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Review

Kenaf seed oil: A potential new source of edible oil

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ABSTRACT

Background: Kenaf is gaining more attention in recent years due to its high fiber content and medicinal usage. It is now cultivated in many countries and its commercial value is being explored. Kenaf seeds, which are usually discarded as waste product have high oil content and can be a new source of edible oil.
Scope and approach: In this review, kenaf seed oil (KSO) will be described in details. Kenaf seed oil can be extracted from kenaf seeds by Soxhlet extraction or supercritical fluid extraction (SFE). In order to prolong the shelf life of kenaf seed oil, microencapsulation is carried out and the storage stability is studied. The health benefits and uses of kenaf seed oil are also studied to explore its commercial value and applications.
Key findings and conclusions: Kenaf seed oil is composed mostly of unsaturated fatty acid with palmitic, oleic and linoleic being the major one. It also contains various bioactive components such as phenols, saponins, tannins and alkaloids. It is reported that Soxhlet extraction gives higher yield than SFE but the latter method is preferred due to safety issue. Spray drying is used to encapsulate the KSO and the microencapsulated KSO has enhanced oxidative stability. KSO possesses various biological activities such as anti-hypercholesterolemic, anti-oxidation, anti-cancer, anti-inflammatory and others due to the presence of phytochemicals. Besides using as edible oil, KSO finds applications in various fields, such as cosmetics, chemicals and fuel.

1. Introduction

With the increasing demands of fats and oils, plant sources have become the target of researchers in exploring their uses and functional properties. In recent years, kenaf (*Hibiscus cannabinus* L.) has received much attention and extensive research has been carried out. The plant is composed of various active components including tannins, saponins, polyphenolics, alkaloids, essential oils and steroids (Yazan, Foo, Ghafar, et al., 2011). Kenaf has become the fourth industrial crop in Malaysia and the government has changed National Tobacco Board to National Kenaf and Tobacco Board, showing the commitment of encouraging development of kenaf industry (Wong, Lau, Tan, Long & Nyam, 2014). Kenaf (*Hibiscus cannabinus* L.) belongs to the Malvaceae family and it is widely grown in many countries, such as China, India and Thailand. This plant is well-known for its fiber content and medicinal usage where it has been prescribed in traditional folk medicine and used in the production of twine, rope, paper and others. Besides, kenaf is also a suitable source of feed crop attributed to the high protein content. According to Daham (2005), kenaf has the potential to replace alfafa as protein supplement for animal.

Currently, cultivation of kenaf plants is more than 20 countries and the total production of kenaf and other allied plants is 284,100 tons in 2010/2011 (International Jute Study Group, 2012). Nowadays, the main kenaf producers are India and China (Table 1) (Monti, 2013). As kenaf seeds contain high oil content, kenaf has been cultivated for seeds production. The seed yield range from as low as 80 kg (in Nigeria) to 997 kg/ha (in Mexico) and 3819 kg/ha (in Southern Florida) across the globe (Agbaje, 2010; Webber and Bledsoe, 2002). Kenaf cultivars can be divided into ultra early, early to medium and late maturing categories and it is reported that the best yielding cultivars belongs to the early to medium maturing groups such as Everglades 41, Everglades 71, Tainung #1, Tainung #2 and N7 (Basri, Abdu, Junejo, Hamid, & Ahmed, 2014). On the other hand, Olasoji et al. (2014) carried out a study on seed yield potential of some selected kenaf genotypes in different locations (Kishi, Ibadan, Ilora) of Nigeria. Of the 20 genotypes, AU-75 and AMC-108 recorded the highest seed yield, with 1454.3 kg and 1451.7 kg per hectare respectively whereas Nigeria local line 36 had

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Table 1
World production of kenaf and allied fibre from 2003/2004 to 2010/2011 in 1000 tonnes (1 tonne = 1000 kg).

Kenaf& allied fibre:	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011 (Provisional)
World	377.29	351.83	327.58	314.4	329.12	279.8	290.1	284.1
Developing countries	370.29	344.83	320.58	307.4	322.12	272.8	283.1	277.3
Far east	329.88	302.02	264.32	250.51	266.06	217.3	227.6	234.5
China	99.78	86.92	82.82	68.8	86.8	80	80	75.0
India	167	156.4	153	144	139.7	120	131.2	140.0
Indonesia	7	7	7	3.1	4	3.8	3.8	4.0
Thailand	41.33	35.66	4.6	3.6	2.2	2.9	1.8	1.8
Vietnam	12.5	14.2	15	10.6	31	8.8	9	12.0
Cambodia	0.65	0.65	0.65	0.83	0.85	0.3	0.3	0.2
Pakistan	1.62	1.19	1.25	1.59	1.51	1.5	1.5	1.5
Latin America	24.01	25.91	39.37	39.91	39.07	38.5	38.5	27.5
Brazil	10.5	12.65	26.1	25.95	25.66	25.1	25.1	15.0
Cuba	10	10	10	10	10	10	10	10.0
Other	3.51	3.27	3.27	3.96	3.41	3.3	3.3	2.5
Africa	12.7	13.2	13.19	13.29	13.29	13.3	13.3	11.7
Near east	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.6
Developed countries	7	7	7	7	7	7	7	6.8

Adapted from International Jute Study Group, 2012.

the lowest yield, only 660 kg per hectare. From this study, it is found that location did not have significant effect on the average seed weight/plant, weight of 100 seeds and seed yield/hectare. This shows that kenaf have higher adaptability to environmental factors than other fiber plants.

2. Kenaf trend in Malaysia

In Malaysia, kenaf was first introduced in the early 1970's, recognised as a potential alternative fibrous materials of board products, such as fibre board and particle board under the Seventh Malaysian Plan (1996–2000) (Mossello et al., 2010). In 2004, foreseen the potential commercial value of kenaf, the government has allocated RM 12 million for research and future development of kenaf-based industry in the states of Terengganu, Pahang and Kelantan under the Ninth Malaysia Plan (2006–2010) to replace the current tobacco cultivation (Junejo, Abdu, Hamid, Ahmed, & Akber, 2014; Mossello et al., 2010). Malaysia Agricultural Research and Development Institute (MARDI) is a pioneer in the development and cultivation of the kenaf (*Hibiscus cannabinus* L.) plant in Malaysia since 2000 and the first kenaf seed production was carried out in Serdang, Selangor (Chan & Ismail, 2009). Although kenaf is usually considered as fibre crop, the entire kenaf plant, stalk and leaves, is suitable as livestock and horse feed. MARDI reported that kenaf whole plant has high protein content (more than 20%) and has potential to replace alfalfa as livestock and horse feed (Daham, 2005). The kenaf plantations and kenaf seed production have been increasing since 2006. In 2006, 7190 kg of kenaf seeds were produced and has been increasing annually to 151,250 kg in 2011 (Ishar, 2012).

Kenaf cultivation in Malaysia for seed production is mainly to ensure seed availability as a fundamental factor for successful development of a novel crop in order to satisfy the strong demand for fibre and forage industrial (Junejo et al., 2014). Due to its high oil content, kenaf seed need to be stored properly to avoid losing its viability when exposed to high temperature and humidity. Kenaf seeds can remain fully viable up to 5.5 years if they stored at 8% relative humidity and at −10 °C, 0 or 10 °C (Webber and Bledsoe, 2002). It is interesting to know that less fertile soil or use of less fertilizer produce higher seeds yield (Basri et al., 2014). This requirement actually benefits farmers with poor resources and for land which has been planted with various crops.

Nyam, Tan, Lai, Long, and Che Man (2009) carried out studies on selected seeds oil and reported that kenaf seeds contain 9.6% moisture, 6.4% ash, 20.4% oil, 21.4% nitrogenous matter and 12.9% crude fiber while the dry press cakes contain 6.0% ash, 6.0% oil, 33.0% protein and 17.4% crude fiber. Sadly, kenaf seeds have always been treated as agricultural waste and discarded after processing. The seeds are actually valuable and able to generate profits due to high oil content and nutraceutical values. The potential for using kenaf seeds as a source of edible oil has still been overlooked when considering kenaf as a fibre and feed crop. For instance, the oil can be used in the manufacturing of soap, linoleum, paints and varnishes. Since kenaf seed oil has great applications, extensive research on the phytochemicals, stability, bioavailability and its potential applications of kenaf seed oil should be carried out in order to fully unitise the plants and seeds of “future crop” as part of source of economic growth.

3. Extraction of kenaf seed oil

As aforementioned, kenaf seeds have high oil content and they can be extracted through several methods. In recent studies, the commonly used methods to extract kenaf seed oil are solvent extraction and supercritical fluid extraction (SFE). Generally, the latter is more preferable as it is cost-effective, environmental friendly and time-saving anddoes not create safety issue due to incomplete removal oil solvent (Chan & Ismail, 2009).

Solvent extraction uses organic solvents such as hexane and petroleum ether to extract oil from kenaf seeds. This method is further divided into classic (SOX/L), rapid (SOX/S) and ultra-sonic assisted (SONIC). The difference between classic and rapid extraction is the number of cycles to extract oil where classic method stops the extraction after 100 cycles whereas rapid extraction will be terminated after 20 cycles. On other hand, the conventional ultra-sonic assisted solvent extraction involves homogenization and sonication and pulsed mode is usually chosen to carry out the processes it requires lower electrical energy consumption, high extraction time reduction and the effect on antioxidant activity is lesser (Wong, Lau, et al., 2014). Wong, Lau, et al. (2014) mentioned that ultrasound-assisted extraction provides advantages over conventional Soxhlet extraction because it enables greater solvent penetration into sample matrix, increase the contact surface area between solid and liquid phase resulting in higher diffusion rate of solute into solvent. Soxhlet extraction is an established method to extract oil but it presents some problems. The organic solvent used during Soxhlet extraction will pollute the final products and further processing is necessary to remove the residual solvent. Besides,

other lipid soluble compounds are extracted along with fatty acids as the organic solvents used do not provide desired selectivity. Therefore, another method known as supercritical fluid extraction is suggested to be an alternative to the conventional method.

Supercritical fluid extraction (SFE) in turn utilizes supercritical fluid solvents, such as carbon dioxide, ethane and nitrous oxide. Supercritical fluids are dense gases that completely fill a container and possess solvating power (Luthria, 2004). They are also low in surface tensions, viscosities and have moderately high diffusion coefficient thereby enhancing the mass transfer (Yazan, Foo, Ghafar, et al., 2011). This method has been used over a decade in food analysis especially for fatty food. SFE has also expanded application to extracting oil from many plant sources, seeds and kernels. The most popular SFE solvent is carbon dioxide because triglycerides, fatty acids and cholesterol are quite soluble in it (Luthria, 2004). Furthermore, carbon dioxide is inexpensive, non-toxic, nonflammable and available at high purity (Goodship & Ogar, 2004). In comparison to Soxhlet extraction, this method avoids the problem of contamination of oil by residual solvent and enables the complete removal of solvent at final stage of extraction. This saves the cost of purification of kenaf seed oil that is required when using conventional solvent extraction. Besides, thermal degradation is less likely to occur since temperature and pressure can be manipulated. This method is also cost-effective, time −saving, non-explosive, safe and environmental friendly.

However, in terms of yield, conventional soxhlet extraction (SE) can give higher yield than supercritical fluid extraction (SFE). Chan and Ismail (2009) compared the yields of three extraction methods; supercritical fluid extraction with carbon dioxide at different temperature and pressure, Soxhlet extraction and conventional ultra-sonic assisted solvent extraction. The yields for SOX/L, SOX/S and SONIC were 24.81%, 22.40% and 21.08% respectively. While for SFE-extracted oil, the yield was ranging from 2.12% to 20.18%. It can be seen that classic solvent extraction gave higher yield than ultrasonic assisted and SFE. This implies that heat treatment is an efficient treatment in extracting oil from seeds. In spite of the higher yield, classic Soxhlet extraction took more than 12 h to complete the entire process which is not convenient from the perspective of mass production.

For SFE, temperature and pressure are two important factors affecting yield of kenaf seed oil and biological activities (Ghafar et al., 2013). According to Yazan, Foo, Ghafar, et al. (2011), when pressure increases at constant temperature, the density of carbon dioxide will also increase and this results in enhanced solute (oil) solubility and subsequently the yield. While at constant pressure, increasing temperature will decrease the density of carbon dioxide and increase the vapour pressure of analytes. This increases the tendency of components to pass through critical fluid and to be extracted thereby increasing the oil yield (Yazan, Foo, Ghafar, et al., 2011). Yazan, Foo, Chan, Tahir & Ismail (2011) and Chan and Ismail (2009) extracted kenaf seed oil using SFE at nine different parameters with varying temperature and pressure and both studies reported that highest yield was obtained at a pressure of 600 bars and temperature of 80 °C. From the result, the yields of kenaf seed oil are generally higher at higher pressure. Hence, it is suggested that pressure play a more dominant role than temperature in affecting the solubility of oil triglycerides (Chan & Ismail, 2009; Markom, Singh, & Hasan, 2011).

4. Kenaf seed oil (KSO)

Kenaf seed oil (KSO) is vegetable oil whose composition similar to cottonseed oil, suggested its potential to be used as edible oil. Depending on the processing temperature, kenaf seed oil producing from heated material is reddish brown colour with mild odour while it is odourless clear yellow oil if it is not heated. It is suitable for human consumption due to its unique fatty acid composition and plenty of functional compounds. The high oil content also reflects that kenaf seed oil is a good source of lipid-soluble bioactives, such as phospholipids, vitamin E, phytosterols and alpha linolenic acid (ALA).

Mohamed, Bhardwaj, Hamama, and Webber (1995) had studied the fatty acid profile, total phospholipids and sterols of various kenaf genotypes. From this study, it is found that the oil percentage of the nine kenaf genotypes ranged from 21.4% to 26.4% and the range is similar to cottonseed oil but higher than soybean oil. For total phospholipid content in kenaf seed, the amount (6.0%) is found to be higher than major oil seeds such as soybean (1.5−3.0%) and cottonseed (2.0%). Nine major phospholipids, which include lysophosphatidyl choline, phosphatidyl choline, sphingmyelin, phosphatidylserine, phosphatidyl inositol, phosphatidyl ethanolamine, phosphatidic acid, phosphatidyl glycerol and cardiolipin were identified in kenaf seed oil. There are another seven minor phospholipids whose identities are unknown. The total sterol present in kenaf seed oil was 0.89% and this is similar to those of soybean and cottonseed oil. The three main sterols identified were β-sitosterol, campsterol and stigmasterol. Furthermore, the unsaturated fatty acid compositions of kenaf seed oil of the genotypes were also investigated and the results are shown in Table 4. It can be seen that the major fatty acids in kenaf seed oil are linoleic, oleic and palmitic acid. The relatively high amount of monounsaturated and polyunsaturated fatty acid put kenaf seed oil an advantage over cotton seed oil and soybean which are used as reference oil.

Apart from that, Nyam et al. (2009) had identified eight main phenolic acids in kenaf seed oil. The predominant were vanillic and caffeic acid and others included protocatechuic, gallic acid, *p*-hydroxybenzoic acid, syringic acid, *p*-coumaric acid and ferulic acid (Table 2). These compounds contribute to the antioxidant activity of seed oil. In addition, phytochemicals screening was carried out by Ng, Choong, Tan, Long, and Nyam (2014) and confirmed that kenaf seed, kenaf seed oil, microencapsulated kenaf seed oil, kenaf seed extract and defatted kenaf seed meal contained terpenoids, tannis, alkaloids, saponins and flavonoids. Cardiac glycosides were also present in kenaf seed oil and microencapsulated KSO. Phytochemicals analysis was also carried out by Nyam, Sin, and Long (2015) and the results are shown in Table 3. These phytochemicals are beneficial to human health where they are able to lower serum lipid level, prevent cardiovascular diseases and provide protection against various diseases (Vasanthi, ShriShriMal, & Das, 2012).

5. Microencapsulation of kenaf seed oil

Despite plentiful of functional compounds in kenaf seed oil, high level of unsaturated fatty acid causes several problems on sensory properties, nutritional quality and safety of kenaf seed oil. Kenaf

Table 2
Phenolic acids of kenaf seed oil.

Phenolic acids	(mg/100 g)
Vanillic acid	0.53 ± 0.01
Caffeic acid	0.40 ± 0.01
Gallic acid	0.24 ± 0.01
p-hydroxybenzoic acid	0.19 ± 0.01
Ferulic acid	0.18 ± 0.01
p-coumaric acid	0.16 ± 0.01
Protocatechuic acid	0.05 ± 0.01
Syringic acid	Trace (<0.05 mg/100 g)
Sum	1.75

Adapted from Nyam et al., 2009.

Table 3
Phytochemical analysis of kenaf seeds.

Sample	TPC (mg GAE/100 g of sample)	TFC (mg catechin/100 g of sample)	Saponin (mg saponin/100 g of sample)	Linalool (mg linalool/100 g of sample)	Alkaloid (%)
KSO	108.46 ± 6.40^{d}	52.94 ± 7.31^{d}	68.14 ± 3.46^{c}	148.76 ± 9.69^{c}	17.40 ± 1.35^{d}
KSE	170.72 ± 16.63^{b}	165.05 ± 11.53^{b}	89.89 ± 3.43^{b}	294.74 ± 16.14^{b}	27.80 ± 1.83^{b}

KSO- kenaf seed oil; KSE-kenaf seed extract. Mean ± standard deviation (n = 4) with different superscript letter ^{bcd}indicate significant differences ($p < 0.05$) between the same column.
Adapted from Nyam et al., 2015.

Table 4
Unsaturated fatty acid composition of kenaf seed oil.

Genotypes	Fatty acid gas-chromatography area (%)							Total
	C16:1	C18:1	C18:2	C18:3	C20:1	C22:1	Cis-12,13-epoxyoleic	
178-18RS-10	1.7	28.1	47.5	0.56	0.20	0.60	0.55	79.1
GR2565	2.1	32.7	42.0	0.76	0.17	0.47	1.39	79.6
Tainung#1	1.6	28.5	47.3	0.93	0.13	0.76	0.41	79.6
Tainung#2	1.5	28.5	45.5	1.14	0.28	0.71	0.91	78.5
Everglades 41	1.6	24.8	50.1	0.59	0.27	0.70	0.26	78.3
Everglades 71	1.6	25.2	47.1	0.47	0.18	0.84	0.62	76.0
Cubano	1.6	31.3	42.6	0.43	0.32	0.83	0.76	77.8
Guatemala 48	1.6	29.8	46.7	0.47	0.10	0.66	0.94	80.3
Indian	1.3	34.1	44.1	0.81	0.28	0.69	0.17	81.5
Mean	1.6	29.2	45.9	0.69	0.21	0.70	0.67	–
C.V. %	7.39	12.39	2.44	11.54	7.65	16.05	10.35	–
Reference oil								
Cottonseed	0.5–2.0	13–44	13–59	0.1–2.1	<0.5	<0.5	–	–
Soybean	<0.5	19–30	44–62	4–11	<0.1	–	–	–

Adapted from Mohamed et al., 1995.

seed oil is susceptible to rapid oxidation and this leads to the production toxic substances. Rancid flavor and taste arise due to oxidation also affects acceptability. However, this problem can be overcome by microencapsulation where oil droplets are surrounded by proteins and/or carbohydrate coat and transformed into powder. Microencapsulation can be carried out by chemically such as through coacervation or molecular inclusion or mechanically through spray drying, spray chilling and freeze drying (Saravanamuthu, Dubey, & Maheshwari, 2010). Spray drying is the most common technique used to encapsulate because this technology is economical, flexible and the equipment is readily available (Jacobsen, Nielsen, Horn, & Sorensen, 2013). It is proven by the study carried out by Ng et al. (2014) that microencapsulation is able to enhance oxidative stability of kenaf seed oil and prevent lipid oxidation. This is also shown in Table 5 that there is no significant change in the amount of all types of unsaturated fatty acid upon storage.

The microencapsulation efficiency (MEE) is affected by factors such as types of wall materials, characteristics of feed emulsion, total solid content and conditions of spray drying (inlet air temperature, air flow and humidity). Generally, the higher the microencapsulation efficiency, the higher the stability of the microencapsulated oil. The wall materials usually used in the microencapsulation of kenaf seed oil are a mixture of sodium caseinate, maltodextrin, protein and carbohydrate with soy lecithin as emulsifier (Ng, Lau, Tan, Long & Nyam, 2013; Ng, Wong, Tan, Long & Nyam, 2013; Ng et al., 2014). The effects of total solid content (TSC) in feed emulsion on microencapsulation of kenaf seed oil were investigated and it was reported that 40% of TSC provided higher MEE than 20% and 30% and this formulation also had lowest degree oxidation (Ng et al., 2014). This suggested that 40% TSC was the best formulation for spray-dried MKSO to protect against lipid oxidation. Furthermore, a study was carried out by Ng, Wong, et al. (2013) to investigate the influence of inlet air temperature (160, 180 and 200 °C) on physicochemical properties and

Table 5
Relative percent compositions of fatty acids in bulk and microencapsulated kenaf seed oil (MKSO) under accelerated storage conditions.

Fatty acid	Storage (days)			
	0		24	
	Bulk KSO	MKSO	Bulk KSO	MKSO
C14:0	1.6 ± 0.1^{a}	0.4 ± 0.0^{a}	2.4 ± 0.0^{c}	0.4 ± 0.1^{a}
C16:0	26.9 ± 0.8^{a}	26.0 ± 0.8^{a}	36.4 ± 0.4^{c}	25.3 ± 0.9^{a}
C16:1	0.8 ± 0.0^{c}	0.7 ± 0.1^{a}	0.6 ± 0.0^{a}	0.7 ± 0.2^{a}
C18:0	3.3 ± 0.2^{a}	3.3 ± 0.2^{a}	7.5 ± 0.5^{d}	2.9 ± 0.5^{a}
C18:1n9c	31.8 ± 0.7^{c}	33.5 ± 1.2^{a}	28.1 ± 0.9^{a}	34.2 ± 1.0^{a}
C18:2n6c	33.6 ± 0.2^{b}	25.7 ± 0.2^{a}	22.3 ± 0.6^{a}	26.2 ± 0.8^{a}
C18:3n6c	0.5 ± 0.0^{d}	0.4 ± 0.0^{a}	0.2 ± 0.0^{a}	0.5 ± 0.0^{a}
C20:0	0.8 ± 0.1^{a}	–	1.7 ± 0.5^{bcd}	–
C20:1	0.2 ± 0.1^{ab}	0.3 ± 0.0^{a}	0.2 ± 0.0^{a}	0.2 ± 0.1^{a}
C20:2	–	5.0 ± 0.1^{a}	–	4.7 ± 0.3^{a}
C22:2	–	4.4 ± 0.4^{a}	–	4.4 ± 0.2^{a}
C24:0	0.5 ± 0.1^{a}	0.3 ± 0.0^{a}	0.6 ± 0.0^{b}	0.5 ± 0.1^{b}
SAT	33.1	30.0	48.6	29.1
MONO	32.8	34.5	28.9	35.1
POLY	34.1	35.5	22.5	35.8

Different superscript letters within the same row indicate significant difference ($p < 0.05$).
Adapted from Ng, Wong, et al., 2013.

oxidative stability of MKSO. It was found that higher temperature negatively affected the microencapsulation efficiency (MEE) and lipid oxidation. At higher inlet temperature, the rates of water evaporation and film forming are imbalance and this causes the crust to break down and release the core oil. The peroxide value, *p*-Anisidine value, free fatty acid content and total oxidation value of MKSO were also higher when higher inlet temperature was used. Hence, it can be proposed that higher total solid content of feed emulsion and lower temperature are able to provide higher oxidative stability to kenaf seed oil. Apart from that, according to Razmkhah, Tan, Long, and Nyam (2013), the protective effect of microencapsulation is provided by the oxygen and moisture barrier

properties of wall matrix and the role played by proteins. In addition, when a mixture of protein and carbohydrate of wall materials are heated, Maillard reaction occurs and the resulting products can act as antioxidant to protect against autoxidation of microencapsulated oils.

Razmkhah et al. (2013) studied the quality changes and antioxidant properties of microencapsulated kenaf seed oil under accelerated storage condition of 65 °C for 24 days.1 day of storage represents 1 month of storage at ambient temperature. It was proven that microencapsulation is an effective method to increase oxidative stability of kenaf seed oil and also resulted in higher retention of bioactive compounds than bulk oil (Ng, Lau, et al., 2013). In addition, oil products with free fatty acid content greater than 3% are inedible. Upon accelerated storage, free fatty acid content of kenaf seed oil and microencapsulated kenaf seed oil produced at 160 °C and 180 °C ranged from 2.17 to 2.77% and 2.27–3.00% respectively but the value exceeds 3% when 200 °C is used (Ng, Lau, et al., 2013). This shows that microencapsulated kenaf seed oil produced at temperature of 180 °C or less is safe for consumption.

6. Biological activities of kenaf seed oil

Extensive research revealed that kenaf seed oil has several functional properties which especially beneficial to human health contributed to the phytochemicals and compounds present. This review focuses on the beneficial biological activities of kenaf seed oil such as anti-hypercholestrolemic, antioxidant, anti-cancer, anti-inflammatory, anti-thrombotic, anti-mutagenic properties and also applications of kenaf seed oil in various fields.

7. Anti-hypercholesterolemic effect

Hyperlipidemia is characterized by elevated blood cholesterol (hypercholesterolemia), low density lipoproteins cholesterol and/or triglyceride level along with decreased high density lipoprotein cholesterol. Hypercholesterolemia, as one of the causes of hyperlipidemia could contribute to the occurrence of atherosclerosis and abnormal lipid metabolism under the influence of oxidative stress (Beery & Workman, 2011; Ng et al., 2015).

Ng et al. (2015) carried out a study on anti-hypercholestrolemic effect of kenaf samples (kenaf seed oil, microencapsulated kenaf seed oil, defatted kenaf seed meal (DKSM) and kenaf seed extract (KSE)) on rats. Elevated malodialdehyde (MDA) in serum is a biological indicator of lipid peroxidation as a result of reaction between reactive oxygen species (ROS) with unsaturated fatty acids. It was reported that MDA level of rats treated with kenaf samples were lower than those untreated and the results had no significant difference with commercial hypocholesterolemic drug, simvastatin. In addition, the effects of kenaf samples on total cholesterol and total triglyceride level were also comparable to simvastatin where no significant difference was reported. From this study, it was shown that the highest anti-hypercholestrolemic effect was found in KSE followed by KSO, MKSO and DKSM. Although kenaf seed extract had higher anti-hypercholesterolemia effect than microencapsulated kenaf seed oil and kenaf seed oil, the cholesterol-lowering effects of kenaf seed oil and encapsulated kenaf seed oil were comparable to the commercial drug, simvastatin. Therefore, this study suggested that kenaf seed oil could be used as an alternative to hypocholesterolemia drug and this property enables it to find more application in food industry.

The anti-hypercholestrolemic effect of kenaf seed oil is due to the cholesterol lowering ability of polyunsaturated fatty acids (PUFAs), phytosterols and tocopherols. The phytosterols content in KSO and MKSO were 6510.3 ± 54.2 mg/100 g and 4680.4 ± 171.9 mg/100 g, respectively while total tocopherols of KSO and MKSO were 186.83 ± 2.70 mg/100 g and 154.89 ± 3.15 mg/100 g, respectively (Ng et al., 2015). The mechanism of unsaturated fatty acid to lower serum cholesterol remains unclear but it is proposed that polyunsaturated fatty acid decreases the production of low density lipoprotein (LDL), increase catabolism of LDL and conversion of polyunsaturated fatty acid into ketone bodies instead of being incorporated into very low density lipoprotein (Hemat, 2004). On the other hand, phytosterols such as beta-sitosterol, campesterol and stigmasterol reduce cholesterol level by replacing the cholesterol in micelles (the compound formed to facilitate fat absorption) thereby decreasing its absorption in intestine. The excess cholesterol will be excreted with feces. Besides, phytosterols increase the level of high density lipoprotein (HDL) cholesterol and also prevent esterification of cholesterol to further reduce absorption (Ng et al., 2015).

8. Antioxidant property

Oxidation and presence of free radicals are the culprits of deterioration in sensory properties, nutritional quality, safety and acceptability. As oxidation is a process that poses many challenges, synthetic antioxidant, such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are added during food processing to prolong shelf life. However, several physiological disorders related to the use of synthetic antioxidants have been reported. Therefore, natural antioxidants are still preferred due to safety issue. Different tests have been used to evaluate the antioxidant activity of kenaf seed oil and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)(ABTS), beta-carotene bleaching (BCB), 2,2- diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) assays show that kenaf seed oil does possess antioxidant property. This is also supported by Chan and Ismail (2009) that compared antiradical activity of several commercial edible oils and reported that kenaf seed oil is high antioxidative oil.

The method and condition of extraction will affect the antioxidant activity of kenaf seed oil to some extent. For ultrasonic assisted extraction, pulsed mode is selected because it will have less effect on antioxidant activity on kenaf seed extract (Wong, Lau, et al., 2014). If kenaf seed oil is extracted at higher temperature, the antioxidant activity will be lowered as some of the antioxidant compounds are destroyed by heat. This is in line with the study carried by Ng, Wong, et al. (2013) where the peroxide value (an indicator of primary oxidation) of MKSO produced at 200 °C was higher than those produced at 160 °C and 180 °C. The higher peroxide value is attributed to the lower total phenolic content as a result of destructive effect of high temperature. In terms of concentration of antioxidants, according to Nyam, Teh, Tan, and Long (2012), ethanol is a better solvent than hexane in extracting phenolic compounds from seeds. This is because ethanol is polar solvent and its polarity enables it to extract hydrophilic phenolic compounds more effectively.

Free radicals are generated from reactive oxygen species (ROS) and reactive nitrogen species (RNS) from chemical reactions in the body, exposure to physicochemical conditions or pathophysiological states. Free radicals can cause alterations of proteins, lipids, DNA and other biomolecules which subsequently result in abnormal metabolism and mutagenesis. A condition known as oxidative stress results when the levels of free radicals and pro-oxidants (ROS and RNS) outgrow the ability of natural antioxidants in body to remove them. Kenaf seed oil is suitable to be used as natural antioxidant because it contains polyphenols, flavonoids and tocopherols that can act as free radical scavengers, reducing agent or quenchers of singlet oxygen. Antioxidants are capable of

neutralizing free radicals at different stages, namely prevention, interception and repair. At preventive stage, antioxidants inhibit the formation of reactive oxygen species whereas free radicals and peroxyl radicals will be scavenged or chain breaking is inhibited during propagating oxidation at interception stage (Wong, Lau, et al., 2014). On other hand, enzymes are usually involved in the repair stage.

Vitamin E is an effective antioxidant. The concentration of tocopherols has effect on the effectiveness of kenaf seed oil as an antioxidant. It is reported by Ghafar et al. (2013) that kenaf seed oil extracted by supercritical carbon dioxide fluid extraction contains more vitamin E than that from solvent extraction. The antioxidant property of kenaf seed oil is affected by factors such as processing conditions, storage conditions and total solid content. Storage conditions such as temperature, light and oxygen can affect compounds such as polyphenols and phenols and might cause hydrolysis, condensation or oxidation to take place.

Apart from that, a study was carried out by Ng, Lau, et al. (2013) to compare the fatty acid and bioactive compounds of bulk and microencapsulated kenaf seed oil upon accelerated storage. It was reported that microencapsulation provided positive effects on storage of kenaf seed oil. The tocopherols, phytosterols and phenolic content in microencapsulated kenaf seed oil (MKSO) did not change significantly during the storage at 65 °C for 24 days. Despite the higher initial phenolic content of bulk kenaf seed oil, the final amount in MKSO is higher than that of KSO. Microencapsulation is able to retain bioactive compounds and therefore the antioxidant activity of kenaf seed oil during prolonged storage (Razmkhah et al., 2013).

Moreover, it is also found out that kenaf seed oil has higher antioxidant activity than corn oil, palm olein oil, canola oil, sunflower seed oil, soy bean oil and olive oil. IC_{50} is defined as the concentration of oil that is able to inhibit 50% of the total DPPH (2,2-diphenyl-1-picrylhydrazyl) radicals. The IC_{50} for kenaf seed oil ranged from 12.27 mg/ml to 39.80 mg/ml whereas commercial oils (palm olein oil, corn oil, soybean oil, canola oil, sunflower seed oil, rice bran oil, olive oil) ranged from 20.59 mg/ml to 70.43 mg/ml. From here, it can be seen that kenaf seed oil has greater radical scavenging ability than commercial oils. Furthermore, similar results were also obtained by beta-carotene bleaching (BCB) assay, another useful method to evaluate antioxidant activity of edible oils where kenaf seed oil exhibited higher antioxidant activity.

9. Anti-cancer property

Several studies have been carried out to investigate the anti-cancer property of kenaf seed oil against different human cancer cell lines such as human cervical cancer, ovarian cancer, breast cancer, colon cancer, lung cancer and leukemic cancer cell lines. Positive results were obtained and kenaf seed oil showed cytotoxic effect towards all studied cancer cell lines aforementioned (Ghafar et al., 2013; Wong, Tan, Tan, Long & Nyam, 2014; Yazan, Foo, Chan et al., 2011, Yazan, Foo, Ghafar, et al., 2011). Studies carried out by Yazan, Foo, Ghafar, et al. (2011) and Foo, Yazan, Chan, Tahir, and Maznah (2011) reported that kenaf seed oil extracted from variety V36 under pressure of 600 bars and 40 °C showed strongest cytotoxic activity towards breast cancer (MDA-MB-231), leukemic cancer cell lines (MOLT-4), human promyelocytic HL-60, murine myelomonocyticWEHI-3B and human chronic myelogenous K562 (Table 6). On the other hand, among the cancer cell lines investigated by Wong, Tan, et al. (2014), it was discovered that kenaf seed oil showed strongest cytotoxic activity toward colon cancer cells was observed followed by breast cancer cells, lung cancer cells and cervical cancer cells. These findings show that kenaf seed oil could be a promising anti-cancer agent. Besides, it is also mentioned in Wong, Tan, et al. (2014) study that polyphenols and conjugates must remain in the gut lumen and gastrointestinal tract in order to inhibit abnormal cell proliferation and protect against cancer.

Similar to antioxidant property of kenaf seed oil, IC_{50} is also used to determine the cytotoxic activity of kenaf seed oil. Oil with IC_{50} value between 125 and 5000 μg/ml is a potential cancer therapeutic agent (Wong, Tan, et al., 2014). Table 6 indicates the effectiveness of kenaf seed oil from variety V36 as anti-cancer agent towards different cancer cell lines. In addition, an inverse relationship was found between cell viability and concentration of kenaf seed oil (Yazan, Foo, Chan, et al., 2011). This reflects that cytotoxic activity is dose-dependent where higher concentration of oil results in lower cell viability. The mode of cancer cell death was also studied and it was revealed that apoptosis and necrosis were two main mechanisms by which cancer cells are killed. In comparison to necrosis, apoptosis is more favorable because it does not trigger inflammatory responses. This confirmed the results obtained by Yazan, Foo, Chan, et al. (2011) where apoptotic cells were significantly higher than necrotic cells. The features of apoptosis include membrane blebbing, chromatin condensation, nuclear margination and fragmentation (Yazan, Foo, Ghafar, et al., 2011).

It is suggested by Ghafar et al. (2013) and Yazan, Foo, Chan, et al. (2011) that linoleic acid, alpha-linolenic acid, phytosterols and vitamin Eare the components in kenaf seed oil responsible for the cytotoxic effects of kenaf seed oil. Linoleic acid is found to be able to inhibit proliferation of human skin, breast, colon, stomach and leukemia *in vitro* and *in vivo* (Yazan, Foo, Chan, et al., 2011). On the other hand, phytosterols inhibit growth of cancer cells through cell cycle arrest and induction of apoptosis as well as reducing metastatic ability of cancerous cells. This is further supported by Awad, Holtz, Cone, Fink, and Chen (1998) that phytosterols can act as anticancer dietary components. It is also proposed that the phytosterols exert effects on membrane structure, integrity and fluidity, membrane-bound enzymes, signal transduction pathway, apoptosis, immune function of host tissues. Similar to phytosterols, vitamin E was found to induce programmed cell death (apoptosis) in human colon cancer cell while inhibiting growth of prostate cancer cell. Apart from that, the anti-cancer property of kenaf seed extract and oil is contributed to certain extent by polyphenols and flavonoids. These two compounds are believed to reduce the risk of cancer.

It is also interesting to note that extraction method can affect the anti-cancer property of kenaf seed oil. Kenaf seed oil extracted from supercritical carbon dioxide fluid extraction has greater cytotoxic effect than from solvent extraction. This may be due to destruction of some heat sensitive bioactive compounds by high temperature used in solvent extraction method.

10. Anti-inflammatory property

Inflammation is a physiological response of body to stimuli such as infections and tissue injury that leads to local accumulation of plasmic fluid and blood cells (Al-Reza, Yoon, Kim, Kim, & Kang, 2010; Shukla et al., 2010). Kenaf is composed of various active components such as tannins, saponins, polyphenolics, alkaloids, essential oils and steroids which have been prescribed in traditional folk medicine. According to Borrelli et al. (2002), various phenolic compounds such as flavonoids, cinnamic acid and its derivatives (ferulic acid, caffeic acid and chlorgenic acid) and steroids possess anti-inflammatory activity. Therefore, the anti-inflammatory effect of kenaf seed oil is contributed by many compounds such as phenols, polyphenols, essential oil and alkaloids. This is also consistent with study carried out by Nyam et al. (2015) on anti-inflammatory effect of kenaf and roselle seeds. Both seeds oils and extracts showed anti-inflammatory effect on induced edema model.

Table 6
IC_{50} values of the kenaf seed oil from variety V36 towards various cell lines.

Cell line	IC_{50} (μg/ml)		
	SFE 600/40	SFE 600/60	SFE 600/80
MCF-7 (breast cancer)	>5000	>5000	>5000
MDA-MB-231 (breast cancer)	483.35 ± 31.97	>5000	>5000
4T1 (breast cancer)	>5000	>5000	>5000
HeLa (cervical cancer)	>5000	>5000	>5000
A549 (lung cancer)	>5000	>5000	>5000
MOLT-4 (leukemic)	153.26 ± 25.43	1657.42 ± 72.83	>5000
HL-60 (leukemia)	178.78 ± 10.52	320.48 ± 11.35	>800
WEHI-3B (leukemia)	189.43 ± 11.63	380.32 ± 15.21	>800
K562 (leukemia)	213.33 ± 15.45	472.34 ± 13.12	>800
CaOV3	211.67 ± 3.79	187.00 ± 5.20	188.33 ± 10.12

Adapted from Foo et al., 2011; Yazan, Foo, Chan, et al., 2011, Yazan, Foo, Ghafar, et al., 2011.

It is mentioned that if essential oil can act as antioxidant, it can also function as anti-inflammatory compound. This is because oxygen consumption increases during inflammation and this result in the dramatic formation superoxide anion radical, a condition known as oxidative burst (Miguel, 2010). As kenaf seed oil is a natural antioxidant, it is also believed that it could be a potential anti-inflammatory component. This statement is also supported by the study carried out by Schubert, Lansky, and Neeman (1999). Phenolic acids, such as ferulic acid decreased the levels of pro-inflammatory cytokines such as interleukin-1β (IL-1 β) and tumor necrosis factor-α (TNF- α). The production of these cytokines is usually induced by lipopolysaccharide (LPS). In addition, polyphenols also affect metabolism of arachidonic acid, modify signal transduction pathway and modulate the pro-inflammatory gene expression such as cyclooxygenase, lipooxygenase and nitric oxide to exert anti-inflammatory effect (Miguel, 2010). Furthermore, alpha-linolenic acid (ALA) as part of the essential omega-3 fatty acids is also present in kenaf seed oil (Nyam et al., 2009). Researchers found that this family has anti-inflammatory effects and it will be metabolized to eicosapentanoic acid, a precursor of eicosanoids that possess anti-inflammatory and anti-thrombotic activity.

Similar to kenaf seed oil, there are many studies show that plant seed oil could be a potent anti-inflammatory drug and carrageenan-induced rat paw odema has always been used to investigate the anti-inflammatory effect of drugs. According to Shukla et al. (2010), *Caesalpinia bonducella* F. seed oil possessed anti-inflammatory effect and it is explained that the oil inhibit the synthesis, release or action of inflammatory mediators such as histamine, prostaglandin and serotonin. Oil from black cumin seed (*Nigella sativa* L.), pomegranate (Punica granatum) and flaxseed oil also exhibit anti-inflammatory effect (Chytilova et al., 2013; Hajhashemi, Ghannadi, & Jafarabadi, 2004; Schubert et al., 1999).

11. Anti-thrombotic property

Thrombosis is a condition characterized by formation of blood clot, known as thrombus in blood circulatory system. This is a fatal disease and it can lead to vascular blockage and acute coronary disorders. Thrombosis occurs when the balance between two systems responsible for creating and breaking down blood clots (thrombus) is upset (Richardson, 2003). Thrombus can obstruct blood flow when it grows bigger. The antithrombotic drugs available in the market can be classified into two, antiplatelet and anticoagulant. The drugs are working based on the principles of preventing formation of clot and inhibiting the production of chemicals in platelet which cause platelets to clump. Therefore, the compounds in kenaf seed oil might as well prevent thrombosis according to the principles mentioned previously.

Phytochemicals present such as tannins, phenolic compounds and polyphenols contributed to the anti-thrombotic effect of kenaf seed oil. Low, Mnonopi, Davids, Naude, and Frost (2008) studied the antithrombotic or anticoagulation of selected medicinal plants and found out that the activities were attributed to the presence of tannins in plant. Antithrombotic/anticoagulation effect was not significant when tannins are removed. Tannins were found to be able to reduce ADP-induced platelet aggregation (Page, 1998).

Platelet aggregation, one of the factors causing thrombosis, is modulated by dietary compounds such as polyunsaturated fatty acid (PUFA), vitamins, alcohols and phenolic compounds. Kenaf seed oil is rich in PUFA and phenolic compounds and this explain its anti-thrombotic effect (Natella, Nardini, Virgili, & Scaccini, 2005). In addition, flavonoids can act as anti-thrombotic agent apart from a strong antioxidant. Flavonoids can reduce the concentration of thromboxane A2, a platelet aggregator in blood. They also function to scavenge free radicals and maintain concentrations of endothelial prostacyclin and nitric oxide (a platelet inhibitor and vasodilator) at appropriate level. One study showed that flavonoids are powerful antithrombotic agents *in vitro* and *in vivo* because of their inhibition of the activity of cyclooxygenase and lipoxygenase pathways.

There are several mechanisms suggested by Natella et al. (2005) by which platelet aggregation occurs. These include inhibition of the transduction pathway mediated by phospholipase C (PLC), phospholipase A2 (PLA 2) and thromboxane A2 (TXA2), inhibition of cytoplasmic calcium increase, inhibition of protein kinase cascades and effect on calcium channels. With regards to that, polyphenols exert anti-thrombotic effect by inhibiting platelet aggregation and interaction between platelet and leukocyte. The risk of thrombosis can be reduced through nutritional supplements that have cholesterol-lowering, anti-inflammatory, antioxidants and blood thinning effects. From here, we can see that kenaf seed oil is a potential dietary component to prevent thrombosis and effective as a treatment of cardiovascular diseases since it has the mentioned functions.

12. Anti-mutagenic property

Mutation is regarded as a permanent change in DNA sequence and this process can be spontaneous or induced (Hawley & Richards, 2011). Spontaneous mutations are due to normal metabolism of DNA whereas induced-mutations are caused by mutagens such as chemicals, ultraviolet light and ionizing radiation (McConkey, 2004; Price & Frey, 2003).

Sultana, Anwar, Mushtaq, Aslam, and Ijaz (2014) explored the antimutagenic, antioxidant and total phenolics of clove (*Syzygiumaromaticum* L.) seed extracts and reported that there was a strong correlation between total phenolics and the biological activities

mentioned. It is observed that antimutagenic activity of cloves seed is directly related to the availability and concentration of phenolic antioxidants. This implies the additional role of phenolic compounds in kenaf seed oil as the antimutagenic agent. Pharmacological investigations have shown that genus *Hibiscus* possesses many biological activities. Research showed that *Hibiscus rosasinensis* possesses antitumor, antidiabetic, anticonvulsant and antidiarrheic activity whereas *Hibiscus syriacus* has antipyretic activity and used as anthelmintic. On the other hand, methanolic extract of *Hibiscus tiliaceus* flowers displayed antioxidant and antimutagenic activities (Rosa et al., 2006).

It is reported that tannic acid is the major compound in kenaf seed extract and this compound possesses antioxidant, antimutagenic and anticarcinogenic properties. Since tannins are also present in the oil, this supports that kenaf seed oil has the ability to prevent cell mutation. Tannic acid is found to suppress mutagenesis in *Escherichia coli* B/Rwp2 trp (Kuroda & Hara, 1999) and enhance excision-repair of DNA system in *E. coli*. Another compound in kenaf seed oil, saponins (steroid or triterpene glycosides) have also been shown that they have significant antimutagenic activity (Helvie, 2012). Furthermore, according to Natella et al. (2005) antioxidants appear to be antimutagenic and anticarcinogenic too. For instance, vitamin E, a well-studied molecule that acts as lipophilic antioxidant can reduce free-radical-induced DNA damage. As cancer is always with mutation, compounds with antimutagenic capacity could well be linked to anticarcinogenic activity (Bakkali, Averbeck, Averback, & Idaomar, 2008).

13. Applications of kenaf seed oil

As mentioned previously, kenaf seed has relatively high oil content with unique fatty acid composition and similar to cottonseed oil. This made kenaf seed oil a suitable substitute for cottonseed oil, which is rather expensive.

Kenaf seed oil can be used in many applications. Firstly, it can be used as salad dressing. In comparison to cottonseed oil, kenaf seed oil has milder odour and thus will be more acceptable by consumers. The high amount of monounsaturated and polyunsaturated fatty acid in kenaf seed oil also provides benefits for cardiovascular health. Besides, kenaf seed oil can be used as cooking oil. However, this type of oil is not suitable for cooking at high temperature and long duration. This is because oil high in unsaturated fatty acid particularly polyunsaturated is unstable and oxidation occurs at a rapid rate and form free radicals and carcinogenic compounds (Whitaker, 2003).

In addition, kenaf seed oil can be used in soap manufacturing especially those hard types. The process of making soap is called saponification and the main ingredient is oil (Letcavage, 2009). The oil used can be of animal or plant source. During saponification, sodium hydroxide will be added into oil and the mixture is heated and stirred. Sodium chloride is added at the end of saponification to precipitate the soap (Singh & Kaur, 2006). Furthermore, kenaf seed oil can also be used in cosmetics products such as lipsticks and milky lotion (Bassam, 2010). The oil functions to enhance penetration, control moisture evaporation and hydrate skin. Before addition, the oil will usually undergo processing in order to remove odours and colour or become hardened oil (Mitsui, 1999).

Apart from that, kenaf seed oil has found applications in industry as lubricants and biofuel (Bassam, 2010). Seed oil is increasingly used in industry as an alternative of mineral oils for several reasons. Firstly, seed oil can have good lubricating properties and the effect is comparable to the conventional lubricants. Using seed oil is also more environmentally-friendly as they are more biodegradable than mineral oil (Black & Bewley, 2000). More importantly, kenaf seed oil is cheaper, renewable and with constant supply. This ensures the continuous industrial operation and production.

14. Conclusion

In a nutshell, kenaf seed oil has emerged as a new source of oil with functional properties to be used in various areas such as food, industrial and medicinal fields. The utilization of kenaf seed, an agricultural waste product to produce kenaf seed oil no doubt leads to better waste management and ensure sustainable production. It is proven that kenaf seed oil, which is rich in unsaturated fatty acid and phytochemicals, provides myriad essential health benefits. More research has yet to be carried out on kenaf seed oil to discover the method for mass production at lower cost and increase the oil yield. Stability of kenaf seed oil is a main concern that needs to be addressed since it is high in unsaturated fats and shorten the shelf life. Comprehensive study can be carried out on kenaf seed oil to explore the industrial potential and discover more applications.

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References

Agbaje, G. O. (2010). Profitability of kenaf seed production as affected by different agronomic practices. *Journal of Food, Agriculture and Environment, 8*(1), 229–233.

Al-Reza, S. M., Yoon, J. I., Kim, H. J., Kim, J. S., & Kang, S. C. (2010). Anti-inflammatory activity of seed essential oil from *Zizyphus jujube*. *Food and Chemical Toxicology, 48*(2), 639–643.

Awad, A. B., Von Holtz, R. L., Cone, J. P., Fink, C. S., & Chen, Y. C. (1998). β-sitosterol inhibits the growth of HT-29 human colon cancer cells by activating the sphingomyelin cycle. *Anticancer Research, 18*, 471–479.

Bakkali, F., Averbeck, S., Averback, S., & Idaomar, M. (2008). Biological effects of essential oils – a review. *Food and Chemical Toxicology, 46*(2), 446–475.

Basri, M. H. A., Abdu, A., Junejo, N., Hamid, H. A., & Ahmed, K. (2014). Journey of kenaf in Malaysia: a review. *Scientific Research and Essays, 9*(11), 458–470.

Bassam, N. E. (2010). *Handbook of bioenergy crops: a complete reference to species, development and applications* (1st ed., p. 227). UK: Earthscan.

Beery, T. A., & Workman, M. L. (2011). *Genetics and genomics in nursing and health care* (p. 240). Philadelphia: F.A. Davis Company.

Black, M., & Bewley, J. D. (2000). *Seed technology and its biological basis* (1st ed., p. 147). UK: CRC Press.

Borrelli, F., Mafia, P., Pinto, L., Lanaro, A., Russo, A., Capasso, F., et al. (2002). Phytochemical compounds involved in the anti-inflammatory effect of propolis extract. *Fitoterapia, 73*(1), S53–S63.

Chan, K. W., & Ismail, M. (2009). Supercritical carbon dioxide fluid extraction of *Hibiscus cannabinus* L. seed oil: a potential solvent-free and high antioxidative edible oil. *Food Chemistry, 114*, 970–975.

Chytilova, M., Mudrunova, D., Nemcova, R., Gancarcikova, S., Koscova, J., & Tkacikova, L. (2013). Anti-inflammatory and immunoregulatory effects of flaxseed oil and *Lactobacillus plantarum*-Biocenol™ LP96 in gnotobiotic pigs challenged with exterotoxigenic *Escherichia coli*. *Research in Veterinary Science, 95*(1), 103–109.

Daham, M. D. (2005). Agromedia, Bil. *Kenaf, Tanaman Industri Berpotensi Tinggi* (vol. 18, pp. 5–13). Serdang: MARDI.

Foo, J. B., Yazan, L. S., Chan, K. W., Tahir, P. M., & Maznah, I. (2011). Kenaf seed oil from supercritical carbon dioxide fluid extraction induced g1 phase cell cycle arrest and apoptosis in leukemia cells. *African Journal of Biotechnology, 10*(27), 5389–5397.

Ghafar, S. A. A., Ismail, M., Yazan, L. S., Fakurazi, S., Ismail, N., Chan, K. W., et al. (2013). Cytotoxic activity of kenaf seed oils from supercritical carbon dioxide fluid extraction towards human colorectal cancer (HT29) cell lines. *Evidence-based Complementary and Alternative Medicine*, 1–8.

Goodship, V., & Ogar, E. O. (2004). *Polymer processing with supercritical fluids*. UK: Rapra Technology Limited (pp. 5, 10, 11).

Hajhashemi, V., Ghannadi, A., & Jafarabadi, H. (2004). Black cumin seed essential oil, as a potent analgesic and anti-inflammatory drug. *Phytotherapy Research, 18*, 195–199.

Hawley, R. S., & Richards, J. E. (2011). *The human genome: a user's guide* (3rd ed., p. 146). US: Academic Press.

Helvie, C. O. (2012). *You can beat lung cancer: Using alternative/integrative interventions* (1st ed., p. 144). UK: John Hunt Publishing.

Hemat, R. A. S. (2004). *Principles of orthomolecularism* (1st ed., p. 169). New Zealand: Urotext.

International Jute Study Group. (2012). *World production of kenaf & allied fibre from 2003/2004 to 2010/2011 [Online]*. Available from: http://www.jute.org/statistics_01.htm#4 Accessed 07.04.15..

Ishar, Z. (2012). *Exploring Kenaf's economic potential. BERNAMA [Online]*. Available from: http://www.bernama.com/bernama/state_news/news.php?cat=nt&id=651573 Accessed 07.04.15..

Jacobsen, C., Nielsen, N. S., Horn, A. F., & Sorensen, A. M. (2013). *Food enrichment with omega-3 fatty acids* (1st ed., p. 207). UK: Woodhead Publishing Limited.

Junejo, N., Abdu, A., Hamid, H. A., Ahmed, K., & Akber, M. H. (2014). Journey of kenaf in Malaysia: a review. *Scientific Research and Essays, 9*, 458–470.

Kuroda, Y., & Hara, Y. (1999). Antimutagenic and anticarcinogenic activity of tea polyphenols. *Mutation Research/Reviews in Mutation Research, 436*(1), 69–97.

Letcavage, E. (2009). *Basic soap making: All the skills and tools you need to get started* (p. 98). Pennsylvania: Stackpole Books.

Low, N. A. K., Mnonopi, N., Davids, H., Naude, R. J., & Frost, C. L. (2008). Antithrombotic/Anticoagulant and anticancer activities of selected medicinal plants from South Africa. *African Journal of Biotechnology, 7*(3), 217–223.

Luthria, D. L. (2004). *Oil extraction and analysis: Critical issues and competitive studies*. UK: The American Oil Chemists Society (pp. 69, 72, 88).

Markom, M., Singh, H., & Hasan, M. (2011). Supercritical CO_2 fractionation of crude palm oil. *Journal of Supercritical Fluids, 20*, 45–53.

McConkey, E. H. (2004). *How the human genome works* (p. 19). UK: Jones &Barlett Learning.

Miguel, M. G. (2010). Antioxidant and anti-inflammatory activities of essential oils: a short review. *Molecules, 15*, 9252–9287.

Mitsui, T. (1999). *New cosmetic science* (p. 122). Netherlands: Elsevier Science.

Mohamed, A., Bhardwaj, H., Hamama, A., & Webber, C. (1995). Chemical composition of kenaf (*Hibiscus cannabinus* L.) seed oil. *Industrial Crops and Products, 4*, 157–165.

Monti, A. (2013). *Kenaf: a multi-purpose crop for several industrial applications, green energy and technology*. London: Springer-Verlag (pp. 1–177).

Mossello, A. A., Harun, J., Tahir, P. M., Resalati, H., Ibrahim, R., Shamsi, S. R. F., et al. (2010). A review of literature related of using kenaf for pulp production (beating, fractionation, and recycled fiber). *Modern Applied Science, 4*(9), 21–29.

Natella, F., Nardini, M., Virgili, F., & Scaccini, C. (2005). Role of dietary polyphenols in the platelet aggregation network- a review of the *in vitro* studies. *Current Topics in Nutraceutical Research, 4*(1), 2–21.

Ng, S. K., Choong, Y. H., Tan, C. P., Long, K., & Nyam, K. L. (2014). Effect of total solids content in feed emulsion on the physical properties and oxidative stability of microencapsulated kenaf seed oil. *LWT-Food Science and Technology, 58*, 627–632.

Ng, S. K., Lau, J. L. Y., Tan, C. P., Long, K., & Nyam, K. L. (2013). Effect of accelerated storage on microencapsulated kenaf seed oil. *Journal of American Oil Chemistry Society, 90*, 1023–1029.

Ng, S. K., Tee, A. N., Lai, E. C. L., Tan, C. P., Long, K., & Nyam, K. L. (2015). Anti-hypercholesterolemic effect of kenaf (Hibiscus cannabinus L.) seed on high-fat diet *Sprague dawley* rats. *Asian Pacific Journal of Tropical Medicine*, 6–13.

Ng, S. K., Wong, P. Y., Tan, C. P., Long, K., & Nyam, K. L. (2013). Influence of the inlet air temperature on the microencapsulation of kenaf (*Hibiscus cannabinus* L.) seed oil. *European Journal of Lipid Science and Technology, 115*, 1309–1318.

Nyam, K. L., Sin, L. N., & Long, K. (2015). Phytochemical analysis and anti-inflammatory effect of kenaf and roselle seeds. *International Food Research Journal, 21*(2), 245–254.

Nyam, K. L., Tan, C. P., Lai, O. M., Long, K., & Che Man, Y. B. (2009). Physicochemical properties and bioactive compounds of selected seed oils. *LWT-Food Science and Technology, 42*, 1396–1403.

Nyam, K. L., Teh, Y. N., Tan, C. P., & Long, K. (2012). *In-vitro* antioxidant activities of extract and oil from roselle (*Hibiscus sabdariffa* L.) seed against sunflower oil autoxidation. *Malaysian Journal of Nutrition, 18*(2), 265–274.

Olasoji, J. O., Aluko, O. A., Agbaje, G. O., Adeniyan, O. N., Kareem, K. O., & Olanipekun, S. O. (2014). Studies on seed yield potential of some selected kenaf (*Hibiscus cannabinus* L.) genotypes. *African Journal of Biotechnology, 13*(24), 2420–2424.

Page, L. R. (1998). *Healthy healing: a guide to self-healing for everyone* (10th ed., p. 210). USA: Healthy Healing, Inc..

Price, P., & Frey, K. B. (2003). *Microbiology for surgical technologists* (pp. 41–43). USA: Cengage Learning.

Razmkhah, R., Tan, C. P., Long, K., & Nyam, K. L. (2013). Quality changes and antioxidant properties of microencapsulated kenaf (*Hibiscus cannabinus* L.) seed oil during accelerated storage. *Journal of American Oil Chemists' Society, 90*, 1859–1867.

Richardson, M. S. (2003). *Health basics: a doctor's planspoken advice about how your body works and what to do when it doesn't* (p. 177). USA: Next Decade Inc..

Rosa, R. M., Melecchi, M. I., DaCosta, H. R., Abad, F. C., Simoni, C. R., Caramao, E. B., et al. (2006). Antioxidant and antimutagenic properties of *Hibiscus tiliaceus* L. methanolic extract. *Journal of Agricultural Food Chemistry, 54*(19), 7324–7330.

Saravanamuthu, R., Dubey, R. C., & Maheshwari, D. K. (2010). *Industrial exploitation of microorganisms* (p. 154). India: I.K. International Publishing House Pvt. Ltd.

Schubert, S. Y., Lansky, E. P., & Neeman, I. (1999). Antioxidant and eicosanoid enzyme inhibition properties of pomegranate seed oil and fermented juice flavonoids. *Journal of Ethnopharmacology, 66*(1), 11–17.

Shukla, S., Mehta, A., Mehta, P., Vyas, S. P., Shukla, S., & Bajpai, V. K. (2010). Studies on anti-inflammatory, antioyretic and analgesic properties of *Caesalpinia bonducella* F. seed oil in experimental animal models. *Food and Chemical Toxicology, 48*(1), 61–64.

Singh, L., & Kaur, M. (2006). *Chemistry for tenth class part 2* (p. 291). India: S. Chand & Company Ltd.

Sultana, B., Anwar, F., Mushtaq, M., Aslam, M.A. & Ijaz, S. In vitro antimutagenic, antioxidant activities and total phenolics of clove (*Syzgium aromaticum* L.) seed extracts. Pakistan Journal of Pharmaceutical Sciences, 27(4), 893–899.

Vasanthi, H. R., ShriShriMal, N., & Das, D. K. (2012). Phytochemicals from plants to combat cardiovascular diseases. *Current Medicinal Chemistry, 19*(14), 2242–2251.

Webber, C. L., III, & Bledsoe, V. K. (2002). Kenaf yield components and plant composition. *Trends in New Crops and New Uses*, 350–357.

Whitaker, J. M. (2003). *Quick & health: Recipes for vibrant living* (p. 19). USA: Silverback Books.

Wong, Y. H., Lau, H. W., Tan, C. P., Long, K., & Nyam, K. L. (2014). Binary solvent extraction system and extraction time effects on phenolic antioxidants from kenaf seeds (*Hibiscus cannabinus* L.) extracted by a pulsed ultrasonic-assisted extraction. *The Scientific World Journal*, 1–8.

Wong, Y. H., Tan, W. Y., Tan, C. P., Long, K., & Nyam, K. L. (2014). Cytotoxic activity of kenaf (*Hibiscus cannabinus* L.) seed extract and oil against human cancer cell lines. *Asian Pacific Journal of Tropical Biomedicine, 4*(1), S510–S515.

Yazan, L. S., Foo, J. B., Chan, K. W., Tahir, P. M., & Ismail, M. (2011). Kenaf seed oil from supercritical carbon dioxide fluid extraction shows cytotoxic effects towards various cancer cell lines. *African Journal of Biotechnology, 10*(27), 5381–5388.

Yazan, L. S., Foo, J. B., Ghafar, S. A. A., Chan, K. W., Tahir, P. H., & Ismail, M. (2011). Effect of kenaf seed oil from different ways of extraction towards ovarian cancer cells. *Food and Bioproducts Processing, 89*, 328–332.