

PHYTOCHEMISTRY AND BIOLOGICAL ACTIVITY OF TERUNG ASAM, INDIGENOUS FRUIT-VEGETABLES OF SARAWAK - A REVIEW

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Abstract: Terung Asam Sarawak or Terung Dayak (*Solanum lasiocarpum* Dunal, previously known as *Solanum ferox* Linn) is an indigenous fruit-vegetable of Sarawak. It is commonly cultivated on Borneo Island, mainly in Sarawak, Malaysia, and Kalimantan, Indonesia. Its fruit is often an ingredient in traditional curry and is used as a paste for conventional hot sauce. The scarcity of research on Terung Asam Sarawak means there is a lack of scientific data, particularly on its phytochemical content, biological activity and preference for agronomic traits. This review covers recent and relevant studies about the extraction of bioactive compounds, phytochemicals, and potential biological activities from *S. lasiocarpum* Dunal. This review highlights the traditional use of *S. lasiocarpum* Dunal as a therapeutic agent for the treatment of several ailments in several countries, the factors influencing the extraction of bioactive compounds (time required for extraction, temperature, solvent type, and composition on phenolic compounds), phytochemical profile, the scientific evidence of their antioxidant, antimicrobial, and anticarcinogenic activities. Advanced knowledge on *S. lasiocarpum* Dunal will support exploration into its pharmacological and food uses and hopefully offer commercialization prospects.

Keywords: *Solanum lasiocarpum* Dunal, phytochemistry, biological activity, bioactive compounds, antioxidants.

Introduction

The utilization of plants to heal ailments has an ancient history. The fundamental components of the medicinal actions of plants are their secondary metabolites. Fighting against infections motivated the use of medicinal plants, and humans searched for medications in seeds, bark, and various plant parts. Various medicinal plants are connected through clinical and drug expert recommendations. They are used or in a blend with an integral prescription. The dynamic parts have antioxidant, antimicrobial, antifungal, and other properties, verified action, and, sometimes, restorative adequacy, which are applied as cures (Petrovska, 2012; Masoko & Makgapeetja, 2015). Traditional medicine has gained official recognition in over 120 countries. In several countries, there are academies and research institutes offering training in pharmaceuticals using folk medicine (Khurramovna & O'g'li, 2021).

Vegetables and fruits are “functional food ingredients” because they contain a variety

of pigments, such as betalains, carotenoids, chlorophylls, and flavonoids (Phebe *et al.*, 2009; Khoo *et al.*, 2011; Chen, 2015). Fruit is selected among all the plant parts because it contains numerous active compounds, which contain nutrients varying in energy and supplement content. Additionally, fruits contain dietary fibre, which is linked to a lowered risk of cardiovascular illness and obesity (Tovar *et al.*, 2020; Ching *et al.*, 2021). Fruits supply vitamins and minerals to the diet and are wellsprings of phytochemicals that act as phytoestrogens, anti-inflammatory agents, antioxidants, and other protection mechanisms (Slavin & Lloyd, 2012; Serafini & Peluso, 2016).

Fruits are also notable for their therapeutic and health-promoting properties. The medicinal properties of fruits are related to the existence of phytochemicals and antioxidants. Locals have realized that tropical fruits have numerous advantages and utilized them in traditional treatment. They contain phytochemical antioxidants that remedy and prevent several

infections (Khoo *et al.*, 2016). For instance, it contains ascorbic acid, phenolic compounds (flavonoids), tocopherols, nitrogenous compounds (chlorophyll derivatives), and carotenoids (Soon & Ding, 2021). They are free-radical scavengers that shield inflammatory and oxidative stress impacts on the body (Khoo *et al.*, 2016; Anwar *et al.*, 2020). In this study, the plant highlighted is the indigenous fruit-vegetable: *S. lasiocarpum* Dunal.

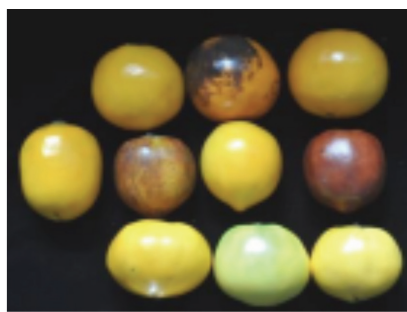
S. lasiocarpum Dunal, previously known as *S. ferox* Linn (suppressed name), also known as Terung Asam Sarawak, is an indigenous non-seasonal plant in the Solanaceae family, related to the tomato and pepper, both of which are native to Southeast Asia (Figure 1). It is a thorny and woody perennial plant which grows to a height of approximately 1.0 to 2.5 meters. It has a tap root system that extends vertically and laterally, as well as branches and leaves with or without prickles and stellate hairs (Lim, 2013; Shariah *et al.*, 2013). The *S. lasiocarpum* Dunal and *Solanum* species from the subgenus *Leptostemonum* are two of the most pertinent crop plants in the Middle and Near East, Southern Europe, Africa and Asia (Knapp *et al.*, 2013; Wiersema *et al.*, 2018). Aside from the variation in geographic location, people, cultures, landscapes, climate and natural resources, scientific studies on this indigenous eggplant are scant. The literature on this vegetable is dispersed across multiple sources and languages (Soon & Ding, 2021).

The native eggplant produces round to oval, medium-sized hairy fruits with a sour taste that is prized as a fruit and as a food additive or flavoring in many dishes, such as hot sauce, jam and puree (Shariah *et al.*, 2013). These eggplants are commonly grown with paddy by local farmers, particularly hill paddy farmers (Bisht, 2020). Nowadays, high local demand for *S. lasiocarpum* Dunal has caused price to go up to RM 6.00-10.00 per kg depending on the size and quality (Shariah *et al.*, 2013; Rahman *et al.*, 2019). It has been cultivated as a special fruit-vegetable crop throughout the state, yielding an average of 16 to 20 tonnes per hectare (Rahman *et al.*, 2019). The proximate nutrient composition of *S. lasiocarpum* Dunal fruit per 100 g of the edible portion is 89.5% moisture, 1.1% protein, 0.9% fat, 5.8% carbohydrate, 1.75% crude fibre and 0.8% ash. The mineral compositions is 27 mg phosphate, 188 mg potassium, 3 mg calcium, 6 mg magnesium, 0.6 mg iron, 2 mg manganese, 0.6 mg copper, 5.2 mg zinc and 8 mg vitamin C (Voon & Kueh, 1999; Shariah *et al.*, 2013).

Besides commonly used as a vegetable by the local communities, the Dayak people use this plant to treat pinworms (AsianItinerary, 2013). Despite *S. lasiocarpum* Dunal's commonness and nutritional value, its biological properties are still under study. Exploring *S. lasiocarpum* Dunal usefulness will widen botanical information, scope of fruit consumption and its applications. This article reviews the phytochemical composition and biological properties of the *S. lasiocarpum*



(A) Whole plant



(B) Fruit shapes and colours

Figure 1: *S. lasiocarpum* Dunal
Source: Shariah *et al.* (2013)

Dunal. and can be a useful reference for future research on food, pharmaceuticals and drug-discovery studies.

Traditional Uses of *S. lasiocarpum* Dunal in Treatment of Ailments

The traditional use of *S. lasiocarpum* Dunal is tabulated in Table 1. The data obtained from these studies reveal that plant parts, preparation prior to usage and therapeutic use are different among countries. In Uttarakhand, India, locals use *S. lasiocarpum* Dunal to treat fever and as an oral remedy. They would place seven leaves on the head during sleep for three nights to manage a fever. For the oral remedy, a decoction of the roots are administered orally (Dwivedi et al., 2019). The Bodo tribes of Assam in India keep the dried flowers or seeds of the *S. lasiocarpum* Dunal in their mouth as a treatment for tooth decay (Saikia et al., 2010).

In Bangladesh, The roots of *S. lasiocarpum* Dunal are steeped in water and drunk twice daily to treat chickenpox. Bangaldeshis also use the whole plant of *S. lasiocarpum* Dunal to treat typhoid. The seeds, blossoms, fruit, leaves, stem and roots are boiled until the water decreases significantly. The remaining fluid is then taken daily. To treat flu, a concoction is made with the leaves and stems of *S. lasiocarpum* Dunal boiled with *Cinnamomum tamala* leaves, *Piper nigrum* fruit, *P. longum* fruit, the bark of *C. verum*, powdered mishri (crystalline sugar) and sea salt. Crushed *S. lasiocarpum* Dunal seeds are used to treat abscesses, by applying it as a poultice. To treat allergies, the entire *S. lasiocarpum* Dunal plant is soaked with leaves of *Azadirachta indica*, rhizomes of *Curcuma longa*, roots of *Flagellaria indica*, leaves of *Tinospora cordifolia*, the bark of *Alstonia scholaris*, and leaves or bark of *Justicia adhatoda*. The water is drunk for a fortnight (Naher et al., 2013). *S. lasiocarpum* Dunal has also been reportedly used to treat toothache and syphilis by the Tonchongya tribe in Bandarban district, Bangladesh (Hossan et al., 2012).

In Sarawak, Malaysia, the Dayak people

use this plant to treat pinworms (AsianItinerary, 2013). The Temuan tribe in Kampung Orang Asli Donglai Baru, Hulu Langat, Selangor consumes the fruit to treat hypertension and spiritual ailments (Ramli et al., 2021). People use the roots of *S. lasiocarpum* Dunal for remedies in cutaneous diseases in Sri Lanka (Abdullah et al., 2014). In the Philippines, the leaves are used as a cataplasm for indolent swelling. (Lim, 2013; Abdullah et al., 2014). People in Indonesia treat diabetes by eating the *S. lasiocarpum* Dunal fruit (Suwardi et al., 2020).

Extraction of Bioactive Compounds and Phytochemical Profile

Over the years, information on the phytochemical composition of *Solanum* spp. has expanded, particularly on the phenolic mixes related to antioxidant movement in vitro (Table 2). A way to improve the recovery of secondary metabolites of *Solanum* spp. is to investigate the impact of the extraction conditions (mass/solvent proportion, solvent types, extraction time, and temperature) on the absolute phenolic substance and antioxidant action of extracts (Munekata et al., 2019).

Among the numerous parameters in the extraction cycle, the mass-solvent proportion was utilized to extract phenolic compounds from *S. lasiocarpum* Dunal accessible from 1:10 to 1:50. Generally, the time needed for extraction was ordinarily as long as 7 days (Table 2). Interestingly, an extraction procedure took only 10 minutes (Mohd Waznul et al., 2019) while another experiment took 72 hours to extract the phenolic compounds (Syarpin et al., 2018). These two factors are viewed as significant variables for extracting phenolic compounds from plant tissue (Azmir et al., 2013). Unfortunately, direct comparison among studies has not been possible due to differences in experimental conditions.

Pure solvents, such as ethanol, methanol, ethyl acetate, petroleum ether, chloroform, and water, are the most common solvents used in the extraction process. The solvent choice appears to affect the phenolic content and antioxidant

Table 1: Traditional uses of *S. lasiocarpum* Dunal

| Location | Species | Part of plant | Traditional preparation | Therapeutic use | Reference |
|--------------------|-----------------------------|----------------|----------------------------|---|---|
| Uttarakhand, India | <i>S. lasiocarpum</i> Dunal | Leaves | Positioned on the pinnacle | Fever | (CCRS, 1999; Dwivedi <i>et al.</i> , 2019) |
| India | * <i>S. ferox</i> Linn | Roots | Decoction | Oral remedy | (Joy <i>et al.</i> , 2001; Khare, 2007) |
| | | Roots, Berries | Decoction | Stimulant, digestive, carminative, astringent, expectorant, diaphoretic, anthelmintic, anticancer, spermicidal, antiviral, antirheumatic. Used for catarrhal affections, asthma, dry cough; dysuria; intestinal worms; colic, flatulence, vomiting. | |
| Bangladesh | <i>S. lasiocarpum</i> Dunal | Roots | Soaked in water | Chickenpox, typhoid, Influenza, allergy, abscess. | (Naher <i>et al.</i> , 2013) |
| Sarawak, Malaysia | <i>S. lasiocarpum</i> Dunal | Whole plants | Boiled in water | Pinworms | (AsianItireary, 2013) |
| | | N.I | N.I | | |
| Selangor, Malaysia | * <i>S. ferox</i> Linn | N.I | N.I | Hypertension and spiritual | (Ramli <i>et al.</i> , 2021) |
| Sri Lanka | * <i>S. ferox</i> Linn | Roots | N.I | Remedies in cutaneous disease | (Abdullah <i>et al.</i> , 2014) |
| | * <i>S. ferox</i> Linn | Leaves | N.I | Cataplasma for indolent swellings | (Lim, 2013; Abdulllah <i>et al.</i> , 2014) |
| Indonesia | <i>S. lasiocarpum</i> Dunal | Fruits | Eaten as vegetables | Diabetes | (Suwardi <i>et al.</i> , 2020) |

N.I: No Indication

**S. ferox* Linn is a suppressed name for *S. lasiocarpum* Dunal

activity of final extracts (Roselló-Soto *et al.*, 2019). For instance, Hwong *et al.* (2020) observed that the total phenolic content (TPC) and antioxidant activity of *S. lasiocarpum* Dunal were influenced by solvent composition. The authors obtained 12.88 to 16.16 mg gallic acid equivalents (GAE)/g dry weight for TPC and 62.39% to 86.80% for antioxidant activity with methanol as solvent. However, when water was used as a solvent, the extract gave out 2.29 to 6.01 mg gallic acid equivalents (GAE)/g dry weight (D.W) for TPC and no indication for the antioxidant activity (Rahman *et al.*, 2019). This is also consistent with the findings of Mohd Waznul *et al.* (2019), who discovered that a 100% methanol extract extracted the most polyphenolics when compared to a 50% methanol and a 100% water extract. These findings revealed that the extraction solvent impacts the recovery of phenolic compounds of *S. lasiocarpum* Dunal. The variation might be due to several factors like the differences in the solubility of targeted active compounds in the extract and polarity of the solvent, which selectively extracts different phenolic compounds.

Another critical factor in the recovery of antioxidant compounds is the time required to perform the extraction (González-Montelongo *et al.*, 2010; Che Sulaiman *et al.*, 2017; Trigueros *et al.*, 2021). In the case of *S. lasiocarpum* Dunal extract, the TPC increased gradually with prolonged extraction time from 0.5 hour (12.88 mg GAE/g of extract) up to 16 hours (16.16 mg GAE/g of extract) (Hwong *et al.*, 2020). The results indicate the importance of optimizing the extraction time to obtain the optimum yield of TPC. Since phenolic compounds are unstable, each phenolic source requires a unique extraction and optimization strategy (Che Sulaiman *et al.*, 2017). Similarly, temperature is another factor that influences the extraction of bioactive compounds from *Solanum* spp. The extraction of TPC increases steadily with the increasing temperature, from 30°C (14.29 mg GAE/g of extract) to 60°C (16.16 mg GAE/g of extract) (Hwong *et al.*, 2020). High

temperature softens the plant tissue and weakens the interaction between the phenol-protein and phenol-polysaccharides in the plant. This will increase the solubility and diffusibility of the phenolic compounds. Hence, more phenolic would be transferred to the extraction solvent portion.

Despite the positive influence of the prolonged extraction time and higher temperature for TPC extraction, more comprehensive testing is needed. Increasing the temperature and prolonging extraction time at a certain level will have drawbacks to the phenolic compounds in the extract. The phenolic compounds are prone to decomposition or denaturation at elevated temperature and time, which degrade their quantification and antioxidant properties. Although rarely studied, the number of extraction steps also influences the efficacy of phenolics and total extractable compounds (González-Montelongo *et al.*, 2010). The relationship between the extraction steps also has a significant impact on the antioxidant activity of the extract. It has been shown that the recovery of phenolic compounds from citrus peels was higher with a single extraction stage (3 hours) than with a double extraction (2 x 1.5 hours) (Li *et al.*, 2006). The parameters mentioned influence the efficacy of extracting the bioactive compounds, and their impacts can be interactive or independent (Lu *et al.*, 2011). Hence, more attention should be paid to establish time-efficient protocols and characterize the influence of extraction for *Solanum* spp. This would help avoid unnecessary waste of time, solvents, quantification of active compounds and the antioxidant activity of the extract.

Numerous bioactive secondary metabolites, including alkaloids, phenolic compounds, glycosides, flavonoids, lignans, AMPs, steroids, terpenoids and simple sugars, have been documented in phytochemical studies of plants from the Solanaceae family, including *Solanum* spp. (Abreu Miranda *et al.*, 2015; Ghatak *et al.*, 2017; Burger *et al.*, 2018; Kaunda & Zhang, 2019). Generally, the leaf has the highest total phenolic and antioxidant content of any *S.*

lasiocarpum Dunal plant part (Ling, 2012). Extracts of both water and alcohol of the leaf contain a high concentration of polyphenolic compounds and have a high antioxidant capacity (Shiow *et al.*, 2013). The extracts can inhibit intracellular tyrosinase activity and decrease melanin content, making it a potential ingredient in skin whitening products (Soon & Ding, 2021). Apart from the leaf, the seed contains palmitic, stearic, oleic and linoleic acids, whilst the flesh contains the sterol alkaloid, solanine (Gupta & Garg, 1966). Studies have discovered that solanine has antitumorogenic effects. Solanine suppresses the metastasis and proliferation of melanoma, pancreatic and prostate cancer cells, thereby mitigating the risk of cancer cells developing in the body (Lv *et al.*, 2014; Shen *et al.*, 2014; Sun *et al.*, 2014; Soon & Ding, 2021).

Furthermore, the fruit of *S. ferox* is rich in secondary metabolites, such as alkaloid, terpenoid and phenolic compounds, equipping it with promising free-radical scavenging activity (Oszmiański *et al.*, 2014; Hardi, 2016; Syarpin *et al.*, 2018). Phenolics have multiple biological effects, including antioxidant and

anti-inflammatory properties, along with flavonoids (Eddine *et al.*, 2016). Evidence from research suggests that diets high in polyphenolic compounds play an effective role in the fight against oxidative stress-related disorders (Ding & Syazwani, 2016; Eddine *et al.*, 2016; Rahman *et al.*, 2019). Unfortunately, phytochemical study for *S. lasiocarpum* Dunal is still underutilized. Qualitative phytochemical analysis is critical for the preliminary evaluation of plant species for which chemical profile studies have not yet been completed. The analysis allows for the detection of secondary metabolites, which could aid in the development of new drugs.

The *Solanum* genus appears to have extraordinary potential, yet most of the species are obscure or sparsely researched for their synthetic constituents. Researching and exploring the vast number of these species would be vital for phytochemists. The tremendous pharmacological activities evinced by numerous components of the *Solanum* spp. ought to be considered in evaluating their definite target site structure-activity relationships and other pharmaceutical applications.

Table 2: The extraction conditions, total phenolic content and antioxidant potential of *S. lasiocarpum* Dunal

| Species | Part of Plants | Extraction Protocol | Antioxidant Assay | Total Phenolic Content | Antioxidant Activity | References |
|-----------------------------|------------------------|--|-------------------|--|---|----------------------------|
| * <i>S. ferox</i> Linn | Fruits, leaves | 1:10 (w/v) macerated in 95% undenatured ethanol. The mixture was filtered and concentrated using a rotary evaporator at 40°C. | N.I | N.I | N.I | (Radian et al., 2019) |
| | Rhizomes | Crushed and soaked with chloroform for seven days. Completely dried and dissolved in DMSO. | N.I | N.I | N.I | (Hardi, 2016) |
| | Skins, pulp, seed core | 1:50 (w/v); 1 g powdered sample in 50 mL solution. The solution used was water, 100% methanol, 50% methanol pH 5, and pH 9. The mixture was centrifuged at 1000x g for 10 mins. The supernatant was filtered using Whatman filter paper and kept at 4°C. | FRAP assay | Water (< 1 mg) 100% methanol (skins 2.26 ± 1.13, 2.35 ± 0.21 mg), (pulp 1.47 ± 0.07, 1.02 ± 0.07 mg) 50% methanol, pH 5 (skins, 1.82 ± 0.91, 1.95 ± 0.03 mg) 50% methanol, pH 9 (skins, 1.65 ± 0.82, 1.72 ± 0.03 mg) | (100% skins, FRAP value) 2.94 ± 0.01, 2.56 ± 0.05mg/g (100% pulp, FRAP value) 1.75 ± 0.02, 0.85 ± 0.02 mg/g | (Mohd Waznul et al., 2019) |
| | Fruits | 1:10 w/v (ethanol) The bottle was closed with aluminum foil and rest for three days. Filtered, concentrated using a rotary evaporator | DPPH assay | N.I | 177.61 ppm | (Syarpin et al., 2018) |
| | Leaves | They were macerated in methanol a few times until clear maceration was produced. Filtered, concentrated using a rotary evaporator | N.I | N.I | N.I | (Hazimah et al., 2018) |
| | Fruits | 1:20 w/v (water) Optimum condition (60°C and 90°C) Varying time (20 to 180 min) Centrifuged for 15 mins, 5000 rpm at 4°C | N.I | Water (2.29 to 6.01 mg GAE/g dry extract) 90°C, 120 mins (6.01 mg GAE/mg dry extract) 60°C, 180 mins (5.95 mg GAE/mg dry extract) 60°C, 150 mins (5.90 mg GAE/mg dry extract) | N.I | (Rahman et al., 2019) |
| <i>S. lasiocarpum</i> Dunal | Fruits | 1:50 (w/v) 80% ethanol (0.5-16 hours) Optimum condition 60°C, Centrifuged for 15 mins, 250 rpm at 4°C. | DPPH assay | 12.88-16.16 mg GAE/mg | 62.39% - 86.80% | (Hwong et al., 2020) |

FRAP; Ferric Reducing Antioxidant Power; DPPH: 2,2-diphenyl-1-picrylhydrazyl; w/v: weight/volume (g/mL); N.I : not indicated; GAE: Gallic acid equivalent
**S. ferox* Linn is a suppressed name for *S. lasiocarpum* Dunal

Antioxidant Activity

An antioxidant is a molecule stable enough to donate and neutralize an electron to a rampaging free radical, reducing its damage potential. These antioxidants delay or inhibit cell damage, mainly via their unfastened radical-scavenging assets (Lobo *et al.*, 2010). Usually, the antioxidant system in the human body could even scavenge these radicals, thereby maintaining the balance between oxidation and antioxidation. Nonetheless, alcohol, radiation, cigarette smoking or environmental toxins cause the production of excessive reactive oxygen species (ROS) and reactive nitrogen oxide species (RNOS), which disrupt the balance of oxidation and antioxidation and result in some chronic and degenerative diseases (Xu *et al.*, 2017). A natural or artificial antioxidant reduces the damage caused by ROS or RNOS to biomolecules (basically proteins, lipids, and DNA). Antioxidant compounds naturally present in plants, such as polyphenols, are diagnosed as free radical or energetic oxygen scavengers. These compounds have been extensively used as antioxidants in the food industry, cosmetics, and pharmaceuticals as alternatives to synthetic antioxidants (Lobo *et al.*, 2010; Mota & Pinto, 2012).

A study evaluated the antioxidant activity of two different *S. ferox* Linn (suppressed name) fruit color phenotypes for the peel, pulp, and seed (Mohd Waznul *et al.*, 2019). The yellow and purple-skinned fruit phenotypes had the highest antioxidant properties in the peel compared to pulp and seed samples, based on the Ferric Reducing Antioxidant Power (FRAP) assay. Compared to other extractions, extraction with 100% methanol gave the highest antioxidant activity. Purple-skinned peel shows higher antioxidant activity with 2.94 ± 0.01 mg/g sample of FRAP value than yellow-skinned peel with 2.56 ± 0.05 mg/g sample of FRAP value. Purple-skinned fruit has a rich source of a flavonoid called anthocyanin, a polar phytochemical that is easily leached into water during bleaching with a polar solvent like methanol (Howard, 2008; Mohd Waznul *et al.*, 2019).

Meanwhile, seed samples for both fruit colors of *S. ferox* Linn (suppressed name) showed no difference in antioxidant properties. The peel sample from purple fruit showed significantly higher antioxidant activity than the yellow-skinned fruit phenotype ($p=0.002$). The 100% methanol extract from purple fruit peel phenotype has 3.4 to 3.5 times higher antioxidant activity than purple fruit pulp and seed core samples. Meanwhile, in the yellow-skinned fruit phenotype, the peel has 1.5 and 2.5 times higher antioxidant activity than pulp and seed core samples, respectively (Mohd Waznul *et al.*, 2019). Based on DPPH Free-Radical Scavenging Assay, the parameter used to determine the data is the value of IC_{50} . The lower the value of IC_{50} , the higher the antioxidant activity. Statistically, a compound is said to possess highest antioxidant activity if the $IC_{50} < 50$ ppm, high ($50 \text{ ppm} < IC_{50} < 100$ ppm), moderate ($100 \text{ ppm} < IC_{50} < 150$ ppm), low ($150 \text{ ppm} < IC_{50} < 200$ ppm), and weak ($IC_{50} > 200$ ppm). With an IC_{50} of 177.16 ppm, ethanol extraction of *S. ferox* Linn (suppress name) fruit possesses a moderate to low antioxidant activity (Syarpin *et al.*, 2018).

In contrast, the antioxidant activity of *S. lasiocarpum* Dunal ethanolic extract was significantly influenced ($p<0.05$) by extraction time as its antioxidant activity was higher in a longer extraction time. The longer extraction time (16 hours) for *S. lasiocarpum* Dunal resulted in a higher antioxidant activity of 62.395-86.80% using the DPPH Free-Radical Scavenging assay (Hwong *et al.*, 2020). This might be because the plant cell wall is solid, and a more drawn-out extraction time with a suitable natural solvent is needed to destabilize the solid cellulose structure of the plant cell wall (Sampath, 2013). The combination of three factors of temperature, time and agitation speed also significantly affected ($p<0.05$) the yield of antioxidant activity in *S. lasiocarpum* Dunal extract. Finally, maximum extraction of antioxidant activity of *S. lasiocarpum* Dunal was optimized at the temperature of 60°C, time of 16 h, and speed of 250 rpm (Hwong *et al.*, 2020). This finding could contribute to the

body of knowledge of this indigenous fruit, particularly the extractability of phytochemicals from *S. lasiocarpum* Dunal.

Antimicrobial Activity

Antimicrobial activity refers to the process by which disease-causing microbes are killed or inhibited. For this purpose, different antimicrobial agents are used. Antimicrobial medication may be antibacterial, antifungal or antiviral (Hazimah et al., 2018). They all have different modes of action to suppress the infection. The search for natural and safe alternatives to prevent microbial growth is a hot research topic among food researchers, processors and healthy regulatory agencies. Part of the concern is attributed to cumulative antibiotic resistance of pathogenic bacteria, mainly due to medicinal reasons and globally prevailing outbreaks. Phenolic compounds stand out as a promising alternative and public strategy to reduce the excessive and sometimes unnecessary use of antibiotics (Munekata et al., 2019). Besides being antimicrobial, it is also important to prevent cancer, degenerative and cardiovascular diseases and slow down the aging process (Singh et al., 2013; Ma et al., 2014; Tyagi et al., 2015).

Several studies have been dedicated over the last decades to clarify the mechanisms involved in the inhibitory activity of phenolic compounds against bacteria. Two mechanisms have been proposed for antimicrobial activity: cell aggregation and direct antimicrobial activity (Cushnie & Lamb, 2011; Agnew et al., 2014; Afroz et al., 2020). A massing or clumping of cell types together where cells can sense other cells to a limited extent will tend to move towards zones with higher numbers of cells (Agnew et al., 2014). Secondly, the study of Terung Asam Sarawak involved direct antimicrobial activity, where antimicrobial peptides (AMPs) are a class of antimicrobial drugs that can be extremely effective in treating diseases caused by multidrug-resistant pathogens (Afroz et al., 2020). They are found in different life forms, from prokaryotes to

mammals (Amerikova et al., 2019). According to studies, the increase in the lipophilicity nature of phenolic compounds improves their antimicrobial activity by facilitating their interaction with the cell membrane (Sikkema et al., 1995; Bouarab-Chibane et al., 2019). This can result in irreversible agglomeration of cell content and cytoplasmic damage and, which can even inhibit intracellular enzymes (Bouarab-Chibane et al., 2019).

Some promising work demonstrated the antibacterial potential of *S. lasiocarpum* Dunal. An antimicrobial study of *S. ferox* Linn (suppressed name) indicates that the ethanol extract effectively suppressed *Pseudomonas* spp. pathogenic bacteria than *Aeromonas hydrophila* on tilapia fish (Hardi, 2016). The study also revealed *S. ferox* Linn as the best plant to inhibit *Pseudomonas* spp. at which 600 mg/mL (10 mm inhibition zone) and 900 mg/mL (11.6-13 mm inhibition zone) were the best concentration to inhibit *Pseudomonas* spp. (Hardi, 2016). Another study also revealed the antimicrobial activity of *S. ferox* Linn leaf methanolic extract against *Escherichia coli* and *Bacillus subtilis*. The extract showed inhibitory zones of 11.67 mm for *E. coli*, and 11.29 mm for *B. subtilis* only at 5.7 µg/mL concentration (Hazimah et al., 2018). On the other hand, Elkington et al. (2014) discovered that extracting parts of *S. lasiocarpum* Dunal, such as stems, leaves, branches and twigs, inhibited the growth of the virulent *Mycobacterium tuberculosis* H37Rv (Mtb) by 71%. The ethanolic extract of *S. ferox* Linn root was also found active against *Staphylococcus aureus* and *E. coli* (Khare, 2007).

In general, there is ample evidence that secondary plant metabolites and their subsidiaries have the potential for numerous biological activities, including conceivable antimicrobial agents. Among the secondary metabolites contemplated, phenolic compounds alkaloids and flavonoids have demonstrated solid antimicrobial activity. Phenolic compounds, as the most abundant metabolites found in plants, were among the most exceptional secondary

metabolites; their antioxidant activity structure was the reason for antimicrobial effects. Alkaloids provided the key basis for developing of a few other antibiotics with a broad range of activity. The capability of these secondary metabolites to act as resistance-modifying agent is a crucial attribute for reducing the incidence of bacterial resistance (Othman *et al.*, 2019).

Other Health-related Potential Activity (Anticariogenic)

Dental plaque is defined as a biofilm formed by cariogenic bacteria attached to the surface of teeth. It plays an important role in developing dental caries, one of the main oral diseases in humans. Among the bacteria, *Streptococcus mutans* is considered cariogenic. It can synthesize extracellular polysaccharides from sucrose, mainly water-insoluble glucan, which triggers plaque formation (Severiano *et al.*, 2010). The ethanolic extract from flesh and leaf of *S. ferox* Linn (suppressed name) has been claimed to possess anticariogenic properties against *S. pyogenes* and *S. aureus* (Raduan *et al.*, 2019). According to the results, the *S. pyogenes* is more susceptible to flesh and ethanol extracts (dosage required is 40-160 mg/mL) compared to *S. aureus* (dosage required is 1280-2560 mg/mL).

The presence of phytochemicals such as alkaloids, flavonoids and tannins, either singly or in combination, may contribute to the anticariogenic properties against the *S. pyogenes* and *S. aureus* (Raduan *et al.*, 2019). Alkaloids are claimed to have bactericidal activity against oral bacteria (Hu *et al.*, 2000). Flavonoids are also known to inhibit the oral pathogen glucotransylferase activity or growth (Tomczyk *et al.*, 2010; 2011). On the other hand, tannins possess cytotoxic effects that effectively treat hemorrhage and swelling of the oral mucosa (Suganthi & Tamilarasi, 2015). Even though the *Solanum* genus was reported to exhibit anticariogenic properties, there is still a lack of study done, particularly for *S. lasiocarpum* Dunal.

Conclusion

In conclusion, *S. lasiocarpum* Dunal, previously known as *S. ferox* Linn (suppressed name), demonstrated promising biological activities, particularly as antimicrobials and antioxidants. It could also be a potential anticariogenic agent. The activity is governed by secondary metabolites, as evidenced by various studies, and the extraction methods have impacted the extraction of the active phytochemicals from the sample. However, research on the phytochemicals and other biological activities of the *S. lasiocarpum* Dunal is still lacking. Exploring ethnopharmacology and the biological properties would benefit the pharmaceutical, food and economic sectors. Future research should focus on comprehensive characterizations of the phytochemicals (extraction methods and factors that influence the extraction of bioactive compounds) to increase information regarding their biological activities to support the possible commercial exploitation of this indigenous fruit.

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