (i.e., the herbs or the container wall) as the bubbles collapse onto those surfaces. These microjets are responsible for the degreasing effect of ultrasound on metallic surfaces, and this technique is commonly used to clean materials (Awad et al., 2012).

2.2.1.7 Pressurized liquid extraction

Several research groups have given different names for pressurized liquid extraction (PLE), including accelerated solvent extraction, enhanced solvent extraction, pressured solvent extraction, accelerated solvent extraction, and high-pressure solvent extraction. High pressure is used during extraction by PLE. High pressure causes solvents to remain in a liquid state above their boiling point, which increases lipid solutes' solubility and rate of diffusion in the solvent as well as the solvent's penetration of the matrix. PLE dramatically decreased the consumption of extraction time and solvent and had better repeatability compared to other methods (Zhang et al., 2018). Pressurized liquid extraction has been successfully applied by the researchers at the University of Macau and other institutes in extracting many types of natural products including saponins, flavonoids and essential oil from traditional Chinese medicine (Lv et al., 2010; Xu et al., 2010). Due to the high extraction temperature, some researchers thought PLE could not be used to extract thermolabile chemicals; however, other researchers thought it could be due to the PLE's shorter extraction time. Maillard reactions occurred when PLE was used at 200 °C to extract antioxidants from grape pomace (Vergara-Salinas et al., 2013). Anthocyanins are thermolabile. Gizir et al (2007) successfully applied PLE to obtain an anthocyanin-rich extract from black carrots because the degradation rate of

anthocyanins is time-dependent, and the high-temperature-short-duration PLE extraction conditions could overcome the disadvantage of high temperature employed in the extraction.

i. Extraction process of Pressurized liquid extraction

It is possible to operate with PLE in static and dynamic modes. According to Lehotay and Schenck (2000) the standard procedure includes adding the solvent to the vessel, heating it, and then performing static extraction (no flow). The extract is collected in a vial after this 0.5–20 minutes stage, at which point flow is commenced (dynamic extraction step). If further analyte recoveries are required, the procedure may be repeated. Even while PLE does not require higher temperatures, they are frequently utilized to speed up the extraction and disrupt analyte-matrix connections. In PLE (and extraction in general), the following factors are often important in the following order: (1) solvent; (2) temperature; (3) time; (4) repetitions; (5) pressure.

2.2.1.8 Supercritical liquid extraction

According to Sapkale et al., (2010) Supercritical fluids have been studied since the turn of the century, with the majority of early commercial interest being on the use of supercritical toluene in the 1970s for refining crude oil and shale oil. Moreover, research is being done on supercritical water as a novel synthesis medium and as a way to eliminate hazardous wastes. Supercritical fluid extraction (SFE) involves employing supercritical fluids as the extracting solvent to separate one component (the extractant) from another (the matrix). Although it is often done from a solid matrix, extraction can also be done from liquids. SFE can be used to remove undesired components from a product (such as caffeine) or collect a desired product on a bigger scale. It can also be used as a sample preparation step for analytical purposes (e.g. essential oils). The most popular supercritical fluid is carbon dioxide (CO2), which can occasionally be altered by co-solvents like ethanol or methanol. Supercritical CO2 is extracted at conditions that are higher than the critical temperature of 31 °C and critical pressure of 74 bar. Adding modifiers can change this a bit. The high-value compounds from natural materials are often extracted by supercritical extraction, which uses carbon dioxide under high pressure. The extraction procedure does not produce any solvent remnants, unlike other methods. Moreover, CO2 is non-toxic, non-flammable, tasteless, odorless, inert, and cheap. Due to its low critical temperature of 31°C, carbon dioxide is known to be perfectly adapted to

food, aromas, essential oils, and nutraceutical industries (Sapkale et al., 2010).

Supercritical fluid (SF) is used as the extraction solvent in supercritical fluid extraction (SFE). SF may dissolve a wide range of natural compounds since it has a similar solubility to liquid and a similar diffusivity to gas. Due to slight pressure and temperature changes, their solvating characteristics dramatically changed close to their critical points. Due to its appealing qualities, such as its low critical temperature (31 °C), selectivity, inertness, low cost, non-toxicity, and capacity to extract thermally labile chemicals, supercritical carbon dioxide (S-CO2) was frequently utilized in SFE. S-CO2's low polarity makes it ideal for extracting naturally occurring non-polar compounds like lipid and volatile oil. Modifiers can be added to S-CO2 to increase its solvating properties.

i. Extraction process of Supercritical liquid extraction

The system requires a CO2 pump, a pressure cell to contain the sample, a way to keep the pressure in the system constant, and a vessel to collect the results. It is heated to supercritical temperatures in a heating zone before the liquid is pumped there. Once inside the extraction vessel, it quickly diffuses into the solid matrix and dissolves the material that must be extracted. The extracted material settles out while the dissolved material is whisked out of the extraction cell and into a separator at reduced pressure. After that, the CO2 can either be released into the atmosphere or chilled before being recompressed and recycled.

a. Pumps

Typically, carbon dioxide is pumped as a liquid at pressures of around 50 bars and temperatures below 5°C. Since the solvent is pumped nearly incompressible when it is a liquid. As a supercritical fluid, a large portion of the pump stroke will be "used up" in compressing the fluid, rather than pumping it. A syringe or reciprocating CO2 pumps are frequently employed for small-scale extractions (up to a few grams/minute). Diaphragm pumps are the most common for larger-scale extractions. Typically, cooling of the pump heads and cooling of the CO2 before it enters the pump are both necessary.

b. Pressure vessels

Simple tubing to more sophisticated, purpose-built vessels with quick-release fittings can all be used as pressure vessels. Most extractions are carried out at less than 350 bars, below the minimum pressure requirement of 74 bars. Nevertheless, there are situations when higher pressures are required. For example, when extracting vegetable oils, pressures over 800 bars are occasionally needed for the two phases to mix completely. The vessel has to have a heating source. Smaller jars can be placed inside an oven, and bigger vessels can be heated using oil or electricity. Care must be given if rubber seals are employed on the vessel because the CO2 may dissolve in the rubber and cause swelling. The rubber will also rupture during depressurization.

c. Pressure maintenance

The pressure in the system must be kept up from the pump right through the pressure vessel. Simple restrictors can be utilized in smaller systems (up to 10 mL/min). For smaller systems, a needle valve or capillary tube is trimmed to the appropriate length, which is adjustable to maintain pressure at various flow rates. The use of a backpressure regulator, which maintains pressure upstream of the regulator using a spring, compressed air, or electronically operated valve, is common in larger systems. Whichever method is used, heating must be provided because the CO2's adiabatic expansion causes significant cooling. But it's really problematic. If the sample contains water or other extracted material, this can be troublesome since it could freeze in the restrictor or valve and lead to blockages.

d. Collection

Lower pressure than the extraction vessel is used to pass the supercritical solvent into the vessel. The density and dissolving power of supercritical fluids vary sharply with pressure. Therefore, the solubility in the lower-density CO2 is much lower, and the material precipitates for collection. A series of vessels at decreasing pressure can be used to fractionate the dissolved material. The CO2 can be recycled, depressurized to atmospheric pressure, and vented. When performing analytical SFE, the pressure is usually reduced to atmospheric levels. At this point, gaseous carbon dioxide is bubbled with a solvent and the sediment components are captured.

e. Heating and cooling

This section is important. Cooling the liquid before pumping and heating it after pressurization preserves the maintained liquid conditions. Heat must be applied to the fluid as it is expanded into the separator to prevent overcooling. For small-scale extractions, it is typically sufficient to pre-heat the fluid in a length of tubing within the oven holding the extraction cell, such as those performed for analytical purposes. The restrictor may be heated electrically or even with a hair drier. The thermodynamic characteristics of the supercritical fluid can be used to calculate the energy needed at each stage of the operation on a larger-scale.

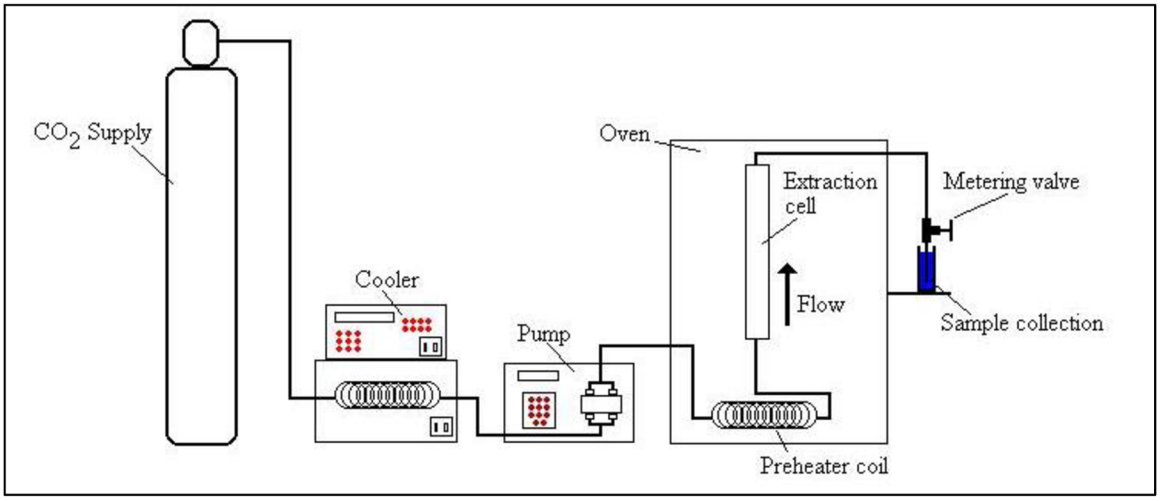

Figure 3. Schematic diagram of SFE apparatus

Table 2. A brief summary of various extraction methods for natural products

Method	Solvent	Temperature	Pressure	Time	Volume of organic solvent consumed	Polarity of natural products extracted
Maceration	Water, aqueous and non-aqueous solvents	Room temperature	Atmospheric	Long	Large	Dependent on extracting solvent
Percolation	Water, aqueous and non-aqueous solvents	Room temperature, occasionally under heat	Atmospheric	Long	Large	Dependent on extracting solvent

Decoction	Water	Under heat	Atmospheric	Moderate	None	
Soxhlet extraction	Organic solvents	Under heat	Atmospheric	Long	Moderate	Dependent on extracting solvent
Pressurized liquid extraction	Water, aqueous and non-aqueous solvents	Under heat	High	Short	Small	Dependent on extracting solvent
Supercritical liquid extraction	Supercritical fluid (usually S-CO2), sometimes with modifier	Near room temperature	High	Short	Small or none	Nonpolar to moderate polar compounds
Ultrasonic assisted extraction	Water, aqueous and non-aqueous solvents	Room temperature, or under heat	Atmospheric	Short	Moderate	Dependent on extracting solvent
Microwave assisted extraction	Water, aqueous and non-aqueous solvents	Room temperature	Atmospheric	Short	None or moderate	Dependent on extracting solvent
Hydro distillation and steam distillation	Water	Under heat	Atmospheric	Long	None	Essential oil (usually non-polar)

Source: (Zhang et al., 2018)

2.2.2 Advantages and disadvantages

2.2.2.1 Advantages of Maceration

a. Maceration is a straightforward process employing uncomplicated
b. Utensils and tools.
c. A skilled operator is not necessary.
d. The energy-saving procedure.
e. Suitable for some substances with very low solubility
f. Suitable method for less potent and cheap drugs

2.2.2.2 Disadvantages of Maceration

a. Unfortunately, the duration of extraction time is long and sometimes takes up to weeks.
b. Do not fully remove the drugs.
c. It is very slow process and time consuming.
d. More solvent is necessary.

2.2.2.3 Advantages of Percolation

a. Takes less time to complete than maceration.
b. It may be able to extract elements that are thermolabile.
c. Appropriate technique for expensive and powerful medications.
d. Quicker and more thorough extraction.

2.2.2.4 Disadvantages of Percolation

a. Takes longer than soxhlation.
b. More solvent is needed.
c. A skilled individual is needed.
d. Throughout the procedure, particular attention should be paid to the material's particle size.

2.2.2.5 Advantages of Decoction

a. Appropriate for extracting chemicals that are heat stable.
b. This technique does not need more sophisticated or expensive equipment.
c. That is simple to carry out.
d. An operator need not be trained.

2.2.2.6 Disadvantages of Decoction

a. Effective for extracting chemicals that withstand heat.
b. Less expensive and complicated equipment is not needed for this procedure.
c. That is simple to perform.
d. An operator need not be trained.

2.2.2.7 Advantages of Soxhlet extraction

a. Significant quantities of plant materials can be removed at once.
b. Consistently employ solvent
c. After extraction, this procedure does not call for filtration.
d. The type of matrix is irrelevant to this method.
e. That is a really easy method.
f. Displacement of transfer equilibrium through repeated contacts between new solvent and the solid matrix.

2.2.2.8 Disadvantages of Soxhlet extraction

a. The possibility of thermally destroying some compounds cannot be disregarded if the plant material contains heat labile compounds since the samples are heated to a high temperature for a length of time.
b. The extraction procedure is time-consuming and labor-intensive.
c. The procedure allows for minor adjustments to a limited number of variables. Because it takes so long and uses so much solvent, the Soxhlet extraction process is heavily criticized.

2.2.2.9 Advantages of Pressurized liquid extraction

a. Shorter extraction time, decreased solvent consumption, decreased sample handling and increased yield
b. Raising the temperature can boost the effectiveness of the extraction process because it makes the target analytes more soluble, which helps to reduce analyte-matrix interactions and promotes analyte diffusion to the matrix surface as well as mass transfer of organic molecules to the solvent.
c. High pressure may boost the solvent's penetration of the sample matrix and keep the solvent in a liquid form at high temperatures.

2.2.2.10 Disadvantages of Pressurized liquid extraction

a. The high-water percentages in the samples reduce the effectiveness of analyte extraction when utilizing hydrophobic organic solvents because water prevents interaction between the solvent and analyte.
b. The pressure and temperature conditions have a direct impact on the PLE's efficiency.

2.2.2.11 Advantages of Supercritical liquid extraction

a. Eco-friendly, simple organic solvent removal.
b. It is speedy because the swift back diffusion of analytes in the SCF shortens the time required for the extraction stage, which is completed in about 20 minutes.
c. It is suitable for extracting and removing low-volatility chemicals from solid or liquid forms.
d. Thermal deterioration is possible (low operating conditions).

2.2.2.12 Disadvantages of Supercritical liquid extraction

a. Natural and spiked samples perform very differently in terms of efficiency.
b. The number of techniques documented in the literature whose efficacy is inferior to that offered by Soxhlet techniques.
c. The weakly durable SF extractors, particularly the limitation and trapping units.

2.2.2.13 Advantages of Ultrasonic assisted extraction

a. Low energy use, short extraction times, minimal damage to active compounds, and high extraction yields
b. Ultrasound-assisted extraction has the potential to accelerate the extraction process.
c. Using ultrasound-assisted extraction, the yield of extracted compounds can be increased.
d. The ultrasound device is more affordable and easier to use than other contemporary extraction techniques, like microwave-assisted extraction.

2.2.2.14 Disadvantages of Ultrasonic assisted extraction

a. It is unable to renovate the solvent during the extraction procedure
b. Following extraction, filtration and rinsing procedures are required, which adds time to the entire process
c. High use of solvents
d. Expensive, producing undesirable changes in molecules, and requiring optimization.

2.2.2.15 Advantages of Microwave assisted extraction

a. Use a small amount of organic solvent to extract many samples simultaneously in MAE.
b. Shorter extraction times.
c. Enhanced yield.
d. Improved precision
e. Suitable for compounds that are thermolabile.

2.2.2.16 Disadvantages of Microwave assisted extraction

a. The system's relatively high maintenance requirements and initial cost are the technique's primary drawbacks.
b. Microwaves can also be ineffective when the target molecules or solvents are nonpolar or volatile, and using high temperatures can result in the degradation of heat-sensitive bioactive substances.

2.3 Quality characteristics and composition of coconut oil

The physical and chemical properties of oil can be used to determine the best application for it, as well as to evaluate the various stages of processing and the oil's quality. Oil's physical and chemical properties heavily influence how it is used in products. Color, boiling point, softening point, slipping point, specific gravity, refractive index, smoke point, solubility, melting point, odor, and flavor are all physical properties of oil. These fatty acids' glycerol properties have a significant impact on the chemical composition of oil. The most important chemical properties are those that have been hydrolyzed and oxidized, which can be determined by measuring the acid and peroxide values, respectively. The saponification number also determines the type of fatty acid, and the iodine value indicates saturation. The physicochemical properties of coconut oil, palm oil, palm kernel oil, and soybean oil are compared in the table below.

Table 3. Physicochemical properties of coconut and other oils

Properties	**Coconut oil**	**Palm oil**	**Palm kernel oil**	**Soybean**
Density (g/kg)	0.920	0.900	0.900-0.910	0.910-0.920
Refactive index	-	1.456-1.458	1.415-1.495	1.471-1.475
Cloud point (°C)	17	-	-	-
Melting point (°C)	14	-	-	-
Iodine value	7.95	48-56	14.20	117-141
Saponification value	261.5	196-205	244-254	189-195
Acid value (%)	0.46	-	-	0.3-3.0

Source: a) Barlina., et al (2022).

2.3.1 Composition of coconut oil

Different fatty acid types can be distinguished from one another based on the degree of bond unsaturation and the length of the carbon atom chain. Depending on how many carbon atoms they contain, fatty acids can be categorized as either MCFAs (C6-C12) or long chain fatty acids (C14-C24). Fatty acids are classified into monounsaturated fatty acids, such as oleic acid, which is found in palm oil and soybean oil, and polyunsaturated fatty acids, such as linoleic and linolenic fatty acids, which are found in soybean oil. Coconut oil is classified as having

saturated fatty acids. The table below compares the types and amounts of fatty acids found in coconut oil to those found in palm oil, palm kernel oil, and soybean oil.

Table 4. Fatty acids in coconut oil compared to other vegetable oils

Fatty acids	Atomic C number	Coconut oil	Palm oil	Palm kernel oil	Soybean
Caproic	C6	-	-	0.3	-
Caprylic	C8	0.25	-	3.9	-
Capric	C10	5.05	-	4.0	-
Lauric	C12	55.90	-	49.6	-
Myristic	C14	22.20	1.23	16.0	-
Palmitic	C16	8.88	41.78	8.0	14.04
Stearic	C18	2.21	3.39	2.4	4.07
Oleic	C18:1, n-9	4.38	41.90	13.7	23.27
Linoleic	C18:2, n-6	1.18	11.03	2.0	52.18
Linolenic	C18:3, n-3	-	-	-	5.63
Arachidonic	C20	-	-	-	-

Source: (Barlina et al., 2022)

Table 5. Quality of virgin coconut oil

Characteristic	**Amount**
Relative density	0.919-0.920
Refractive index	1.4480-1.4492
Moisture content	0.1-0.5
Insoluble impurities	0.05
Soap value	250-260
Iodine number	4.10-11.00
Free fatty acid, max (%)	0.50

Source: (Barlina et al., 2022)

Table 6. Fatty acid composition of virgin coconut oil

Atomic number	**C6**	**C8**	**C10**	**C12**	**C14**
Amount	0.4-0.6	5.0-10.0	4.5-8.0	43.0-53.0	16.0-21.

Table 7. Fatty acid composition of virgin coconut oil

Atomic number	**C16**	**C18**	**C18:1**	**C18:2**	**C18:3**
Amount	7.5-10.0	2.0-4.0	5.0-10.0	1.0-2.5	<0.5

Table 8. Quality characteristics of virgin coconut oil from Mapanget Tall coconut and Asian Pacific Coconut Community (APCC)

Quality parameters	**Mapanget Tall**	**APCC standard**
Color	clear	Clear
Odor	Not rancid	Not rancid
Peroxides number (meq/kg)	0.73	≤3.0
Moisture content (%)	0.11	≤0.5
Iodine number	7.24	4.1-11.0
Saponification value	255.67	250-260

Source: a) Barlina., et al (2022).

2.4 Characterization of coconut oil and detection of adulteration

In India, 14 brands of coconut oil are banned by the Food Safety and Standards Authority of India (FSSAI) due to adulteration (Priya et al., 2022). In addition to disappointing consumers, this adulteration poses safety and health risks. The sale of coconut oil that has been tampered with harming oil millers. A report noted that 90% of the oil traded as coconut oil is palm kernel oil (Priya et al., 2022). There are two standard methods to detect and quantify adulterants in CO and VCO that have been reported, viz, spectroscopic techniques and chromatographic techniques coupled with chemometric tools such as principal component analysis, partial least square regression, discriminant analysis, and clustering analysis (Priya et al., 2022). Therefore, authentication and adulteration control are critical in the VCO industry. Different analytical techniques such as spectroscopic techniques (FTIR spectroscopy, NIR spectroscopy, Raman spectroscopy, ultraviolet–visible spectroscopy, mass spectroscopy, nuclear magnetic spectroscopy), chromatographic techniques (gas chromatography and high-performance liquid chromatography), thermal techniques (differential scanning calorimetry) and other techniques have been applied for the identification and quantification of VCO adulteration to date. Some of the techniques are described below.

2.4.1 Vibrational Spectroscopy for the Determination of Adulteration in coconut oil

When electromagnetic radiation interacts with the vibrational states of the atomic nuclei within the corresponding molecules, vibrational spectroscopy analyzes the results. Vibrational spectroscopic techniques have various advantages over other analytical techniques, such as nondestructive, rapid analysis, no tedious sample preparation, and low running costs (Priya et al., 2022). Infrared (near, mid, or far) and Raman spectroscopy are included in vibrational spectroscopy. The food business has made extensive use of vibrational spectroscopy in conjunction with chemometrics. In the works cited below, which are discussed in the following sections, it has been explained how to use Raman and infrared spectroscopic techniques to identify and quantify the adulterants found in coconut oil.

2.4.1.1 Determination of Adulteration by FTIR Spectroscopy

In FTIR spectroscopy (Figure 4), multiple frequencies can be measured simultaneously by interferometric modulation of radiation in the range of 4000 to 400 cm−1 wavenumber to

identify and quantify food constituents conjugated FTIR with attenuated total refectance (ATR) and chemometrics (partial least square regression — PLS) to detect the adulterant (palm kernel olein) in virgin coconut oil (VCO) (Priya et al., 2022).

For data collection using FTIR, 14 sets of pure VCO and 18 sets of adulterated VCO containing up to 50% by volume of palm kernel oil were used. The cross-validation produced a high coefficient of determination (R2) value of 0.9875 and a 1.70 RMSECV value for the PLS calibration model created with the actual adulteration concentration versus the predicted adulteration concentration. In order to classify the pure and adulterated samples, discriminant analysis (DA) using 10 principal components (PC) factors was used. This method produced 100% accurate classification, with not a single sample being misclassified. The detection and measurement of adulterated palm oil in VCO was done using FTIR in conjunction with ATR and PLS. The PLS calibration model was developed using twenty-four sets of VCO samples that had been tampered with by adding palm oil mixtures containing between 1 and 50% by weight while being exposed to chloroform. For the calibration of the model, forty independent samples were used. The spectral regions were used to establish an APLS calibration model in order to establish the level of adulteration that displayed a linear relationship. R2 (0.999) and SEC (0.533) values were used to describe the differences between the actual and FTIRpredicted values. R2 and the standard error of prediction (SEP) were both 0.996 and 0.993 as a result of the cross-validation. Additionally, they were able to categorize pure and adulterated coconut oil with 100% accuracy using discriminant analysis using seven principal component factors, demonstrating that the developed model is capable of predicting adulteration up to a 1% lower control limit.

The virgin coconut oil adulterated with sunfower oil and corn oil was determined using FT-MIR spectroscopy in conjugation with chemometrics (PLS and DA) (Rohman and Man 2011). The classification of pure and adulterated oil samples by discriminant analysis using 10 principal components was 100% accurate. The PLS regression model produced the lowest RMSEP values for both adulterants and the highest R2 (0.999) value for the adulterants that could be quantified successfully.

2.4.1.2 Determination of Adulteration by NIR Spectroscopy

When measuring the molecular overtones and combination bands of a few fundamental vibrations, near infrared (NIR) spectroscopy (Figure 4) makes use of the NIR region (800 to 2200 nm) of the electromagnetic spectrum (Pandiselvam et al., 2022; Rathnakumar et al., 2020). The adulteration of palm olein in VCO was detected and quantifed by FT-NIR using a PLS model (Jayatunga et al., 2020). Twenty VCO samples were prepared for the analysis using a vortex at 1500 rpm for two minutes, ranging from 1 to 70% v/v adulteration of palm olein in CCO. For the purpose of predicting adulteration, a PLS model was created and validated, and its regression coefficients (R2) ranged between 0.9997 and 0.9993. The calculated PLS values and the actual adulteration levels have a strong correlation. In order to identify adulteration in edible oils, NIR spectroscopy has been used. For example, a study found that coconut oil had been tainted with paraffin oil (Raj et al., 2018). The samples, which are labeled P0, P1, P2, P3, P4, P5, P10, and P100, are made with varying amounts of paraffin oil: 0, 1, 2, 3, 4, 5, 10, and 100%. Pure paraffin oil has additional peaks in its NIR spectrum (1200–1800 nm) that correspond to the vibration of an alkyl group. In contrast, the spectrum of coconut oil also has peaks at 1904, 1928, and 2132 nm, which corresponds to the vibration of the carbonyl group. The adulterant content was quantified with the highest R2 value of 0.986 at 2132 nm, where the intensity of the peak decreased with a decrease in paraffin oil content. The electromagnetic region between 750 and 2600 nm is where NIR spectroscopy operates. The samples' C-H, O-H, and N-H bond molecules absorb NIR waves at a particular wavelength. These absorbances are used to predict adulteration, and the difference in absorbance is measured.

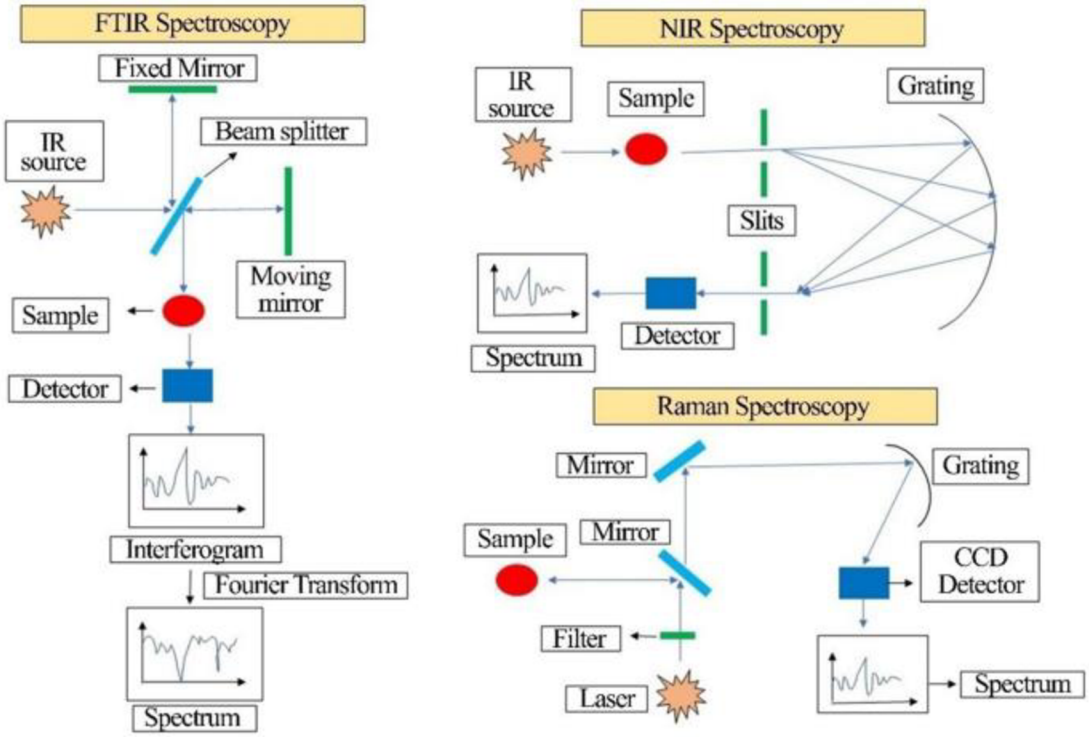

Figure 4. Schematic diagram of (a) FTIR spectroscopy and (b) NIR spectroscopy

2.4.1.3 Determination of Adulteration by Raman Spectroscopy

The molecular structure of a sample can be determined using Raman spectroscopy, which offers distinct fundamental vibrations. When coconut oil was tainted with other relatively cheap oils like palm kernel, castor bean, peanut, soybean, sunflower, and vaseline oils, Raman spectroscopy and multivariate curve resolution alternating least squares (MCR-ALS) were used to identify the adulteration. The collected spectra had a resolution of 2 cm1 and ranged from 3200 to 200 cm1. According to reports, the control charts successfully distinguished between adulterated samples (adulteration level — greater than 2%) and pure ones. They were produced using the MCR-ALS analysis score values. Regression models built using the MCRALS algorithm were used to quantify the adulterant content, and the results were excellent (De Géa Neves and Poppi, 2018).

2.4.2 Chromatographic Techniques for the Determination of Adulteration in coconut oil

The chromatographic methods (Figure 5) used to detect adulterated coconut oil are based on quantifying particular marker compounds. The marker compounds that can be determined by HPLC include tocopherols, triglycerides, tocotrienols, phenolic compounds, polar fraction, and pyropheophytins, whereas the marker compounds that can be determined by gas chromatography include fatty acid methyl esters (FAME), sterols (stigmasterol and campesterol), sigmastadiene, triacylglycerol, and volatile compounds (Priya et al., 2022).

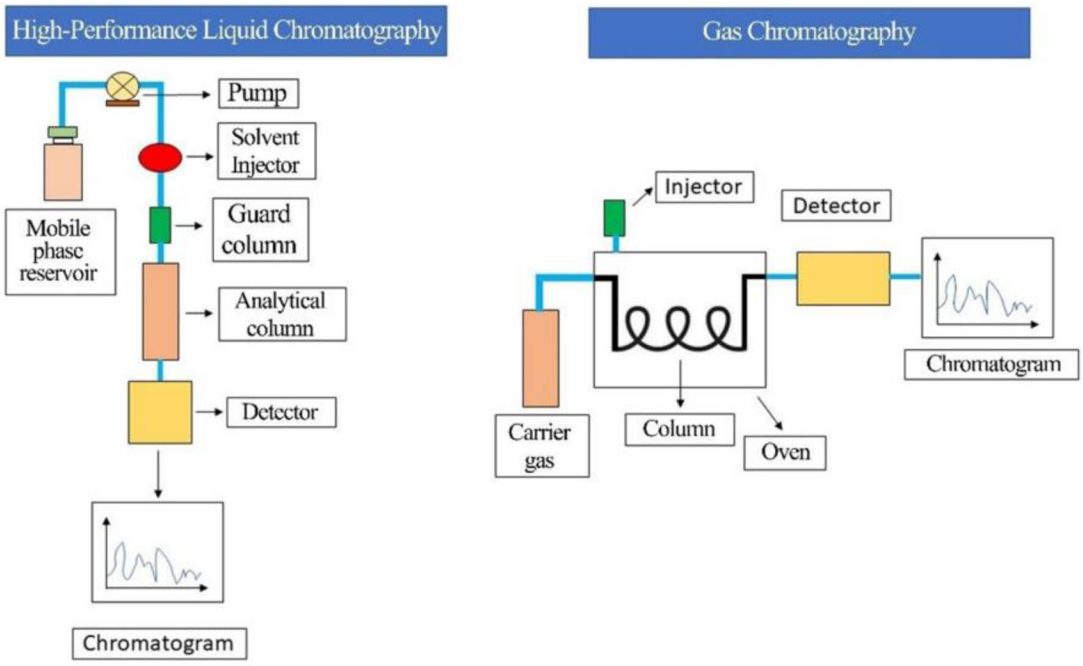

Figure 5. Schematic diagram of (a) FTIR spectroscopy and (b) NIR spectroscopy

2.4.2.1 Determination of Adulteration by High-Performance Liquid Chromatography

Trilaurin (C36), dilaurin-monocaprin/myristin-caprylin-laurin (C34), and dilaurin-monomyristin (C38), which are the three main triacylglyceride molecular species of coconut oil, was chosen as a detection index for quantifying the level of palm kernel oil. While the ratio of the peak areas of dipalmitoyl-monoolein and trilaurin was selected as a detection index to measure the amount of palm olien adulterant in coconut oil. Depending on the type of oil and degree of adulteration, the developed RP-HPLC based method performs satisfactorily, with detection accuracy ranging from 78 to 98% and a lowest limit of detection of 2 to 4 percent.

Since there was a lack of information regarding the HPLC method for CO and VCO authentication, it was discussed as a potential tool for identifying adulteration in other oils. HPLC was employed to differentiate the oil quality by calculating the amounts of phenols and tocopherols in virgin olive oil. Methanol and an isopropanol-methanol mixture were used to extract virgin olive oil simultaneously. The extract was then separated by HPLC using a reversed phase C18 column and a solution of acetic acid, water, methanol, acetonitrile, and isopropanol (Tasiola-Margari and Okogeri 2001). Similarly, in another study, triglycerides of extra/virgin olive oil tainted with 5% soybean oil were determined by HPLC for adulteration detection (Jabeur et al., 2014). The extra-virgin olive oil was adulterated with the soybean, sunflower, and corn oils at the levels of 1, 2, 3, 4, 5, and 10% w/w which were separated using an ion trap mass spectrometer interfaced to the HPLC system through an atmospheric pressure chemical ionisation (APCI) (Fasciotti & Pereira Netto, 2010). A 60:40 acetone/acetonitrile mixture, a 137-column temperature of 30 °C, a flow rate of 1.5 mL/min, and an injection volume of 20 L of the sample were used in the study to separate the TAGs at isocratic elution. The TAGs were then identified by their mass and equivalent carbon number (ECN). In comparison to extra-virgin olive oil, all seed oils had a greater absolute difference between theoretical and experimental ECN42 content (ECN42). The value of the ECN42 cannot be greater than 0.20 for edible virgin olive oil, 0.30 for lampante olive oil, 0.50 for olive pomace oil, and 0.60 for crude olive pomace. A reverse-phase LiChrospher octadecyl (ODS) column (250 mm3 mm; 5 m) and a guard column with comparable properties (Vydac ODS, 201TP54, 2.1 mm; 10 mm) were used in the HPLC analysis of extra virgin olive oil (EVOO) and a commercial oil blend labeled as 15% (w/w) of olive oil in soybean oil. The analysis parameters included a constant flow rate of 0.7 mLmin1, a 35 °C column temperature, and a 5L injection volume.

2.4.2.2 Determination of Adulteration by Gas Chromatography

Gas chromatography mass spectrometry (GC–MS) and NMR fngerprinting techniques in conjugation with chemometrics were employed for the classifcation of diferent types of oil, including coconut oil (Fang et al., 2013). 14 different types of oils could be grouped together using both PCA models. When compared to models created using NMR data, the PLS-DA and OPLS-DA models (orthogonal projections to latent structures — discriminant analysis) produced better classification specificity and sensitivity. However, information from either of the two methods can be effectively used to build a database of oils and fats for the identification

of unidentified samples. Cholesterol was used as a marker in a new technique that uses two-dimensional gas chromatography (GC GC) coupled with time-of-flight mass spectrometry (TOF-MS) to detect the presence of animal fats in VCO. In comparison to one-dimensional GC, GCGC systems provided a better baseline separation of trimethylsilyl ether (a sterol derived from cholestanol and cholesterol), allowing for accurate determination of the adulterant content. This method can identify the presence of chicken fat, beef tallow, mutton tallow, lard, or their blends in VCO, with a detection limit as low as 0.25% (Xu et al., 2015). GC system can be used to detect and quantity of adulteration in VCO by developing and validating an appropriate method.

3 Materials and Methods

3.1 Experiments under uniaxial compression loading

The experiments were conducted at the laboratory of the Department of Mechanincal Engineering, Faculty of Engineering, Czech University of Life Sciences Prague.

3.2 Sample

The sample (desiccated coconut medium) was obtained from the Department of Mechanincal Engineering, Faculty of Engineering, Czech University of Life Sciences Prague. Using an electronic balance Kern 440-35 (Kern & Sohn GmbH, Balingen, Germany) with an accuracy of 0.001 g, a sample with a constant weight of 130.22 g was weighed before drying and the experiment was continued. The experiment was carried out in a laboratory wtih a temperature of 20.63 ± 1.17 °C and humidity of 32.5 ± 6.10 %.

3.3 Determination of moisture content

The sample moisture content was determined to be 2.60 ± 0.08 (% w.b.) according to Blahovec (2008) as described in equation (1).

$$MC = \left[\left(\frac{m_b - m_a}{m_b}\right) \cdot 100\right] \quad (1)$$

where MC is the percentage of moisture content of sample (% w.b.), $m_a$and$m_b$are the masses of the sample before and after oven drying (g).

3.4 Determination of oil content

The sample percentage oil content of 61.88 ± 0.42 % was used as determined by Andriani (2022) according to the Soxhlet extraction procedure (Niu et al., 2014; Danlami et al., 2015).

3.5 Pretreatments of sample

The laboratory temperature of 20 ◦C of desiccated coconut medium samples were served as the control of the experiment. Before the compression test, samples were pre-heated at 40, 60, 80, 100, and 120 °C at a time duration of 30 minutes using the Memmert oven UF110 (MEMMERT GmbH + Co. KG, Germany).

3.6 Compression tests of sample

The control without pre-treatment and pre-treatment samples were compressed using a universal compression testing machine (ZDM 50, Czech Republic) and a pressing vessel with a diameter of 60 mm, a plunger. The sample's initial pressing height was measured to be 100 mm. Control experiments were carried out at a speed of 5 mm/min and forces of 400kN. Experiments on pretreatment were also carried out at a speed of 5 mm/min but with a force of 200kN. The force-deformation data from each compression test was used to calculate the parameters mentioned in Section 4.2. The mass of the seedcake was then measured using an electronic balance (Kern 440-35; Kern & Sohn GmbH, Balingen, Germany) with an accuracy of 0.01 g. The compression test of the sample and extracted oil are shown in Appendix 1-11.

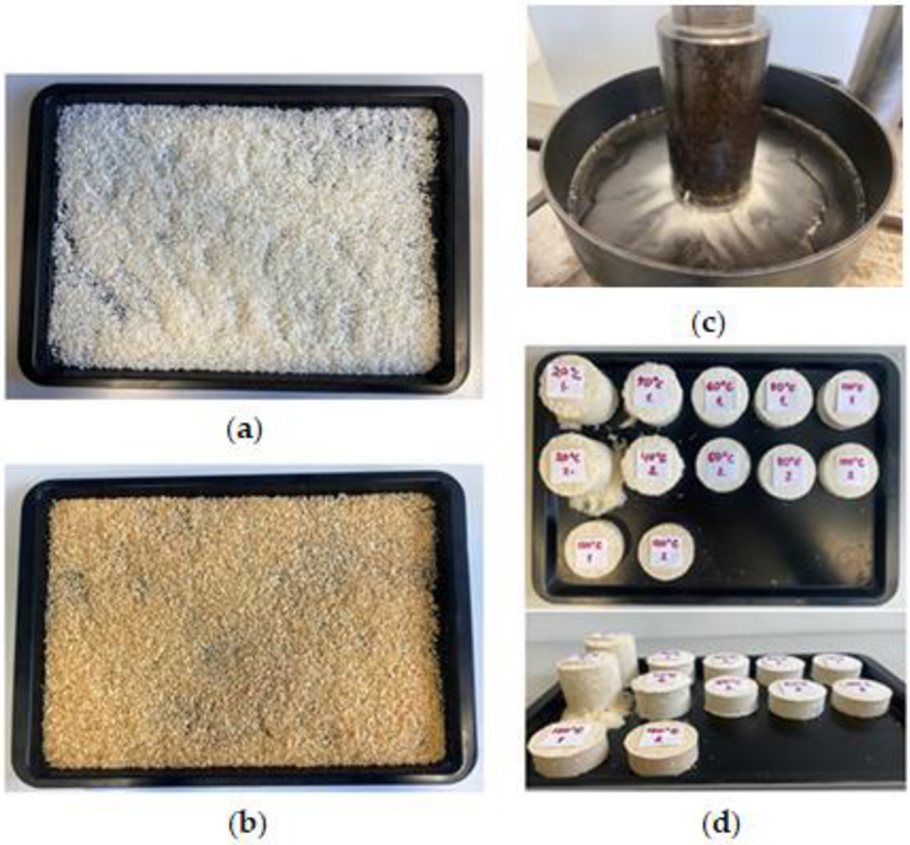

Figure 6. Measured sample (a) at control temperature of 20 °C; (b) pretreatment temperature at 120 °C; (c) compression test of sample and (d) seedcake obtained after the compression test.

3.7 Parameters determined from the compression tests

3.7.1 Oil yield

The oil yield was determined according to Deli et al., (2011) and Chanioti and Tzia, (2017) as given in equation (1).

$$O_{yd} = \left[\left(\frac{M_{ol}}{M_{is}}\right) \cdot 100\right] \quad (1)$$

where $O_{yd}$is oil yield (%), M_{ol} is the mass of oil determined as the difference of mass of the seedcake and the initial mass of the sample M_{is} (g).

3.7.2 Oil expression efficiency

The oil expression efficiency was determined according to (Hernandez-Santos et al., (2016)) as given in equation (2).

$$O_{exp} = \left[\left(\frac{O_{ld}}{O_{sc}}\right) \cdot 100\right] \quad (2)$$

where O_{exp} is the oil expression efficiency (%) and O_{sc} is percentage of oil content (%) in sesame seeds sample determined by soxhlet extraction.

3.7.3 Deformation energy

The deformation energy was determined according to Gupta and Das (2000) and Herak et al., (2015) as given in equation (3).

$$E_{df} = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2}\right) \cdot (x_{n+1} - x_n)\right] \quad (3)$$

where E_{df} is the deformation energy (J), $F_{n+1} + F_n$ and $x_{n+1} - x_n$are the compressive force (kN) and deformation (mm), *n* is the number of data points and *i* is the number of sections in which the axis deformation was divided.

3.7.4 Force and deformation

The force, F_R (N) and deformation D_F (mm) values were obtained directly from the compression tests output data.

3.7.5 Hardness

The hardness of the samples was calculated according to Chakespari, Rajabipour and Mobli (2010) as given in equation (4)

$$H_D = \frac{F_R}{D_F} \tag{4}$$

3.7.6 Strain

The strain of the samples was calculated according to Chakespari, Rajabipour and Mobli (2010) as given in equation (5).

$$\varepsilon_T = \frac{D_F}{H_P} \tag{5}$$

where $\boldsymbol{\varepsilon_T}$ *is the strain (-).*

3.7.7 Stress

The stress of the samples was calculated according to Chakespari, Rajabipour and Mobli (2010) as given in equation (6).

$$\sigma_S = \frac{F_R}{A} \tag{6}$$

where $\boldsymbol{A}$ *is the area of the pressing vessel which was calculated to be 2827.43 mm*^{2}*).*

3.8 Statistical analysis

The experimental data were statistically analyzed by employing descriptive statistics, correlation and regression techniques using STATISTICA 13 software (Statsoft 2013). Graphical illustrations were also done by the above-mentioned software and Microsoft Excel.

4 RESULTS AND DISCUSSION

4.1 Mechanical properties of sample

The deformation, strain, force, hardness, and stress were calculated. The results are shown in Table 9, and the highest deformation was 89.87±210 mm, obtained at a temperature of 60 °C, and the lowest deformation was 66.88±4.37 mm, obtained at a temperature of 20 °C. For strains, it was 0.67±0.04 at 20 °C to 0.90±0.02 at 60 °C. The compression force is constant at 200 kN. The highest hardness was 2.34± 0.10 kN/mm, obtained at a temperature of 40 °C, and the lowest hardness was 1.09± 0.09 kN/mm at 20 °C. The stress was 70.74 ± 0.00 MPa. In the 20 °C, stress was 25.60± 0.57 MPa.

Table 9. Determined mechanical properties of sample under cold and hot pressing.

Temperature (°C)	**Time (min)**	**Deformation (mm)**	**Strain (-)**	**Force (kN)**	**Hardness (kN/mm)**	**Stress (MPa)**
20*	0	66.88 ± 4.37	0.67 ± 0.04	72.37 ± 1.60	1.09 ± 0.09	25.60 ± 0.57
40**	30	85.55 ± 3.68	0.86 ± 0.04	200 ± 0.00	2.34 ± 0.10	70.74 ± 0.00
60**	30	89.87 ± 2.10	0.90 ± 0.02	200 ± 0.00	2.23 ± 0.05	70.74 ± 0.00
80**	30	88.26 ± 2.07	0.88 ± 0.02	200 ± 0.00	2.27 ± 0.05	70.74 ± 0.00
100**	30	85.83 ± 4.50	0.86 ± 0.05	200 ± 0.00	2.33 ± 0.12	70.74 ± 0.00
120**	30	88.57 ± 2.05	0.89 ± 0.02	200 ± 0.00	2.26 ± 0.05	70.74 ± 0.00

* Cold pressing (laboratory temperature); ** Hot pressing

4.2 Force-deformation curves of sample

The force–deformation curves of the combination of the factors for all the experiments are illustrated in Figure 7. The deformation energy is represented by the area under the curve. For extracting coconut oil at various temperatures, a maximum force of 200 kN was determined at a speed of 5mm/min. All of the force-deformation curves below exhibited smooth curve behavior, indicating that the maximum oil output was obtained based on the input factors. There was no serration effect on the curves, except the oil sample of 20°C. For the control

experiment, a maximum force of 400 kN was applied with the above-mentioned factors, and the serration effect was observed on the force-deformation curve after 72 kN. The serration effect is characterized by the ejection of the seedcake through the pressing vessel's holes, which affects the compression process.

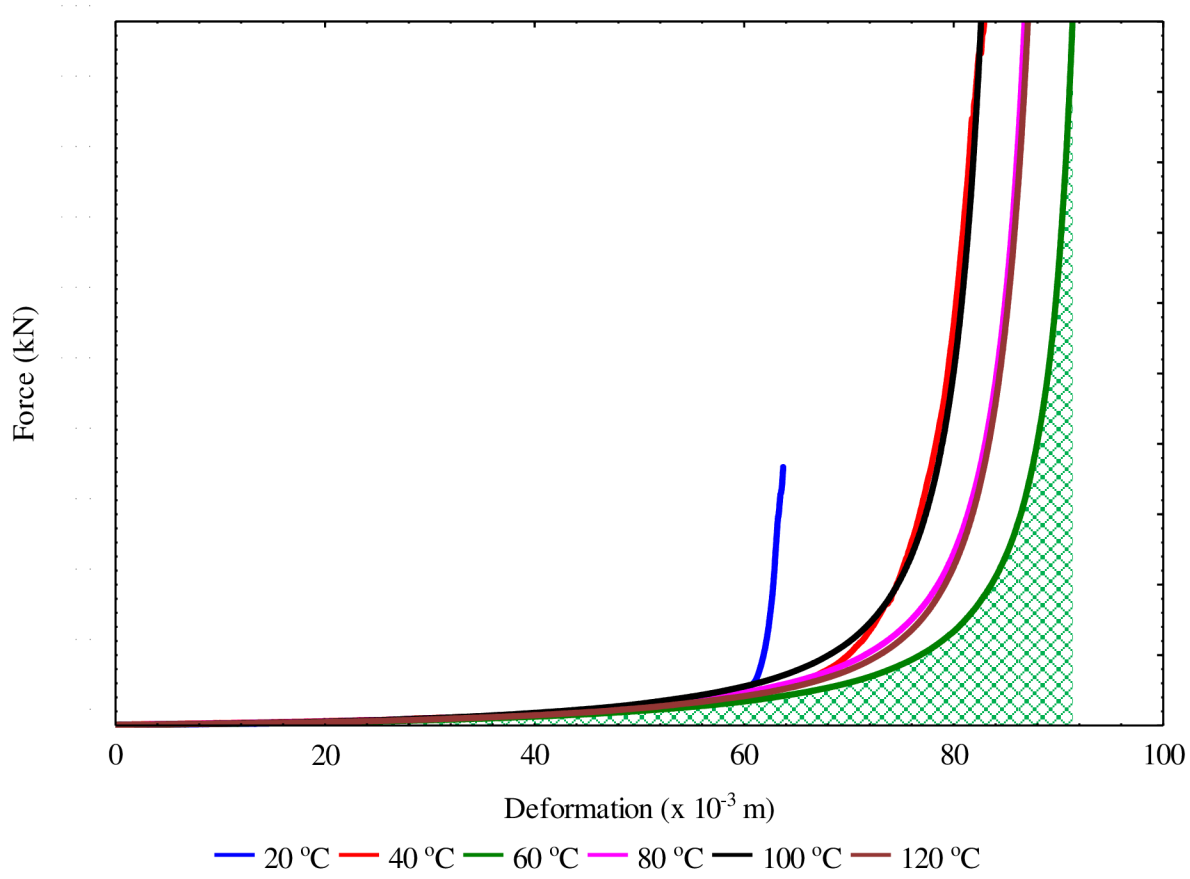

Figure 7. Temperature effect on oil output at initial mass of sample before and after pressing.

4.3 Oil extraction yield and energy demand of sample

The calculated parameters from the sample's initial weight of 130.22 g were the mass of oil, deformation, oil yield, oil expression efficiency, and energy (Table 10). It was observed that the determined or calculated amounts of oil yield and oil expression efficiency increased linearly with the increase in temperature. Energy values increased from heating temperature 20°C to 80°C, and then decreased heating temperature of 80°C to 120°C (Table 10 and Figure 9). At a temperature of 120 °C, the oil mass was measured to be 76.26 0.57 g, and at 20 °C, it was measured to be 11.10 1.05 g. The mean and standard deviation values for oil yield ranged from 8.52± 0.80 to 58.56± 0.43 g, for oil expression efficiency, it's from 13.78± 1.30% to

94.64± 0.70%, for energy from 0.24± 0.01 kJ to 1.20± 0.01 kJ. Figure 8 shows that Sample after pressing and oil output are inversely related. The effect of temperature on mass of oil, oil yield, oil expression efficiency and energy of sample is graphically shown in Figure 10.

Table 10. Determined oil output parameters and energy of sample under cold and hot pressing.

Temperature (°C)	ms_b **(g)**	ms_a **(g)**	ms_{OL} **(g)**	**Oil yield (%)**	OL_{EF} **(%)**	**Energy (kJ)**
20*	130.22	119.12 ± 1.05	11.10 ± 1.05	8.52 ± 0.80	13.78 ± 1.30	0.24 ± 0.01
40**	130.22	69.60 ± 0.98	60.62 ± 0.98	46.55 ± 0.75	75.23 ± 1.21	1.17 ± 0.13
60**	130.22	59.54 ± 0.08	70.68 ± 0.08	54.28 ± 0.07	87.71 ± 0.11	1.20 ± 0.02
80**	130.22	55.53 ± 0.21	74.69 ± ± 0.21	57.36 ± 0.16	92.69 ± 0.26	1.24 ± 0.01
100**	130.22	54.49 ± 0.31	75.73 ± 0.31	58.16 ± 0.24	93.98 ± 0.39	1.21 ± 0.02
120**	130.22	53.96 ± 0.57	76.26 ± 0.57	58.56 ± 0.43	94.64 ± 0.70	1.20 ± 0.00

* Cold pressing (laboratory temperature); ** Hot pressing; ms_b and ms_a: Mass of sample before and after pressing and OL_{EF}: Oil expression efficiency.

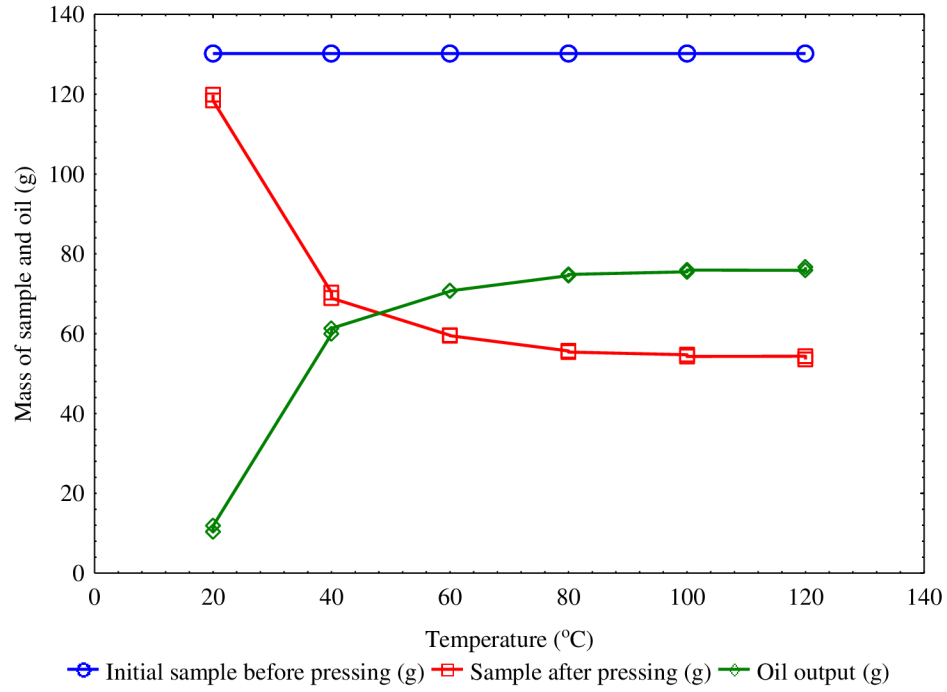

Figure 8. Temperature effect on oil output at initial mass of sample before and after pressing.

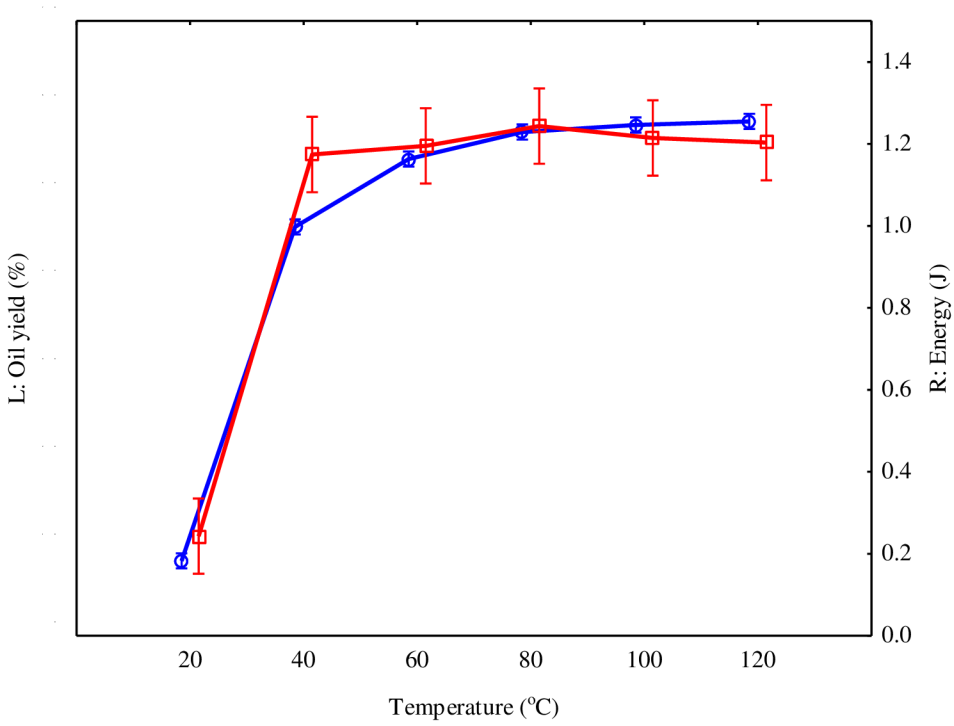

Figure 9. Temperature effect on oil yield and energy of sample.

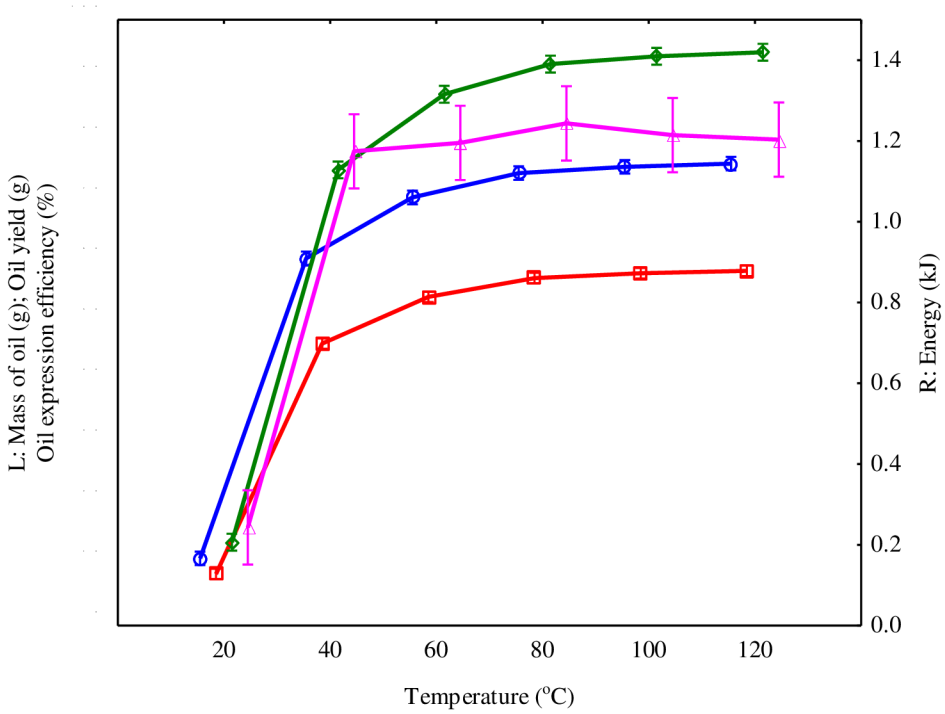

Figure 10. Temperature effect on mass of oil, oil yield, oil expression efficiency and energy of sample

4.4 Statistical interpretation of experimental data

In this section how the response variables: oil yield (%), hardness (kN/mm), deformation (mm) and energy (kJ) were affected by the independent temperature (20, 40, 60, 80, 100, 120 °C) of coconut oil processing under uniaxial compression. The effect of the processing factors on the calculated responses was statistically analyzed using the ANOVA tests of significance (Appendix 12-15). The significance of the models was evaluated based on F-values > P-values or P-values < 0.05. Based on the correlation results of the effect of temperature on oil yield, deformation, energy and hardness of the sample given in Table 11, the varying temperature and deformation, hardness, oil yield, energy had a significant effect ($p < 0.05$) on the responses between 63% to 79%. The ANOVA results showed that deformation, hardness, oil yield, and energy were significant (P-value < 0.05) with high coefficients of determination (R^2) between 92 and 95 % (Table 12)s.The statistical parameters of the determined amounts and regression model for deformation (mm) with temperature effect are given in Tables 13, hardness with temperature effect are given in Table 14, oil yield and energy with temperature effect are given in Table 15 and 16. The ratio of the t-value and the model coefficient gives the standard error. The smaller

standard error values obtained show the statistical accuracy of the regression model for predicting oil yield, deformation, energy, hardness of the sample under temperature changes.

Table 11. Correlation results of the effect of temperature on oil yield, deformation, energy and hardness of the sample.

Effect	**Deformation (mm)**	**Hardness (kN/mm)**	**Oil yield (%)**	**Energy (kJ)**
Temperature (^{o}C)	0.64	0.63	0.79	0.67
P-value	< 0.05	< 0.05	< 0.05	< 0.05

P-value < 0.05 is statistically significant.

Table 12. ANOVA results of the effect of temperature on sample deformation, hardness, oil yield and energy.

Parameters	**R^2**	**F-value**	***P*-value**
Deformation (mm)	0.92	13.568	< 0.05
Hardness (kN/mm)	0.98	68.494	< 0.05
Oil yield (%)	0.99	3070.608	< 0.05
Energy (kJ)	0.99	109.824	< 0.05

P-value < 0.05 is statistically significant; R^2 is the coefficient of determination.

Table 13. Simple regression parameter estimates for sample deformation (mm).

Effect	**Model parameter**	**Standard error**	**t-value**	***P*-value**
Intercept	73.39	4.55	16.11	< 0.05
Temperature (^{o}C)	0.15	0.06	2.63	< 0.05

P-value < 0.05 is statistically significant.

Table 14. Simple regression parameter estimates for sample hardness (kN/mm).

Effect	**Model parameter**	**Standard error**	**t-value**	***P*-value**
Intercept	1.50	0.25	5.93	< 0.05
Temperature (°C)	0.01	0.00	2.60	< 0.05

P-value < 0.05 is statistically significant.

Table 15. Simple regression parameter estimates for sample oil yield (%).

Effect	**Model parameter**	**Standard error**	**t-value**	***P*-value**
Intercept	18.43	7.87	2.34	< 0.05
Temperature (°C)	0.41	0.10	4.08	< 0.05

P-value < 0.05 is statistically significant.

Table 16. Simple regression parameter estimates for sample energy (kJ).

Effect	**Model parameter**	**Standard error**	**t-value**	***P*-value**
Intercept	0.55	0.19	2.84	< 0.05
Temperature (°C)	0.01	0.00	2.86	< 0.05

P-value < 0.05 is statistically significant.

5 Conclusions and Recommendations

5.1 Conclusions

In this study, the following findings were established. Mass of oil, oil yield, oil expression efficiency increased linearly from 11.10 ± 1.05 to 76.26 ± 0.57, and 8.52 ± 0.80 to 58.56 ± 0.43, and 13.78 ± 1.30 to 94.64 ± 0.70 with heating temperatures from 20 to 120 ◦C. The force-deformation and the relaxation force-time curves of the medium desiccated coconut sample were described. The result showed that factors and calculated parameters, the maximum mass of oil of 76.26± 0.57 g, the oil yield of 58.56±0.43 %, and oil expression efficiency of 94.64± 0.70 % were recorded for the factor of force: 200 kN; temperature: 120 °C, and heating time: 30 min. The corresponding energy was 1.20±0.00. The experiment results showed that the optimum conditions for compression of desiccated coconut medium are found to be the heating temperature of 120 °C. The regression models for estimating the deformation (mm), hardness (kN/mm), oil yield (%), and energy (kJ) were determined, and the P values were significant ($P < 0.05$).

5.2 Recommendations

(i) The oil yield (%), the oil expression efficiency (%) and the deformation energy (J) of the desiccated coconut medium should be evaluated by heating only the pressing vessel and plunger without pretreatment the sample.

(ii) To estimate the oil yield or oil expression efficiency, it is necessary to study desiccated coconut medium at different heating times under uniaxial oil extraction process.

(iii) It is important to consider the interactions between the pretreatment temperatures of the medium desiccated coconut and the constant heating of the pressing vessel at a particular temperature during the compression process to estimate highest the oil yield or oil extraction efficiency.

(iv) Using different pressing vessel diameters should be investigated for the medium desiccated coconut under a higher compression load.

(v) To optimize the oil processing factors and their responses, a similar design of experiment should be used in the non-linear compression process involving a mechanical screw press.

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7 APPENDIXES

Appendix 1. Compression test of sample at 20 °C (control temperature) showing the output oil.

Appendix 2. Compression test of sample at 40 °C showing the output oil.

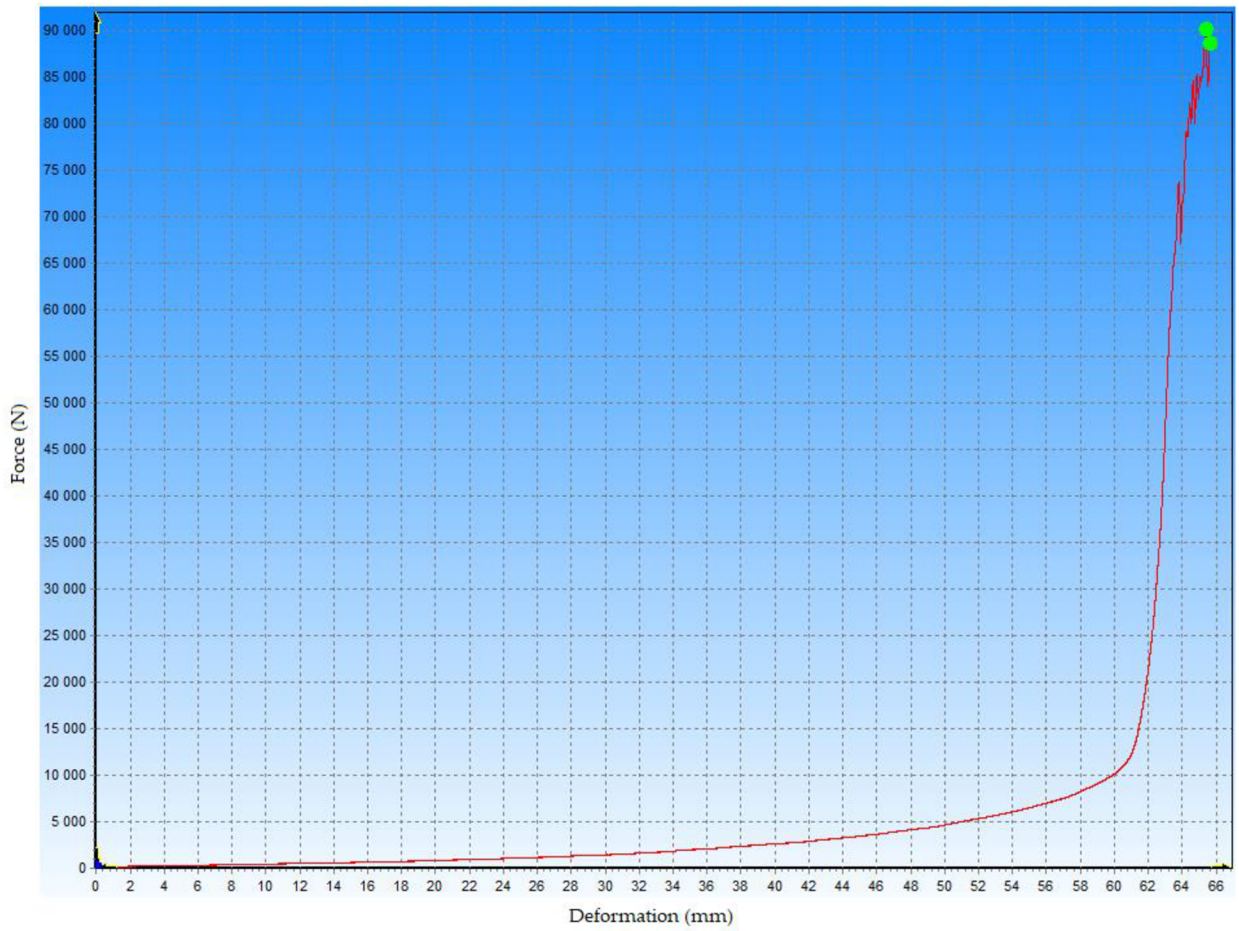
Appendix 3. Compression test of sample at 60 °C showing the output oil.

Appendix 4. Compression test of sample at 80 °C showing the output oil.

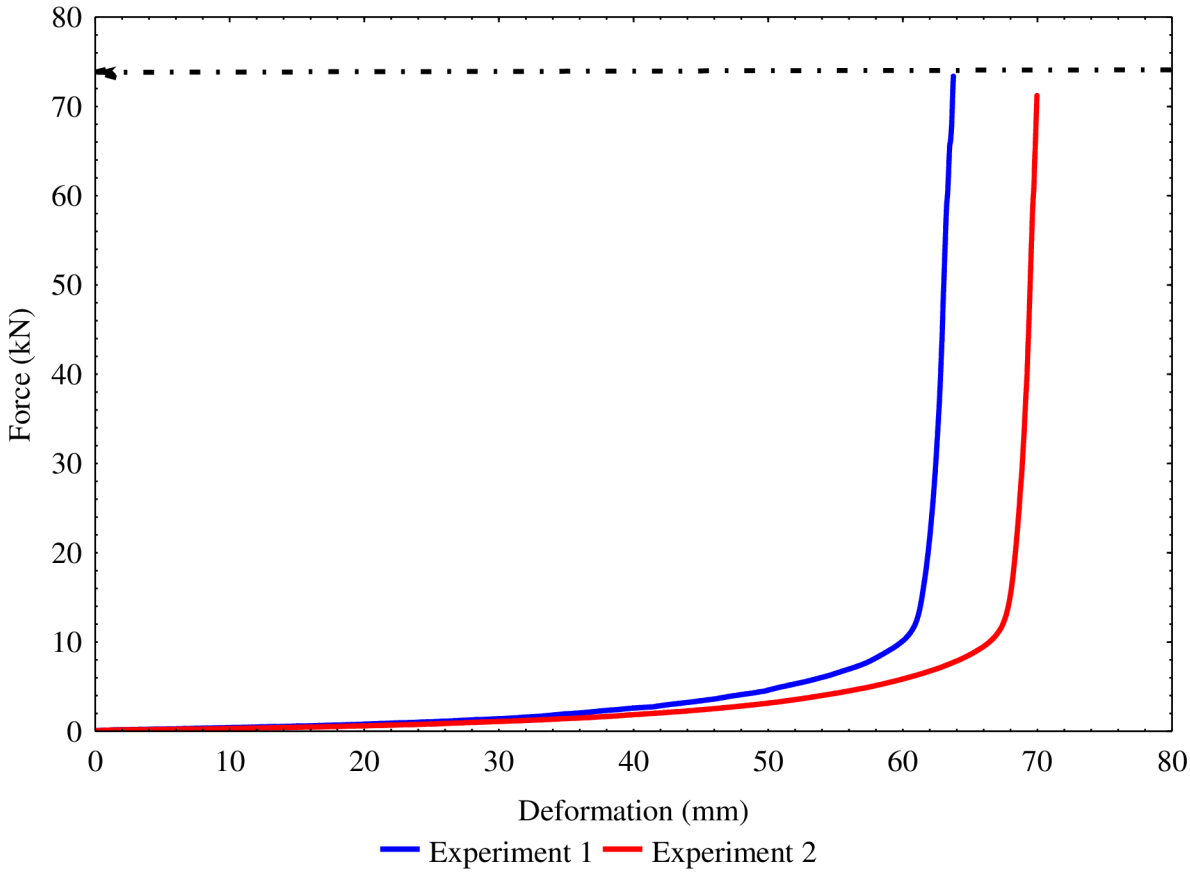
Appendix 5. Compression test of sample at 100 °C showing the output oil

Appendix 6. Compression test of sample at 120 °C showing the output oil.

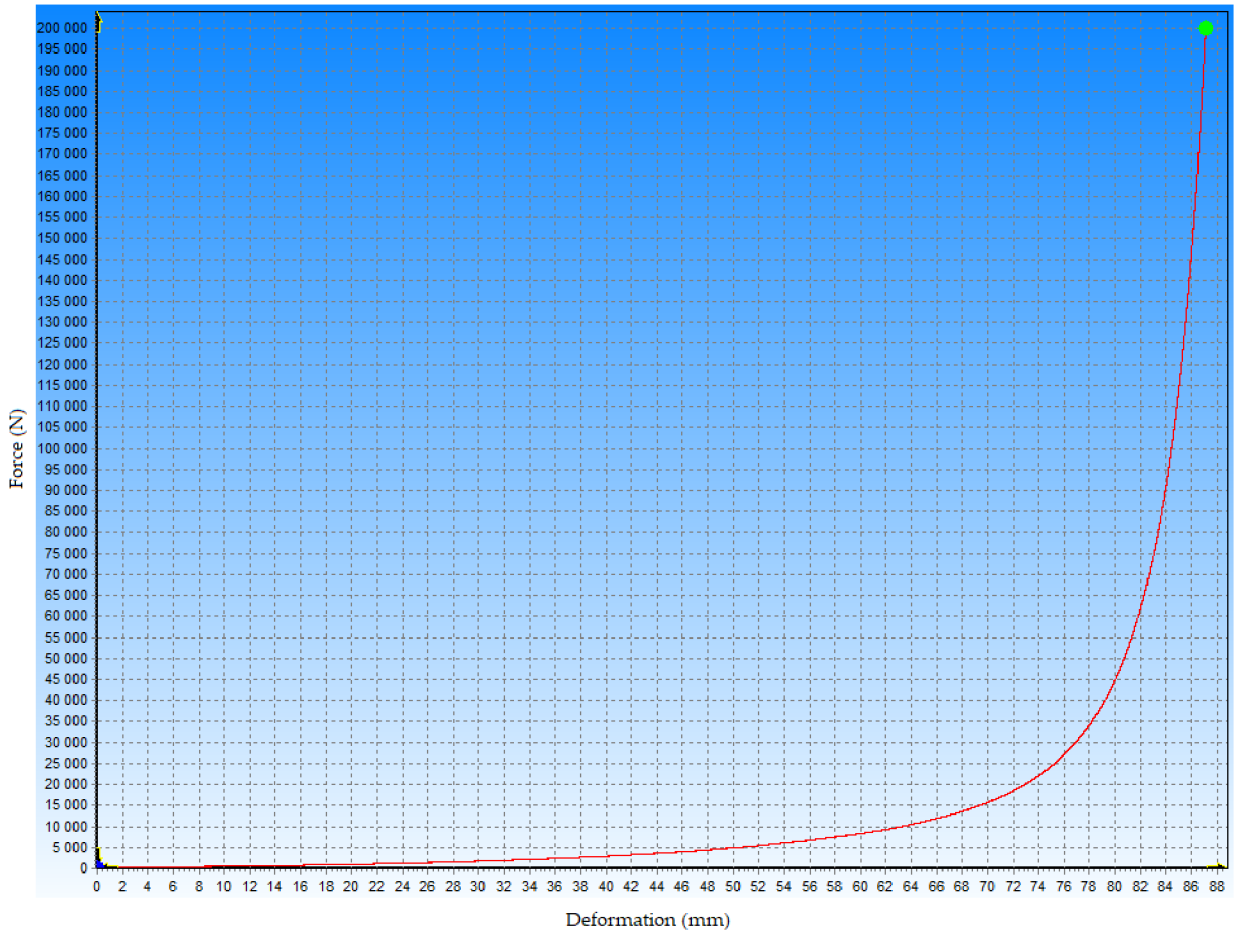
Appendix 7. Output oil of sample (coconut desiccated medium) from the compression tests.



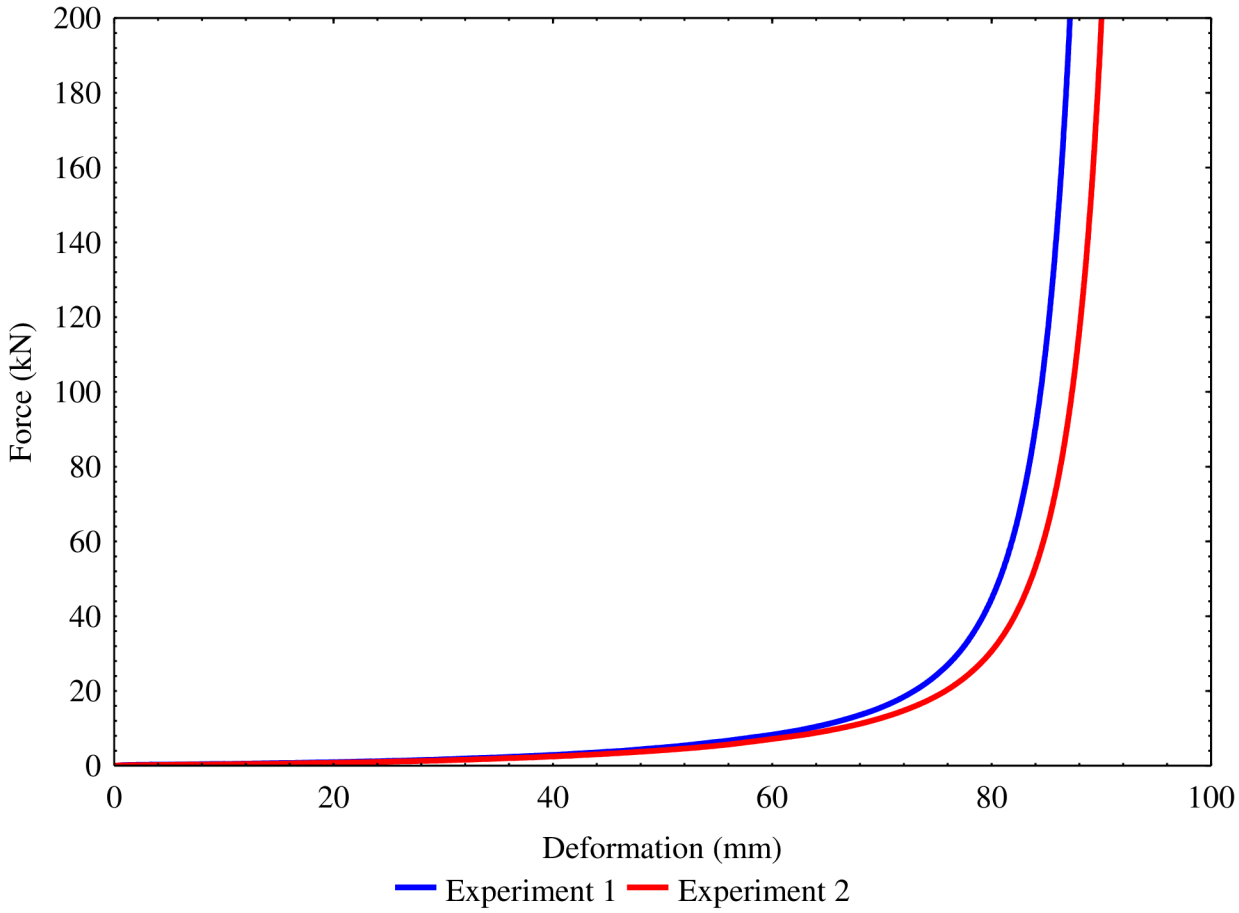
Appendix 8. Force-deformation curve for sample at a laboratory temperature of 20 °C showing the serration-effect above 70 kN force.



Appendix 9. Force-deformation curves for sample repeated twice at 20 °C showing the maximum force without the serration-effect.



Appendix 10. Force-deformation curve for sample at a temperature of 120 °C like the temperatures between 40 and 100 °C.



Appendix 11. Force-deformation curves for sample repeated twice at a temperature of 120 °C like the temperatures between 40 and 100 °C.

Appendix 12. Univariate results for sample deformation (mm) under the effect of temperature.

Effect	df	SS	MS	F	*P*-value
Intercept	1	84989.82	84989.82	7748.354	*< 0.05*
Temperature	5	744.13	148.83	13.568	< 0.05
Error	6	65.81	10.97		
Total	11	809.98			

df: Degree of freedom; SS: Sum of squares; MS: Mean squares; F-value; *P*-value < 0.05 is statistically significant.

Appendix 13. Univariate results for sample hardness (kN/mm) under the effect of temperature.

Effect	df	SS	MS	F	*P*-value
Intercept	1	52.17027	52.17027	7386.528	*< 0.05*
Temperature	5	2.41884	0.48377	68.494	< 0.05
Error	6	0.04238	0.00706		
Total	11	2.46122			

df: Degree of freedom; SS: Sum of squares; MS: Mean squares; F-value; *P*-value < 0.05 is statistically significant.

Appendix 14. Univariate results for sample oil yield (%) under the effect of temperature.

Effect	df	SS	MS	F	*P*-value
Intercept	1	26777.15	26777.15	108265.8	*< 0.05*
Temperature	5	3797.23	759.45	3070.6	< 0.05
Error	6	1.48	0.25		
Total	11	3798.72			

df: Degree of freedom; SS: Sum of squares; MS: Mean squares; F-value; *P*-value < 0.05 is statistically significant.

Appendix 15. Univariate results for sample energy (kJ) under the effect of temperature.

Effect	df	SS	MS	F	*P*-value
Intercept	1	13.12112	13.12112	4644.326	*< 0.05*
Temperature	5	1.55136	0.31027	109.824	< 0.05
Error	6	0.01695	0.00283		
Total	11	1.56832			

df: Degree of freedom; SS: Sum of squares; MS: Mean squares; F-value; *P*-value < 0.05 is statistically significant.