A Comprehensive Review of *Canarium odontophyllum* Fruits and Their Multifaceted Benefits

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ABSTRACT

The rare plant *Canarium odontophyllum* Miq., locally known as "dabai," is found in Sarawak, Malaysia. The fruit is often consumed for its purported health benefits, but it remains underutilized due to its short shelf life, particularly in rural areas. Despite being a seasonal fruit, dabai is recognized for its nutritional value, and some studies have explored *Canarium odontophyllum*'s biological properties to support its use as a nutraceutical and health supplement. The pulp, peel, and kernel of the dabai fruit are all nutrient-dense, bioactive components, rich in dietary fiber. The fruit contains flavonoids, tannins, and terpenoids. Furthermore, crude extracts from *Canarium odontophyllum* have shown a variety of therapeutic benefits, including antimicrobial, antimalarial, antioxidant, anticancer, antidiabetic, and antifungal effects. Dabai is particularly notable for its high nutritional content, which includes significant amounts of protein, fat, and carbohydrates. Electronic databases such as PubMed, Scopus, Web of Science, and Google Scholar were searched from 1980 through November 2023 to identify relevant publications.

Keywords: *Canarium odontophyllum*; dabai; physical properties; phytoconstituents; nutritional values; pharmacological activity.

1. INTRODUCTION

In recent times, nutraceuticals and functional foods have emerged as a new frontier in natural therapeutic and protective agents. They have emerged as a safer alternative to medicinal herbs. This is because nutraceuticals are derived from plant foods that are regularly and continually consumed by humans without adverse health effects [1]. In contrast, many medicinal herbs are not commonly part of the regular diets, thereby nutraceuticals are considered safer. Nutraceuticals, derived from botanical or animal food sources, are bioactive constituents used to prevent or treat chronic diseases and are available in pharmaceutical forms. Functional foods, rich in bioactive constituents, protect against chronic diseases and are consumed in their standard food product form. Both nutraceuticals and functional foods can act as protective agents against diseases or complement drugs, allowing for a reduction in drug dose and its adverse effects [2]. The phytoconstituents of plants are used as antioxidants, antibacterial, anthelmintic, blood coagulants, diuretics, larvicides, and laxatives [3-7].

Borneo's native dabai (*Canarium odontophyllum* Miq.) is a member of the Burseraceae family of fruit-bearing plants. The fruit's rich nutritional content, which promotes health, makes it a delicacy in Sarawak, where residents eat it as a snack. *C. odontophyllum* fruit is considered an underutilized fruit because, despite its abundance, its

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potential is still mostly unrealized [8]. The Malaysian Agricultural Research and Development Institute has introduced dabai pickles and frozen dabai pulp to assure a continuous supply even during the off seasons, thereby expediting the growth of the dabai market. The produced products improve dabai fruit's potential for further exploration and allow for consistent processing of the fruit throughout the year.

Recent attention has been given to the nutritional values and health benefits of *C. odontophyllum*, with increasing recognition and thorough investigation. The current trend in literature focuses on profiling the phytochemical content and biological activities of various parts of the *C. odontophyllum*, including the skin, flesh or pulp, kernel, and leaf. The versatility of *C. odontophyllum* fruit (Figure 1) allows for its transformation into various food products. Presently, several food items incorporate dabai, such as dabai fried rice, dabai sauce, dabai mayonnaise, dabai ice cream, and dried dabai [9]. With the advancements in food research and development technology, there is potential for the creation of more dabai-based products. Leveraging the complete utilization of dabai fruit presents opportunities for profitable goods in the food industry and other sectors, offering a diverse range of food-based and waste-processing products with significant economic importance.

Figure 1: *Canarium odontophyllum* Miq. (Dabai) fruits [Adopted from Ref. 10]

2. METHOD

In this paper, electronic databases such as PubMed, Scopus, Web of Science, and Google Scholar, were searched from the start of 1980 to the end of November 2023 to extract pertinent publications. The terms used for search were: "*Canarium odontophyllum*" and "phytoconstituents" or "lung" or "biological activity" or "pharmacological activity" "nutraceuticals" or "propagation" or "culinary use" or "traditional use".

3. *CANARIUM ODONTOPHYLLUM* Miq. (DABAI)

3.1. Origin

Sarawak, a region in Malaysia, is renowned for its rich diversity of plant species, particularly indigenous fruits and vegetables, which play a crucial role in the diets of rural communities. Despite the growing popularity of these indigenous fruits among a significant portion of the population, many of these fruits remain underutilized, not reaching their full potential. Approximately 100 species of fruit-bearing trees of the Burseraceae family make up the large genus Canarium. These trees are primarily found in tropical Asia and the Pacific, as well as Africa [11]. More than half of Canarium spp. is native to the old-world tropics of southeast Asia [12]. Within this genus, two species have received notable attention in research, which are the African black olive (*C. sweinfurthii*) and the Chinese olive (*C. album*) [13]. In the context of Malaysia, four distinct Canarium species have been identified. Among these, *C. odontophyllum* stands out as the most popular and well-recognized species [14]. This highlights the significance and popularity of *C. odontophyllum*' within Malaysia and underscores its potential for various applications and commercialization within the region.

C. odontophyllum is a popular indigenous fruit in Sarawak with the potential to become a specialty fruit for the region. Its resemblance to olives in appearance, smooth texture, and rich flavor has earned it the nickname 'Sibu olive.' Belonging to the Burseraceae family of the

Sapindales order within the Eudicotyledoneae class, this fruit is part of a family comprising 16 genera and approximately 550 species found in tropical regions across the globe [15]. Despite its promising attributes, *C. odontophyllum* remains relatively underexplored due to a lack of promotion. *C. odontophyllum* is a seasonal fruit and is abundant in Sibu, a town in Sarawak, Malaysia. It ranks among the top six highly prized indigenous fruits in Sarawak and holds promise for commercialization. This fruit has two peak production seasons, typically occurring in July-August and November-December, subject to weather patterns [16].

Within the local markets, various genotypes of *C. odontophyllum* fruit could be found, with the six most common ones being Besar, Biasa, Jernah, Bujur, Seluang, and Bulat (Figure 2). These different genotypes exhibit variations in physical properties, sensory characteristics, and nutritional values [17]. Chew et al. (2011) reported that the nutritional and physical features of fruits are affected by cultivar, growing region, climate, maturity, and cultural techniques [13]. Determining the physical attributes and nutritional worth of *C. odontophyllum* fruit from various genotypes would therefore aid in the selection of better plants that bear fruits with desired qualities aimed at particular food and medicinal markets.

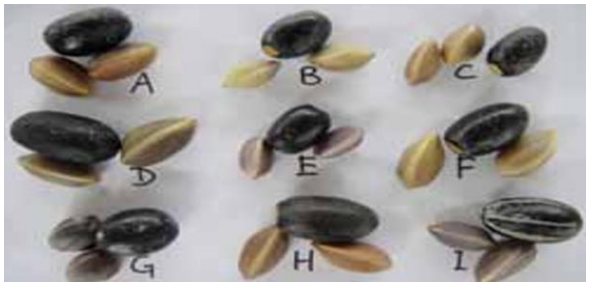

Figure 2: **Different genotypes of *C. odontophyllum* fruit: Besar (A), Biasa (B), Jernah (C), Bujur (D), Seluang (E) and Bulat (G)** [Adopted from Ref. 18]

3.2. *C. odontophyllum* propagation

The *Canarium odontophyllum*, or *C. odontophyllum* tree, is naturally found in specific regions of Sarawak, particularly along riverbanks in areas such as Sibu, Sarikei, Kapit, and Limbang Divisions, except in swamps and coastal sands. While *C. odontophyllum* trees grow naturally in the forests of Sarawak, there is a growing trend of cultivating them in regions like Sarikei, Sibu, and Kapit Divisions. *C. odontophyllum* fruits are seldom marketed beyond their grown area because the supply is still low and easily damaged by heat. Given the economic potential and value of *C. odontophyllum* as an indigenous fruit in Sarawak, there is a growing need for research to facilitate mass propagation of *C. odontophyllum* trees.

The uncommon tropical fruit *C. odontophyllum* is mostly propagated from seeds. The inconsistent and poor germination rate of this fruit species' seeds is shown by the paucity of documentation available on the subject [18]. It is crucial to acquire improved understanding and techniques for handling the seeds as planting materials because fruit supply is seasonal. This will make it possible to cultivate *C. odontophyllum* trees more effectively, guaranteeing a steady supply of fruit to satisfy consumer demand. Efforts to improve the propagation and cultivation of *C. odontophyllum* trees can not only benefit the local economy but also promote the broader appreciation and commercialization of this unique and culturally significant fruit in Sarawak.

It is better to sow *C. odontphyllum* seeds fresh. A study conducted in 2020 by Masarip et al. found that seeds taken from fresh fruits could withstand rapid desiccation utilizing desiccation bags (DBs) to moisture content (MC) of less than 10% [19]. The disadvantage of this rapid desiccation technique is that it may cause tiny fissures in the endocarp, which is not good for storing seeds. However, this quick desiccation method has a drawback as it can result in fine cracks in the endocarp, which is not ideal for seed storage. On the other hand, a slower desiccation process to achieve moisture content below

10% at a temperature of 40°C in a convection oven was found to be detrimental to the seeds. This means that attempting to dry the seeds slowly at these conditions may harm their viability. Maintaining low seed moisture content, especially below 10%, is crucial for successful seed storage and preventing microbial damage. Unfortunately, this poses a challenge when propagating *C. odontophyllum* through seeds. As a result, alternative methods, such as vegetative propagation, may be more reliable for cultivating *C. odontophyllum* trees, particularly when dealing with seeds that may not meet the required quality for germination.

To propagate *C. odontophyllum* trees, both traditional vegetative propagation methods and advanced in vitro techniques can be employed to produce planting materials. Conventional vegetative propagation, such as bud grafting, is a widely used method. It involves taking buds from hermaphrodite *C. odontophyllum* trees and grafting them onto seedling rootstocks. These grafted buds will develop into plants that are genetically identical to the parent *C. odontophyllum* tree and bear fruit even earlier than those propagated by seeds. Nevertheless, the utilization of bud grafting for *C. odontophyllum* propagation is hindered by the challenges associated with bud takes and bud break. Bud take refers to the successful union between a bud and a rootstock, while bud break is the process in which the bud elongates. An alternate approach is in vitro cultivation, which has the capacity to efficiently grow genetically identical plants on a large scale. Nevertheless, there has been no prior endeavor to employ this method for *C. odontophyllum* transmission, resulting in a dearth of information regarding the optimal cultural conditions and medium.

To ensure the production of fruit, it is highly suggested to use bud-grafted hermaphrodite plants. As a consequence of this method, *C. odontophyllum* trees exhibit precocious fruiting, commencing as early as 3 to 5 years post-planting. The Agriculture Research Centre in Semongok, Sarawak, Malaysia, has identified two exceptional bud-grafted clones, specifically 'Laja' and 'Lulong,' for the purpose of commercial production. At the onset of the reproductive phase, a tree that has been grafted with a bud can produce approximately 10 kg of fruit. Over time, as the tree grows and becomes at least 10 years old, this output steadily rises to 80-100 kg per tree. This method presents significant economic opportunities, as each individual tree has the ability to generate a minimum gross annual return of MYR 9,000.00. Furthermore, a hectare of land, with trees planted at a spacing of 12 m x 12 m, can yield a minimum gross annual return of MYR 612,000.00. Utilizing bud-grafted hermaphrodite plants for *C. odontophyllum* cultivation offers substantial benefits [20].

3.3. Physiology and characteristics

The tall, straight trunk of the *C. odontophyllum* tree (Figure 3), which normally begins to branch at a height of roughly 2-3 m above the ground, is what makes the tree distinctive. It can reach a height of over 20 m and a stem girth of more than 150 cm. The tree has a round, dense crown and gray-brown bark. With a terminal leaflet, the spirally arranged leaves have three to eight pairs of pinnately arranged leaflets. These leaflets have an oblong to lanceolate shape and measure between 4 and 11 cm in width and 9.5 to 28 cm in length.

Figure 3: Female *C. odontophyllum* tree that is 15 years old with a height of about 20 m
[Adopted from Ref. 21]

C. odontophyllum trees possess androdiecious traits, wherein they bear staminate (male) and hermaphrodite (possessing both male and female components) inflorescences on separate plants. Nevertheless, instances of flowers with prominent stamens and underdeveloped pistils have also been documented. Staminate plants exhibit elongated and slender inflorescences containing diminutive flowers, whereas hermaphrodite plants possess compact and stout inflorescences with significantly bigger blooms. The hermaphrodite blooms are situated on terminal inflorescences. Male trees generally initiate the process of flowering at a relatively young age, normally around 4-5 years. In contrast, hermaphrodite trees commence flowering and producing fruit at a later stage, approximately 6-8 years after being planted. Juvenile *C. odontophyllum* trees have the capacity to produce up to 10 kg of *C. odontophyllum* fruit, whilst fully grown trees (aged 10 years or more) can generate a range of 80 to 100 kg [22]. This suggests that during each season, an estimated 200,000 to 500,000 kg of *C. odontophyllum* fruit could be harvested. *C. odontophyllum* trees have the potential to reach heights of 30 to 40 m and can live for approximately 40 years [23]. Fruit production typically begins around 5 years after planting, and a fully mature tree can yield up to 800 kg of fruit all at once [24].

The *C. odontophyllum* tree belongs to the *Canarium L.* species, which has the natural ability to flourish in various soil types. The optimal circumstances for the growth of these trees are characterized by a moist, deep, crumbly, and organically rich sandy loam soil with a pH level ranging from 4.5 to 6.5. In addition, they have the ability to withstand mildly alkaline conditions with a pH of up to 7.4 and can adjust to poorly drain woodland habitats [25]. A recommended spacing of 10 meters is suggested between *C. odontophyllum* trees, which mean that approximately 100 trees can be planted in one hectare of orchard land [22].

The *C. odontophyllum* fruit consists of three primary components: an exterior skin known as the epidermis, a fleshy interior called the mesocarp, and a solid seed referred to as the endocarp. The composition of this fruit typically consists of approximately 5.6% skin, 61.4% flesh, and 37% seed. This categorizes it as a drupe berry, characterized by a thin skin that encloses the flesh and seed [26]. The endocarp, the innermost layer, is characterized by its durability and thickness, measuring around 2.5 to 3.5 cm in length and 1.6 to 2.0 cm in diameter [27]. The *C. odontophyllum* fruit's flesh exhibits varying thickness, ranging from 0.2 to 0.7 cm, and its hue spans from pale yellow to golden. The seed contained within the fruit exhibits a sub-triangular morphology, characterized by three distinct chambers (Figure 4). The *C. odontophyllum* seed possesses a resilient and lignified endocarp that envelops a consumable cotyledon internally, and the morphological characteristics of this shell closely match those of a palm kernel shell [16].

Figure 4: **Seed and kernel of *C. odontophyllum* fruits** [Adopted from Ref. 23]

The *C. odontophyllum* fruit is distinguished by its elongated form, delicate and consumable outer layer, and its inner meat, which can be either white or yellow, with differences observed among different cultivars. It has a distinctive taste [28]. The immature *C. odontophyllum* fruits are white (Figure 5). When *C. odontophyllum* fruit is fully ripe, its skin takes on a color between black and blue (Figure 5), mainly due to the presence of the pigment anthocyanin

(cyanine-3-glucoside) in the skin [29]. The fruit is usually oval or ellipsoid in shape, with a length of approximately 3.5 to 4.0 cm and a width of 2.0 to 2.5 cm. The weight of a single *C. odontophyllum* fruit can reach up to 18 grams, and the fruit is composed of pulp, peel, and kernel [30]. These discoveries are consistent with previous research conducted by Prasad and colleagues in 2010, which also reported that *C. odontophyllum* fruit has an elongated shape, with a length ranging from 3 to 4 centimeters and a weight between 10 to 13 grams per fruit [31].

Figure 5: **Immature *C. odontophyllum* fruits in white colour (left) and ripen *C. odontophyllum* fruits turned purple in colour** (right)

[Adopted from Ref. 32]

C. odontophyllum fruits of superior quality are distinguished by their plumpness, weighing approximately 18 grams apiece, possessing thick and yellow flesh, emitting a pleasant nutty fragrance, and having a smooth and creamy texture that provides a neutral or slightly acidic flavor. These characteristics render them exceptionally desirable. Typically, *C. odontophyllum* fruit has a short shelf life of three days. Its shelf life at room temperature is limited to three days, as moisture loss causes the skin to wrinkle [33]. The alterations in appearance diminish the palatability, indicating additional decline. This attribute presents a substantial obstacle for the dissemination and promotion of *C. odontophyllum* fruit on both a domestic and global scale.

3.4. Phytochemical constituents

Scientific studies that have undergone peer review have provided several pieces of data indicating the advantageous effects of extracted chemicals derived from different portions of the *C. odontophyllum* plant [34]. The *C. odontophyllum* fruit contains a substantial amount of bioactive chemicals in all its sections, including the pulp, skin, and kernel. The *C. odontophyllum* fruit is composed of many components that contain phytochemicals such as flavonoids, tannins, and terpenoids. These compounds have been linked to a variety of positive effects on health. The benefits encompass the reduction of cholesterol levels, decreased risk of atherosclerosis, inhibition of cholinesterase activity, display of antibacterial characteristics, and probable provision of anti-diabetic effects [8]. The chemical structure of the phytoconstituents of *C. odontophyllum* fruit are given in Table S1 (Supplementary).

3.4.1. Phenolic compounds (flavonoids and anthocyanin)

Research has demonstrated the antioxidant properties of various parts of the *C. odontophyllum* fruit, including the skin, flesh, and kernel [35]. *C. odontophyllum*, especially the outer skin has been found to contain high levels of antioxidant compounds, such as phenolics, flavonoids, and anthocyanins, making it a significant source of antioxidants [36]. C. odontophyllum's skin emerges as a major source of antioxidants due to its high phenolic content, whereas the kernels have the lowest levels of phenolics [34]. Flavonoids, a type of compound found in *C. odontophyllum*, have been shown to offer various health benefits. They serve as natural antioxidants in diets, helping to neutralize the harmful effects of free radicals and thereby contribute to the prevention of certain disorders. Additionally, flavonoids interact with various cellular targets, exhibiting anti-inflammatory, antiviral, antibacterial, anti-aging, and even anticancer properties [37].

Research has also looked into the extraction of

antioxidant chemicals utilising ethylacetate, butanol, and water from the peel, pulp, and seeds of *Canarium odontophyllum*. According to Prasad et al. (2011a), the peel's ethyl acetate fraction had the highest concentration of phenolic and flavonoid compounds and shown robust antioxidant properties that were on par with those of commercial BHT antioxidants. These findings raise the possibility of using this extract as a natural antioxidant [38]. Furthermore, numerous studies confirm the existence of phenolic chemicals in *C. odontophyllum*. These substances, which include anthocyanins, flavonoids, and phenolic acids, have been found in the pulp, peel, and kernel of the fruit, among other sections [39]. The fruits included ethyl gallate, five flavonoids (catechin, epicatechin, epicatechin gallate, epigallocatechin gallate, and apigenin), two phenolic acids (ellagic and vanillic acids), and ethyl gallate. Furthermore, three anthocyanidins (cyanidin, pelargonidin and delphinidin) and four anthocyanins (malvidin-3,5-di-O-glucoside, cyanidin-3-O-glucoside, cyanidin-3-O-rutinoside and peonidin-3-O-glucoside) were detected (Table 1) [40].

Notably, different districts in Malaysia where *C. odontophyllum* fruits are grown exhibit variations in nutritional composition and antioxidant properties. Areas with lower pollutant exposure tend to positively influence the phytochemical properties of *C. odontophyllum* fruits. Kapit, in particular, stands out for producing elite fruits with high levels of total phenolics, flavonoids, and anthocyanins, along with significant antioxidant activities [13]. The deep purple hue of *C. odontophyllum* peel is due to the presence of anthocyanins (Figure 6), which are a prominent class of phenolic compounds found in the peel. *C. odontophyllum* peel has been shown to contain different varieties of anthocyanins, including cyanidin glucoside, malvidin glucoside, and peonidin glucoside [40]. These anthocyanins contribute to the fruit's antioxidant properties and its appealing color.

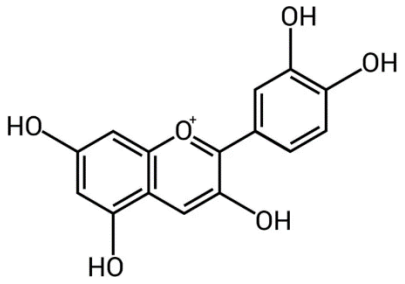

Figure 6: **Structure of anthocyanin**

3.4.2. Carotenoids

Carotenoids are lipophilic compounds that are responsible for red, orange and yellow hues of fruits and vegetables [41]. Numerous fruits and vegetables contain these chemicals, which have been demonstrated in studies to help lower the risk of heart disease, several malignancies, and other health issues [42]. Carotenoids from underutilized fruits have recently attracted more attention, especially from rural communities [43]. The two classes of carotenoids are xanthophylls and carotenes. The most prevalent form of carotene in nature is β-carotene, which gives objects a yellow-orange color. The main phytochemical that gives some fruits their orange-red color is lycopene. According to Khoo et al. (2011), lutein, a xanthophyll, is generally found in green leafy vegetables but is also occasionally found in fruits. The main carotenoid in plants is all-trans β-carotene, which is essential to the antioxidant defense mechanism of the plant [44]. All-trans β-carotene is the predominant carotenoid in plants, playing a crucial role in the plant's antioxidant defense system. Some green-colored fruits may contain a high amount of carotenoid because the yellow-orange-colored carotenoid pigments are masked by chlorophylls [45].

A study conducted by Prasad et al. (2011) examined *C. odontophyllum* Miq. and detected carotenoids from its peel, pulp, and seed fractions (Table 1) [38]. The peel had the greatest concentration of all-trans-β-carotene, with the pulp and seed following suit. Furthermore, 15-cis-β-carotene, 9-cis-β-carotene, and 13-cis-β-carotenes played

a significant role in the carotenoid levels found in the peel, pulp, and seed portions. The pulp shown remarkable β-carotene bleaching and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging properties, whilst the peel revealed superior scavenging action against 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) radicals. All samples had a significant inhibitory impact on the oxidation of haemoglobin produced by hydrogen peroxide. The findings of this study indicate that the fruit of *C. odontophyllum*, due to its abundant carotenoid content and antioxidant characteristics, has the potential to serve as a natural antioxidant. It might be utilized in the development of functional foods to offer various health advantages.

The fruit of *C. odontophyllum* contains a significant amount of phenolics, flavonoids, anthocyanins, and carotenoids, making it a promising source of natural antioxidants and acetylcholinesterase inhibitory agents. Carotenoid-rich meals have been found to provide protection against cancer, heart disease, and diabetes, as indicated by epidemiological research [43]. Carotenoids, which are responsible for the pigmentation of fruits, result in a greater concentration of carotenoids in the outside flesh of the fruit as opposed to the seed. Previous studies on the carotenoid profiles of the peel, pulp, and seed of *C. odontophyllum*, as well as their antioxidant capacities, found that the peel and pulp contained a higher amount of all-trans-β-carotene (Figure 7) compared to the seed [46].

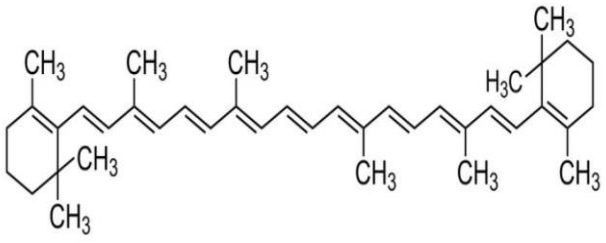

Figure 7: Structure of beta-carotene

3.4.3. Terpene and terpenoids

Terpenoids are a broad and varied group of naturally occurring organic compounds that are linked to terpenes [47]. Terpenes and terpenoids are organic compounds found naturally in plants. Fruit includes many types of terpenes, including monoterpene, triterpene, and sesquiterpene. In addition to carotenoids, saponin is a type of terpenoid that is present in the defatted *C. odontophyllum* fruit [48]. Terpenoids, particularly saponins, play a crucial role in combating infectious diseases, functioning as potent antimicrobial agents. According to Murugeasn et al. (2010), the majority of terpenoids, including saponins (Figure 8), have the potential to act as antioxidants (Table 1) [49]. In addition to their antioxidant activity, saponins offer various health benefits [50].

Studies on *C. odontophyllum* leaves have identified flavonoids, tannins, terpenoids, and phenols. The results indicate that the leaves of *C. odontophyllum* may possess therapeutic chemicals that could be effective against *S. aureus*, offering a viable alternative treatment for skin and soft tissue infections caused by *Staphylococcus aureus* [51].

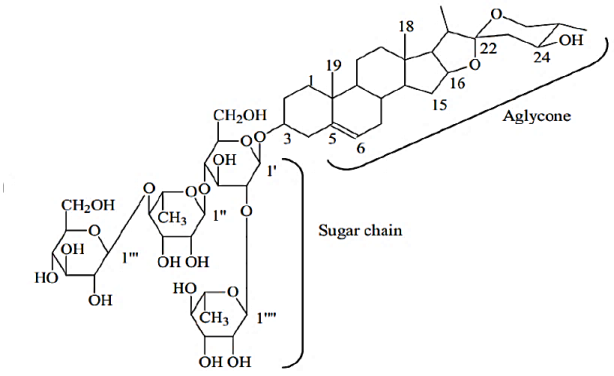

Figure 8: **Structure of saponin**

Table 1. Phyconstituents of *Canarium odontophyllum* fruit

Type [34]	Sub type	Compound
Flavonoids	Flavonoids	Catechin, epicatechin, epicatechin gallate, epigallocatechin gallate, and apigenin [40]
	Anthocyanidins	Cyanidin, pelargonidin and delphinidin [43]
	Anthocyanins	Malvidin-3,5-di-O-glucoside, cyanidin-3-O-glucoside, cyanidin-3-O-rutinoside and peonidin-3-O-glucoside [40]
	Phenolic acids	Ellagic and vanillic acids [40]
Carotenoids	All-trans-β-carotene	15-cis-β-carotene, 9-cis-β-carotene, and 13-cis-β-carotenes [40]
Terpenoids	Saponins [49]	--

3.5. Nutritional values

3.5.1. Proximate compositions

Proximate analysis serves as a method to quantify the components of food substances, encompassing parameters such as ash, moisture, crude protein, total fat, total carbohydrates, and dietary fiber [52]. The *C. odontophyllum* fruit is known for its high nutritional value, containing 339 kcal of energy per 100 g of edible portion. It also contains significant amounts of protein (3.8%), fat (26.2%), carbohydrates (22.1%), crude fibre (4.3%), ash (2.3%), phosphorous (65 mg per 100 g of edible portion), potassium (810 mg per 100 g of edible portion), calcium (200 mg per 100 g of edible portion), magnesium (106 mg per 100 g of edible portion), and iron (1.3 mg per 100 g of edible portion) (Table 2) [21]. The fruit's oil possesses significant antioxidant capabilities [27].

The nutritional composition and antioxidant properties of *C. odontophyllum* Miq. fruits were investigated in a study undertaken by Chew et al. throughout various districts in Malaysia, namely Kanowit, Sarikei, Kapit, and Song in Sarawak. *C. odontophyllum* fruits from different districts exhibited variations in their nutritional composition and antioxidant characteristics, mostly due to regional reasons. *C. odontophyllum* fruits exhibited enhanced phytochemical qualities in areas with less pollution exposure. The red *C. odontophyllum* fruit discovered in Sarikei has notable distinctions from the typical purplish-black *C. odontophyllum* fruit. The ash, moisture, and fat levels of *C. odontophyllum* fruit remain consistent throughout different growing zones. However, the carbohydrate and protein contents of *C. odontophyllum* fruit exhibit variations depending on the specific region in which they are grown [13]. In addition, the carbohydrate content of *C. odontophyllum* fruit gathered from Sarikei (9.16%) and Song (8.97%) was approximately twice as high as that of Kanowit (4.45%) and Kapit (5.07%). However, there was only a little variation in the protein content of *C. odontophyllum* fruit taken from different places in Sarawak. The primary macronutrient present in *C. odontophyllum* fruit is fat, and its composition remains consistent regardless of the variations in growing locales. The red *C. odontophyllum* fruit type obtained from Song, Kapit, and Kanowit is a rich source of carbohydrates, although it contains less protein compared to the purple variation [53]. Investigation of the edible portions (peel, pulp, and kernel) revealed that *C. odontophyllum* peel had higher ash and moisture content, while the kernel exhibited the highest percentage of fat and protein [54].

Table 2. Nutritional value of *Lepisanthes fruticose* fruit

Nutrition	Quantity
Protein	3.8%
Fat	26.2%
Carbohydrates	22.1%
Crude Fibre	4.3%
Ash	2.3%
Phosphorous	0.65 %
Potassium	0.81%
Calcium	0.20%
Magnesium	0.11%
Iron [21]	0.001%
Palmitic Acid	--
Oleic Acid	--
Linoleic acid [36]	--
Iron	0.002 – 0.003%
Zinc	0.00077-0.00092%
And Copper [13]	0.00021-0.00047%

C.odontophyllum kernel is known for its significant di etary fibre content, which can reach to 22%. This attribute is linked to several health advantages, such as a decreased likelihood of developing type 2 diabetes and heart disease [16]. Dietary fibre refers to the parts of plants that can be eaten but cannot be broken down or absorbed by the digestive system. Dietary fibre can be classified based on its ability to be digested in the small intestine into two types: soluble and insoluble dietary fibre. In a study, it was discovered that all genotypes of *C. odontophyllum* fruit exhibit minimal amounts of soluble dietary fibre (ranging from 0.00 to 0.16 g/100g) and significant amounts of insoluble dietary fibre (ranging from 9.29 to 22.98 g/100g) (Table 2) [13].

3.5.2. Fatty acid and amino acid compositions

The *C. odontophyllum* fruit is notable for its abundant and diverse nutritional content. A single *C. odontophyllum* fruit weighing 100 grams contains 339 kilocalories of energy, consisting of 26.2 grams of fat, 22.1 grams of carbohydrates, and 3.8 grams of protein [55]. This attribute renders it a fruit with a high caloric density, particularly due to its elevated fat content in comparison to other fruits with high fat content, such as olive (23 g/100g) and avocado (25 g/100g).

The nutritional value, physical qualities, and stability of fat are influenced by the compositions of fatty acids. The primary fatty acids found in *C. odontophyllum* pulp and kernel oils are palmitic acid (16:0), oleic acid (18:1), and linoleic acid (18:2). Azlan et al. discovered that palm oil and *C. odontophyllum* pulp oil had comparable fatty acid compositions, with around 40% saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs), as well as approximately 12-13% polyunsaturated fatty acids (PUFAs) [36]. Despite the overall high fat content of *C. odontophyllum*, the MUFAs in *C. odontophyllum* pulp oil, at 42%, are notably lower than those in avocado oils (65-68%), as indicated by studies conducted by Shakirin et al. (2010) [54] and Azlan et al. (2010) [36].

Further studies by Kadir et al. (2021) revealing the presence of saturated fatty acid oleoresin in *C. odontophyllum* pulp [56]. The *C. odontophyllum* pulp has been scientifically demonstrated to have low levels of peroxide and free fatty acids, while being abundant in vitamin E (α-tocopherol) [55]. The study conducted by Kadir et al. (2021) investigated the potential of *C. odontophyllum* pulp oil (DPO) and defatted *C. odontophyllum* pulp (DDP) to reduce cholesterol levels and provide hepatoprotective effects in hypercholesterolemic rats [57]. DDP, which is rich in anthocyanin and syringic acid, has been shown to effectively reduce cholesterol, low-density lipoprotein, and β-hydroxy β-methylglutaryl-CoA (HMG-CoA) reductase, an enzyme that is vital in the formation of cholesterol.

The acid value, peroxide value, iodine value, and saponification value of the extracted crude oils from both *C. odontophyllum* fruit flesh and kernel were analyzed [33]. The results showed that the characteristics of the crude oils obtained from both *C. odontophyllum* fruit flesh and kernel were similar to those of commercially available palm and olive oil. The *C. odontophyllum* meat oil exhibited a yellowish hue and displayed physicochemical

parameters that closely resembled those of olive oil. The elevated acid concentration in *C. odontophyllum* meat oil can be linked to the presence of unbound fatty acids in its crude state, which contrasts with the reduced acid content seen in commercially available palm and olive oils that have undergone refining processes. In addition, the protein found in *C. odontophyllum* fruit has been shown to be particularly abundant in aspartic and glutamic acids, which make up 45-49% of the total amino acids present [13].

3.5.3. Minerals and vitamins composition

Minerals and vitamins are essential micronutrients necessary for the proper functioning and overall health of the organism. *C. odontophyllum* is a highly nutritious fruit, abundant in energy, protein, and potassium [55]. In addition, the research conducted by Chew, L. Y. et al. also indicated that lipids are the main macronutrient in *C. odontophyllum* fruits, with calcium, sodium, and potassium being the prominent minerals [13]. The *C. odontophyllum* fruit contains a significant amount of calcium (16.00–67.88 mg/100 g fresh weight (FW)), salt (7.26–11.19 mg/100 g FW), and potassium (3.64–7.19 mg/100 g FW) [16]. However, the mineral concentrations showed substantial variation based on geographical location and variety [13]. However, Hoe and Kueh's study revealed that *C. odontophyllum* fruit contains high levels of potassium (810 mg per 100 g of edible portion), calcium (200 mg per 100 g of edible portion), magnesium (106 mg per 100 g of edible portion), and phosphorus (65 mg per 100 g of edible portion), making them the most abundant minerals in the fruit [55].

However, conflicting findings exist regarding the impact of geographic regions on fruit mineral compositions. While some studies [58] assert a strong influence of geographic regions on the mineral compositions of fruit, others, like [59], report no such effect. The locations and cultivation variations of *C. odontophyllum* fruit have a significant impact on its mineral content. Specifically, iron (2.10-3.14 mg/100g), zinc (0.77-0.92 mg/100g), and copper (0.21-0.47 mg/100g) are regarded as minor minerals, while calcium (28.47-43.72 mg/100g), sodium (5.02-6.93 mg/100g), and potassium (5.02-6.93 mg/100g) emerge as important minerals (Table 2) [13]. All things considered, these differences highlight how crucial it is to take location and diversity into account when evaluating the mineral content of *C. odontophyllum* fruit. Overall, these variations underscore the importance of considering both variety and location when assessing the mineral composition of *C. odontophyllum* fruit.

3.6. Pharmacological properties

3.6.1. Antioxidant

Studies were conducted on the antioxidant potential of the skin, pulp, and seed of the *C. odontophyllum* fruit (Table 3) [54]. The carotenoid makeup of these fruit components was investigated in a separate 2011 study by Prasad et al. [38]. Furthermore, Chew and colleagues investigated the possible antioxidant characteristics of *C. odontophyllum* fruits, both purple and red [13]. According to a study conducted by Chew et al., *C. odontophyllum* fruit has an impressive antioxidant capacity of 0.68 ± 0.09 mmol Trolox equivalents per gramme of dry weight. The fruit's potential to considerably postpone the oxidation process of compounds susceptible to oxidation is indicated by the high concentration of antioxidants found in *C. odontophyllum*. This discovery is especially noteworthy since it suggests possible therapeutic advantages in treating a number of illnesses, such as cancer, liver problems, and cardiovascular ailments [13].

3.6.2. Anti-cholinesterase

Acetylcholinesterase, an important enzyme that breaks down acetylcholine, is found in *C. odontophyllum* fruits. In order to protect the brain system against the depletion of cholinergic neurons—a situation linked to diseases like Alzheimer's disease—acetylcholinesterase is essential. Cognitive performance declines as cholinergic neurons gradually disappear in Alzheimer's disease. Acetylcholinesterase has been found in *C. odontophyllum* fruits, which may indicate that the enzyme plays a

supportive role in preserving the integrity of the nervous system and may have implications for lessening the effects of neurodegenerative illnesses, especially those that include failure of the cholinergic system.

3.6.3. Cholesterol-lowering

Ensuring a nutritious diet is essential for effectively controlling cholesterol levels in the human body. The *C. odontophyllum* fruit has exhibited properties that can combat obesity and lower cholesterol levels, although the specific effects may differ depending on the type of cultivar. Azlan et al. (2013) have shown that *C. odontophyllum* pulp oil plays a crucial role in lowering triglyceride and total cholesterol levels (Table 3) [60].

Extracts from *C. odontophyllum* have demonstrated effectiveness in reducing plasma cholesterol levels, thereby lowering the level of low-density lipoprotein (LDL), a significant contributor to atherosclerosis development in arteries. In a study conducted over a period of eight weeks, rabbits that were fed a diet high in cholesterol were given a defatted *C. odontophyllum* extract at a concentration of 5%. The results showed that this extract led to a decrease in both total cholesterol and LDL-cholesterol levels when compared to a control group [61]. Additionally, rabbits fed with a high-cholesterol diet and defatted *C. odontophyllum* pulp experienced a significant increase in high-density lipoprotein levels [62]. In addition, the atherosclerotic plaques in the rabbit group that was fed a high-cholesterol diet and supplemented with defatted *C. odontophyllum* extracts showed a decreased severity compared to the control group. Hence, the extracted defatted *C. odontophyllum* fruit is considered a promising nutraceutical resource owing to its antiatherosclerotic characteristics. Although animal studies have shown encouraging outcomes, there is currently no human-based research available to confirm the cholesterol-lowering properties of defatted *C. odontophyllum* extract. To fill this need, it is advisable to conduct a human intervention study in future research, particularly due to *C. odontophyllum*'s potential for commercialization as an underutilized fruit that offers substantial health advantages.

Beta-carotene has been studied as a potential preventive agent in the atherosclerosis process due to its recognition of the significance of low-density lipoprotein (LDL) oxidation [46]. Epidemiological studies have indicated that there is a negative relationship between levels of beta-carotene in the blood and fat tissue, and the likelihood of developing coronary heart disease. However, randomized clinical trials have not consistently demonstrated the advantages of taking beta-carotene supplements, and in certain instances, have even suggested potential harmful consequences. The inconsistency between trials and epidemiological evidence may be influenced by various factors, such as correlations with other carotenoids in diet and blood, as well as the presence of other plant-derived compounds. Although the trial results do not substantially support the idea that beta-carotene can prevent heart disease, the overall epidemiological evidence indicates that consuming a diet abundant in foods high in carotenoids is linked to a decreased risk of heart disease. In view of this, *C. odontophyllum* fruits which are rich in carotenoid contribute to cholesterol lowering, reducing the risk associated with heart disease.

3.6.4. Antibacterial

An acetone shell extract derived from the seeds of *C. odontopyhllum* fruit demonstrated antimicrobial activity, particularly with bactericidal effects against Acinetobacter baumannii. While its effectiveness against inhibiting the growth of *P. mirabilis* was relatively lower, the antimicrobial properties of the acetone shell extract were attributed to the presence of terpenoids and tannins among its phytochemical components. These findings suggest that the extract has promising potential as an alternative phytotherapeutic approach for addressing a range of bacterial infections (Table 3) [63]. In a different investigation, Basri et al. investigated the antibacterial properties of distilled water, acetone, and methanol

extracts from the *C. odontophyllum* tree's stem bark against a variety of microbes. According to the study, *Acinetobacter baumannii* was bacteriostatically affected by the methanol and acetone extracts of the *C. odontophyllum* stem bark, while Staphylococcus aureus was bactericidally affected by them (Table 3) [64].

Table 3. Phamacological activity of *Lepisanthes fruticose* fruit

Parts	Compounds	Pharmacological/Biological Activity
Pulp, seed	Carotenoids	Antioxidant [54]
Pulp oil	--	Lowering triglyceride and total cholesterol levels [60].
Acetone extract of fruit	Terpenoids and tannins	Antibacterial [63]
Water and methanol extract of fruit	--	Antibacterial [64]
Hexane and acetone extract of pulp	Flavonoids	Antifungal [65]

3.6.5. Antimalarial

It is imperative that chemicals produced from plants be explored in order to develop antimalarial medications. Notably, vital antimalarial drugs like quinine and artemisinin have been derived from plant sources, underscoring the critical role that botanical contributions have played in the advancement of this discipline. Ishak et al. (2020) have researched *C. odontophyllum* leaf extracts' potential as an antimalarial drug in great detail [66]. The study showed that the methanol extract of *C. odontophyllum* leaf might hinder the growth of plasmodium when it reaches 5% parasitemia, affecting several phases of its development, such as young trophozoite, mature trophozoite, and schizont. This discovery implies the potential for advancing *C. odontophyllum* leaf extract as a pharmaceutical treatment for malaria. Shamsuddin et al. (2021) made a noteworthy contribution to this field by demonstrating that the combination of *C. odontophyllum* leaf extract and acetone provides valuable information about the antimicrobial mechanism. This research has the potential to identify a specific protein target for the development of new therapies against methicillin-resistant Staphylococcus aureus infections [67].

3.6.6. Antifungal

The study conducted by Chew et al. (2011) confirmed the existence of flavonoids (catechin, epicatechin, epicatechin gallate, epigallocatechin gallate, and apigenin) and anthocyanidins (cyanidin, pelargonidin, and delphinidin) in the fruit of *C. odontophyllum* [13]. Flavonoids, which are frequently present in different plant components such as fruits, vegetables, nuts, seeds, stems, flowers, tea, wine, propolis, and honey, have been used for ages in the treatment of human ailments because of their physiological effects. Due to the extensive capacity of flavonoids to hinder the development of spores from plant diseases, flavonoids have been suggested for their potential application in combating fungal pathogens in humans. The existence of flavonoid in *C. odontophyllum* suggests that flavonoid could be the active component accountable for the antifungal activity. Extensive research has been conducted on the antibacterial properties of *C. odontophyllum* fruit. Basri et al. (2014) found that extracts of hexane and acetone from the pulp of *C. odontophyllum* have antifungal properties against *Candida glabrata*. This suggests that *C. odontophyllum* fruit has the potential to be used as an anti-yeast agent (Table 3) [65].

3.6.7. Anticancer

C. odontophyllum is a natural plant that shows promise in its potential to have anticancer effects. The acetone extract obtained from the stem bark of *C. odontophyllum* exhibits greater sensitivity towards HCT 116 in comparison to HT 29. The extract's ability to inhibit the

growth of HCT 116 and HT 29 cells suggests that it could be used as an anticancer drug for treating colorectal cancer [68]. The acetone extract derived from the stem bark of *C. odontophyllum* has great potential in the development of an anticancer drug that specifically targets HCT 116 cells. Importantly, this extract does not have any harmful effects on human colon fibroblast cells [69].

Attempts have been undertaken to establish a connection between the antioxidant characteristics of phytoextracts and their potential for combating cancer. Although there is no definitive proof of such a connection, it is proposed that the antioxidant properties of phytoextracts could be an indication of their ability to prevent cancer. The extract of the leaves of *C. odontophyllum* contains terpenoid, tannin and flavonoid. The absence of alkaloids in the leaves of C. odontophyllum suggests that chewing the leaves or consuming *C. odontophyllum* tea may be considered safe for use as a chemo preventive supplement against colon cancer. The cytotoxic activity of the leaf extracts may be correlated with the phytoconstituents, as flavonoids, tannins, and terpenoids are recognized for their protective role as antioxidants [70]. The importance of tannins and flavonoids as anticancer agents is supported by a study where the ethanol extracts of leaves from *Canarium patentinervium* Miq. exhibited radical scavenging activities primarily attributed to the presence of tannins and flavonoids [71].

3.6.8. Anti-hyperglycemic

The aqueous extract derived from the leaves of *C. odontophyllum* Miq. has exhibited the capacity to decrease blood glucose levels in mice with diabetes [72]. In a 4-week research, it was found that the *C. odontophyllum* extract, when administered at a concentration of 600 mg/kg bw, had a notable effect in reducing plasma glucose levels compared to a dose of 300 mg extract/kg bw. Nevertheless, the *C. odontophyllum* extract did not elevate the insulin level, but it did enhance insulin sensitivity and alleviate insulin resistance (HOMA-IR). The finding suggests that the *C. odontophyllum* extract has been found to have antihyperglycemic characteristics, which means it can temporarily lower glucose levels [73].

4. CONCLUSION

The various components of *C. odontophyllum*, such as its skin, flesh, and seed, possess distinct nutritional attributes, each exerting specific health benefits. With its increasing significance, *C. odontophyllum* is poised to become a key crop in Sarawak, gaining recognition alongside other globally esteemed fruits. This suggests a potential improvement in its position within the global market. The economic implications are considerable, as *C. odontophyllum* is expected to play a major role in driving the nation's GDP growth. In essence, *C. odontophyllum* emerges not only as a promising agricultural commodity but also as a multifaceted resource with implications for health, biodiversity, and economic development. The unique combination of nutritional richness, health benefits, and economic viability underscores its potential to become a valuable asset both locally and globally.

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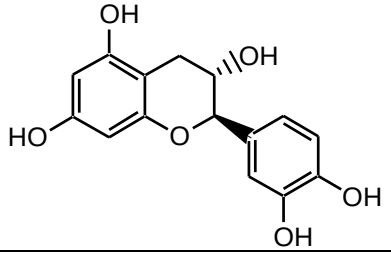
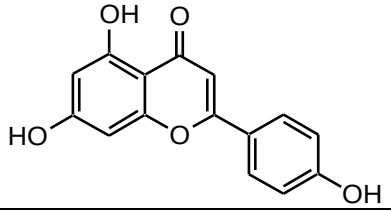
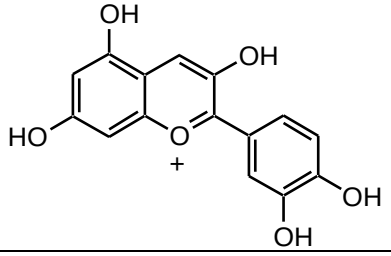
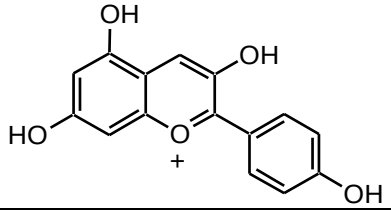
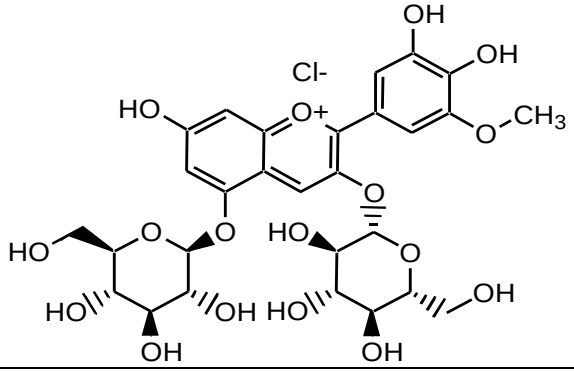
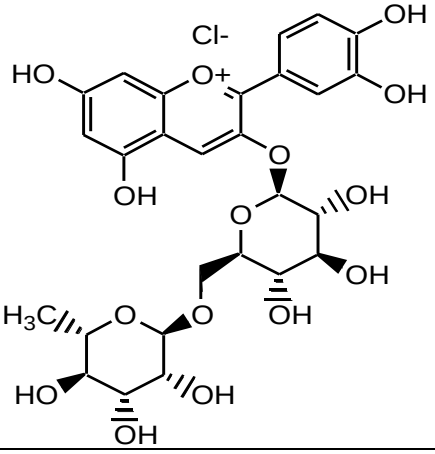
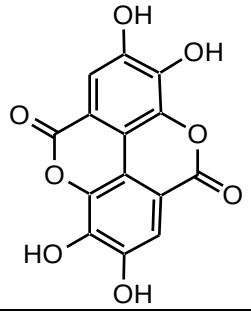
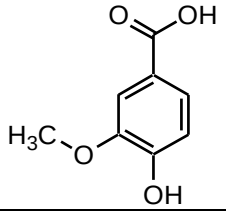
Conflict of interest statement

The authors declare that there is no conflict of interest.

Table S1: Chemical structures of phytoconstituents of *Canarium odontophyllum* fruit

Compound	Chemical Structures
Catechin	
Apigenin	
Cyanidin	
Pelargonidin	
Malvidin-3,5-di-O-glucoside	

Compound	Chemical Structures
Cyanidin-3-O-rutinoside	
Ellagic acid	
Vanillic acid	

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مراجعة شاملة لفواكه *Canarium odontophyllum* وفوائدها المتعددة الأوجه

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ملخص

تم العثور على نبات Canarium odontophyllum Miq النادر، والمشار إليه باسم "dabai" باللغة المحلية، في ساراواك، ماليزيا. غالبًا ما يتم استهلاك الفاكهة بسبب فوائدها الصحية المزعومة، ولكن لا يتم استغلالها بشكل كافٍ بسبب مدة صلاحيتها القصيرة، خاصة في المناطق الريفية. على الرغم من كونها فاكهة موسمية، إلا أن داباي معروفة بقيمتها الغذائية، وقد بحثت بعض الدراسات الطبية في السمات البيولوجية لنبات Canarium odontophyllum لدعم استخدام النبات كمكمل غذائي وصحي. إن لب فاكهة داباي وقشرها ونواتها كلها مواد مغذية للغاية ونشطة بيولوجيًا وتحتوي أيضًا على ألياف غذائية. تحتوي فاكهة داباي على مركبات الفلافونويد والعفص والتيربينويدات. بالإضافة إلى ذلك، أظهرت المستخلصات الخام من Canarium odontophyllum مجموعة متنوعة من الفوائد العلاجية، بما في ذلك التأثيرات المضادة للميكروبات ومضادات الملاريا ومضادات الأكسدة ومضادات السرطان ومضادات السكر والفطريات. يتميز داباي بمحتواه الغذائي العالي، بما في ذلك كميات كبيرة من البروتين والدهون والكربوهيدرات. تم البحث في قواعد البيانات الإلكترونية، مثل PubMed، وScopus، وWeb of Science، وGoogle Scholar، منذ بداية عام 1980 وحتى نهاية نوفمبر 2023 من أجل استخراج المنشورات ذات الصلة.

الكلمات الدالة: Canarium odontophyllum، dabai، الخصائص الفيزيائية، المكونات النباتية، القيم الغذائية، النشاط الدوائي.

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