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Review

Bioactivities of Kenaf Biomass Extracts: A Review

Danial 'Aizat Norhisham [1,2], Norsharina Md Saad [2,*], Siti Rokhiyah Ahmad Usuldin [1,2], Diwiyaa A G Vayabari [1], Zul Ilham [3,4], Mohamad Faizal Ibrahim [5] and Wan Abd Al Qadr Imad Wan-Mohtar [1,4,*]

1 Functional Omics and Bioprocess Development Laboratory, Institute of Biological Sciences, Faculty of Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia; danialaizat99@gmail.com (D.'A.N.); rokhiyah@nibm.my (S.R.A.U.); diwiyaa99@gmail.com (D.A.G.V.)
2 Agro-Biotechnology Institute, National Institutes of Biotechnology Malaysia, Jalan Bioteknologi, Serdang 43400, Malaysia
3 Environmental Science and Management Program, Institute of Biological Sciences, Faculty of Science, Universiti Malaya, Kuala Lumpur 50603, Malaysia; ilham@um.edu.my
4 Bioresources and Bioprocessing Research Group, Institute of Biological Sciences, Faculty of Sciences, Universiti Malaya, Kuala Lumpur 50603, Malaysia
5 Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, Serdang 43400, Malaysia
* Correspondence: norsharina@nibm.my (N.M.S.); qadyr@um.edu.my (W.A.A.Q.I.W.-M.)

Abstract: Kenaf or *Hibiscus cannabinus* is an annual herbaceous crop that grows well in temperate regions with high rainfall and abundant solar radiation. This *Malvaceae* member is famously known for its high-quality fibre that is directly retrieved from its dried stem materials and is useful in various industries, mainly in paper and pulp, bio-composite, textiles and manufacturing. With recent discoveries, kenaf can now be regarded as a multipurpose crop as its usage has been extended beyond its traditional applications, which include applications within the medicinal, pharmaceutical and food industries since its extracts possess several bioactivities that include anticancer, antimicrobial, antihypertensive, antidiabetic and antithrombotic abilities along with many more. The plant's versatile applications and pharmaceutical activities come from its different plant parts such as its leaves, seeds, flowers and stems. This demonstrates that kenaf can also be safely regarded as a zero-waste crop, which is crucial for the sustainable development of any kenaf-based medicinal or therapeutic compounds. However, the biological properties of kenaf are still not known by many as industries mainly focus on the direct application of its fibre material. If this trend continues, the true potential of kenaf could be halted and undermined. Therefore, this paper aims to provide a concise overview of kenaf's bioactivities that will hopefully provide better knowledge and understanding about this overlooked crop. This paper reviews the latest findings on kenaf's bioactivities from its extracts that are retrieved from either its seeds, leaves, flowers or stems and provides additional information about its current status in Malaysia.

Keywords: *Hibiscus cannabinus*; kenaf; extracts; bioactivities; therapeutic; Malaysia

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1. Introduction

Kenaf is a herbaceous dicotyledonous annual plant with the scientific name of *Hibiscus cannabinus*. This plant is believed to be of African origin, and it taxonomically originates from the Malvaceae family, the same family as cotton and okra [1]. This plant can be found to be actively cultivated and propagated in countries such as Thailand, India, China and Malaysia [2]. With abundant solar radiation along with high rainfall, kenaf can thrive well and has the ability to grow up to 5 m in height in fewer than 6 months [3]. Typically, kenaf is largely known for its good and reliable natural fibre source that is directly retrieved from its dry stem material. At its peak, the production of kenaf's dry stem material can reach up to 30 $t.ha^{-1}$ [4]. This natural fibre derived from kenaf is useful in industries such as paper and pulp, bio-composites, absorption materials and even textiles [3].

Recent discoveries have recognised kenaf's potential as its applications can be further extended beyond its traditional uses. This is because kenaf's extracts either from its seeds, leaves or flowers are proven to have active pharmacological activities such as antimicrobial, antifungal, antioxidant, anticancer, anti-hypertensive and anticoagulant properties along with many more [5–10]. The manifested pharmacological activities of the extracts have been highly attributed to kenaf's phytochemical composition, which includes phenols, flavonoids, terpene, siloxane, citric acid, tocopherols and tocotrienol. For instance, oil that is extracted from kenaf seed has phytochemicals such as Vitamin E, sterol and polyunsaturated fatty acid that can help in combating cancer cells [7]. Even the simplest form of oral intake through tea that is made from kenaf leaves can help to minimise the risk of type-2 diabetes [11]. This proves that kenaf has the potential to be a natural source for plant-based medicine and food production. With the ever-increasing demand for healthier communities and lifestyles, the utilisation of kenaf could not have come at a better time as natural-based products are deemed to be much cheaper, safer, and more consumer and environmentally friendly than ever before [12].

Furthermore, the utilisation of every component of the kenaf plant (leaves, seeds, flowers, stems and roots) [13] for different purposes will ultimately place kenaf in the zero-waste category. This concept reiterates that every part of a plant is valuable and can be turned into something beneficial. The concept also strongly encourages that no trace of a plant should be left behind in the production of desired products. Since every component of kenaf can be utilised, the amount of waste generated can be significantly reduced [14]. This can help in building a sustainable practice when it comes to the usage of the kenaf plant.

However, the true potential of kenaf is not known by many and is often overlooked due to the mass application of its raw fibre. Many industries are currently limiting the usage of kenaf to building materials without ever realising its versatility. For example, there are readily available kenaf-based products for pet care, home living and gardening. Every component of the kenaf plant can come in handy as each has its own phytochemicals that can be extracted for further uses. The bioactivities of kenaf, which were reported previously, prove that this fibrous industrial crop is a 'sleeping giant', awaiting the right time to be called upon to benefit a diverse range of other industries. The bioactivities of kenaf should not be undermined as well because they set the foundation for the crop to not be undervalued. Thus, fulfilling its potential is not beyond our reach. Once the knowledge of kenaf is realised by the community, it is just a matter of time before anyone starts to venture into kenaf plantation, not for crop production, but for its extracts.

However, on a literacy level, there is a lack of reports that specifically address the pharmacological activities or bioactivities along with the potential usage of each kenaf plant component. This makes it difficult for the bioactivities of kenaf to be known and discovered by many. Furthermore, to date, there are also few reviews regarding its latest status in Malaysia. Therefore, this review aims to give a concise overview of kenaf's background, its status in Malaysia, its individual components' pharmacological activities along with its potential applications. This review aims to provide a solid foundation on kenaf's bioactivities, which can hopefully instigate new initiatives on utilising this crop not only for its fibre, but for other industries as well such as the pharmaceutical, cosmeceutical, food and nanotechnology industries. This review is also hoped to be useful for industrial players and researchers who would like to get a first glance at the bioactivities of kenaf.

2. Taxonomy and Botanical Description

Hibiscus cannabinus, most commonly known as kenaf goes by many names according to its geographical locations such as Mesta, Ambari, Til, Gambo, Stokroos and Java Jute in India, Taiwan, North Africa, West Africa, South Africa and Indonesia, respectively [1,3]. The word kenaf itself is taken from a Persian word, *kanab*, that comes from the scientific nomenclature for hemp or marijuana, *Cannabis sativa*. However, despite the similarity of their nomenclature origins, both kenaf and hemp are not related to each other as hemp belongs to the family of *Moraceae* [1,15]. Meanwhile, kenaf originated from the *Malvales* order and *Malvaceae* family that resides under the genus of *Hibiscus*, which is more closely associated with *Gossypium hirsutum* (cotton), *Hibiscus esculentum* (okra), *Hibiscus hibiscum* (hibiscus) and *Althaea rosea* (hollyhock) [1,16]. The genus of *Hibiscus* can be further divided into several sections: *Azanza*, *Calyphillia*, *Ketmia*, *Abelmoschus*, *Alyogen* and *Furcaria*. Kenaf has been classified taxonomically to belong in the *Furcaria* section, which is known to host plants that are important for their food, fibre and medicinal properties [16].

Traditionally, kenaf is well-known for its high-quality fibre source, which is directly obtained from its stem. Kenaf stem can be categorised based on the types of fibre it produces: bast, core and pith [3]. Kenaf bast is the outer part of the stem, which constitutes up to 30% of the stem's dry weight and is said to produce a superior fibre quality compared to other parts of the stem [2]. The inner white part of the stem is the kenaf core, which makes up the rest of the stem's dry weight, and the kenaf pith can be recognised by its polygonal parenchymal cells [17]. Prickly and unbranched kenaf can possess stems with green to reddish colour and can rise to a height of 4–5 m under abundant solar radiation and high rainfall due to its high growth-rate ability (Figure 1A). This trait allows this fibrous plant to be harvested for industrial applications in fewer than 6–8 months [18].

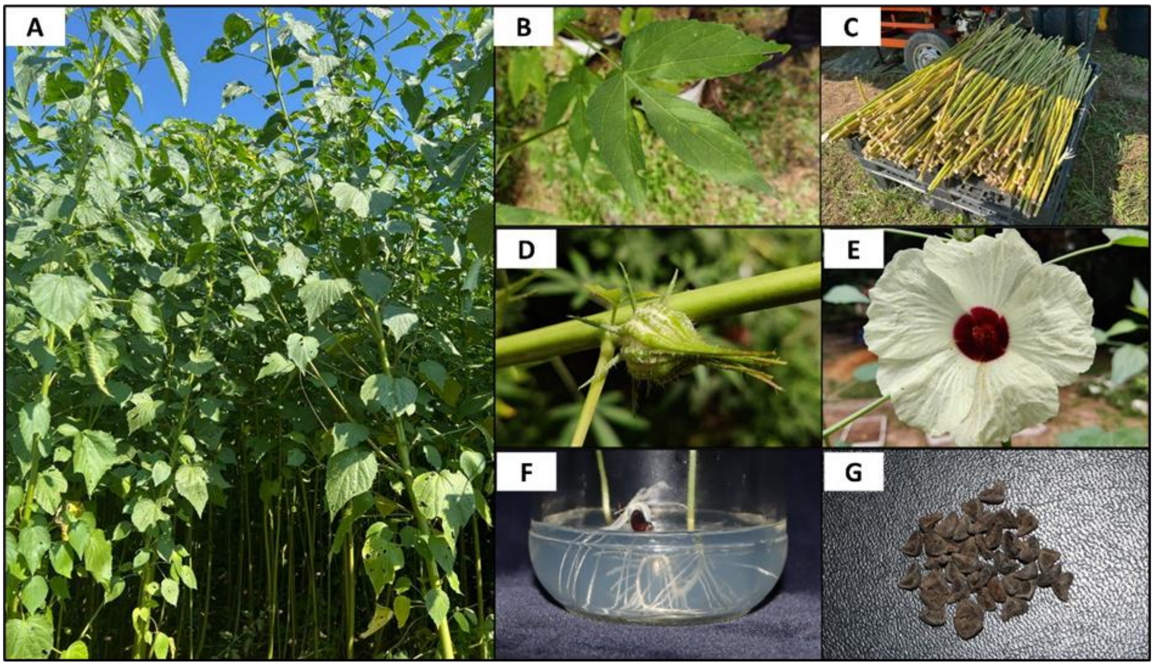

Figure 1. *Hibiscus cannabinus*. (**A**) Whole plant. (**B**) Leaf. (**C**) Stems. (**D**) Fruit. (**E**) Flower. (**F**) Roots. (**G**) Seeds.

Botanically, depending on its variety and age, kenaf can produce either simple (entire) or compound (divided) green leaves that are arranged alternately along the kenaf stem (Figure 1B). Typically, young leaves found on kenaf seedlings are simple, entire and cordate. However, as the plant matures, new palmately compound leaves begin to appear and resemble the palm of a hand with leaflets ranging from 3 to 7 in number radiating outwards from a single point.

Additionally, kenaf produces creamy to light-yellow-coloured flowers with reddish-to-maroon-coloured centres that are bell-shaped and widely open, which makes the flowers hugely conspicuous (Figure 1E). The flowers, which open and close in a single day, are solitary with short stalks that consist of 5 petals, 5 sepals and numerous stamens. Nevertheless, the flower is said to have a superior ovary, whereby other floral organs such as sepal, petal and stamen are arranged below or around it. In terms of pollination, kenaf flowers can conduct both self-pollination and cross-pollination characterised by the twisting–closing movements of the petals and the help of domesticated honey bees, respectively [19].

Kenaf fruit is distinguished by its hairy, rounded and coarse structure that is segmented (Figure 1D). Most segments are seeded with each containing 20–26 seeds. Kenaf seeds are hairless with kidney bean-like triangular (wedged) shapes along with sharp corners that are brown with bright yellow dots (Figure 1G) [19,20]. Furthermore, for a better absorption rate, the kenaf plant has a long tap root with extensive lateral roots (Figure 1F) that consequently make it more sensitive to changes in soil moisture and provide it with better soil penetration for deep-soil water absorption [21].

3. Current Status in Malaysia

The idea of kenaf plantations in Malaysia started way back in 1999, which was initiated by the National Economic Action Council (NEAC) to study its potential to become an alternative industrial crop in addition to oil palm and rubber. Since 2000, multiple agencies including the Malaysian Agricultural Research and Development Institute (MARDI), Malaysian Rubber Board (RRIM), Malaysian Palm Oil Board (MPOB) and Universiti Putra Malaysia (UPM) have come together, forming a committee that has driven research and development of kenaf, which has subsequently fast-tracked its progress and adoption within the country. Since then, many types of research covering aspects of upstream and downstream processing including variety screening, agronomic practices for cultivation, harvesting and mechanization, retting and fibre processing for industrial applications such as bio-composite and animal feed have been undertaken [2]. This can be exemplified by the recent increase in the publication and citation trends related to kenaf (Figure 2). Initially, kenaf cultivation was conducted in 2004 as a familiarisation crop mainly in the East coast region of Malaysia, Kelantan and Terengganu on BRIS (Beach Ridges Interspersed with Swales) soil before being cultivated nationwide for commercial purposes in 2010. The introduction of the kenaf crop into the country concurrently served as an alternative to the tobacco plant, which is also a part of the government's strategies to counter the price and import duty reduction of tobacco [22,23]. The commencement of the ASEAN Free Trade Area (AFTA) in 2010 has been expected to negatively impact the competitiveness of Malaysian tobacco planters. This is because it was reported that production cost in Malaysia is almost twice as much as other tobacco producers such as Thailand and Indonesia [24,25]. Thus, kenaf has been viewed as a potential crop to replace tobacco.

As of 2021, according to the National Kenaf and Tobacco Board (LKTN), the kenaf crop is being cultivated in Malaysia for two purposes: seed production and fibre and crop production. Here, kenaf cultivar V36 was chosen to be cultivated commercially due to its high growth rate and yield with the crop taking approximately 90 to 150 days, depending on the purpose of cultivation, to mature for harvesting [18]. For seed production, kenaf cultivation is conducted in the states of Kedah and Perlis, which amount to almost 500 hectares of land used. Meanwhile, for fibre and core production, crop hectarage in total is about 1000 hectares and can be found in the states of Kelantan, Terengganu, Pahang, Johor, Melaka, Perak, Negeri Sembilan and Kedah (Figure 3). Due to the suitable tropical climate in Malaysia along with the adaptability of kenaf accession V36, classified as a photoperiod-insensitive and late-flowering cultivar, kenaf seeds' germination rate per hectare for both of the aforementioned purposes is above 80%. This, in return, produces a yield per hectare of 0.25 tons and 10 tons for seed production and fibre and core production, respectively. Regarding seed production, seeds are sold at MYR 15 (USD 3.15) per kg, which generates a gross income of MYR 3750 (USD 788.63) per hectare. Meanwhile, MYR 5000 (USD 1051) per hectare can be gained from the fibre and core production as the kenaf dried stems are sold at MYR 500 (USD 105) per ton [18].

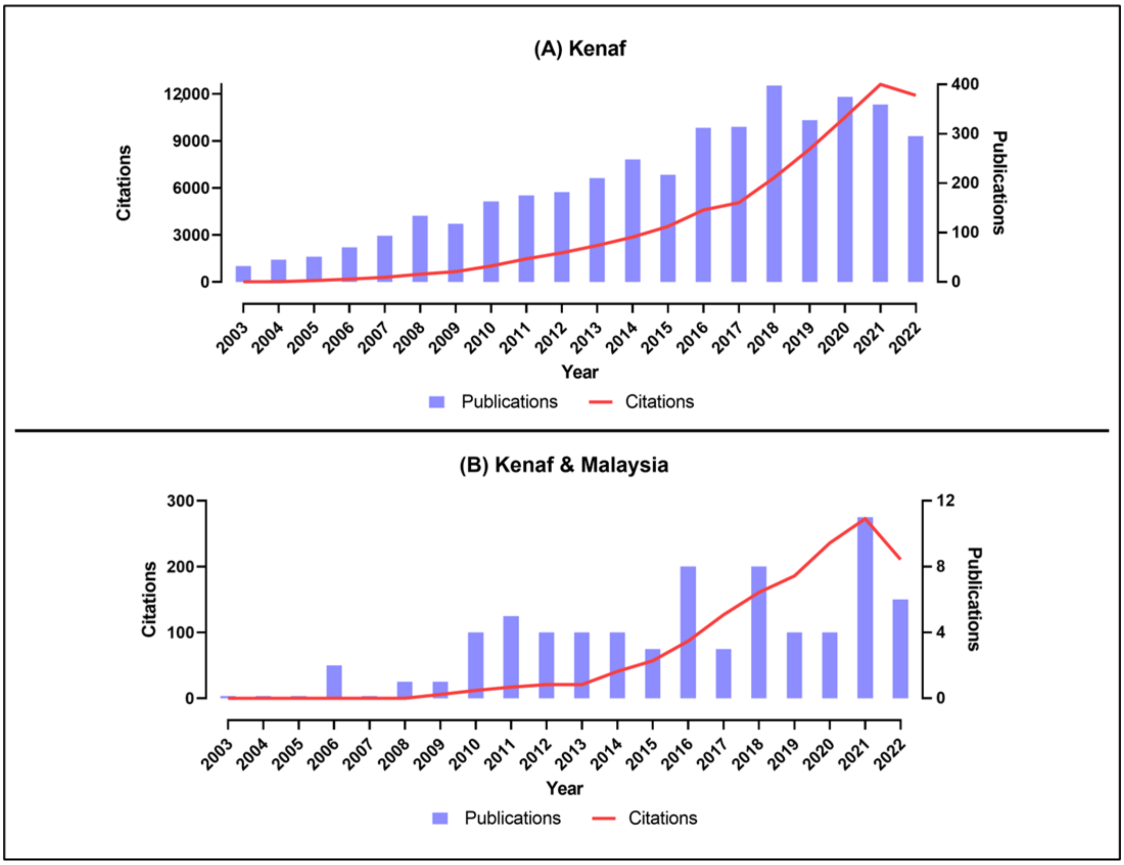

Figure 2. Publication and citation trends of kenaf from 2003 to 2022 using the keywords (**A**) Kenaf and (**B**) Kenaf and Malaysia. Data retrieved from Web of Science.

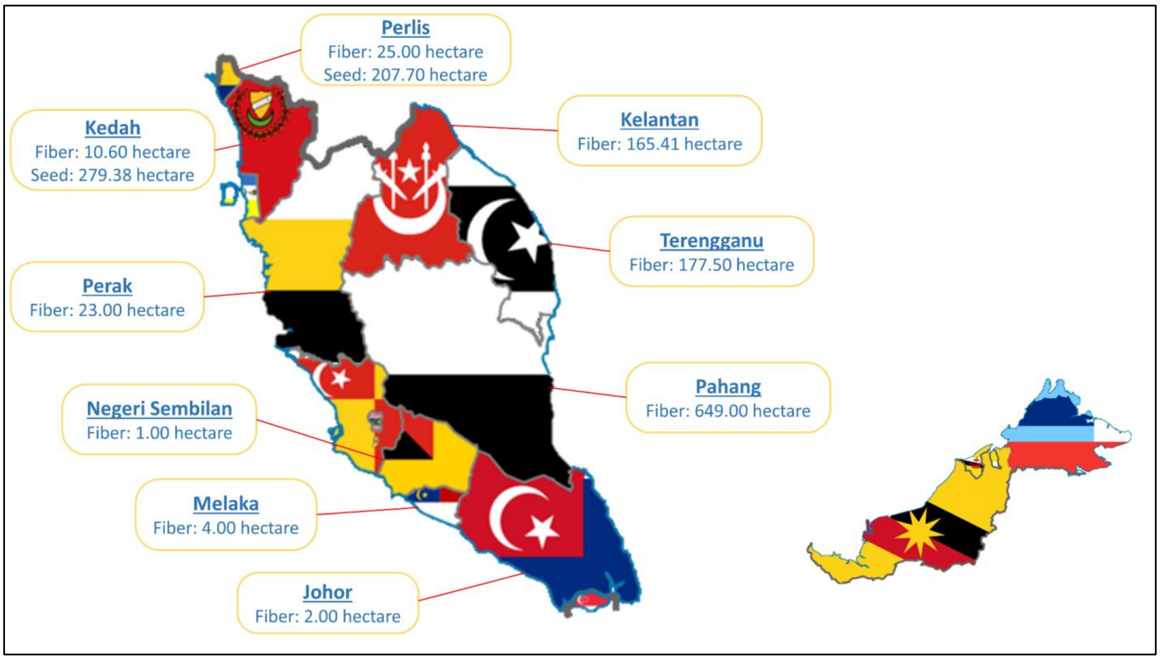

Figure 3. Kenaf and seed hectarage according to state (hectare).

However, despite the increase in the gross income per hectare for kenaf fibre and core production from MYR 2250 in 2019 to MYR 3750 in 2021, the yield of kenaf's dried stems suffered a huge decrease, recording a drop in productivity from more than 7000 tons in 2019 to just 3800 tons in 2021 (Figure 4). This could be caused by the reduction of the number of kenaf growers (928 in 2019 to 733 in 2021) for dried-stem production, which can also be seen in the decrease in kenaf hectarage for dried-stem production from 1364 hectares in 2019 to 1057 hectares in 2021 [18]. A study conducted by Kamaruddin and Othman [26] suggested that the two main factors that affect farmers' acceptability of the kenaf crop are crop performance and resource availability. Farmers will only support the kenaf industry if they witness that kenaf programs implemented by the government and other stakeholders are successful and will in return benefit them in the long run. According to LKTN [18], there was an increase in terms of the damaged crop per hectare from 21% in 2019 to 34%, which subsequently deteriorated its performance and hindered the efforts of the government to convince local farmers to cultivate kenaf. Furthermore, farmers will likely reject kenaf adoption if resources such as incentives, infrastructure, mechanization and facilities are limited, especially when the programs they undertake experience failures [26]. However, the same trend is not shown for kenaf cultivation for seed production. Even though the number of farmers for this purpose still decreased, its productivity in terms of seed production along with kenaf hectarage recorded an increase, which may be highly associated with the involvement of several companies in Kuala Nerang, Kedah and Lembah Chuping, Perlis.

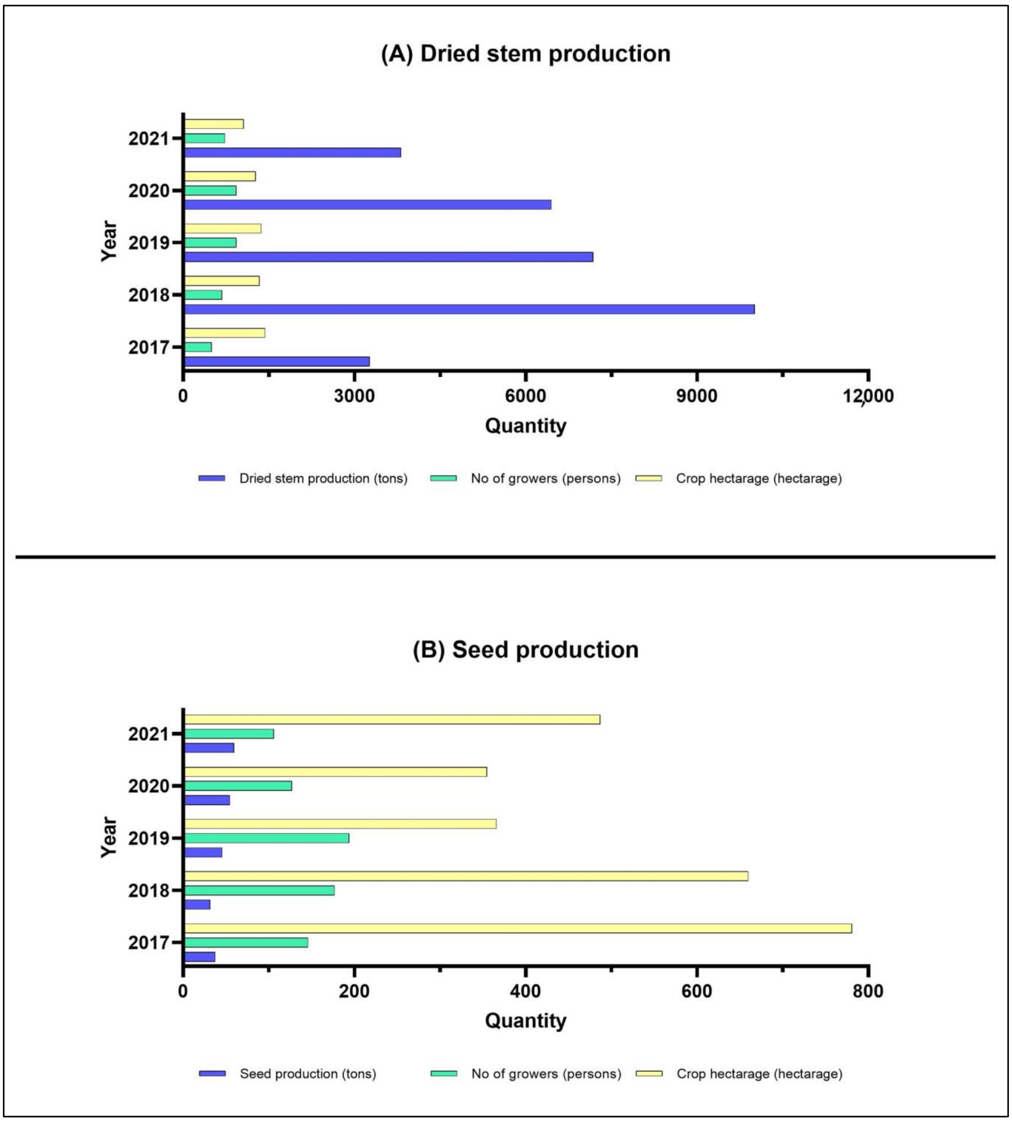

Figure 4. Kenaf plantation in Malaysia for;(**A**) dried-stem production and (**B**) seed production. Data retrieved from LKTN [18].

Going forward, the National Kenaf and Tobacco Board (LKTN) set a target in increase kenaf plantation areas up to 10,000 hectares nationwide by the end of 2023 [27]. In fact, LKTN does provide various incentives to local farmers who intend to cultivate kenaf either for its fibre or seed production to realise the goal of making kenaf one of the nation's main commodities. This exemplifies the immense support from the government to accelerate the adoption of the kenaf plant, especially within the industries. This trend also highlights the upcoming significance of kenaf in contributing to the economic sector of Malaysia as the plant is deemed to be a 'super-crop' as it can be highly profitable for farmers and stakeholders without causing unnecessary damage to nature.

4. Bioactivities of Kenaf Extracts

Traditionally, kenaf has long been used as folk medicine to treat bilious conditions, fever and puerperium in regions such as Africa and India due to its active components such as saponins, tannins, phenolics, essential oils and alkaloids [10,13,28,29]. For instance, the peelings from kenaf's stems have been used as a haematic agent to treat anaemia and fatigue. Its leaves have been utilised to treat blood and throat disorders and dysentery. Furthermore, conditions such as aches and bruises can be treated using its seeds, which are also deemed to be fattening. Additionally, kenaf is also considered to be a purgative, aperitif, anodyne stomachic and aphrodisiac [3,13,30]. Moving forward, with more discoveries being made, many pharmacological activities relating to kenaf's extracts have been reported, which could unearth its true potential. Its reported pharmacological activities are discussed according to each kenaf's part.

4.1. Anticancer Properties

Seed Extract

Kenaf seed oil retrieved via supercritical carbon dioxide fluid extraction with the parameters of 600 bars at 40 °C manifested strong cytotoxicity against human colorectal cancer cell lines (HT29) with an IC_{50} of 200 µg/mL. The observed chemopreventive capacity could be highly attributed to the presence of antioxidant compounds within kenaf seed oil such as vitamin E, alpha-linolenic acid and β-sitosterol (Figure 5). This led to a decrease in the number of viable cells of HT29 via apoptosis, which can be characterised by the plasma membrane blebbing whereby this mechanism is more favoured compared to necrosis as apoptosis is a programmed cell death that does not inflict any inflammatory responses [7]. Furthermore, an in vivo test using kenaf seed supercritical extract on azoxymethane-induced rats was also conducted. Azoxymethane is a chemical carcinogen that induces the formation of aberrant crypt foci (ACF), putative preneoplastic lesions, with the characteristics of tumours such as abnormal cell growth along with excessive expression of tumour-related antigens and dysplasia on the surface of colon rodents that can be used as a reliable biomarker for screening assay of colon carcinogenesis. After 13 weeks, azoxymethane-induced rats that were treated with 1500 mg/kg of kenaf seed supercritical extract showed a 53% reduction in the number of ACF recorded compared to the untreated group. This indicates that kenaf seed extract through supercritical extraction may act as a chemopreventive agent to reduce colon cancer risk [31]. Moreover, kenaf seed extract using n-hexane and ethanol as solvents also showed promising anticancer properties in a dose-dependent and solvent-dependent manner. The usage of 1000 µg/mL of ethanolic kenaf seed extract and n-hexane kenaf seed extract recorded up to 37% and 34% cell death of lung cancer cells (A549), respectively. However, despite the remarkable cancer-cell inhibition during the anti-lung-cancer test, the ethanolic extract of kenaf seed is deemed to be safer as the usage of n-hexane for kenaf seed extraction showed toxicity against mouse embryonic fibroblast cells (NIH3T3) [5]. The n-Butanol fraction of kenaf seed extract also exhibited cytotoxic activity towards breast cancer cells (MCF-7) and colon cancer cells (HT29), recording IC_{50} levels of 895 µg/mL and 780 µg/mL, respectively. Throughout the treatment, the development of apoptotic characteristics such as cell shrinkage and membrane blebbing could be observed, notably for HT29 under an inverted light microscope [28].

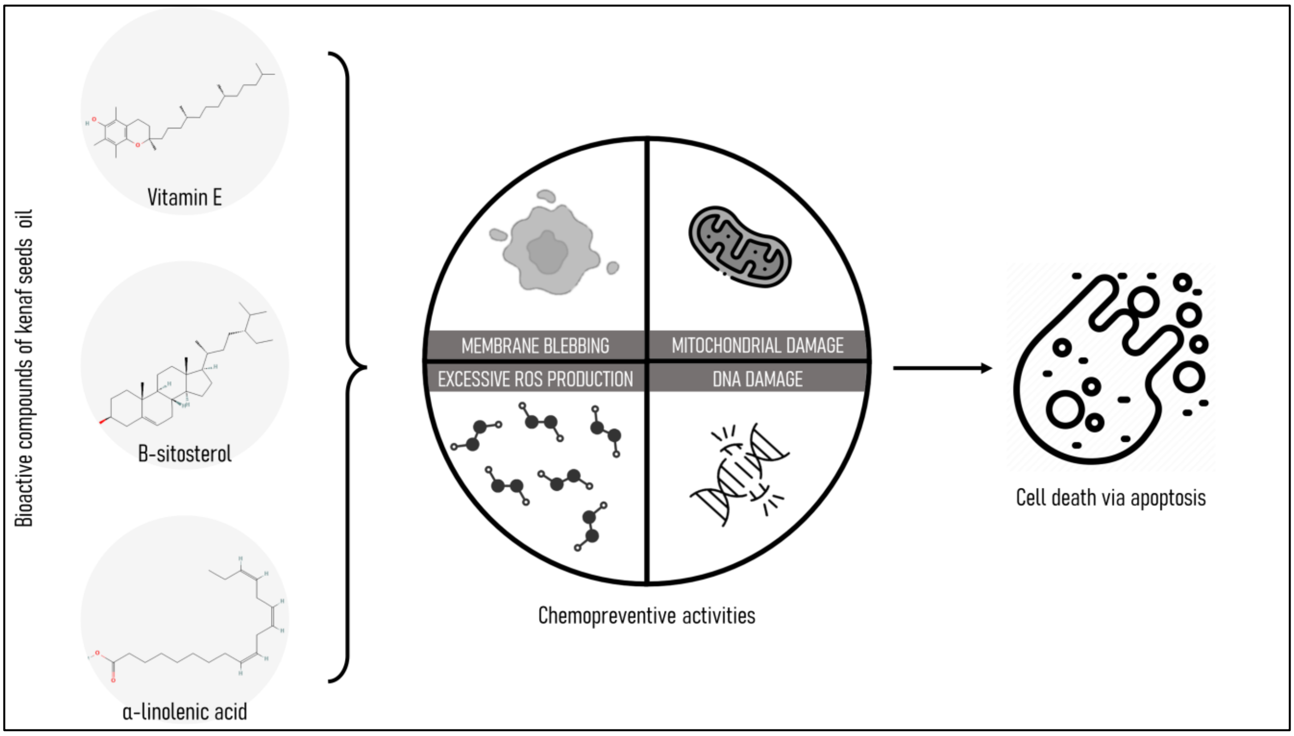

Figure 5. Graphical illustration of kenaf seed oil mechanism in combating cancer cells.

4.2. Antibacterial Properties

4.2.1. Seed Extract

Kenaf seed extracts acquired using ethyl acetate, ethanol and water also successfully expressed their antibacterial properties against both Gram-positive (*Bacillus cereus* and *Bacillus subtilis*) and Gram-negative bacteria (*Escherichia coli*). An outstanding inhibitory performance was observed using the ethyl acetate extract of kenaf seed against *E. coli* with a zone of inhibition of 15 mm, followed by *B. cereus* and *B. subtilis* at 13 mm and 12 mm, respectively [5]. The efficiency of kenaf seed extract against the bacteria could be attributed to its high content of phenols and flavonoids. This allows the extract to have a broader spectrum of antimicrobial activity by either destabilizing bacterial membranes or disrupting cellular function. In addition, kenaf seed peptides that are produced through a process of fermentation using *Lactobacillus casei* demonstrated an exceptionally high antibacterial activity at 98–94% along with a minimum inhibitory concentration (MIC) and a minimum bactericidal concentration (MBC) at 11–22 µg/mL against *B. subtilis*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella typhimurium*, *E. coli* and *Vibrio parahaemolyticus* [32]. Therefore, kenaf seeds have the potential to be a source of a potent antibacterial compound.

4.2.2. Leaf Extract

Kenaf leaf extracts obtained through the reflux method using ethanol showed antimicrobial activity against *Staphylococcus aureus* and *Escherichia coli* by stopping their growth in a disc diffusion assay. One study suggested that the antimicrobial effect of the kenaf leaf could be highly related to its phenolic, flavonoid and polysaccharide content as they prevent the growth of microbes by disrupting membrane integrity and permeability [33]. Another study conducted by Chew, et al. [34] demonstrated the antibacterial properties of kenaf leaf extracts. Using ultrasonic-assisted extraction, the extracts from kenaf leaves exhibited a minimum inhibitory concentration (MIC) of 5 mg/mL for *Staphylococcus aureus*, *Salmonella enterica* and *Escherichia coli* and a MIC value of 2.5 mg/mL for *Staphylococcus epidermis* and *Pseudomonas aeruginosa*. The study also proposed that the kenaf leaf extracts are more effective against Gram-negative bacteria compared to Gram-positive bacteria. This was further demonstrated by the minimum bactericidal concentration (MBC) of 5 mg/mL that was recorded for Gram-negative bacteria.

4.3. Antifungal and Phytotoxic Properties

4.3.1. Seed Extract

Antifungal activity against *Fusarium* sp. and *Aspergillus niger* was also recorded using kenaf seed peptides that were produced through a fermentation process with the help of *Lactobacillus pentosus*. The peptide content within the cell-free kenaf seed peptides mixture was able to achieve a minimum inhibitory concentration (MIC) and minimum fungicidal concentration (MFC) of 0.18 mg/mL and 0.7 mg/mL, respectively, for *Fusarium* sp. while recording 1.41 mg/mL and 2.81 mg/mL, respectively, for *A. niger*. The study suggested that the kenaf seed peptide can severely affect the fungal membrane integrity by disrupting the fungal membrane lipid bilayer, which can be demonstrated by the increase in the leakage of its nucleic acid and protein, which ultimately leads to cell death [6]. A similar activity can be observed for kenaf seed peptides that are produced using *L. casei* through fermentation as well. In one study, a high antifungal activity against *A. niger*, *Aspergillus flavus* and *Fusarium* sp. was recorded, ranging between 99–97% in terms of its effectiveness. The MIC and MFC recorded for the tested fungi were 43 μg/mL and 86 μg/mL, respectively [32]. Thus, kenaf seed is another promising antifungal agent that can be widely applied in multiple industries.

4.3.2. Leaf Extract

Interestingly, even the essential oil extracted from kenaf leaves managed to manifest phytotoxic and fungicidal activities. The essential oil started to show its phytotoxic capability at 0.1 mg/mL as it reduced the growth of lettuce and bentgrass seedlings. It also successfully inhibited the growth of several plant pathogenic fungi including *Colletotrichum fragariae*, *Colletotrichum gloeosporioides* and *Colletotrichum accutatum* [10].

4.4. Antithrombotic Properties

Seed Extract

Furthermore, kenaf can also be used to treat cardiovascular complications. Hanumegowda, et al. [8] demonstrated that protein extract of kenaf seed (PEKS) acquired from ammonium sulphate precipitation can prevent the progression of thrombotic disorders as it can function as both an anticoagulant and antiplatelet agent. The usage of 30 μg of PEKS showed a platelet aggregation inhibition of 56% with an IC_{50} of 13.05 μg and 34% with an IC_{50} of 22.0 μg for adenosine diphosphate (ADP) and epinephrine-induced platelet aggregation, respectively. PEKS also exhibited an anticoagulant effect by prolonging the clotting time of both platelet-rich plasma and platelet-poor plasma as well as delaying the in vivo bleeding time of mice. The study also indicated that this occurred because PEKS interferes with the intrinsic pathway of blood coagulation as it specifically affects the clotting time of the activated partial thromboplastin time only.

4.5. Anti-Hypercholesterolemic Properties

Seed Extract

In addition, kenaf seed was also proven to have anti-hypercholesterolemic (Figure 6) properties when Kai, et al. [9] discovered that hypercholesterolemic rats on a high-fat diet that were treated with kenaf seed extract (KSE), kenaf seed oil (KSO), defatted kenaf seed meal (DKSM) and microencapsulated kenaf seed oil (MKSO) were shown to have a lower amount of serum total cholesterol (TC, 1.59–1.86 mmol/L) and malondialdehyde (MDA, 0.06–0.08 μmol/L) levels compared to untreated hypercholesterolemic rats (2.29 mmol/L TC, 0.14 μmol/L MDA). The anti-hypercholesterolemic effect shown by all the kenaf samples was comparable to hypercholesterolemic rats treated with the widely commercially available hypercholesterolemic drug simvastatin (1.53 mmol/L TC, 0.6 μmol/L MDA). Hypercholesterolemic rats treated with KSE and MKSO also showed a lower atherogenic index (AI, 0.15 and 1.42, respectively) and coronary risk index (CRI, 0.23 and 1.56, respectively), which are reliable indicators of the deposition of cholesterols into tissues that are being metabolized or excreted compared to the untreated group (0.84 AI, 2.16 CRI). Similarly, Cheong, et al. [35] found that rats on a high-cholesterol diet that were treated with KSO, kenaf seed oil-in-water macroemulsion (KSOM), kenaf seed oil-in-water nanoemulsions (KSON) and emulsifier mixtures (EM) had a lower amount of serum total cholesterol, low-density lipoprotein cholesterol (LDL-C) and lipid peroxidation levels compared to untreated hypercholesterolemic rats. Among the samples, KSON was deemed to be the most efficient in terms of having cholesterol-lowering properties as hypercholesterolemic rats treated with the sample had 1.72 mmol/L TC, 0.26 mmol/L LDL-C, 0.18 AI and 1.22 CRI, values that were lower than the untreated group with 3.75 mmol/L TC, 1.53 mmol/L LDL-C, 1.29 AI and 2.35 CRI. The cholesterol-lowering properties shown by kenaf seed suggested that it could be an alternative natural therapeutic medicine that can help in combating cardiovascular diseases such as atherosclerosis, coronary artery disease and cerebral vascular disease.

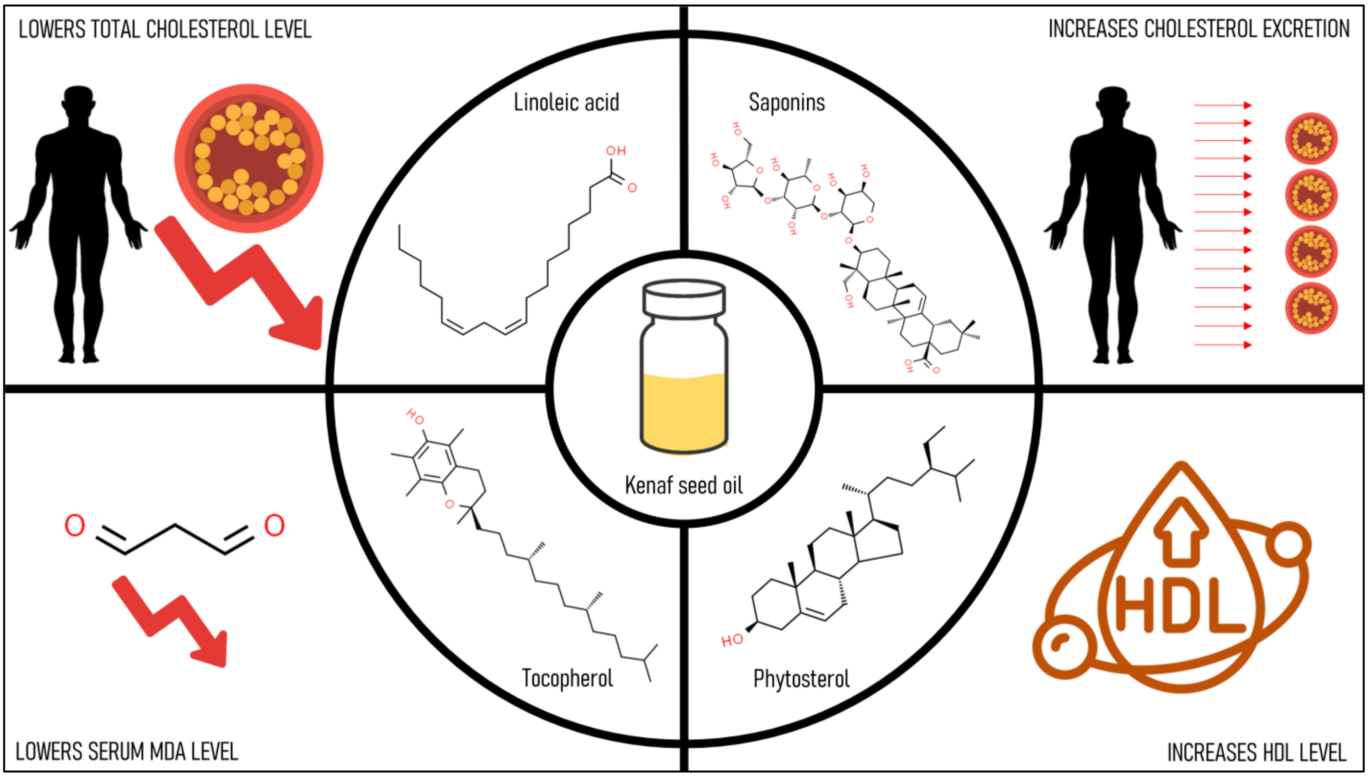

Figure 6. Graphical illustration of kenaf seed oil mechanism in addressing hypercholesterolemia conditions.

4.6. Anti-Hyperpigmentation, Skin Whitening and Anti-Aging Properties

4.6.1. Seed Extract

Interestingly, kenaf seed can also exhibit anti-hyperpigmentation activity, an important property within the beauty and cosmetic industries. Skin hyperpigmentation is a skin condition denoted by the appearance of dark spots, darker tones and discoloration, which has been classified as one of the most common dermatologic disorders. It is caused by the excessive production of the skin-darkening pigment called melanin that is produced through a physiological process known as melanogenesis governed by the enzyme tyrosinase (Figure 7). Sim, et al. [36] used a lotion made from kenaf seed oil and kenaf leaf extract at a non-cytotoxic concentration of 0.5 mg/mL to treat normal human epidermal melanocytes (NHEM). The study reported a reduced intracellular melanin content along with a comparable cellular anti-tyrosinase activity effect at 25.6% compared to the positive control at 29.17%, which highlighted kenaf seed's potential as an anti-hyperpigmentation agent. The study also indicated that the lotion derived from kenaf seed oil and leaves can work synergistically to interfere with melanin production at transcriptional and translational levels as the expression of genes and proteins of melanogenesis such as tyrosinase, tyrosinase-related protein 1, tyrosinase-related protein 2 and microphthalmia-associated transcription factor are suppressed (Figure 7). Thus, kenaf seed could be used as a therapeutic option in treating skin hyperpigmentation.

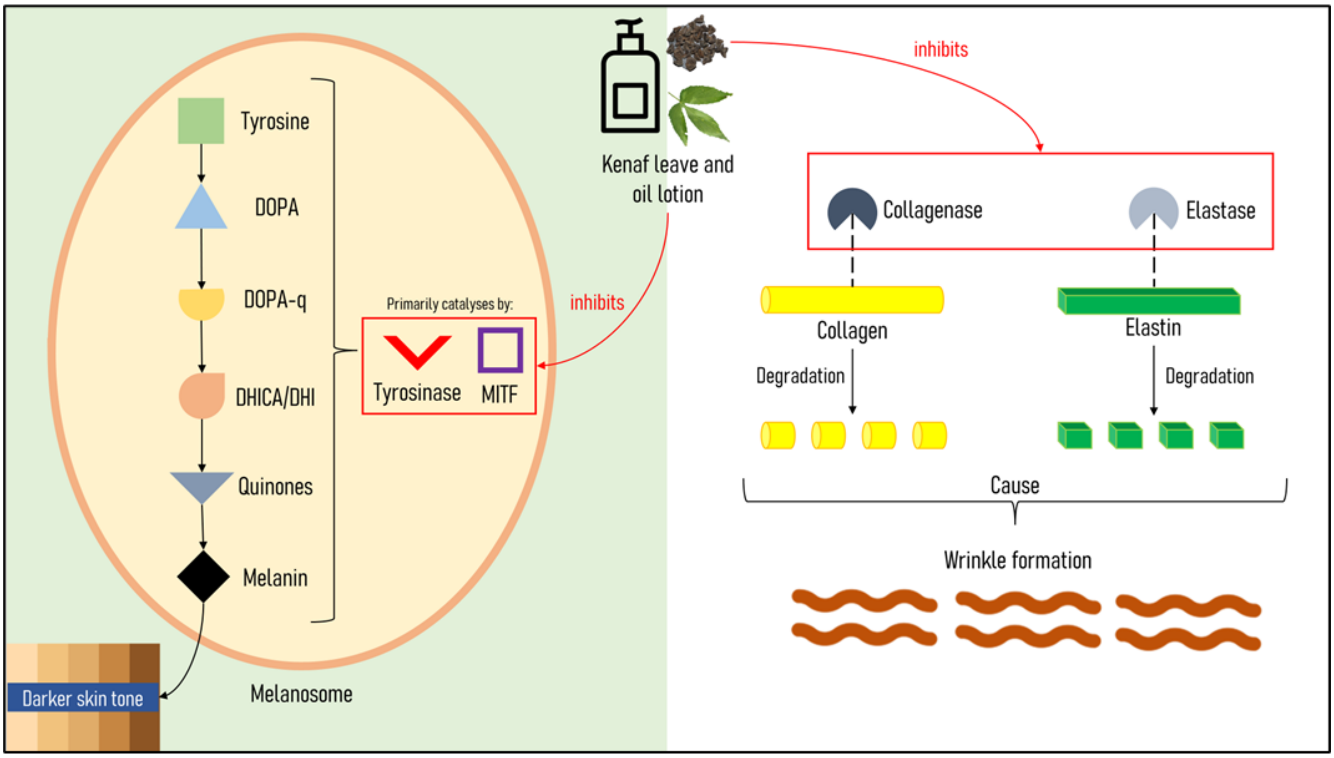

Figure 7. Graphical illustration of kenaf leave and oil-based lotion mechanism in addressing hyperpigmentation and ageing. DOPA: dihydroxyphenylalanine, DOPA-q: DOPA quinone, DHICA: 5,6-dihydroxyindole-2-carboxylic acid, DHI: 5,6- dihydroxyindole, MITF: microphthalmia-associated transcription factor.

4.6.2. Leaf Extract

Furthermore, the benefits of kenaf leaf extract also apply to the beauty and cosmetic industries as Sim and Nyam [12] demonstrated its skin whitening and anti-aging properties when it was formulated into a lotion with kenaf seed oil as its lotion base. Using B16F10 melanoma cell models, the kenaf leaf extract lotion (KLEL) was able to inhibit the activity of an important enzyme for melanin synthesis, tyrosinase, by 32.35% and reduced its melanin content (a skin-darkening pigment). An in vitro anti-aging characteristic was also observed in the activities of two enzymes that can degrade collagen and elastin; collagenase and elastase were inhibited by 36.41% and 23.13%, respectively. The reduction of the degradation of collagen and elastin prevents wrinkle formation (Figure 7), one of the major signs of aging, which subsequently preserves the integrity of skin.

4.7. Antioxidant Properties

4.7.1. Seed Extract

Moreover, the extract of kenaf seed also possesses antioxidant capabilities as it showed a good scavenging capacity, especially in a water extract in DPPH-free radical assay (73%)

and hydroxyl (H_2O_2)-free radical assay (67%). Its scavenging ability is relatively solvent-dependent as water extract of kenaf seed showed a better capacity compared to other extraction solvents such as ethyl acetate (54% DPPH), ethanol (52% DPPH) and hexane (28% DPPH, 26% H_2O_2). This could be attributed to the higher content of secondary metabolites in the water extract such as polyphenol and flavonoids, whereby it is suggested that the usage of high-polar solvents bring about the best free radical scavenging ability [5]. Even defatted kenaf seed meal (DKSM) when its oil content had been removed, which is always regarded as waste, can be utilised as an antioxidant agent. Chan, et al. [37] proved that the n-Butanol fraction of the crude ethanolic extract of DKSM shows an antioxidant characteristic using free radical system assays such as DPPH-free radical assay, ABTS radical cation scavenging capacity and hydroxyl radical scavenging activity along with lipid peroxidation system and a Beta-carotene bleaching assay. The study also proposed that the presence of antioxidant activities recorded were strongly correlated with the high content of phenolics and saponins in the kenaf seeds, which are the major phytochemicals responsible for antiradical capabilities. Kenaf seed's antioxidant ability has also been demonstrated in vivo by Hanumegowda, et al. [8]. Their study indicated that the protein extract from kenaf seeds can normalize the liver, kidney and small intestine of diclofenac-induced oxidative stress rats. This was depicted in a decrease in stress markers (malondialdehyde and protein carbonyl content), the restoration of antioxidant enzymes (superoxide dismutase and catalase), the normalization of biochemical parameters (albumin, globulin and total protein) in the liver and the improvement of organ morphology and structure.

4.7.2. Leaf Extract

Birhanie, et al. [33] also reported the antioxidant properties of ethanolic kenaf leaves extract. This was depicted by the results of DPPH radical scavenging activity (79.77% of inhibition), ABTS assay (88.3% of inhibition) and FRAP assay (5.08 mmol Fe^{2+}/g of dry weight). The study proposed that the reported radical scavenging activities are highly attributed to the total phenolic content and polysaccharide content of the extract. Other studies also reported likewise [11,12,34].

4.7.3. Flower Extract

In addition, even the extract from the flower of kenaf can also be utilised as an antioxidizing agent which was proven by Ryu, et al. [13]. In the study, the water extracts and methanolic extracts of kenaf flower recorded a DPPH radical scavenging activity of 80.6% and 71.84%, respectively. Besides, both water and methanolic kenaf flower extracts also manifested the maximum superoxide dismutase (SOD) activity among the other extracts (ethanol, chloroform). The study proposed that the promising total phenolic content and total flavonoid content found in the extracts of the kenaf flower could contribute to its antioxidant properties which subsequently raises its value which could be used as a potential functional food source or natural food colorant.

4.7.4. Stem Extract

According to Ryu, et al. [13], the extracts of kenaf stems possess antioxidative properties through DPPH radical scavenging activity. However, the efficacy of the extracts in scavenging free radicals is solvent-dependent as the water, ethanol and methanol extracts of kenaf stems showed a DPPH radical scavenging activity of 29%, 15% and 1%, respectively [13].

4.8. Antihypertensive Properties

Seed Extract

Additionally, protein hydrolysates derived from kenaf seeds produced through enzymatic hydrolysis have been shown to have an antihypertensive effect both in vitro and in vivo. This is important as hypertension or high blood pressure is considered a chronic medical condition that is closely related to brain, heart and kidney diseases.

Zaharuddin, et al. [38] reported a 95.47% inhibition of angiotensin I-converting enzyme (ACE) activity using a papain-generated protein hydrolysate from kenaf seeds. ACE is responsible for converting angiotensin I to angiotensin II, a vasoconstrictor, while inactivating bradykinin, a vasodilator, wherein it eventually elevates blood pressure, leading to the development of hypertension (Figure 8). An antihypertensive effect was also depicted in spontaneously induced hypertensive rats. A treatment with papain-generated protein hydrolysate managed to reduce systolic blood pressure by 46 mmHg, which was comparable to a commercial antihypertensive drug, captopril, which showed reduction by 50 mmHg.

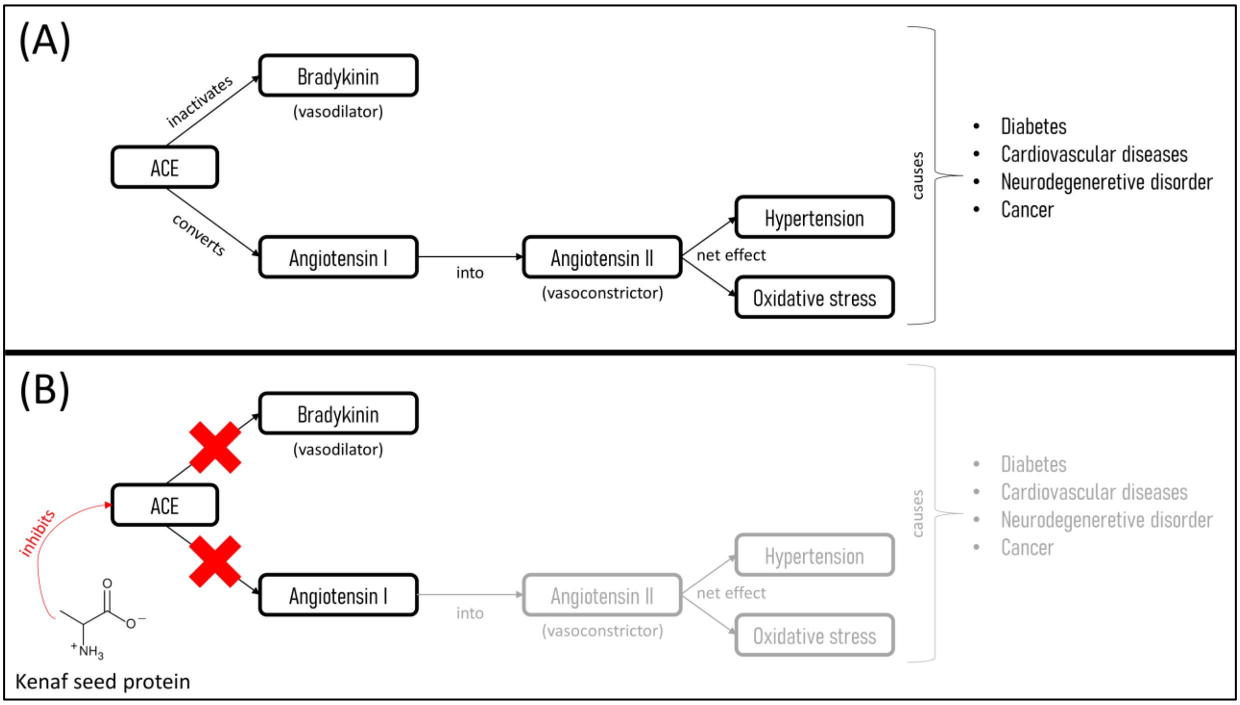

Figure 8. Graphical illustration of kenaf seed protein mechanism in addressing hypertensive conditions. (**A**) Without kenaf seed protein. (**B**) With kenaf seed protein. ACE: Angiotensin-converting enzyme I.

4.9. Antidiabetic Properties

Leaf Extract

Moreover, the kenaf leaves can also be processed into tea that has functional values such as anti-diabetic properties. According to Goh, et al. [11], the infusion of kenaf leaf tea with goji berries and red date tea (6:4) managed to exhibit hypoglycaemic effects by inhibiting the activity of the α-amylase enzyme. The study proposed that the mixture of both teas can work synergistically to disrupt the α-amylase enzyme, which plays a role in carbohydrate (starch, and glycogen) digestion (Figure 9). The study also suggested that the infusion of kenaf leaf tea with the flavour of goji berries and red dates is necessary in order to mask and alleviate its sour flavour, which was fairly reflected in the acceptance rate of 50 panellists, giving it an overall score between 7 to 8 out of 10. The antidiabetic effect of kenaf leaf extract was also demonstrated in vivo through the histopathological observation of the submandibular salivary glands of alloxan-induced diabetic albino rats. The treatment of the diabetic albino rats through daily oral administration of the methanolic extract of kenaf leave for four weeks managed to decrease the symptoms of diabetically-damaged glands such as loss of the structure of the glands (acini, duct system, blood vessels and connective tissue stroma) and the accumulation of numerous intracytoplasmic vacuoles in the glands [39].

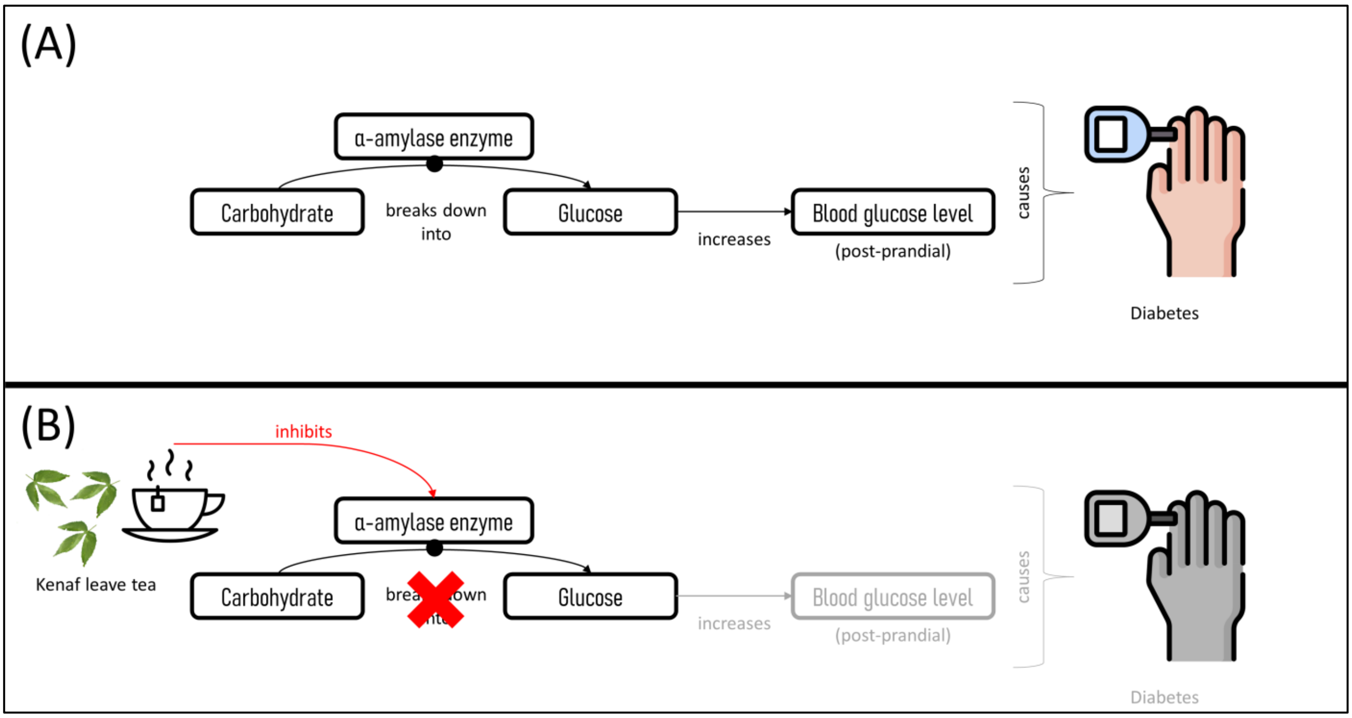

Figure 9. Graphical illustration of kenaf leaf tea mechanism in addressing diabetes. (**A**) Without kenaf leave tea. (**B**) With kenaf leave tea.

4.10. Immunomodulatory Effects

Leaf Extract

Kenaf leaf extract is also able to modulate macrophages (differentiated tissue cells that are responsible for removing cell debris), killing pathogens and processing and presenting antigens to the lymphocytes that correlate with both innate and adaptive immunity. Lee, et al. [30] demonstrated that the ethanolic extract of kenaf leaf was able to suppress the production and mRNA expression of pro-inflammatory cytokines such as tumour necrosis factor (TNF)-α, interleukin (IL)-3 and IL-12 in the lipopolysaccharide-stimulated macrophage cell line RAW264.7 cells. The extract was also able to disrupt the secretion of inflammatory mediators such as nitric oxide, reactive oxygen species and prostaglandin E_2 while inducing the expression of a potent cytoprotective molecule, heme oxygenase-1 (HO-1) mRNA. Thus, the study suggested that kenaf leaf extract may be able to modulate macrophage-mediated responses, which indirectly relates to its immunomodulatory effect. In fact, the inhibition of the inflammatory responses of kenaf leaf extract was proven in vivo by Shaikh, et al. [40]. In their study, aqueous extract and methanolic extract of kenaf leaves at concentrations of 200–400 mg/kg were used to treat carrageenan-induced rat paw oedema. At the highest treatment concentration, kenaf leaf methanolic extract and aqueous leaf methanolic extract showed to inhibit rat paw oedema at 52% and 49%, respectively, which ultimately exemplified the extracts' anti-inflammatory activities [40].

However, to date, no studies have ever reported on the pharmacological activities of extracts from kenaf's roots. That said, according to farmers, after harvesting plants, roots are left to biodegrade on-site. This will eventually help to restore soil fertility for other crops such as rice. This indicates that the roots of kenaf may have the potential to be turned into an organic fertiliser. Furthermore, it is premature to neglect kenaf's root potential as the extracts of other plants from the same genus, *Hibiscus rosa sinensis* and *Hibiscus vitifolius*, showed antidyslipidemic and hepatoprotective activity, respectively [41,42].

4.11. Phytochemistry of Kenaf Biomass Extracts

4.11.1. Seed

Kenaf seed oil contains both forms of Vitamin E: tocopherols (δ-tocopherol, α-tocopherol and γ-tocopherol) and tocotrienols (δ-tocotrienol, α-tocotrienol and γ-tocotrienol) [43,44]. The presence of this class of vitamin is essential in preventing oxidation of lipids in the body, important for the prevention of cancer, potentially lowering blood-cholesterol levels and manifesting cardioprotective and neuroprotective effects [9,43,45].

Additionally, α-linolenic acid, a plant-based essential ω-3 polyunsaturated fatty acid, has been discovered in kenaf seed oil as well, and this type of fatty acid can lower the risk of type 2 diabetes and cardiovascular diseases [46]. However, according to Ryu, et al. [13], the major constituent of fatty acid in kenaf seed oil is linoleic acid that can play a major role in reducing total cholesterol levels [47].

Kaempferol, a major type of flavonoids in kenaf seed oil, is suggested to show various pharmacological activities including anticancer, antioxidant, antimicrobial and antidiabetic properties [48].

Moreover, phenolic compounds can also be found in the seed extracts of kenaf with p-hydroxybenzoic acid as the most abundant phenol [13]. Phenolic compounds play an important role in maintaining health as the compounds can act as anti-inflammatory, antioxidant, anti-aging and antiproliferative agents [29].

Phytosterol was found in kenaf seed oil, too [9]. Phytosterol such as β-sitosterol can help in combating high cholesterol levels as it can inhibit cholesterol absorption and reduce the level of triglycerides while elevating the amount of blood-HDL [49].

Other than the phytochemicals present in kenaf seed oil, kenaf seed peptides are also pharmacologically useful. The peptides identified by Arulrajah, et al. [32] possessed a low molecular weight with a net positive net charge due to the abundant presence of the basic amino residues lysine and arginine. The manifested antibacterial and antifungal properties are due to the strong insertion of positively charged peptides into negatively charged membranes, disrupting its lipid bilayer structure that forms pores, which leads to the leakage of intracellular components and the deaths of bacteria or fungi [50]. However, protein extracts from kenaf seed that possess antithrombotic properties appear to be acidic in nature, and they also possess carbohydrate moieties [8].

Other phytochemicals that were found in kenaf seed oil or extracts with important bioactivities were gallic acid, syringic acid, p-coumaric acid and tannic acid [13].

4.11.2. Leaves

Kenaf leaf is a dependable source of phenolic and flavonoid compounds. Caffeic acid is found to be the most abundant phenolic compound in kenaf leaves and it is also rich in kaempferitrin [13]. Caffeic acid, a polyphenolic compound, is famously known for its strong radical scavenging activities. Meanwhile, kaempferitrin was found to possess blood-glucose-lowering properties [51]. Polysaccharides can also be obtained from kenaf leaf extracts, which possess antioxidant and antibacterial properties [33].

Additionally, essential oils can also be retrieved from kenaf leaves, and phytol is the main component [10,13]. Phytol is a type of terpene, specifically an acyclic diterpene alcohol, which can be utilised as a precursor for Vitamin E and K_1 production [52].

Other important phytocompounds found in kenaf leaf extracts include, chlorogenic acid, catechin hydrate, caffeic acid, kaempferol glycoside, afzelin and tannic acid [13,53].

4.11.3. Flowers and Stems

For kenaf flowers, several compounds are present such as anthocyanins, myricetin glycoside, p-hydroxybenzoic acid and caffeic acid [13]. Anthocyanin is a natural pigment that has antioxidant properties and can produce colours which are useful in multiple colouring industries such as medicine, cosmetics and food [54].

Meanwhile, gallic acid, vanillin and caffeic acid were also found in the kenaf stem extracts [13].

4.12. Extraction Methods for Kenaf Biomass Extracts

Kenaf's final yield and phytochemical preservations are two important factors in determining the right and suitable extraction parameters and processes. Extraction parameters employed such as type and concentration of the extraction solvent, extraction time, extraction pH, extraction temperature and the chemical nature of the targeted compounds influence final extraction efficiency [55]. For instance, phytochemicals from plants such as phenolic compounds have different structures, polarities and physicochemical properties, which eventually affect the final efficiency of the extraction process. Thus, an optimization study in determining the optimum extraction parameters to extract the desired compounds from a specific part of the plant is worth consideration to maximise the yield of the product [56], which was demonstrated by Chew, et al. [34].

Besides the extraction parameters, the type of extraction method must also be properly considered based on its pros and cons. Several factors such as the cost, complexity, safety and extraction yield of the selected method along with its impact on the environment must be taken into account [57]. One of the most commonly chosen methods for the extraction of kenaf biomass extracts is solvent extraction using solvents such as n-hexane and ethanol [5,9], n-butanol [28,37], ethyl acetate [5] and methanol [10]. Despite its relatively easy procedure, this method has several drawbacks, which include the loss of targeted phytochemicals due to oxidation, ionisation, and hydrolysis and long extraction times along with environmental concerns [58]. Additionally, extracts obtained through solvent extraction are often doubted for their safety due to the potential presence of solvent residue [7,31]. For example, Adnan, et al. [5] reported that kenaf seed extracts retrieved using n-hexane possessed toxicity properties against mouse embryonic fibroblast cells (NIH3T3). Therefore, other safer methods such as supercritical fluid extraction and ultrasonic-assisted extraction can be considered.

Ultrasonic-assisted extraction (UAE) is said to be more effective and efficient in the extraction process [59]. Its simplicity and cost-effective, eco-friendly and time-saving nature along with its high reproducibility makes it attractive compared to other traditional methods. This method assists in the extraction process by generating a range of frequencies that disintegrate the cell walls of the plant, which releases targeted compounds [34]. Additionally, supercritical fluid extraction (SFE) can also be selected [7,31]. SFE uses a supercritical fluid such as carbon dioxide (CO_2) to separate one component from the other. A supercritical fluid is any substance wherein pressure and temperature are above its thermodynamic critical point, granting it the ability to dissolve materials like a liquid and diffuse through solids like a gas [60]. Furthermore, the benefit of opting for this method is shown through the manipulation of its temperature and pressure, which can eventually alter the solvent's density according to the extraction's needs. This method also allows extraction to be performed at low temperatures wherein all solvents can be removed in the final stage of the process [61]. Furthermore, SFE has a higher diffusion coefficient and lower surface tension and viscosity compared to liquid solvents, which makes SFE preferable in terms of mass transfer [60].

5. Kenaf-Based Products

Based on the previous reports and findings, kenaf extracts have been shown to be a very promising bioactive agent that can be utilised diversely, including within the pharmaceutical and medicinal sectors. However, to date, most of the readily available kenaf-based products focus on other categories such as pet care, home living and gardening (Table 1).

Table 1. A list of kenaf-based products.

Category	Product	Description/Function	Pictures
Pet	Flea and tick powder	Control ticks, fleas and lice	
	Shampoo	Possesses antibacterial, anti-inflammatory and anodyne properties, which help eliminate ticks, fleas and lice	
	Pet litter	Effectively and naturally absorbs and eradicates unpleasant odour	
	Bedding	Reliable odour control with a good absorbent property	
Home living	Mattress	A long lasting, comfortable and toxin-free mattress	
	Air purifier	Made from kenaf core that can avoid bad odours naturally produced, such as in shoes and refrigerators	
Gardening	Compost	Can be mixed with plant medium such as top soil to improve soil structure and promote tree growth	

6. Future Potential Applications

Based on the previous reported bioactivities of kenaf, it cannot be denied that this little-known wonder crop has the potential to be used in multidisciplinary fields. It is best to no longer consider the plant as a fibrous or cordage crop only, but we should instead start looking at its broader range of potential applications. This is to ensure that the plant will not be overlooked and will receive the recognition it deserves. Some of the most notable applications of kenaf extracts that can have direct effects on everyday consumers include its use in the medicinal, cosmeceutical, food and beverage and nanotechnology industries (Figure 10).

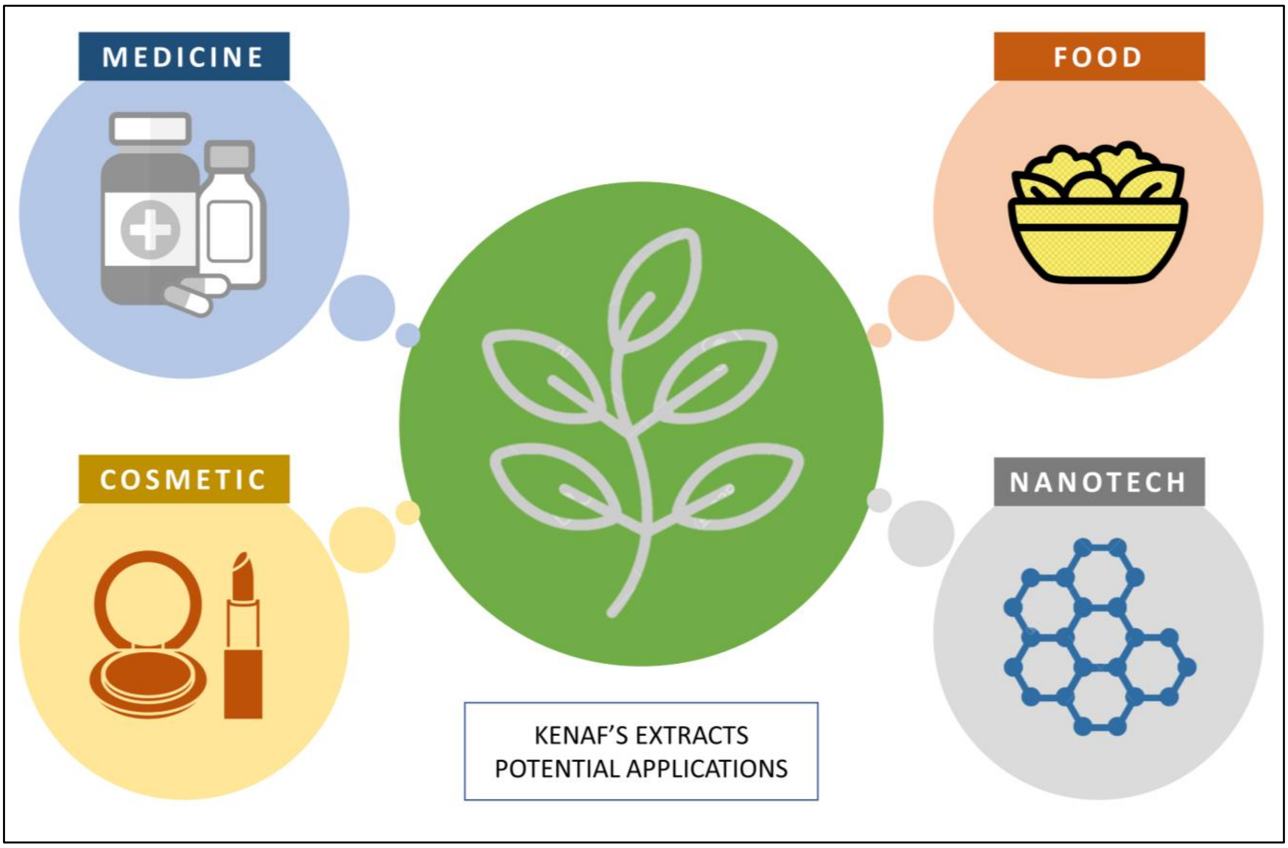

Figure 10. Kenaf extracts' future potential applications.

6.1. Pharmaceutical Applications

The extracts of kenaf seeds, leaves and even its flowers have been proven in previous studies to have beneficial pharmaceutical activities such as anticancer, antibacterial, antifungal, antithrombotic, anti-hypercholesterolemic, antihypertensive, antioxidant and many more properties [5–9,28,36,37]. This opens up an opportunity for novel drug discoveries and development that are specifically derived from a natural source, which is deemed to be much safer, non-toxic, readily available and inexpensive. For instance, there is a need to replace some commonly used synthetic antioxidants such as butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA) and tertiary butyl hydroquinone (TBHQ) that can be harmful to human health in the case of long-term exposure [5]. Even the alarming question of the rise of antibiotic-resistant bacteria, which is threatening global public health, could be answered by returning to nature. Medicinal plants such as kenaf could play a crucial role in addressing the issue through bioprospecting plans, which ultimately can disrupt a wide range of microbial pathways as natural products tend to have higher chemical diversity, bioactive compounds and metabolites [5]. However, to fully utilise the pharmacological activities of kenaf, the yield of the phytochemicals from it should be constantly high enough to meet the demand of the industry while considering other crucial extraction method factors such as its complexity, cost, safety and environmental effects [34]. A good example of kenaf's potential to be developed into a competent drug was depicted by [7] wherein they reported cytotoxic activity of kenaf seed oil against a colon cancer line (HT29) with an IC_{50} of 200 μg/mL. According to Manosroi, et al. [62], any extract that has an IC_{50} value between 125 and 5000 μg/mL has a high possibility to be developed into a chemo-preventive agent. Taking into account all the previous studies, kenaf should be explored for its therapeutic properties, which can come in handy within the pharmaceutical industry.

6.2. Food Applications

Considering the large number of bioactive compounds extracted from kenaf, either from its leaves, seeds or flowers, this plant has the potential to be integrated into the food industry as functional foods that can offer health benefits. For example, it can be turned into a medicinal tea or healthy beverage whereby a pure kenaf tea, prepared from its dried powdered leaves, managed to show antioxidant activities [11]. Moreover, Ryu, et al. [13] suggested kenaf flowers, which also have antioxidative capacity, can be a new source of edible flowers and food colourants. Even the seeds with their oil extracted from them, defatted kenaf seed meal, can be processed into edible flour with antioxidant properties [37,63]. Edible flour is an essential ingredient in the production of staple foods such as bread, cookies, noodles and cakes. Furthermore, Arulrajah, et al. [6] managed to produce antifungal peptides from kenaf seeds that can delay fungal growth on tomato puree. This showed that kenaf has the potential to be utilised as a natural bio-preservative agent in extending the shelf life of food products on the market. Therefore, the potential of kenaf to be incorporated into the food industry should not be neglected.

6.3. Cosmetic Applications

The use of kenaf extracts can also be extended to the cosmetic industry, which is in accordance with the concept of 'returning to nature', as the utilisation of nature-based extracts is greatly accepted by consumers [12]. This is because naturally derived products can be deemed to be much safer, milder and healthier as compared to products that are made entirely from synthetic compounds such as hydroquinone, ascorbic acid and kojic acid [64]. For instance, kenaf leaf extract lotion (KLEL) has been able to exhibit valuable biological activities such as antioxidant, anti-tyrosinase, and anti-aging properties and managed to reduce melanin content, a skin-darkening pigment [12]. Even the incorporation of kenaf seed oil into kenaf-leaf-extract-based lotion was able to manifest the same antioxidant and anti-tyrosinase properties [36]. These studies depicted that kenaf can be further developed into a natural cosmetic product to solve skin concerns such as skin hyperpigmentation.

6.4. Nanotechnology Applications

Other than that, kenaf extracts have also been used for the synthesis of nano-sized particles. Nanoparticles have a wide range of applications such as in the areas of the space industry, physics, biology, medicine and chemistry. Plant materials can play a significant role during nanoparticle synthesis as they can be the substitute for hazardous materials as capping and reducing agents during the process, which can be lethal to healthy cells. This greener approach was demonstrated by Adnan, et al. [65]. They used kenaf seed extract as a bilateral mediator for reducing and capping silver (Ag^+) ions under hydrothermal conditions, which successfully produced kenaf-seed-based Ag^+ nanoparticles (KS@AgNPs) that were spherical. KS@AgNPs were found to possess antimicrobial, and anticancer properties and were observed to be non-toxic to a healthy cell line [65]. A similar non-toxic effect towards healthy cell lines along with anticancer properties was also reported using kenaf-seed-based gold (Au^{3+}) nanoparticles (KS@GNPs) that were produced through microwave heating [66]. Hence, a much cleaner and eco-friendlier synthesis of nanoparticles can be achieved through green technology, which involves plants such as kenaf in the process.

7. Challenges and Limitations

However, the reported bioactivities and therapeutic potentials of kenaf have come directly from the plant itself either from its leaves, seeds, stems or flowers. This subsequently creates a never-ending demand for kenaf's raw materials that are highly dependent on traditional farming. This method of producing the desired therapeutic compounds from kenaf is deemed to be unsustainable in the long run as several concerning issues will arise. Even for the mass production of kenaf's therapeutic compounds for upscaling purposes, our total dependency on traditional farming will have the potential to pose a threat to both mankind and nature (Figure 11).

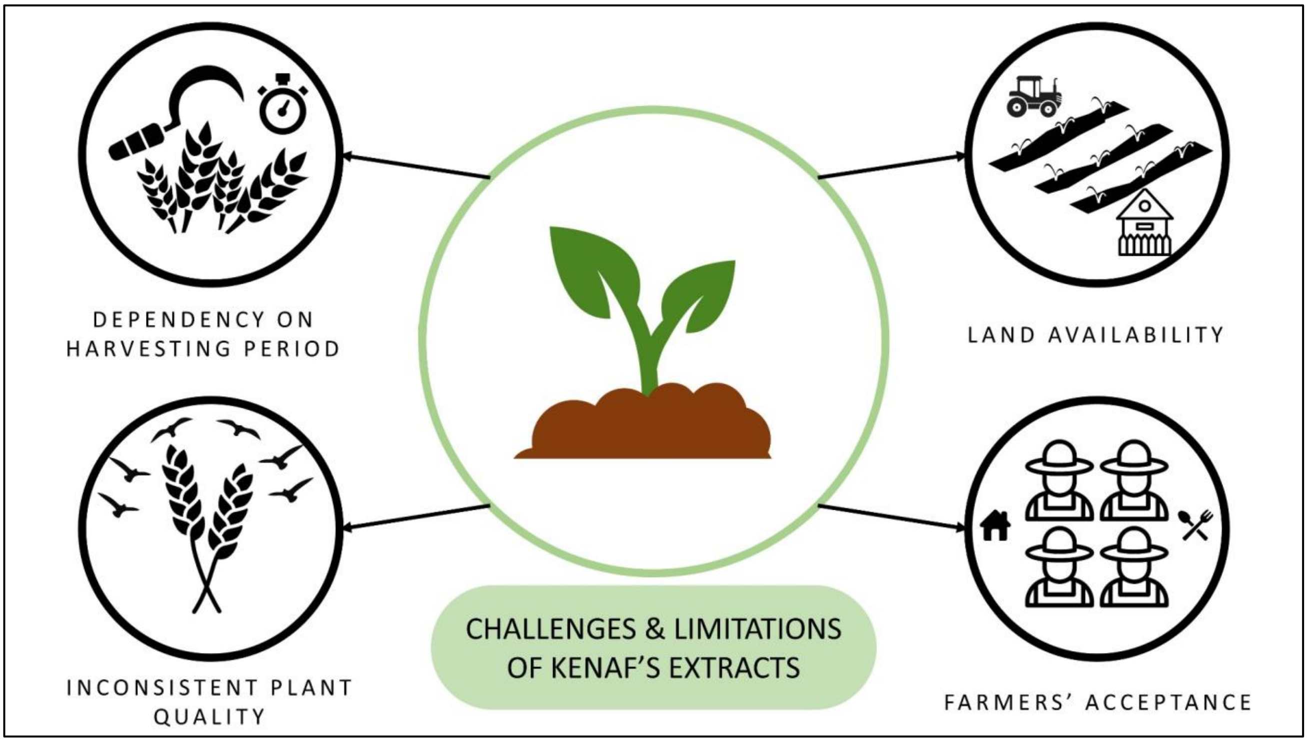

Figure 11. Challenges and limitations of kenaf extracts.

7.1. Dependency on Harvesting Period

Typically, for kenaf cultivation, it takes up to five months before the plant can be harvested and processed. Therefore, there is a long waiting period to retrieve kenaf's raw materials. This condition is unfavourable if we want to meet industrial needs and demands. This situation could also mask the true potential of kenaf to be utilised in the medicinal and pharmaceutical fields as industrial players may opt for an easy route by using synthetic products.

7.2. Inconsistent Plant Quality

Cultivation of kenaf traditionally could also result in inconsistent plant quality. Traditional farming is highly influenced by many factors such as climatic changes, plant varieties, farming practices or even diseases and infestation. These uncontrollable factors impact the outcome of the cultivation, whether it be on plant size, quality or survivability. Bringing the potential of kenaf into a readily competitive market would require high product consistency in terms of its quality and efficacy. Thus, the issue of varying kenaf's quality may arise through the infinite dependency on traditional cultivation.

7.3. Land Availability

Depending on traditional farming to produce kenaf's therapeutic compounds or extracts will create severe pressure on reserve forests as more hectares of land will be needed to conduct the cultivation. This seemed to be inevitable when more industries started looking at the potential of kenaf. In poorly planned states or regions, the activity of deforestation will surely increase, which results in the irreversible destruction of invaluable flora and fauna. This practice is not sustainable as it goes against SDG 13: Climate Action and SDG 15: Life on Land.

7.4. Farmers' Acceptance

Kenaf's traditional cultivation would require tremendous support from farmers as they are the people who will handle and manage the farming right from the beginning. Farmers will be on board with kenaf plantations if they are profitable and there are incentives and continuous support from local authorities. Additionally, the ease of handling the plant is another factor that will influence the farmers' decisions. When it comes to constructing the selling and ceiling price of kenaf, the rights of farmers should not be neglected. Thus, it is also necessary to convince farmers about the prospect and future of kenaf so the issue of inadequate human resources can be avoided.

8. Conclusions

Kenaf, a little-known nature's wonder, is a species that will definitely gain the attention of many in the upcoming years. The encouraging signs of publications and citations along with the immense support from local authorities provide the perfect platform for industrial players to come on board in kenaf's journey. For example, according to the Deputy Prime Minister of Malaysia, Datuk Seri Fadillah Yusof, all parties, especially LKTN as the pioneer, must multiply their efforts in turning kenaf into a primary commodity that can generate a stable annual income for the country. With its potential applications in crucial industries such as the pharmaceutical, food and cosmeceutical industries, this underrated crop could blossom for many years to come. Additionally, its versatility in terms of its usage and applications make it stand out among other plants. With the possibility to generate little to no waste from this plant due to its high functionality, it can be safely considered a crop for the future.

Author Contributions: Conceptualization, D.'A.N. and W.A.A.Q.I.W.-M.; methodology, S.R.A.U. and D.A.G.V.; software, N.M.S. and M.F.I.; validation, N.M.S., Z.I. and W.A.A.Q.I.W.-M.; formal analysis, D.'A.N. and D.A.G.V.; investigation, D.'A.N. and N.M.S.; resources, Z.I. and W.A.A.Q.I.W.-M.; data curation, S.R.A.U. and N.M.S.; writing—original draft preparation, D.'A.N and W.A.A.Q.I.W.-M.; writing—review and editing, D.'A.N. and M.F.I.; visualization, D.'A.N.; supervision, Z.I. and W.A.A.Q.I.W.-M.; project administration, N.M.S., Z.I. and W.A.A.Q.I.W.-M.; funding acquisition, N.M.S. and W.A.A.Q.I.W.-M. All authors have read and agreed to the published version of the manuscript.

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