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Review Article

A REVIEW ON RECENT ADVANCES ON ETHNO-MEDICAL PLANT: *AVERRHOA BILIMBI*

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ABSTRACT

Conventionally folk remedy includes *A. bilimbi* for various ailments such as fever, mumps, skin allergies, scurvy, rheumatism, etc. The plant parts possessing medicinal value are primarily leaves and fruits. The plant contains phytoconstituents such as flavonoids, alkaloids, saponins, and triterpenoids. This tropical plant holds great importance in folk medicine. Additionally, the fruit, leaves and bark extract also exhibit a wide range of pharmacological activities, for instance, antidiabetic, antihyperlipidemic, antibacterial activity, anti-inflammatory, antioxidant and antithrombotic activity. The plant parts are also of special culinary interest in various cuisines. The fruits are used to prepare pickles, jams and as an additive in curries. In Malaysia, fruit-based jams are prepared. In Indonesia and Philippines, it is used in curries as a souring agent while in the Kerala region of India it is used for making pickles. The recent scientific study regarding pharmacological evaluation reveals prominent antidiabetic, anticancer activities. The recent researchers have formulated many formulations like Black tea, pectin extract, ZnO nanoparticles, Viscosifier beverages, Pectin edible films, Tofu, Iron nanoparticles, furfural compounds, Bilimbi candy, etc.

Keywords: *Averrhoa bilimbi (A. bilimbi),* Ethylthiazolyldiphenyl-Tetrazolium Bromide (MTT), chloroform soluble fraction (CSF), 2,2-Diphenyl-1-(2,4,6trinitrophenyl)-hydrazyl (DPPH), ascorbic acid equivalent (AAE), Ultrasonic-assisted extraction (UAE).

1. INTRODUCTION

Averrhoa bilimbi is a commonly found plant in the Indian subcontinent and Southeast Asia. The plant parts possessing medicinal value are primarily leaves and fruits. *A. bilimbi* flourishes in tropical and subtropical environments. The plant has been a particular interest of mankind due to its medicinal as well as culinary usage. The recent scientific study regarding pharmacological evaluation reveals prominent antidiabetic, anticancer activities. The bilimbi tree reaches 5-10meters in height. Its trunk is small and divides up into ramifications. The trunk and branches of tree has to be exposed to sunlight for fruits to form which is achieved by removing leaves except from branch end. Bilimbi is an attractive, long lived perennial evergreen tree widely cultivated throughout Asia. It has a petite trunk which divides into several branches. The trunk is stout, Corky brown. Bilimbi leaves which are 3-6 cm long is alternate, imparipinnate and cluster at branch extremities. It has compound leaves with 20-40 leaflets each and 5-10cm long. The leaves are hairy with pinnate shapes and form clusters at the end of the branches consists of compound imparipinnate leaves mainly clustered at the apex alternate 10 to 25 inches (30 to 60cms) long with 10 to 35 alternate or downy sub-opposite leaf lets, ovate or oblong with rounded base and pointed tip, medium green on upper surface and pale on the lower surface 0.75 to 4 inches (2 to 10cms) long and 0.5 to1.2 inches (1.25 to 2.25cms) wide. Flowers are fragrant, with 5 petal flowers. The fruits are ellipsoidal or nearly cylindrical, faintly 5 sided, 1.5 to 4 inches (4-10 cm) long, persistent five lobed calyx, five petals pinkish deciduous corolla. The tree is cauliflorous with 18-68 flowers in panicles that form on the trunk and other branches. The flowers are heterotristylous with petal 10-30m long. The fruit is crunchy when unripe, turns bright green to yellowish-green, ivory or white when ripe. The outer skin is shiny, very thin and is very acidic. Ripe bilimbi fruits have elevated Vitamin C concentration than half ripe ones. The levels of vitamin C in ripe and half ripe bilimbi fruits are different i.e., 20.82mg/100g to 60.95mg/100g respectively. This may be due to climatic factors. During the dry season, an increase of photosynthetic activity produces higher levels of vitamin C, as this vitamin is synthesized from hexose sugar precursors. Therefore, the medicinal use of this fruit against scurvy, which was

recommended by can be justified. Seeds are about 6-7 in number compacted disc like about 0.25 inches 4-6 mm wide, smooth and brown.

A. Bilimbi could possibly be originated in Moluccas, Indonesia; the species is now cultivated and found throughout the countries such as Philippines, Indonesia, Sri Lanka, Bangladesh, Maldives, Burma and Malaysia. In India, it is usually found in coastal regions of Kerala. Outside of Asia, however the tree is cultivated in Zanzibar. In the year 1793, the bilimbi was introduced to Jamaica from Timor and after some years, was cultivated throughout Central and South America where it is recognized as mambo. The tree was introduced to Queensland at the end of the 19th century; it has been grown commercially in the region since then. This is basically a tropical tree, less resistant to cold compared to the *Averrhoa carambola*, and grows best in rich and well-drained soil (but also stands limestone and sand). Evenly distributed rainfall throughout the year is preferred, but with a 2- to 3-month dry season. The fruit is a natural source of vitamins B and C, iron, phosphorus and antioxidants, and relieves hemorrhoids, stings itches, pimples and skin eruptions. In the Philippines, the fruits are eaten either raw or dipped in rock salt. It can be either curried or added as a souring agent for common Filipino dishes. It is being sun dried for preservation. It is also used to make salad mixed with tomatoes, chopped onions with soy sauce as dressing. In the Far East, where the tree originated, it is sometimes added to curry possibly to enhance acidity [1].

Averrhoa bilimbi has been extensively used in traditional medicine for the treatment for cough, itches, boils, rheumatism, diabetes, whooping cough, and hypertension. In the Philippines, the leaves are applied as a paste or applied directly on itches, swellings of mumps and rheumatism, and on skin eruptions. Elsewhere, they are applied to soothe snake bites. Malaysians take the leaves either fresh or fermented as a healing for venereal disease. A leaf infusion is a cure for coughs and is taken after childbirth as a tonic. A leaf decoction is taken to ease the rectal inflammation. A flower infusion is supposed to be effective against coughs and thrush. In Java, the fruits combined with pepper are consumed to cause sweating when people are feeling unwell. A paste of pickled bilimbi is applied to for quick recovery after a fever. The fruit conserve is administered as a cure for beriberi and biliousness. Syrup prepared from the fruit is used as to heal fever, inflammation and to stop rectal bleeding and reduce internal hemorrhoids. In addition, *A. bilimbi* has been extensively reported for its numerous ethnopharmacological properties such as anti-inflammatory, anti-scorbutic, astringent, anti-bacterial, and postpartum protective properties. In Indonesia it has a significant medicinal reputation as a potent folk remedy especially in the treatment of diabetes mellitus. Along with other antioxidant components, polyphenols (e.g., flavonoids) present in fruits and vegetables have been reported to be probable candidates in reducing cardiovascular diseases. The protecting effects could be due to their properties as free radical scavengers, hydrogen-donating compounds, singlet oxygen quenchers and/or metal ion chelators [2]. The sole purpose of this review is to compile the data related to the all aspects of folk medicine, cultivation, collection, description, extraction, isolation, traditional uses, phytochemistry, pharmacology of *A. bilimbi* till this date while focusing on its formulation and advances.

2. CULTIVATION, COLLECTION AND DESCRIPTION

Being a tropical tree, *A. bilimbi* requires direct sunlight and seasonally humid climate with evenly distributed rainfall throughout the year, but there must be a 2-3-month dry season. It is more sensitive to cold [3]. The tree makes slow growth in the shade while it grows excellent in rich, moist, well-drained soil. It fruits quite well on sand or limestone. In Philippines, a form of bilimbi having sweet fruits had been discovered. Even though efforts at grafting and budding have not been rewarding, Air-layering has been practiced in Indonesia. However, the tree is more widely grown from seed, trees are vigorous and didn't obtain special horticultural attention [4]. *A. bilimbi* tree has a short trunk soon dividing into many upright branches which grows about 5-10m in height. Description of the *A. bilimbi* has been given in table 3.

3. EXTRACTION

A 100 grams *A. Bilimbi* were pressed to become smaller size by using a juicer. The filtrate was then placed into a bottle which was after that pasteurized at a temperature of 80°C for 10 minutes [9].

Two different techniques namely maceration and ultrasound-assisted extraction were performed using different solvents (distilled water, ethanol and methanol) and fruits, leaves and twig of *A. bilimbi* were utilized. Based on experiment, it has been revealed that fruit gave highest percentage yield for both techniques [10].

The maximum yield of extraction and total flavonoid content were achieved at 240 minutes extraction time

using ethanol 96% as a solvent. The result of this research was heavily influenced by the effect of extraction time on total flavonoid and the yield of extraction. The longer of extraction time will provide the longer of contacting time between solvent and the substance to be dissolved. It is also notable that *A. bilimbi* leaves contain flavonoid as bioactive compound that can be used as natural antioxidant [11].

Table 1: Various names of *A. Bilimbi* [4-6]

Language/ Country	Plant Name
English	bilimbi, cucumber tree, tree sorrel
Tamil	Pulima
Malayalam	Irumban puli
Kannada	Belambu
Telugu	Gommareku
Filipino	kamias, lba
French	blimblim, blinblin, carambolier bilimbi, zibeline, zibeline blonde, cornichon des Indes
Indonesian	belimbing asam, belimbing wuluh
Khmer	tralong tong
Malay	belimbing asam, belimbing buloh, billing billing
Spanish	pepino de Indias, grosella china, mimbro, tiriguro, vinagrillo
Thai	kaling pring, taling pling
Creole	bimbling plum, blimblin
Vietnamese	Khe tau

The fruits were cut into small pieces and lyophilized using a freeze dryer. The lyophilized samples were then ground into powder, sieved (30 mesh size screen) and stored at 4°C prior to extraction. During the extraction, the *A. bilimbi* powder was suspended in Deep eutectic solvents (DES) at different concentrations with different molar ratios, followed by incubation at different temperatures and time. The extraction took place in KS 4000i shaker with constant shaking at 250 rpm. After incubation, the slurries were filtrated through muslin cloth. The filtrates were then precipitated using 4 volumes of 98% (v/v) ethanol at room temperature for 2 h. The precipitates were then separated from aqueous phase using a muslin cloth. The pectin was then lyophilized, ground into powder and stored in a desiccator at room temperature prior to analysis. The extraction yield was expressed as percent yield [12].

Table 2: Taxonomical classification of *A. Bilimbi* [4]

Kingdom	Plantae
Subkingdom	Tracheobionta
Super division	Spermatophye
Division	Magnoliophya
Class	Dicotyledonae
Subclass	Rosidae
Order	Oxalidales
Family	Oxalidaceae
Genus	Averrhoa
Species	bilimbi L.

Table 3: Description of the plant [3, 7, 8]

Part of plant	Description
Leaves	Generally, 31 leaflets present, Compound leaf having swollen base & acute apex with length 6.48 cm & width 2.243 cm, Pubescent surface, reticulate venation, petiole of length 41.3 cm & width 0.26 cm, alternate and imparipinnate phyllotaxy
Flowers	10-22 mm long, fragrant, auxiliary 5-petalled, yellowish green to reddish- purple in color, borne in small, hairy panicles emerging directly from the trunk
Fruit	4-10 cm ellipsoid, faintly 5-sided, long; covered by a thin, star-shaped calyx at the stem end and tipped with 5 hair- like floral remnants at the apex. Upon ripening, the fruit turns from bright green to yellowish green, the outer skin is shiny extremely thin, soft, tender and the flesh inside is green in appearance and jelly- like
Seeds	6-7 flattened, disc-like, 6 mm wide, smooth texture, brown
Wood	White, soft but tough, even grained

4. ISOLATION

UV, FTIR, LCMS and NMR analysis was carried out from which the isolated compound was found to bedihydromyricetin i.e. (2*R*,3*R*)-3,5,7-trihydroxy-2-(3,4,5-trihydroxyphenyl)-2,3-dihydrochromen-4-one (Fig.1) having molecular formula C15H12O8 and molecular mass 320.0529 [13].

The crude methanolic extract was subjected to sequential extraction with hexane, dichloromethane, and ethyl acetate solvents. Experiment resulted in isolation of seven metabolites pure from the crude extract of *A. bilimbi*. Their structures were elucidated and were found to be compounds not formerly reported from this plant. Two novel derivatives of phytol namely

3-(6,10,14-trimethylpentadecan-2-yl) furan-2(5H)-one (Fig.2) and 2,3-bis (-2,6,10-trimethylundeca-1,5,9-trienyl) oxirane (Fig.3) were identified. Additionally, a new phenolic compound 4,5-Dihydroxy-2-methylene-hydroxybenzal-dehyde(Fig. 4) was elucidated [14].

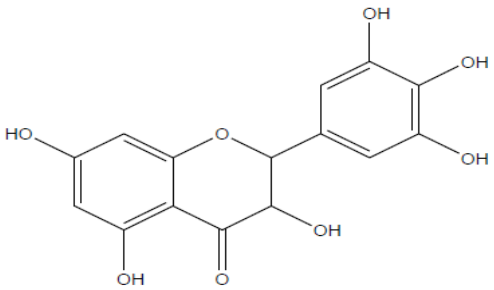

Fig. 1: Structure of dihydromyricetin [13]

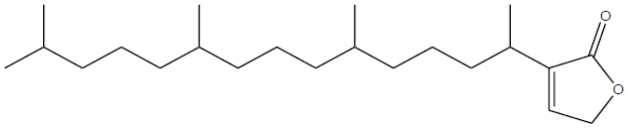

Fig. 2: Structure of 3-(6,10,14-trimethylpenta-decan-2- yl) furan-2(5H)-one [14]

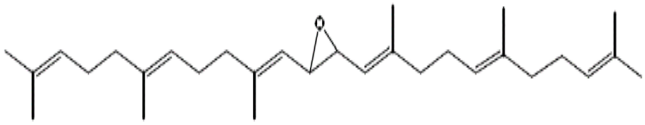

Fig. 3: Structure of 2,3-bis (-2,6,10-trimethy-lundeca-1,5,9- trienyl) oxirane [14]

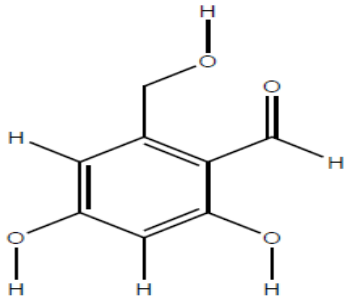

Fig. 4: Structure of 4,5-Dihydroxy-2-methylene-hydroxybenzaldehyde [14]

5. PHYTOCHEMISTRY

5.1. Leaves

The phytochemical screening of the leaves of *A. bilimbi* resulted in the conclusion that it contains primary and secondary metabolites. The primary metabolites include aldehyde, sugar, and protein while secondary metabolites include are cardiac glycoside, flavonoid, alkaloid, phenol, tannin, and coumarin [7]. Seven compounds isolated from the methanolic extract of leaves of *A. bilimbi* showed presence of squalene (Fig.5); 3-(6,10,14-trimethylpentadecan-2-yl) furan-2(5H)-one; 2,3-bis (2,6,10-trimethylundeca-1,5,9-trienyl) oxirane; phytol (Fig.6); 3,4-Dihydroxy-hexanedioic acid (Fig.7); malonic acid (Fig.8) and 4,5-Dihydroxy-2-methylenehydroxy-benzaldehyde (Fig.9) [14].

5.2. Fruit

The fruit extract contains various phytoconstituents such as flavonoids, saponin, triterpenoid, proteins, amino acids, and tannins. The fruits are rich in compounds like vitamin C and oxalic acid [4, 15]. The isolation of 2,4-Dihydroxy-6-[(4-methylpentyloxy) methyl] benzaldehyde from the fruit extract of *A. bilimbi* has been recorded in 2013 [15]. Malaysia's *A. bilimbi* fruits comprise of hexadecenoic acid [palmitic acid] (20.4%), 2-furaldehyde (19.1%) (Fig.10) and (Z)-9-octadecenoic acid (10.2%) (Fig.11). It was also noted that esteric compounds butyl nicotinate (1.6%) and hexylnicotinate (1.7%) (Fig.12) were present in greater quantities [14]. Fruit pulp had just about 6 mg/kg of total volatile components out of which 62 compounds were identified by the study carried out on *A. bilimbi* plant that grew in Cuba. The major compounds were nonanal (2.7mg/kg), (Z)-3-hexenol (0.48mg/kg), hexadecenoic acid (0.31mg/kg), octane (0.29), tricosane (0.27mg/kg), (E)-2-decenal(0.26 mg/ kg), nonanoic acid (0.25mg/kg), (Z)-9-pentacosene (0.24 mg/kg), 2-furfural (0.18 mg/kg), and (Z)-9-tricosene (0.11mg/kg) [14].

5.3. Bark

The bark extracts contain alkaloids, saponins, flavonoids [16].

5.4. Fruit and leaves

A. bilimbi fruits and leaves contains pure procyanidins with a moderate average proanthocyanidin size. Epicatechin (Fig.13) accounted for 94-97% of the flavan-3-ol subunits and these polymers had mean degrees of polymerization ranged from 5 to 14. Pure proanthocyanidins (Fig.14) are not so common in edible fruits. Thus *A. bilimbi* fruits and leaves are potentially valuable source for proanthocyanidins [17].

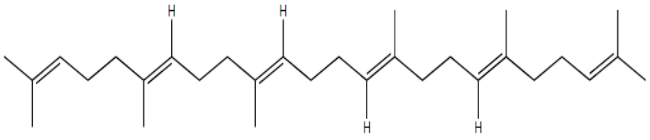

Fig. 5: Structure of squalene. [14]

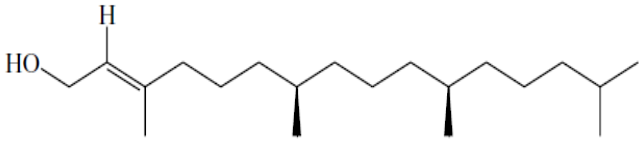

Fig. 6: Structure of phytol [14]

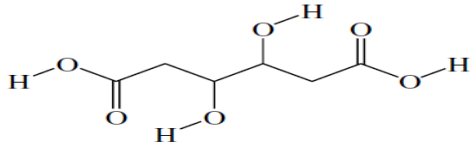

Fig. 7: Structure of 3,4-Dihydroxyhexanedioic acid [14]

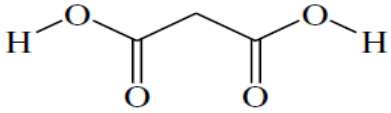

Fig. 8: Structure of malonic acid. [14]

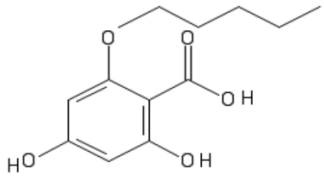

Fig. 9: Structure of 2,4-Dihydroxy-6-[(4-methyl-pentyloxy) methyl] benzaldehyde [14]

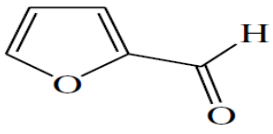

Fig.10: Structure of 2-furaldehyde [14]

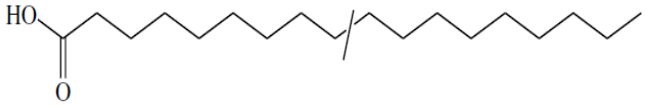

Fig. 11: Structure of 9-octadecenoic acid [14]

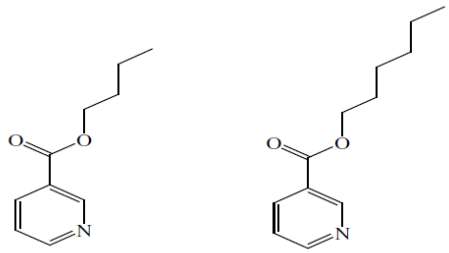

Fig. 12: Structure of butyl nicotinate (1.6%) and hexyl nicotinate [14]

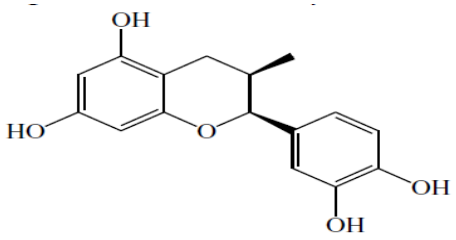

Fig. 13: Structure of Epicatechin [17]

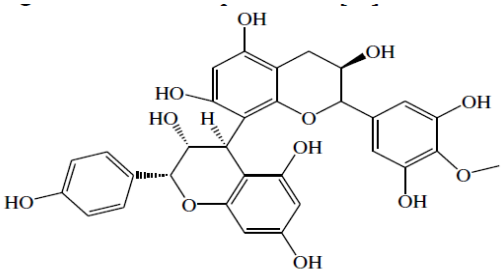

Fig. 14: Structure of proanthocyanidins [17]

6. TRADITIONAL USES

Grated fruits, with a little salt added, are applied on the face to treat pimples. Fruit juice is employed in the treatment of scurvy (being rich in vitamin c) whooping cough, hypertension, obesity, and diabetes. It is also administered as a treatment for coughs, beriberi, and biliousness. Syrup prepared from the fruit is taken as a cure for fever and inflammation and to stop rectal bleeding and alleviate internal hemorrhoids. The paste of leaves is used in the treatment of itches, boils, skin eruptions, bites of poisonous creatures, rheumatism, cough, cold, and mumps. In Malaysia, leaves or fermented leaves are used for treating venereal disease. The infusion of leaves is a remedy for coughs and is taken after childbirth as a tonic. A leaf decoction is taken to relieve rectal inflammation. The infusion of flowers is said to be helpful against coughs and thrush. In Java, when people are unwell eating fruits with pepper to induce sweating. A paste of pickled bilimbi is

smeared all over the body to speed up recovery after a fever. In some villages, in India, the fruit of the bilimbi was used in folk medicine to control obesity. This led to further studies on its Antihyperlipidemic properties [4, 18, 8].

7. PHARMACOLOGICAL ACTIVITY

7.1. Antibacterial activity

Various extracts of the fruit of *A. bilimbi* were prepared out of which chloroform extract has shown promising antibacterial activity. Chloroform extract when taken in the concentration of (150 mg) comparatively showed strong inhibition against the gram-positive strains such as *Bacillus* and *Staphylococcus* also the same extract was found to be more effective against the *Bacillus* than *Staphylococcus*. The antibacterial activity of the chloroform and methanol extracts of the fruits of *A. bilimbi* against gram-negative bacterial strains such as *Klebsiella* and *Serratia* given in a concentration of 150 mg gave good antibacterial activity. However, petroleum extract failed to show significant inhibitory action against gram-negative and positive bacteria. In conclusion, only the chloroform extracts of *A. bilimbi* gave inhibiting action against both strains of bacteria [19]. Methanolic extract of both leaves and fruits of concentration (40µg/disc) were taken against Kanamycin (30µg/disc) which was taken as the standard. The highest antibacterial activity obtained was for the fruit extract against the Gram-negative *Salmonella paratyphi* (23.0±0.50 mm) and the Gram-positive *Bacillus megaterium* (19±0.40 mm) thus further confirming fruit extract with promising antibacterial activity [20].

7.2. Anticancer and cytotoxic activity

The MTT profile of fruit and leaf extract of *A. bilimbi* was carried out. The cytotoxic effect was determined using MCF-7 tumor cell lines. It was revealed as both fruit and leaf extracts were active on MCF-7 cell lines. Thus, concluding that *A. bilimbi* fruit and leaves extract hinders the propagation of MCF-7 breast cancer cells with the association of apoptosis. The IC_{50} value for fruit extract was reported as 154.9µg.ml^{-1} while a maximum inhibition of cell growth was obtained at 300µg.ml^{-1}. On the other hand, the ethanolic leaf extract of *A. Bilimbi* showed an IC_{50} value 668.3 µg.ml^{-1}. The fruit extract showed a better possibility of cytotoxic activity as compared to leaf extract. This is maybe assigned to the higher amount of flavonoids present in the fruit extract. The results revealed that *A. bilimbi* fruit extract could be regarded as a potential chemotherapeutic agent in cancer treatment [21].

Brine shrimp lethality bioassay which used the methanolic extracts of leaves and fruit was evaluated against *Artemia Salina* with taking Vincristine sulfate (VS) as a positive control. The LC_{50} was found to be 12.96, 92.51, and 3.05µg/ml for fruit, leaf, and Vincristine sulfate respectively. The fruit extract showed better cytotoxic activity than its leaf counterpart [20].

7.3. Antihyperlipidemic activity

Recurring administration of the ethanol extract of the leaves (250mg/kg/day) of *A. bilimbi* considerably lowered blood triglyceride by 130%when compared with the vehicle in streptozotocin-induced diabetic rats as assessed. The treatment, furthermore markedly augmented the anti-atherogenic index and HDL-cholesterol to total the cholesterol ratio [21-23].

The leaf extract has shown cholesterol uptake inhibition in an *in vitro* assay by using the Caco-2 cell model of intestinal absorption. The fruit of quantity 125 mg/kg, as well as its aqueous extract 50 mg/kg, was additionally found to be efficient in lowering lipids in the high fat diet fed rats [23].

7.4. Anti-thrombotic activity

The bark extract of the *A. bilimbi* shows prominent antithrombotic activity. By the addition of 100µl Streptokinase (lyophilized Altepase), used as a positive control (30,000 I.U.), to the clots was carried out. Their subsequent incubation for 90 minutes at 37°C, resulted in a 92.81% lysis of clot simultaneously, distilled water was treated as the negative control which exhibited negligible lysis of clot (1.32%). In this study, the chloroform soluble fraction (CSF) displayed maximum thrombolytic activity (8.13%) [24].

In an experiment carried out, oral administration of ethanol extracts of leaves and fruits (250 mg/kg) of *A. bilimbi* for 14 days could cause major anticoagulant effects as observed by elevated prothrombin time. In another similar study, a crude methanol extract accompanied by partitioned fractions of leaves established significant thrombolytic activity (17.06 - 27.72%) done by *in-vitro* assay [25].

7.5. Antioxidant activity

A. bilimbi is believed to show antioxidant activity. The leaf extracts (0.02% w/v) of *A. bilimbi* displayed fair antioxidant activity in the presence of ferric thiocyanate

and thiobarbituric acid. Additionally, it was examined to be inactive in 2,2-Diphenyl-1-(2,4,6trinitrophenyl)-hydrazyl (DPPH) assay. Contrasting to the leaves, the fruit extracts showed strong DPPH radical scavenging activity with IC_{50} value of 20.35µg/ml. It also displayed remarkable total antioxidant ability (417.093±6.577 mg/g) in ascorbic acid equivalent (AAE) [26].

In other studies, the photoprotective effect ethanol extract of the leaves of *A. bilimbi* against ultraviolet light (UV) (200-400 nm) induced oxidative damage in albino mice. This experiment revealed that topical application of an extract (4%) lowered the effect of UV light-induced photo-aging in mouse skin by diminishing malondialdehyde level to its half compared to an irradiated control group. The extract treated animals also showed the slightest signs of histological modifications [27].

The leaves of *A. bilimbi* possess good *in-vitro* antioxidant capacity as scavenging effect of free radicals as well as inhibition of xanthine oxidase has been observed. This antioxidant property was found to be significant in the n-butanol fraction, as revealed by the IC_{50} value. LC-MS-QTOF analysis, as well as molecular docking studies, led to the tentative identification of 5,7, 40-trihydroxy-6-(1-ethyl-4-hydroxyphenyl) flavone-8-glucoside cucumerin A and afzelechin 3-O-alpha-L-rhamnopyranoside as the compounds that are likely to be accountable for the antioxidant effect of this plant [28].

7.6. Antidiabetic activity

The hypoglycemic effects of *A. bilimbi* were concluded using leaf extract in streptozotocin (STZ) induced diabetic rats. The experiment showed that ethanol extract of the leaves (125mg/kg twice daily) significantly lowered blood glucose compared to the vehicle [29].

In another research carried out, the potential mechanism of the hypoglycemic action by using various fractions of butanol, ethyl acetate, hexane and aqueous fractions of *A. bilimbi* ethanolic leaf extract in streptozotocin-diabetic male Sprague-Dawley (SD) rats. The hypoglycemic activity of different fractions was evaluated at a dose of 125-mg/kg body weight in streptozotocin (STZ)-diabetic rats. Results showed that oral administration of the aqueous fraction to STZ induced diabetic rats extensively improved insulin secretion and elevated glucose tolerance whilst hepatic glucose-6-phosphatase activity was considerably suppressed. The resultant augmentation in serum insulin level was assumed to be the possible mechanism of action of the plant [30].

Ethanolic leaf extract of *Averrhoa bilimbi* and its semi-purified fractions evaluated revealed to have significant hypoglycemic properties in Type I diabetic rats when administered intraperitoneally [31].

The effect of *A. bilimbi* on insulin signaling pathway when inspected, revealed that different leaf extracts exhibited strong inhibition of protein tyrosine phosphatase 1B (PTP1B) in an *in vitro* enzyme assay at 10µg/ml. The diethyl ether extract established the strongest inhibition with 0.7% residual PTP1B activity followed by a petroleum ether extract with 5.7%, whereas butanol and water extracts showed less potency with residual PTP1B activity of 34.9 % and 35.0 %, respectively [32].

8. FORMULATIONS

Black Tea with *A. bilimbi* leaf extract was formulated. The black tea extract was mixed with water, then *A. bilimbi* leaf extract in different percentages of 2%, 4%, 6%, 8% and 10% was added. The addition of *A. bilimbi* extract on tea beverage was affected to increase antioxidant activity, total polyphenols, catechins, vitamin C, total sugars, total plate count. This could give a new flavor to the tea. The sensory evaluation test for color, aroma and taste of *A. bilimbi* tea was also done and it gives good results as accepted by the 40-80% panelists [9-13].

ZnO nanoparticles were synthesized through green synthesis by using fruit extract of *A. bilimbi*. The size, shape and structure of the prepared nanoparticles were authenticated through SEM, DLS and XRD measurements. The optical properties associated with the ZnO nanoparticles were obtained from UV-Vis and PL spectroscopy. The biomolecules involved in this reduction of ZnO were confirmed by FTIR spectra. The photoelectrochemical properties examined though LSV curves as well as EIS measurements prove that the obtained ZnO nanoparticles show good photoelectrode characteristics for solar cell applications [33].

The use of Deep eutectic solvents (DES) was proven to be an effective extraction medium for the extraction of pectin from *A. bilimbi*. The optimal condition was determined: percentage DES of 3.74% (w/v), an extraction temperature of 80°C, extraction time of 2.5 h, and molar ratio of DES components of 1:1. This optimum condition yielded Pectin from *A. bilimbi* (ABP) of ~14.44%. Based on the physico-chemical properties determination results, the extract confirmed as an acidic

pectin with high purity. ABP was found to be an acidic heteropolysaccharide which composed predominantly of galacturonic acid as back bone with highly branch portions that consisted of arabinose, xylose, and glucose. It also showed decent functional properties such water holding capacity which was 3.70 g/g, oil holding capacity of 2.40 g/g, and foaming capacity of 133.33% to name a few. ABP also exhibited its potential as a functional polysaccharide which could be used as food ingredient to enhance the food properties. Apart from that, ABP exhibited potential in antioxidant activities. These findings demonstrated that pectin extracted from *A. bilimbi* could be explored as free radical scavenging activity of 41.46%, ferric reducing antioxidant power of 1.15 mm, novel promising natural pharmacological biopolymer and/or potential functional food ingredient. For examples, ABP obtained with high degree of esterification (DE > 50%) could be used as gelling agent and preservatives in jam making, stabilizer in acidic dairy products or viscosifier in beverages [12].

Large branch of *Averrhoa bilimbi* pectin-based edible films were prepared and the study concluded that, it prevented the plasticizer from interacting with pectin chains, thus decreasing the segmental mobility and inter-molecular area between the pectin chains [34].

Tofu has prepared by using *A. bilimbi* and lime juice as a coagulants. Tofu made from soymilk coagulated with 20% (w/w) of bilimbi juice or 5% (w/w) of lime juice has highest protein contents and antioxidant activities. Yellow intensities, hardness, gumminess and chewiness of the treated tofu were higher than the commercial one. The presence of organics acids in natural acid coagulants could facilitate the hydrolysis of parent proteins found in soybean as indicated by SDS-PAGE results, to yield antioxidative peptides and free amino acids [35].

Furfural was synthesized using *Mikania micrantha* powder and addition of organic acid from *A. Bilimbi*. Mile-a-minute weed (100-70 mesh size), bilimbi acid and salt (NaCl) were reacted in a three neck round bottom flask at 80-140°C for 120-330 min. Furfural was extracted from water using solvent extraction method using chloroform as a solvent. Furfural was purified by evaporating chloroform. The optimum condition for synthesizing furfural from using *Mikania micrantha* and *A. bilimbi* acid as catalyst was at 100°C for 300 min which yielded 7.2 % furfural which was later confirmed by FTIR and GC-MS methods [36].

Iron nanoparticle were synthesized from different plant parts of *A. bilimbi* such as leaves, fruit, twigs and bark using Cold maceration (CM) and ultrasonic-assisted extraction (UAE) technique and water as a solvent. The antioxidant activity was examined by using total phenolic content (TPC) assay and DPPH assay both revealed that the fruit has the highest antioxidant activity [37].

9. CONCLUSION

The extensive literature survey revealed that *Averrhoa bilimbi* L. is an important medicinal plant with diverse pharmacological and phytochemical spectrum. The plant shows the presence of many constituents like alkaloids, glycosides, flavonoids, saponin and triterpenoids. Varied pharmacological and medicinal properties like anti-diabetic cytotoxic activity, anti-Thrombotic, anti-microbial, antihyperlipidemic, and antioxidant activity are also revealed. Furthermore, it also shows culinary representation across many cultures. Despite the beneficial use of *A. bilimbi* in the traditional medicinal system and its scientifically proven pharmacological activities; there is very little information involving the bioactive compounds present in this plant. More efforts need to be taken in isolation of the chief components responsible for the potential medicinal value. Knowledge of bioactive constituents can lead to the development of a new drug from the plant using a pure compound or standardized extracts using advanced and technology. Assessment needs to be approached on *Averrhoa bilimbi L.* to explore both well-known and little-known areas and their practical clinical applications, which can be useful to cure various diseases and to establish *A. bilimbi* as a potential multipurpose plant.

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Conflict of interest

The authors declare no conflict of interest.

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