PALM KERNEL TESTA REMOVAL AND ITS EFFECTS ON EXTRACTED OIL QUALITY

by

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Thesis submitted in fulfillment of the requirements
for the degree of
Master of Science

April 2016

ACKNOWLEDGEMENT

First, I would like to express my highest appreciation to my supervisor, Prof. Ir. Dr. Mohd Omar Abd. Kadir, and Prof. Dr. Nik Norulaini Nik Abd. Rahman for their enthusiasm and invaluable guidance that I finally managed to complete my research project and thesis. A heartfelt 'Thank You' to Mr. Mark Harris Zuknik, who took the time to supervise my experiment as well as entertain my questions regarding the tasks delegated to my project. My humblest gratitude goes to Dr. Abbas Fadhl Mubarek Al-Karkhi and Prof. Ahmad Shukri bin Yahya, who taught me the basics of using ANOVA and regarding statistic software.

In addition, I would like to express my greatest appreciation to all lab assistants and Dr Japareng Lalung for their guidance and assistance during the experiment in the laboratory. Next, I also wish to express my heartiest thanks and deep gratitude to my colleagues, Siti Azahani, Mazratul Amyra, Rohaslinda, Tengku Nadiah, Tengku Salwani and Zul Azmi for constructive comments, guidance and all the kind of helps that they had given to me.

Finally, to my beloved father Wan Sharuddin bin Haji Wan Omar, my lovely mother Norni Bt Mohamad Tajuddin, my sister Wan Nursyuhana and my family who had understanding and supportive for giving me spiritual support all this while. To everyone who has played a part directly or indirectly in my experiment, thank you for giving me a taste in terms of technicality. Last but not least, I would like to thank to Mr. Abdul Fattah bin Fadzil, Shalima, Nadia Zuhairi and my housemates for always giving me support during my research and to all the people who have helped and taught me during my project, and apologize to all who I have offended during that period.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
C_1	Concentration solution of sodium carbonate
$C_{16:0}$	Palmitic acid
$C_{18:0}$	Stearic acid
$C_{18:1}$	Oleic acid
$C_{18:2}$	Linoleic acid
C_2	Concentration solution of hydrogen peroxide
CPO	Crude palm oil
FAME	Fatty acid methyl ester
g	gram
H_2O_2	Hydrogen peroxide
kg	kilogram
mg	milligram
MPOB	Malaysian Palm Oil Board
Na_2CO_3	Sodium carbonate
PK	Palm kernel
PKO	Palm kernel oil

PKT	Palm kernel testa
PK_t	Palm kernel with testa/ untreated palm kernel
PK_w	Palm kernel without testa/ treated palm kernel
PO	Palm oil
PORIM	Palm oil research institute of Malaysia
RSM	Response surface methodology
SEM	Scanning electron microscope
T_1	Temperature treatment of sodium carbonate
t_1	Time treatment of sodium carbonate
T_2	Temperature treatment of hydrogen peroxide
t_2	Time treatment of hydrogen peroxide

PENYINGKIRAN TESTA ISIRONG KELAPA SAWIT DAN KESANNYA TERHADAP KUALITI MINYAK YANG DIEKSTRAK

ABSTRAK

Isirong kelapa sawit disaluti oleh lapisan nipis perang kegelapan yang merupakan testa. Testa amat sukar untuk tersingkir kerana testa kuat melekat pada biji benih isirong. Kehadiran testa akan menjejaskan warna minyak. Maka, testa akan dibuang sebelum proses pengekstrakan bagi meningkatkan kualiti minyak. Ciri-ciri fizikal isirong kelapa sawit dikenal pasti sebelum dan selepas proses penyingkiran kulit biji isirong kelapa sawit. Kulit biji isirong kelapa sawit telah disingkirkan dari isirong kelapa sawit menggunakan satu kaedah turutan rawatan dengan natrium karbonat (Na_2CO_3) diikuti dengan hidrogen peroksida (H_2O_2). Eksperimen penyaringan dan pengoptimuman dijalankan ke atas proses penyingkiran testa dan ditentukan bahawa parameter optimum adalah pada kepekatan Na_2CO_3 adalah 23% (C_1), suhu untuk Na_2CO_3 adalah 91°C (T_1), kepekatan H_2O_2 adalah 23% (C_2), dan suhu untuk H_2O_2 adalah 86°C (T_2), dengan masa 80 min untuk (t_1) dan 50 min untuk (t_2). Satu model regresi peringkat kedua yang mana telah dikembangkan bersesuaian dengan nilai data R^2 adalah sebanyak 0.9259. Imbasan imej mikroskop elektron (SEM) isirong sawit (PK_t) dan isirong tanpa testa (PK_w) yang menunjukkan bahawa penggunaan proses penyingkiran testa tidak membawa sebarang perubahan besar dalam struktur sel isirong sawit. Hasil jumlah minyak dari (PK_t) dan (PK_w) ialah 48.2% dan 47.3%, masing-masing, menunjukkan bahawa proses pemindahan testa tidak membawa perubahan yang drastik dalam kandungan

minyak isirong kelapa sawit. Kajian penentuan warna yang dijalankan ke atas minyak yang diekstrak daripada Soxhlet ke atas PK_t dan PK_w melalui pengekstrakan dengan n-heksana ditentukan bahawa perubahan warna berlaku antara dua warna adalah sebanyak 48.22. Indeks kekuningan (YI) untuk minyak yang diekstrak daripada PK_t dan PK_w adalah 83.20 dan 10.87 masing-masing, yang menyatakan bahawa proses penyingkiran testa mengakibatkan minyak kekurangan pigmentasi warna kuning. Spektroskopi jisim gas kromatografi (GC-MS) menunjukkan bahawa semasa asid-asid lemak bebas hadir dalam, minyak dari PK_t, asid-asid lemak bebas dikurangkan dengan banyak dalam minyak dari PK_w. Ujian kekerasan telah dikenal pasti melalui Instron UTM 5582 yang ditentukan beban maksimum untuk pecah inti PK_t dan PK_w adalah 565.0 N dan 148.3 N, masing-masing. Ini menggambarkan bahawa PK_w adalah lebih lembut daripada PK_t.

PALM KERNEL TESTA REMOVAL AND ITS EFFECTS ON EXTRACTED OIL QUALITY

ABSTRACT

Palm kernel (PK) has surrounded by a thin dark layer brown which is testa. Testa are very difficult to be removed because testa strongly attached to the kernel seed. The presence of testa will affects the color of the oil. So, the testa needs to be removed before extraction process to improve the quality of oil. The physical characteristics of PK before and after the palm kernel testa (PKT) removal process were investigated. PKT was removed from the palm kernels using a method consisting of sequential treatment with sodium carbonate (Na_2CO_3) followed by hydrogen peroxide (H_2O_2). Screening and optimization experiments carried out on the testa removal process determined that the optimum parameters were at Na_2CO_3 concentration (C_1) of 23%, Na_2CO_3 temperature (T_1) of 91°C, H_2O_2 concentration (C_2) of 23% and H_2O_2 temperature (T_2) of 86°C at 80 min (t_1) and 50 min (t_2), respectively. A second-order regression model which was developed fitted the data adequately with an R^2 value of 0.9259. Scanning electron microscopy (SEM) images of palm kernel with testa (PK_t) and palm kernel without testa (PK_w) showed that application of the testa removal process did not result in any major changes in the cellular structure of PK. Total oil yield for PK_t and PK_w was 48.2% and 47.3%, respectively, indicating that the testa removal process did not result in a drastic alteration of the oil content of PK. Colour measurements carried out on oil extracted from PK_t and PK_w via Soxhlet extraction with *n*-hexane determined that colour change between two color occurred about 48.22. The yellowness index (YI) for oil extracted from PK_t and PK_w was 83.20 and 10.87, respectively, which indicated that the testa removal process resulted in oil with less yellow pigmentation. Gas chromatography-mass spectrometry (GC-MS) results showed that while free fatty acids (FFA) were present in oil from PK_t, they were greatly reduced in oil from PK_w. Hardness testing was carried out via Instron UTM 5582 to determine the maximum load to rupture the kernel for PK_t and PK_w was 565.0 N and 148.3 N, respectively. This indicated that PK_w was softer compared to PK_t.

CHAPTER ONE

INTRODUCTION

1.1 Palm Oil

The origin of the oil palm is believed to be in Africa, but the most productive regions are located in Southeast Asia, especially Malaysia and Indonesia, which together account for around 85% of the total world production (Sime Darby, 2014). Palm first received its botanical name from Jacquin in 1763 as *Elaeis guineensis* (Corley & Tinker, 2003). Palm oil is more saturated than soybean oil and rapeseed oil as its major fatty acids include palmitic ($C_{16:0}$), stearic ($C_{18:0}$), oleic ($C_{18:1}$), and linoleic ($C_{18:2}$). Palm oil can be fractionated at ambient temperature (25–30 ^{o}C) into palm olein or oleic-rich oil (liquid fraction) and palm stearin or stearic-rich oil (solid fraction). Due to the saturated fatty acids contained in this oil, it has superior oxidation stability as compared to other vegetable oils (Issariyakul & Dalai, 2014). Crude palm oil (CPO) is additionally one of the wealthiest wellsprings of normal vitamin E of tocopherols (18%-22%) and tocotrienols (78%-82%). Furthermore, research has also been carried out to explore the utilization of palm vitamin E as a novel source of cancer prevention agents for cultivated fish (Keong, Yan, & Hay, 2008).

1.2 Palm Kernel and Palm Kernel Oil

Palm kernels are important by-products from crude oil palm mills. Palm fruit products of oil palm (*Elaeis guineensis*) contain around 45% palm kernels. On a wet basis, palm kernels contain about 45–50% of oil that, the term for which is ‘palm kernel oil' (PKO) (Teoh, 2002). Palm kernel oil (PKO) differs greatly in its characteristics and properties from palm oil (PO), which is from the mesocarp layer (Goh, 1993). PKO is rich in lauric acid, C_{12} (48.3%) but also contains other pure unsaturated fats for example myristic, C_{14} (15.6%) and oleic acids, $C_{18:1}$ (15.1%) ((Tang & Teoh, 1985); (Goh, 1993); (Omar, Rahman, & Hassan, 1998)). PO is rich in palmitic acid (C_{16}) and $C_{18:1}$, which together constitutes about 44% and about 36% of its content, respectively. Other major fatty acids of PO are stearic acid ($C_{18:0}$) and linoleic acid ($C_{18:2}$). This fatty acid profile gives the fats a solid consistency at surrounding temperature that melts below 30 °C (Rossell, King, & Downes, 1985). There are three types of conventional methods being used in Malaysia for extracting palm kernel oil (PKO) from palm kernel such as mechanical extraction utilizing high pressure screw press, direct solvent extraction and pre-pressing followed by solvent extraction (MPOB, 2003). However, these methods required much time and are very costly. Palm kernel oil (PKO) is regarded as a food-grade oil that is high quality (I. S. M. Zaidul, 2003). The palm fruit consists of pericarp and palm kernels. The pericarp contains three layers; the exocarp (skin), mesocarp, and endocarp. Two types of oil can be extracted from the oil palm fruit: palm oil (PO), which is extracted from the fibrous mesocarp; and palm kernel oil (PKO), which is extracted from the kernels (seeds) of the fruit. Although both types of oils are extracted from the palm fruit, the chemical and nutritional properties of PO and PKO are different (Tang & Teoh, 1985).

1.3 Palm Kernel Testa

Palm kernel has a thin seed coat forming 3-5% of the kernel. The testa is dark brown and contains tannins and phenolic constituents. Tannins within the testa of seeds function as a defense against insect consumption, and are also known to bind with proteins within the digestive tract by forming insoluble complexes (Sreedhara & Kurup, 1998).

The seed of the oil palm is the nut which remains after the mesocarp has been removed from the fruit. The nut comprises of an endocarp, or external shell, and a kernel. It is the kernel that constitutes the seed proper from a botanical perspective. In any case, the term “seed” is normally used to refer to the nut, which constitutes both endocarp and kernel. This is due to the fact that in agriculture, it is the nut of the palm fruit which is stored, germinated and planted. The kernel lies within the endocarp and is constituted of greyish-white endosperm surrounded by a dark-brown testa secured with a network of fibers. The endosperm is hard and contains palm kernel oil. Palm kernel meal acquired from undehulled palm kernel is dark brown in color because of the presence of testa. The presence of testa within palm kernel meal has been shown by studies to lower its acceptability by animals (Sreedhara & Kurup, 1998).

1.4 Problem Statement

Since 1963, the palm oil industries are looking for the best extraction method for natural white pearl color palm kernel oil. The testa of the palm kernel is strongly attached to the kernel. The presence of the testa also affects the color of the oil extracted using the screw press method, as compounds which contribute to the color of the testa are transferred into the PKO during the screw press extraction process.

Sreedhara, Arumughan, & Narayanan, (1992) developed a method for the removal of testa from palm kernel which involved treating the palm kernels with hydrochloric acid (HCl) at high temperatures followed by mechanical action to remove the testa. However, HCl is a highly corrosive acid, which poses a hazard when handling. A process for the removal of palm kernel testa which utilizes less harmful materials is therefore desirable. Also, treatment times with hydrochloric acid must be short since palm kernels which are soaked for too long will swell and become degraded (Omar et al., 1998).

The production of clear or colourless PKO directly from palm kernels would also render the use of any bleaching process unnecessary. Bleaching earth is a sedimentary clay or clay-like earthy material used to decolorize, filter, and purify animal, mineral, and vegetable oils and greases. Bleaching earth that has been utilized for the absorption of impurities and pigmentation from vegetable and animal oil is termed "used bleaching earth" (UBE). The high costs of doing so, however, make the recovery uneconomical, which results in up to 10 000 metric tonnes of UBE being disposed of as waste yearly. UBE is a hazardous environmental pollutant due to the fact that oil and fats trapped within the UBE matrix are combustible (Hertrampf & Piedad-Pascual, 2012). By bypassing the refining stage and thus precluding the use of bleaching earth in the production of PKO, economic and environmental advantages will be accrued in the form of reduced production costs and waste reduction.

Therefore, in order to acquire colorless PKO, the testa needs to be removed before the extraction process. Therefore, an alternative testa removal method is necessary. The effects of the alternative testa removal method on the parameters of palm kernel which has undergone the testa removal process, such as free fatty acid profile, color, hardness and oil yield, will be studied.

1.5 Objectives of the Research

1. To identify the optimal parameters such as time, chemical concentrations and temperature, in the separation of the testa from the palm kernel.
2. To determine the changes in the fatty acid profile of palm kernel oil.
3. To study the effect of chemical treatment on the physical characteristics of the palm kernel and palm kernel oil in testa removal processes.

1.6 Scope of the Research

The main focus of this research is removal the testa from the palm kernel to obtain colorless and good quality of palm kernel oil. Palm kernel are divided by two condition which are palm kernel with testa and palm kernel without testa. Soxhlet extraction are extract oil from two different condition which are palm kernel with testa and palm kernel without testa. Palm kernel testa removal process undergone optimization to get best optimal level of each parameter. The chromatographic method of gas chromatographic mass spectroscopy (GCMS) is applying for detection and quantification of compound in the extracted oil of palm kernel. The characteristics of palm kernel with testa and palm kernel without testa will be discuss due to physical characteristic via total oil yield, scanning electron microcopy images, compressive strength and color detection. The physical characteristics will be determine in order to prove the improving the quality of the oil itself.

CHAPTER TWO

LITERATURE REVIEW

2.1 Palm Oil Industry in Malaysia

The oil palm (*Elaeis guineensis*), is an abundant and renewable resource that is largely cultivated in Malaysia, primarily for its edible oil. Malaysia is one of the largest producers and exporters of palm oil in the world, producing an average of 19.67 tonnes of crude palm oil per hectare. In Malaysia, the oil palm planted areas in 2014 reached 5.39 million hectares, an increase of only 3.1% against 5.23 million hectares recorded in previous year, mainly due to the increase in planted areas in Sarawak (MPOB, 2015).

Malaysia has cultivated oil palm commercially since the 1960s. A great deal of research has been carried out on oil palms in relation to increased yield, management, processing, specific fertilizers, cloning technology, planting materials, benefits, and more. It consists of mainstream and downstream industry (Hai, 2002). The implementation of new technology, to improvise the current system in the oil palm sector, is necessary to sustain the growing global need for fats and oils (Hazir, Shariff, & Amiruddin, 2012).

Production of palm oil also generates several by-products, often considered as waste in the past, which offer a significant potential for biodiesel production. Edible oil is of course the main priority for two fundamental reasons, which are that it fetches a higher price as demand for food products continue to grow, and that there is not a direct competition with food while at the same time taking advantage of better utilization of by-products (Rosillo-Calle, Pelkmans, & Walter, 2009).

According to Septevani, Evans, Chaleat, Martin, & Annamalai, (2015) the oil palm fruit produces two types of oils which are palm oil (PO), obtained from the mesocarp, and palm kernel oil (PKO), acquired from the seed of the palm fruit. Palm oil presently occupies the first place among all dietary vegetable oils, with an annual global production of vegetable oils (USDA, 2015). The present consumption rate of palm oil both in the food and manufacturing industries, coupled with its intensive recent exploitation as biofuel Rosillo-Calle et al., (2009), contributes to the continuing increase in its production for fear that demand may outweigh supply.

Palm oil processors of all sizes go through a set of unit operational stages where every stage differs in the level of mechanization and the interconnecting material transfer mechanism, which may make the system batch or continuous (Demirbas, 2008). Another method to get palm oil is using simple crystallization and separation processes to obtain solid (stearic) and liquid (oleic) fraction of various melting characteristics. Different properties of the fractions will make them suitable for a variety of food and non-food products (Kellens, Gibon, Hendrix, & De Greyt, 2007).

Palm oil is rich in natural chemical compounds important for health and nutrition. It is reddish in color, because it contains a high measure of beta carotene. It is utilized as cooking oil, to make margarine and is an ingredient of numerous food processes. Palm oil is one of only a handful couple of vegetable oils moderately high in saturated fats composition and may contribute to an increased risk of high blood cholesterol and heart disease in susceptible people (Ronzio, 2003). The structure of palm fruit as shown in Figure 2.1.

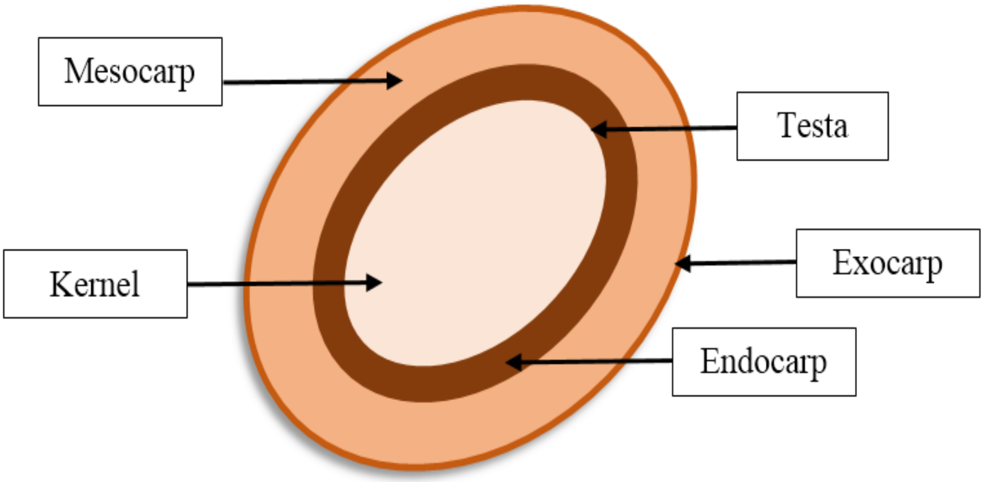

Figure 2.1 The structure of palm fruit. Source: (Geoffrey Mrema)

Because of its economic importance as a high-yielding source of consumable and specialized oils, the oil palm is presently developed as a plantation crop in many nations with high precipitation and tropical climates situated within 10° of the equator. The palm bears its natural product in groups weighing from 10 to 40 kg. The individual organic product, as indicated Plate 2.1 ranging from 6 to 20 g, are comprised of an external skin (the exocarp), a pulp (mesocarp) containing the palm oil in a fibrous matrix; a nut comprised of a shell (endocarp); and the kernel, which itself contains an oil. Palm kernel oil is entirely distinct from palm oil, and is similar to coconut oil (Poku, 2002).

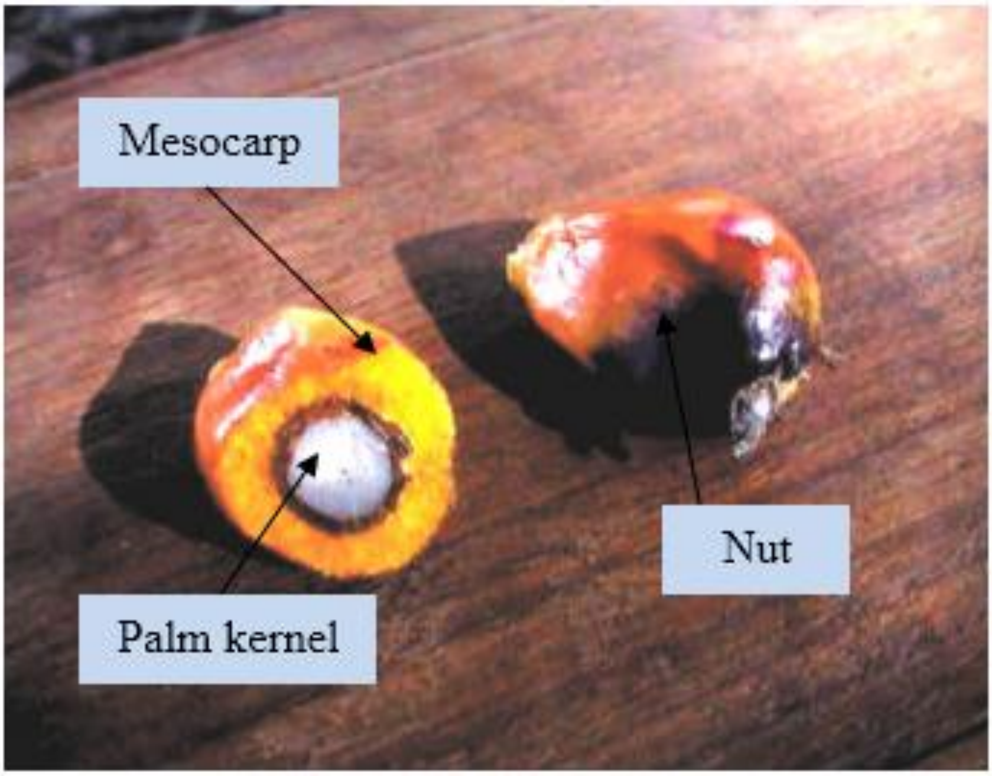

Plate 2.1 Fresh oil palm fruit (on the left is a cut fruit) showing the mesocarp and the nut with palm kernel.

Table 2.1 Ideal composition of oil palm fruit bunch (Poku, 2002).

Composition of oil	Weight/bunch (%)
Bunch Weight	23-27 kg
Fruit/bunch	60-65 %
Oil/bunch	21-23 %
Kernel/bunch	5-7 %
Mesocarp/bunch	44-46 %
Mesocarp/fruit	71-76 %
Kernel/fruit	21-22 %
Shell/fruit	10-11 %

On the other hand, such significant returns are seldom accomplished practically speaking on the grounds that climatic conditions are typically not perfect. Precipitation is flighty in Central and West Africa and thus the oil palm trees endure water-related stresses. The management of excessive inputs of work, imported fertilizers, pesticides and harvesting machinery, is likewise a trouble that hampers the yield of estates (Poku, 2002). Table 2.1 shows the ideal composition of oil palm fruit bunch.

Palm oil has been important as a resource for the food and oleo chemicals industries (Reijnders & Huijbregts, 2008). It is emerging as a source of biofuel. The calorific value of palm kernel oil is estimated at 40 GJ/ton (Yusoff, 2006). In Malaysia, palm oil is utilized in the production of biodiesel (palm oil methylester or palm oil diesel) for buses and cars and a major expansion of Malaysia diesel production with 5% palm oil fuel is expected from 2006 (Kalam & Masjuki, 2002). In Brazil, palm oil is expected to contribute to the Green Biodiesel Programmed and to electricity generation in the Amazon Region (da Costa, 2004).

2.2 Types of Oil Palm Fruits

Oil palm belongs to the Arecaceae family, in the order of Arecales (Corley & Tinker, 2003). It is anatomically similar to, and is grouped with Cocos (the coconut) and other genera in subfamily of Cocosoideae. Oil palms in Malaysia (*Elaeis guineensis*) are Tenera hybrids which are cross products of Dura (thick shell palm) and Pisifera (shell-less palm) (Kok, Ong-Abdullah, Ee, & Namasivayam, 2011).

The oil palm fruit provides two types of oil; palm oil (extracted from the mesocarp) and palm kernel oil (extracted from the kernel), which differ in their fatty acid composition (Rival, 2007). Due to global demand and versatile usage of palm oil, elite oil palm clones have been generated to increase the oil yield. The elite clones are developed from highly productive individual palms of Tenera hybrid, via tissue culture techniques. Cloning of oil palm is carried out by inducing somatic embryogenesis on calli derived from tissues sources (Jouannic et al., 2005).

Dura palms have a thick and hard shell, while Pisifera have no shell but a small kernel surrounded by a fibrous ring. The Dura palm has a low oil extraction ratio (OER) of 12 to 16% unlike the Tenera palm, which has a much improved OER of over 25% (Bennama, 2014). Plate 2.2 shows a palm fruit a) fresh fruit bunch and b) detached ripe fruits, respectively. Plate 2.3 shows *Dura* (*Sh/Sh*) fruit forms have a thick lignified shell surrounding the kernel, which is absent in *pisifera*(*sh/sh*). F_1 hybrid palms (*Sh/sh*) have an intermediate fruit form (*tenera*) that is much higher yielding than either parent in terms of mesocarp oil.

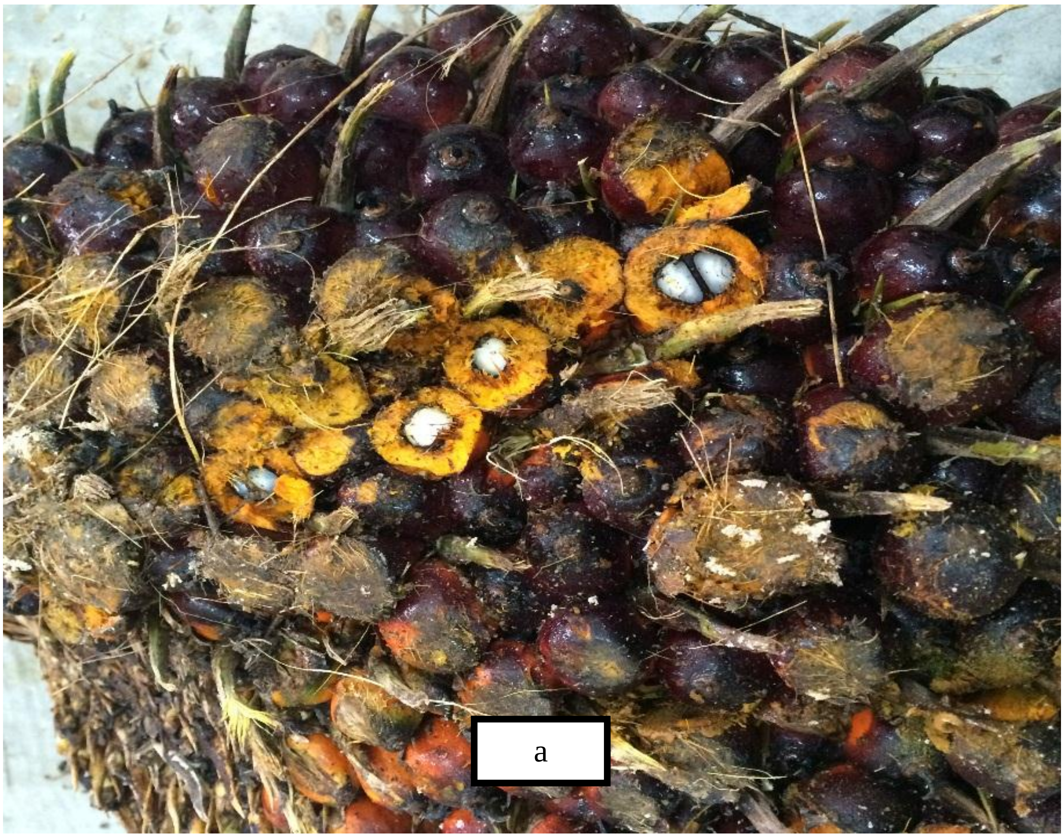

Plate 2.3 Oil palm fruits, (a) Fresh fruit bunch, (b) Detached ripe fruits.

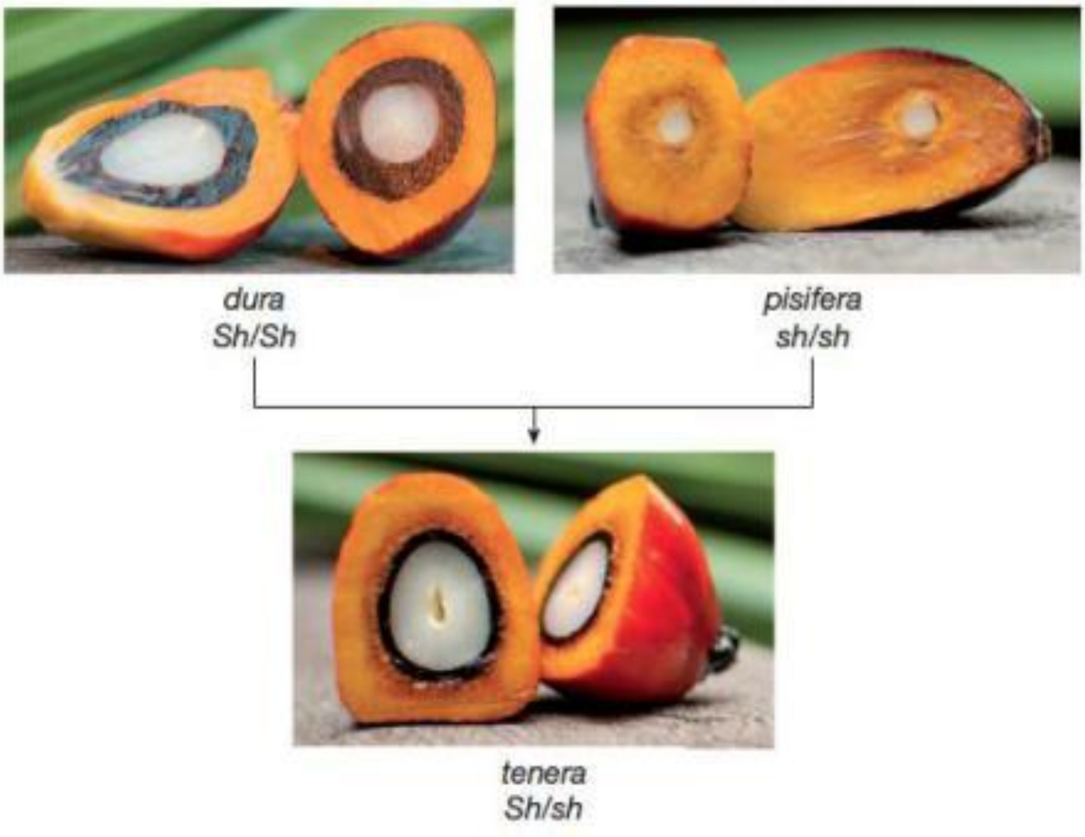

Plate 2.3 Oil palm fruit of Dura, Pisifera and Tenera. Source: (YCW76, 2013)

2.3 Palm Kernel Oil

Palm kernel oil (PKO) is acquired from the kernel of the oil palm fruit. Palm kernel contains about 45 to 50% oil on a wet basis (Tang & Teoh, 1985). Palm kernel oil is a food-grade vegetable oil rich in lauric acid, fatty acids and a small amount of unsaturated acids. Palm kernel oil is a white to yellowish oil which is solid at a normal temperature of 27 ^oC and is considered a secondary product of palm kernel fruit (Zulkafli, Othman, Lazim, & Jalar, 2013).

Fractionation of PKO generates palm kernel olein and palm kernel stearin. Palm kernel olein is the liquid element of PKO, though palm kernel stearin is the stronger division of PKO (Bennama, 2014). Palm kernel olein finds its primary use in non-food applications, especially as precursors to fatty alcohols, fatty amines, fatty amides, glycerol and biodiesels. Palm kernel stearin finds its primary use in food applications, especially as precursor to lauric cocoa butter substitutes (Choo, Ma, Basiron, Yung, & Cheng, 2012). Conventional methods are inefficient for oil extraction because not all PKO can be extracted from the palm kernels and the soluble constituents of the oil cannot be adequately removed (Bennama, 2014).

2.3.1 Physicochemical Properties of Palm Oil and Palm Kernel Oil

The application of palm oil and palm kernel oil are very limited in their original form due their specific chemical compositions. Modification is done to diversify the functions and usage of fats and oils, especially to improve the physiochemical characteristics and stability of the original oil.

Palm oil (PO) and palm kernel oil (PKO) differ in their physicochemical properties. These differences include specific gravity, melting point, density, acid value, refractive index, iodine value percentage of unsaponifiable content, peroxide value, and fatty acid composition. Some of the physicochemical properties of the PO and PKO are described in the following sections.

2.3.1(a) Melting Point

Oil with higher percentages of saturated fatty acids generally have higher melting points (Amri, 2011). The melting point (MP) of PO is 32 to 40 °C; PO and PKO are semi-solid at room temperature (28 °C) (Gunstone, 2011). Table 2.2 lists the physicochemical properties of palm oil and palm kernel oil and its fractions. According to the (Edem, 2002; Setianto, Atmaji, & Anggoro, 2010), some of properties of palm oil and palm kernel oil was outlined in Table 2.2.

Table 2.2 Physicochemical properties of palm oil and palm kernel oil and its fractions.

Physicochemical properties	Palm oil	Palm olein	Palm stearin	Palm kernel oil
Melting point (^{o}C)	34.2	21.6	44.5-56.2	25-30
Iodine Value (IV)	47.0 - 55.83	55.0 – 61.54	21.6 – 49.4	14.0 – 20.0
Refractive index (η)	1.46	1.47	1.45	1.45
Unsaponifiable matter (%)	0.01 – 0.5	0.001 – 0.5	0.1 – 1.0	0.2 – 0.8

2.3.1(b) Iodine Value

PKO generally has an iodine value (IV) of 16.5– 18.75, as shown in the draft Malaysian Standard. The IV of PKO in Codex Standard (14.1 – 21.0) is higher than that of coconut oil (6.3 – 10.6) due to the higher level of oleic acid in the former (Amri, 2011). A high IV has a positive correlation with the level of unsaturation of

PO. Oil with a high iodine value can be highly unsaturated and subsequently produce more liquid oil (Prabhakaran Nair, 2010).

2.3.1(c) Density

The density of PKO depends on its saponification value (molecular weight). The saponification value of Malaysia's PKO is 243–349 with a mean value of 245, while its unsaponifiable matter is 0.1 to 0.8 with a mean value of 0.3. The moisture and impurity content are consistently below 0.5% (Tang & Teoh, 1985). Density is one of the most important parameters from a business perspective because it is utilized for volume-to-weight conversions. It is moreover used as a purity indicator of vegetable oil (Basiron & Abdullah, 1995).

2.3.1(d) Fatty Acid Composition

The fatty acid composition of palm oil is comparable with other edible vegetable oils consumed by humans (Edem, 2002). The main difference between PO and PKO is the fatty acid composition. PO is rich in palmitic acid (C_{16}), with a percentage of about 44%, and about 36% of oleic acid ($C_{18:1}$). The other fatty acids present in PO are linoleic acid, and stearic acid. The major fatty acids in PKO are lauric acid, myristic acid, oleic acid, and palmitic acid (Palm Oil World, 2008). Table 2.3 lists the percentages of the fatty acid components within PKO.

Table 2.3 Fatty acid profile of palm kernel oil (PKO).

Type of fatty acid	Percentage (%)
Caprylic ($C_{8:0}$)	3.3
Capric ($C_{10:0}$)	3.4
Lauric ($C_{12:0}$)	48.2
Myristic ($C_{14:0}$)	16.2
Palmitic ($C_{16:0}$)	8.4
Stearic ($C_{18:0}$)	2.5
Oleic ($C_{18:1}$)	15.3
Linoleic ($C_{18:2}$)	2.3
Others (unknown)	0.4

Source: (Alamu, Akintola, Enweremadu, & Adeleke, 2008)

2.3.1(e) Applications of Palm Kernel Oil

Palm kernel oil (PKO) has both food and non-food applications. PKO is regarded as a high quality oil suitable for food use and is commonly used in cosmetics and cooking due to the fact it remains stable at high temperature and can be stored longer compared to the other vegetable oils (Willing, 1999).

In terms of production cost, PKO is the least expensive oil relative to other major vegetable oils. Palm kernel oils like most of other vegetable oils in their original state, have a limited application when utilized as such. Hence their properties have to be modified in order to extend the range of utilization (Hossain, 2013).

2.4 Conventional Method for Palm Kernel Oil Extraction

Oil palm (*Elaeis guineensis*) produces two different types of oil which are palm oil and palm kernel oil. PKO also known as white palm oil, is obtained from the seed known as kernel or endosperm. However, when oil has been extracted from the kernel, the remains is known as palm kernel cake (Lee & Saen, 2012). Several methods have been obtained around the world to extract PKO. Malaysian PO industries used the mechanical extraction to extract PKO in earlier days. In recent years, most PO industries in Malaysia extract PKO from palm kernels using three conventional methods: mechanical extraction using a high-pressure screw press, direct solvent extraction, and pre-pressing followed by solvent extraction (MPOB, 2009).

2.5 Study of the Extraction Kinetics

The extraction yield relies on upon the extraction productivity and substance change of the objective compound. In the extraction process, the target compound is initially transferred into the extraction solvent. The measure of the target compound transferred into the solvent is defined as the extraction efficiency. After the target compound is moved into the extraction solvent, substance changes may happen for the target compound at some experimental condition, which can specifically impact the last extraction yield of the target compound (Chen et al., 2008).

2.6 Overview of Soxhlet Extraction

The discovery of the Soxhlet extraction technique was accomplished by Franz Von Soxhlet in 1879 for the study of fat determination in milk (Virot, Tomao, Colnagui, Visinoni, & Chemat, 2007). Next, it was generally used for extraction in agricultural chemistry, before becoming the most used tool for solid-liquid extraction in many fields like environment, foodstuffs, and also pharmaceutics (Virot et al., 2007).

Other than that, Soxhlet extraction is a general and well-established technique, which surpasses in performance other conventional extraction strategies.

However, it is limited in its utilization for the extraction of thermolabile compounds (De Castro & Garcıa-Ayuso, 1998).

In conventional Soxhlet extraction, as shown in Figure 2.2, palm kernel or palm kernel cakes are put in a thimble-holder and loaded with fresh solvent from distillation flask. At the point when the liquid reaches the overflow level, a siphon directs the solution out of the thimble-holder and unloads it back into the refining flask, carrying extracted solutes into the mass fluid. In the solvent flask, the solute is isolated from the solvent utilizing distillation. The solute is left in the flask and fresh solvent goes over into the palm kernel or palm kernel cakes once more. The operation is repeated until complete extraction is accomplished (Wang & Weller, 2006).

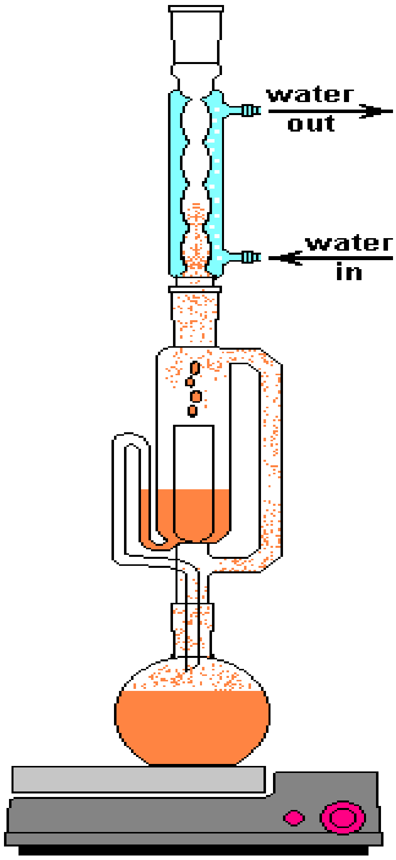

Figure 2.2 Schematic Diagram of Experimental Soxhlet Extraction Apparatus. Source : (Harwood, Moody, & Harwood, 1989)

2.6.1 Solvent Choice for Soxhlet Extraction

A suitable extraction solvent should be selected according to the desired output. Different solvents will yield different extracts and extract compositions (Zarnowski & Suzuki, 2004). The most widely-used solvent to extract edible oils from plant sources is hexane. Hexane has a fairly narrow boiling point range of approximately 63^oC – 69^oC and is an excellent oil solvent in terms of oil solubility and ease of recovery (Mamidipally & Liu, 2004).

2.6.1(a) n-Hexane

Hexane is an alkane hydrocarbon with the chemical formula $CH_3(CH_2)_4CH_3$. The "hex" prefix refers to its six carbons, while the "ane" ending indicates that its carbons are connected by single bonds. Hexane isomers are largely nonreactive, and are frequently used as an inert solvent in organic reactions because they are very non-polar. In Table 2.4, physical and chemical characteristics of hexane is shown below:

Table 2.4 Physical and chemical characteristics of hexane.

Description	Colourless liquid, gas
Molecular formula	C_6H_{14}
Molecular weight	86.10 g/mol
Boiling point	68.95^oC
Melting point	-95.3^oC
Density	0.660 g/cm^3 @ 20^oC
Vapor pressure	150 Torr @ 25^oC
Solubility	Insoluble in water; soluble in most organic solvents; Very soluble in alcohol
Conversion factor	1 ppm = 3.52 mg / m^3 @ 25^oC
Grade	Grade AR

2.6.2 Advantages and Disadvantages of Soxhlet Extraction

The advantages of applying conventional Soxhlet extraction incorporates:

(1) the displacement of transfer equilibrium by repeatedly bringing fresh solvent into contact with the solid matrix;

(2) keeping a generally high extraction temperature with heat from the distillation flask, and;

(3) no filtration prerequisite after leaching. Moreover, favorable circumstances of Soxhlet extraction methods result from the fundamental hardware, reasonable and easy to work (De Castro & Garcıa-Ayuso, 1998).

In any case, the biggest drawbacks of conventional Soxhlet extraction include:

(1) long extraction duration;

(2) a lot of amount of solvent is used;

(3) stirring cannot be used in the Soxhlet device to quicken the procedure;

(4) the large amount of solvent utilized require an evaporation process; and

(5) the likelihood of thermal decomposition of the target compounds cannot be ignored as the extraction usually occurs at the boiling point of the solvent for a long time. The long duration necessity and the prerequisite a lot of amounts of solvent lead to wide feedback of the conventional Soxhlet extraction technique (Grigonis, Venskutonis, Sivik, Sandahl, & Eskilsson, 2005).

Moreover, limited solvent choice Grigonis et al., (2005) and lower extraction efficiency in Soxhlet extraction is due to the fact that the temperature of condensed solvents flowing into the thimble is lower than its boiling point (Höfler, Jensen, Ezzel, & Richter, 1995). Besides that, the long extraction time (16–24 hours) and the high temperatures needed for Soxhlet extraction are its main shortcomings as they might cause changes in the extract composition (Priego-Capote, Ruiz-Jiménez, & de Castro, 2007). The Soxhlet technique also has distinct drawbacks such as high temperature and extended concentration steps which can result in the loss or degradation of volatile components in the extract (Pekic, Zekovic, Petrovic, & Adamovic, 1999);(Schmidt & Soyke, 1992).

Next, the use of large amounts of highly purified organic hazardous solvents, with high costs of both purchase and disposal, and its use over an extended period can create health problems. In addition, long extraction times are needed due to slow diffusion and desorption from the sample matrix into the extraction fluid. The Soxhlet method generates dirty extracts, and the sample preparation has been estimated to constitute about two-thirds of the total time of analysis as well (Özcan & Özcan, 2004).

2.7 Palm Kernel without Testa (PKw)

Palm kernel is a by-product of the oil palm industry which has great potential as a source of oil and dietary protein. The kernel of the oil palm fruit is surrounded by a dark brown testa, which constitutes 3 – 5% of the kernel weight and is strongly bound to the kernel by a thin layer of gum or lignin. Palm kernel oil is akin to coconut oil in its fatty acid composition (Sreedhara et al., 1992). The testa of the oil palm kernel is surrounded by a network of fibers, while the kernel is comprised of layers of hard, oil-bearing endosperm and is greyish-white in color (Sreedhara & Kurup, 1998).

The dehulling processes usually practiced include water soaking, treatment with different chemicals, such as sodium bicarbonate, soda ash or lime, sodium carbonate, sodium borate sodium hypochlorite alkali or a combination of alkali-acid (Sreedhara et al., 1992). Sreedhara et al., (1992) developed a method for removal of testa from palm kernel which involves treating the palm kernels with hydrochloric acid (HCl) at high temperatures followed by mechanical action to remove the testa. This method was employed in a subsequent study by Sreedhara & Kurup, (1998) where it was found that rats which were fed palm kernel meal with the testa removed absorbed more protein compared to rats that were fed palm kernel that included the testa. Hence, protein digestibility of palm kernel meal appeared to improve with HCl treatment to remove the testa (Sreedhara & Kurup, 1998). However, HCl is highly corrosive acid, which poses a hazard when handling. A process for the removal of palm kernel testa which utilizes less harmful materials is therefore desirable.

In higher seed plants, the function of the testa is mainly to protect the seed from damage that may be inflicted upon it from the environment and also to control the germination of the seed itself via such mechanisms such as impermeability to water and oxygen and mechanical resistance to protrusion of the radicle (Debeaujon, Léon-Kloosterziel, & Koornneef, 2000).

Debeaujon et al., (2000) found that certain properties are related to the color of the testa of the seed of diverse plant species, which is itself the product of the presence of phenolic compounds. According to Waniska, (2000), phenolic compounds are primarily responsible for the pigmentation in the pericarp and testa of sorghum grains. The testa of peanuts themselves contain greater total phenolic content compared to the peanuts without testa (Khaopha, Senawong, Jogloy, & Patanothai, 2012).

2.7.1 Removal of Testa of Palm Kernel

One of the applications of the treated palm kernels is using the defatted treated palm kernels to produce palm kernel flour. The flour produced from defatted treated palm kernels is nutritionally superior to flour produced from untreated palm kernels. This is due to the fact that although phenolic compounds in the testae of plant seeds may exert strong antioxidant effects, they also exert strong antinutritional effects which in turn affect foods that are derived from the seed of such plants. Sreedhara & Kurup, (1998) derived the method developed by Sreedhara et al., (1992) to produce defatted palm kernel flour by treating raw palm kernels in 4M HCl for 6 to 7 minutes at 95 ^{o}C. After treatment, the palm kernels were subsequently defatted with hexane. Sreedhara & Kurup, (1998) found that when compared to untreated palm kernel flour, treated palm kernel flour had higher protein content, with the untreated palm kernel flour containing 183 g/kg protein and the treated palm kernel flour having a protein content of 198 g/kg. The difference in protein content between the treated and untreated samples were attributed to the absence of testa in treated palm kernel flour (Sreedhara & Kurup, 1998).

Sreedhara & Kurup, (1998) also conducted *in vivo* digestibility studies, which were conducted on rats fed a diet containing pure casein, treated palm kernel meal or untreated palm kernel meal, all for a period of 10 days. It was found that rats fed the casein diet absorbed 94% of food nitrogen, while for rats that were fed the casein diet absorbed 94% of food nitrogen, while for rats that were fed diets containing treated and untreated palm kernel meal, 80% and 65% of food nitrogen was absorbed, respectively. Rats fed the casein diet had the highest gains in body weight, gaining an average 64.2 g. Rats fed the treated palm kernel meal had an average body weight gain of 59.5 g while rats that were fed untreated palm kernel meal had average body weight gain of 42.5 g. The increase in the protein content of the treated palm kernel flour when compared to untreated palm kernel flour, as well as increased protein absorption and weight gain in rats when fed treated palm kernel meal compared to untreated palm kernel meal, all indicate that treatment to remove palm kernel testa from palm kernel improved the flour and meal that was subsequently manufactured from the kernels.

George et al., (2000) found that method for removing the skins or hulls from seeds, including legumes, grains, drupes, silques, and achenes involves wetting the seeds with an alkaline solution and then with a peroxygen solution. However, the process according to present invention was applied to hazelnut and not applied on palm kernel. The process under the following conditions:

Step 1: 4% $NaHCO_3$ at 160^o for 30 seconds, followed by draining

Step 2: 15% H_2O_2 at 160^o for 90 seconds

Results: Skins removable.

Removal of skin or hull for such seeds is desired for a variety reasons. For example, some skins such as those found on hazelnuts, coffee beans and Brazil nuts have unpleasant bitter tastes. For almonds, removal of the skin is desired to prevent the skin from coloring foods that are prepared using the seeds.