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SONNERATIA CASEOLORIS: A COMPREHENSIVE REVIEW ON RECENT ADVANCES IN THE BIOLOGICAL ACTIVITIES OF MANGROVE FRUITS

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ABSTRACT

Mangrove plants are widely distributed in the coastal area of India. This plant is a unique halophytic species that thrives in intertidal ecosystems. Mangrove had enriched bioactive compounds particularly fruits have gained increasing scientific attention due to their nutritional value and pharmacological potential. The fruits contain a wide range of secondary metabolites, exhibit broad-spectrum antifungal activity against pathogenic fungi such as Candida albicans, Aspergillus species, and other clinically relevant fungal strains. The antifungal mechanisms are attributed to membrane disruption, inhibition of fungal enzyme systems, and oxidative stress induction in fungal cells. Additionally including flavonoids, phenolic compounds, tannins, alkaloids, terpenoids, saponins, glycosides, and steroids, which contribute to their various therapeutic properties. This review summarize the current knowledge about mangrove fruits and highlight their significant biological activities, with special emphasis on antifungal and anthelmintic effects. Several studies have demonstrated that extracts and isolated compounds from mangrove fruits, mangrove fruit extracts have shown promising anthelmintic activity against different helminth models, potentially through interference with parasite neuromuscular activity, energy metabolism, and structural integrity. The presence of tannins, flavonoids, and saponins is considered to play a key role in these effects. Beyond these activities, mangrove fruits also possess antioxidant, antimicrobial, anti-inflammatory, and antidiabetic properties, indicating their broad therapeutic potential. In conclusion, mangrove fruits represent a promising source of bioactive compounds with significant antifungal and anthelmintic activities. However, further studies focusing on isolation and structural characterization of active constituents, elucidation of mechanisms of action, toxicity evaluation, and clinical validation. This review provides a comprehensive overview of the phytochemical profile and pharmacological potential of mangrove fruits, emphasizing their therapeutic importance in the society.

KEYWORDS: Mangrove fruit, antifungal, flavonoids, anthelmintic activity.

INTRODUCTION

Mangrove forests form a unique, productive group of coastal ecosystems occurring at the interface of the land and the sea, mainly in tropical and subtropical parts of the world. Apart from the critical ecological roles played by mangroves which include increasing coastal stability, protecting the biodiversity of the area and providing essential ecosystem services, mangroves are an abundant source of functional foods and traditional medicines that are not well-exploited.

The mangroves provide security of food supply and economic sustainability of the coastal communities such as the communities in the regions of Indonesia, India, Bangladesh, and China through provision of “blue foods” and medicinal compounds. Environmental stresses, pandemics, and natural disasters in the past have had the effect of disrupting the regular global food supplies leading to the need to search for sustainable alternative food sources. One of the major sister species of the Sonneratia genus, S. apetala is widely found in

coastal areas and estuaries of India, including Sundarbans. Fruit of this species is extensively used in traditional medicine for the regulation of glucose metabolism due to the presence of a high level of water-soluble phenolics and special flavonoids which inhibit carbohydrate metabolizing enzymes (α-amylase and α-glucosidase).

Though abundant, many edible mangrove products face challenges when it comes to wide use. Communities may avoid eating certain mangrove fruits because of processing challenges, lack of information on the chemical makeup of the plant products or their very bitter and sour taste This notion has been recently changed following many studies involving bioprospecting and pharmacology validation. Extensive studies suggest that different parts of the mangrove tree including the fruit, leaf, bark, sap, stem, and twig contain increased amounts of the primary metabolites such as carbohydrates, proteins and essential lipids that can be consumed as daily food Similarly, the compounds contain increased amounts of the therapeutic secondary metabolites such as phenolics, flavonoids, tannins, terpenoids and steroids .These chemicals provide both nutritional and medicinal value with known effects including antioxidant, antimicrobial, antidiabetic, anti-inflammatory and antitumor activities.

VERNACULAR NOMENCLATURE OF SONNERATIA CASEOLORIS

Global Common English	**Mangrove Apple, Crabapple Mangrove**
ASIAN VERNACULARS	Kannada: Karpu
	Malayalam: Chakkarakantal, Nakshathrakandel
	Marathi: Karpu, Chipi
	Telugu: Pedda Kalinga
	Bengali: Sadachak keora
	Konkani: Pandhari Chipi
	Odia: Orua

Taxonomic Classification of *Sonneratia caseolaris*

Kingdom	Plantae
Class	Magnoliopsida
Sub-kingdom	Viridiplantae
Super-order	Rosanae
Infra-kingdom	Streptophyta
Order	Myrtales
Phylum	Tracheophyta
Family	Lythraceae
Sub-phylum	Spermatophytina
Genus	*Sonneratia*
Species	*Sonneratia caseolaris*

Morphology

Vegetative Structure & Bark: *Sonneratia caseolaris* is an evergreen medium or tall tree able to grow up to 15-20 meters high (sometimes even up to 10 meters). The bark of the tree is brown-colored and grows vertically out of the soil having deep breathing roots. The structure does not have buttress roots and prop roots. On the contrary, it is notable for long and sharp vertical pneumatophores growing upward in the intertidal soil to enable oxygen exchange.

Leaves: The leaves of the tree are coriaceous, rough and opposite. The leaves are symmetrical along their stalks and have the typical elliptical shape reaching 7 cm in length.

Organography of Flowers: The species produces distinctive flowers which are remarkable due to the presence of red-colored petals. The structure of the flower has calyx which forms a star-like base of persistent nature under the developing ovary.

Fruit & Seed Composition: The tree produces a distinctive, edible fruit widely known as the "mangrove apple." Morphologically, the fruit is a large, rounded, light green leathery berry that measures up to 8 cm in diameter. It features a ball-shaped bottom entirely covered by the flower petals at its base, tapering into a stemmed end. The fruit is completely safe to consume directly from the tree, possessing a characteristically sour taste and a distinct scent that contributes to its local appeal. It contains beneficial nutritional compounds and holds multiple small seeds inside.

Figure: 1 Whole Plant, Fruit, Bud and Leaves of Mangroove Apple (*Sonneratia Caseolaris*).

Phytochemical composition of Mangrove Fruit (*s*)

Plant Part	Phytoconstituents Reported
Leaves	Gallic acid, Ellagic acid, Chlorogenic acid, Caffeic acid, *p*-Coumaric acid, Ferulic acid, Luteolin, Quercetin, Apigenin, Myricetin, Luteolin-7-*O*-glucoside, Isovitexin, Quercitrin, Riccionidin A, Cyanidin 3-*O*-[β-D-xylosyl-(1→2)-β-D-galactoside], Epigallocatechin gallate, Naringenin, Tannic acid, Aspirin, 2-Phenylethyl compound, Vanillin, 3,5-Di-*tert*-butyl-4-hydroxybenzaldehyde, Abietin, Squalene, Campesterol, 28-Isofucosterol, Cholesterol, Stigmasterol, 13S-Hydroxyoctadecadienoic acid, 9-Hydroperoxy-11-(3-pentyl-2-oxiranyl)-10-undecenoate, 9,12,13-Trihydroxy-10-octadecenoate, Butanoic acid, Myristynoylpantetheine, Tridecanedial, 13-Heptadecyn-1-ol, 2-Hexadecanol, 1-Octanol, Tert-hexadecanethiol, Azelaic acid, Hexose, Sorbitol, Rhamnose, Xylose, Mannose, Galactose, Diisobutyl phthalate, Bis(3,5,5-trimethylhexyl)phthalate, Monobutyl phthalate, Bis(2-ethylhexyl)phthalate, Betaine, Choline, Hexamethylenetetramine, TEMPO, Caprolactam, 2-[(2-Chlorobenzyl)sulfanyl]-4,6-dimethylnicotinonitrile, Zearalenone, Tributyl phosphate, Bis(4-ethylbenzylidene)sorbitol, DL-Arginine, Bis(2-ethylhexyl)benzene-1,2-dicarboxylate
Fruits	Ellagic acid, Vanillic acid, Luteolin, Myricetin, Luteolin-7-*O*-glucoside, 3,7,8-Trihydroxy-5,10-dioxochromenochromen-2-olate, (−)-(R)-Nyasol, (−)-(R)-4′-*O*-Methylnyasol, 3,8-Dihydroxy-6H-benzo[b,d]pyran-6-one, 3-Hydroxy-6H-benzo[b,d]pyran-6-one, Benzyl-*O*-β-glucopyranoside, β-Curcumene, Cubedol, α-Santonin, Oleanolic acid, Maslinic acid, Rhodopin, β-Sitosterol-β-D-glucopyranoside, Prednisone, Safrole
Bark	Kaempferol glucoside, Vanillin, Oleanolic acid, Lupeol, Ursolic acid, Sitosterol, Cholest-5-ene-diol, Octanoic acid, Decanal

Stem and Twigs	Luteolin, Quercetin-3-*O*-β-L-arabinopyranoside, (+)-Dihydrokaempferol, Methyl gallate, 3,3′-Di-*O*-methylether ellagic acid, 3,3′,4-Tri-*O*-methylether ellagic acid, Oleanolic acid, Lupeol, Ursolic acid, Lup-20(29)-en-3β,24-diol, 3β-*O*-(E)-Coumaroyl alphitolic acid, 3β-Acetyl oleanolic acid, 3β,13β-Dihydroxy-urs-11-en-28-oic acid-13-lactone, 3β-Hydroxy-20(29)-lupen-24-oic acid, Sitosterol, Cholesterol, Stigmasterol, Cholest-5-ene-diol, β-Sitosterol palmitate, Stigmast-5-en-3β-*O*-(6-*O*-hexadecanoyl-β-D-glucopyranoside), Daucosterol, 6′-*O*-Acetyl-β-daucosterol, Bis(2-ethylhexyl)benzene-1,2-dicarboxylate
Wood	Piperonal, 1H-Cycloprop[e]azulen-4-ol derivative, Tetradecanal, Trans-9-hexadecen-1-ol, 4,8,12,16-Tetramethylheptadecan-4-olide, Oxacycloheptadec-8-en-2-one, 13-Methyloxacyclotetradecane-2,11-dione, Pentadecane, 1-Hexadecene, 1-Docosene, Octacosane, Hentriacontane, Heptadecane, 2-Methyl-nonadecane, Diethyl phthalate, Trimethylamine
Wood and Bark	Piperonal, Dodecanamide, 2-Heptenal, 2-Octenal, Nonanal, 2,4-Decadienal, 2-Undecenal, Hexadecanal, Pentadecane, 1-Hexadecene, 1-Docosene, Octacosane, Hentriacontane, 17-Pentatriacontene, Isobutane, 3-Methylhexane, 1-Chloroheptacosane, 1,2-Benzenedicarboxylic acid bis(2-methylpropyl) ester, 7,9-Di-*tert*-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione, Ethaneperoxoic acid derivative
Leaves (Polysaccharide Fraction)	Rhamnose, Xylose, Mannose, Galactose

Nutritional Constituents: Carbohydrates, Proteins, Lipids/Fats, Amino acids, Dietary fibers, Vitamins (Vitamin C, A, B2, B5, B6), Minerals (Iron, Zinc, etc.), Omega-3 fatty acids.

TRADITIONAL USES

Traditionally, mangrove fruits and other parts of the mangrove plant have been used in folk medicine to treat a wide range of ailments, including digestive disorders such as diarrhoea and other gastrointestinal problems, diabetes and glucose imbalance, wounds, bleeding, and skin diseases. They have also been used for the management of gastric ulcers, piles, swelling, inflammation, pain, asthma, cough, and fever, as well as for their astringent properties in controlling haemorrhage. In addition, traditional medicinal systems have employed mangrove plant parts for the treatment of liver disorders, epilepsy, conjunctivitis, dermatitis, hematuria, and leprosy.

PHARMACOLOGICAL ACTIVITY OF MANGROOVE APPLE

Anti-bacterial

In Vitro activity was found to be promising against human pathogens like Staphylococcus aureus, Streptococcus sp., multi drug resistant Salmonella typhi, Proteus vulgaris and Proteus mirabilis using ethanol and aqueous extracts of leaves.[1] Aqueous extract obtained from leaves, fruits and bark was observed to be active against E.coli and S. aureus.[3] Antimicrobial activity of methanol extract of bark was found to be promising against eleven different kinds of bacteria tested i.e. *Staphylococcus auerus, Salmonella typhimurium.*

Anti-fungal

S. alba fruit extracts obtained from n-hexane, ethyl acetate, and ethanol were moderately active in inhibiting the growth of Candida albicans fungus, while fruit extracts from methanol were able to inhibit the growth of *Helminthosporium sp*. fungus that causes corn leaf blight.[6,7] The effect of methanol leaf extract on the fungus Cryptococcus neoformans has also been described.[5] CTC fraction of methanol bark extract was observed to be mildly antifungal to C. albicans, Aspergillus niger, and Saccharomyces cerevisiae.[4]

S. caseolaris has broad antimicrobial action, which is reported against a wide variety of Gram-positive and Gram-negative bacteria and fungi. It is noteworthy that the antimicrobial actions differ considerably depending on the plant part used, type of solvent, and target organisms. No in vivo and clinical study reports on antibacterial and antifungal effects of *S. caseolaris* extracts are currently available.[8,9,10,11]

Antioxidant

Sonneratia caseolaris (L.) Engl. is a mangrove species with strong antioxidant potential due to its high levels of phenolics, flavonoids, and tannins. Methanolic, ethanolic, and aqueous fruit extracts show strong DPPH and FRAP activity, indicating effective free radical scavenging and oxidative stress reduction. Kundu et al. (2022) and Thuoc et al. (2018) reported strong antioxidant activity in fruit extracts and juice, while Yoong and Rozaina (2021) found ethanolic extracts inhibit lipid oxidation and improve oil stability. Hosen et al. (2020) confirmed a positive correlation between antioxidant activity and total phenolic content. Overall, *S. caseolaris* fruits are a promising natural antioxidant source for functional foods and pharmaceutical use.

Anti-atherosclerotic

Atherosclerosis is characterized by inflammation of the blood vessels, particularly the medium size of arteries, and is one of the important risk factors for cardiovascular disease. Masdar et al. utilized an animal model study, particularly a rat in vivo model to investigate the effects of the S. alba fruit extract against atherosclerosis. The atherosclerosis was modeled in Wistar rats by giving a high-fat diet to the animals. Methanol extracts of

Sonneratia alba fruits inhibited high-fat diet-induced atherosclerosis, however, there were no changes in the lipid profile of blood in Wistar rats.[19]

Anti-malarial

As per an in vitro study conducted on 2, 6-Dimethoxy-p-benzoquinone, a constituent found in the twigs of S. alba, this compound has shown its strong antimalarial activity with an IC50 value of 3.08 µg/ml against multidrug-resistant *P. falcipar*.

Anti-Inflammatory Activity

In vitro anti-inflammatory efficacy of *S. caseolaris* has been assessed using animal models, specifically mice. Kundu et al., in a study, observed that the fruit ethanolic extract (250–500 mg/kg) reduced paw edema induced by formalin, but the effect produced was lower than that of ibuprofen (100 mg/kg). In another study by Munira et al., the stem petroleum ether fraction (150-300 mg/kg) caused 37.7% reduction in edema at 4 h, which was lower than that of indomethacin (62.3% at 10mg/kg.)

Analgesic Activity

Moreover, according to Kundu et al., employing the tail immersion technique, fruit ethanol extract (250-500 mg/kg) caused an increase in latency of 22.5-37.5% while tramadol (10 mg/kg) showed an increase in latency.

CNS-Depressant Activity

Kundu et al. found that the extract from fruits of *S. caseolaris* (ethanol) in the range of 250-500 mg/kg body weight showed antilocomotor activity in mice in the open field test; however, it was not as strong as diazepam, which was used at a dose of 1 mg/kg.

Anticholinesterase Activity

Wetwitayaklung et al. investigated the methanol extracts of different plant parts of *S. caseolaris* for the acetylcholinesterase inhibitory activity. Methanol extracts of seeds, stamens, meat of fruits, calyx, pneu matophore, and leaves showed the IC50 values of 10.52, 55.58, 84.74, 140.12), 126.15, and IC50 values of 153.03 µg/mL and 146.66 µg/mL were obtained for 1 and 2, respectively, while the IC50 value of the positive control drug, tacrine was recorded as 0.01 µg/mL.

Anticancer Activity

Recently, gold nanoparticles obtained from the fruits have been demonstrated to exhibit cytotoxic activities against A549 non-small cell lung adenocarcinoma cells.[27]

In another research by Wu et al., nine compounds derived from the fruits have been studied. Among those, (−)-(R)-nyasol (34), (−)-(R)-4′-O methylnyasol (35), and maslinic acid (43) revealed moderate cytotoxic effects on cancer cells with the IC50 ranging from 19.0 to 31.8 µg/mL. Their activities were less active than those of the reference compound 5-fluorouracil with an IC50 of 5.84 µg/mL.[28]

S. caseolaris has been tested in vitro using human cancer cell lines in terms of the cytotoxic effects of crude extracts and individual compounds. Wu et al. studied nine compounds derived from the fruits. Among those, (−)-(R)-nyasol (34), (−)-(R)-4′-O methylnyasol (35), and maslinic acid (43) have shown moderate cytotoxic effects on cancer cells with the IC50 ranging from 19.0 to 31.8 µg/mL. The activities were less active than those of the reference compound 5-fluorouracil with an IC50 of 5.84 µg/mL.

Luteolin(27), isolated from S. caesolaris, shows strong cytotoxic test invitro activity against SMMC-7721 human liver cancer cells with the IC50 value of 2.8 µM.17 ParacaseolinD (26) reveals significant cytotoxic effect against A549 cells with the IC50 value of 1.89 µM. ParacaseolinA (23) shows significant anti-H1N1 virus activity with an IC50 of 28.4 µM.16 30-Hydroxy-40-methoxy-40-dehydroxymetaberberine. Showed cytotoxicity against K562 and HL-60 celllines at an IC50 of 1.99 and 3.13µM, respectively. 19 The two compounds of interest from S. ovata include (7S,8R)-dehydroconiferolalcohol (53) and (7S).

Anti-Hyperglycaemic Activity

It has been observed in research that all the four extracts of acetone, ethanol, methanol, and water extracted from the plant S. apetala have shown significant effect on α-glucosidase inhibition activity.[32]

Tiwari et al.[35] reported the isolation of oleanolic acid from the fruit methanol extract, which showed significant decrease in blood glucose level by 22%, 21% and 12% respectively at 30, 60 and 90 minutes after the administration of starch in mice. Supportively, Rahmatulla et al.[36] reported the significant reduction of blood glucose up to 41.4% (400 mg/kg b.w.) in the oral glucose tolerance test (OGTT) with the methanol extract in a dose dependent manner but the efficacy was lower than glibenclamide (63.9% at 10 mg/kg b.w.). Dev et al.[34] further confirmed the antidiabetic efficacy of ethanol fruit extract (300-500 mg/kg b.w.) that significantly reduced glucose level in OGTT as well as STZ-induced diabetic mice. It also improved the biochemical parameters associated with diabetes having comparable performance with glibenclamide. Similarly, Barman et al.

Hypocholesterolaemia Effect

Jariyah et al.[37] showed the lipid lowering activity of the fruit water extract of *S. caseolaris* in rats. The diets containing 3%, 6% and 9% extract resulted in the dose dependent reduction of total cholesterol (32.45-58.87 mg/dL), LDL-c (32.06-55.54 mg/dL) and triglycerides (9.20-23.93 mg/dL) without any significant effect on HDL-c level.

Anti-Obesity Activity

The hot water extract of the whole fruit of *S. caseolaris* significantly attenuated the body weight gain in the high fat diet mouse model by Van Thuoc et al.[23] After the five weeks of treatment the extract fed mice showed the body weight of 53.1 g whereas the control high fat diet group had body weight of 62.1 g.

Antidiarrheal Activity

The antidiarrheal activity of *S. caseolaris* has been reported in vivo by castor oil induced diarrhea models in mice. Similarly, the fruit extracts also showed significant efficacy. Hosen et al.[38] reported that ethanol methanol (1:1) extract at 250 mg/kg resulted in increasing the latency to 273 min and reducing defecation by 87.7%, closely matching the effect of loperamide (3 mg/kg). Similarly, Kundu et al.[25] found that the ethanol fruit extract (250-500 mg/kg) increased the latent period to 95.8-119 min (versus 32 min control; 171 min loperamide) and decreasing the defecation by 43.33-64.44%.

Anthelmintic Activity

Kundu et al.[25] examined the effect of ethanol-based fruits extract of P. cervi in vitro. Paralysis was achieved within 39.6, 29.5, and 20.6 minutes, respectively, and mortality after 40.3, 36.8, and 29.9 minutes when tested at concentrations of 12.5, 25, Kundu et al. assessed the effect of the ethanol fruit extract on the process of coagulation modulation. The extract caused a significant decrease in blood clotting time from 6.72 min to 5.016, 5.517, and 5.866 min at concentrations of 100, 50, and 25 mg/mL, respectively. The effects of the extract were less pronounced than those of Phyto menadione (vitamin K1; 3.33 min).[25]

Anti-Allergic Activity

Anti-allergic activity was studied by Dev et al. through *in vivo* experiment using an allergic mouse model induced by Toluene 2,4-diisocyanate (TDI) at doses 300 and 500 mg/kgb.w. There was improvement observed in sneezing (26.43 ± 2.59 and 20.33 ± 2.64), scratching (126.71 ± 14.03 and 96.5 ± 10.74), and nasal score (1.2 ± 0.2 and 0.4 ± 0.24) when compared to untreated TDI-induced mice (31 ± 2.78, 161.33 ± 6.73, 3) which was near the results obtained from cetirizine (13.75 ± 1.49, 63.0 ± 9.93).

Antipyretic Activity

In vivo, Kundu et al., using brewer's yeast to cause pyrexia, found that 250-500 mg/kg body weight of fruit ethanol extract significantly lowered the rectal temperature but not as much as ibuprofen (100 mg/kg b.w.).

Hepatoprotective activity

It was previously found that the crude polysaccharide of *S.apetalafruit*(SAP) can significantly inhibit the increase in liver index and serum transaminase levels caused by acetaminophen(APAP) and alleviate liver tissue damage caused by excessive APAP, that is, the poly saccharides of *S.apetala* fruit can alleviate the hepatotoxicity of APAP.

The *S. caesolaris* fruit extract (SAFE) showed a potential protective effect against APAP-induced acute liver injury. SAFE also increased the levels of glutathione (GSH) and the activity of GSH-Px, enhanced the activity of catalase (CAT) and total antioxidant capacity (T-AOC), and decreased the level of MDA in the liver. These results suggest that S. apetala and its fruit can be used as a new source of functional foods with liver protection effects.

The 10 mg/kg 90% ethanol extract of S. apetala fruit alleviated neutrophil elastase-induced alveolar collapse in mice, suggesting that S. apetala fruit extract has the potential for inhibiting human neutrophil elastase. Moreover, ethanol, ethyl acetate, and n-butanol extracts of S. apetala fruit can enhance learning and memory by increasing the activities of endogenous antioxidant enzymes.

CONCLUSION

Sonneratia caseolaris (L.) Engl., commonly known as mangrove apple, has emerged as a valuable medicinal and nutritionally important mangrove species with significant therapeutic potential. The fruit contains a wide range of bioactive phytochemicals, including phenolic compounds, flavonoids, tannins, terpenoids, steroids, fatty acids, and other secondary metabolites, which are responsible for its diverse pharmacological properties. Experimental studies have demonstrated potent antioxidant, antimicrobial, anti-inflammatory, antidiabetic, antiviral, analgesic, antipyretic, antidiarrheal, cytotoxic, acetylcholinesterase inhibitory, tyrosinase inhibitory, and antihyperglycemic activities, highlighting its potential as a multi-target natural therapeutic agent. In particular, the high polyphenol content contributes to its remarkable antioxidant and free radical scavenging capacity, supporting its traditional use in the management of oxidative stress and inflammation-related disorders.

Beyond its medicinal value, the edible fruit possesses considerable nutritional benefits and shows promise as a source of functional food ingredients, nutraceuticals, natural antioxidants, and cosmetic formulations. Its acetylcholinesterase inhibitory activity suggests potential applications in the management of neurodegenerative disorders such as Alzheimer's disease, while tyrosinase inhibitory activity indicates possible use in skin depigmentation and cosmetic products.

Although current findings strongly support the pharmacological potential of S. caseolaris, most evidence is derived from in vitro experiments and animal studies.

Further investigations are required to isolate and characterize novel bioactive constituents, elucidate their molecular mechanisms of action, establish standardized

extraction protocols, evaluate long-term safety and toxicity, and conduct well-designed clinical trials to confirm efficacy in humans. In addition, sustainable conservation and cultivation strategies are essential to ensure the long-term availability of this ecologically important mangrove species. Overall, S. caseolaris represents a highly promising natural resource for the development of innovative pharmaceuticals, nutraceuticals, functional foods, and cosmetic products, making it an attractive candidate for future multidisciplinary research and commercial applications.

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