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Review

Phenological Variations and Pharmacological Properties of *Cassia Fistula*: A Review of Environmental and Therapeutic Dimensions

Shiva S,[1, 2], Vundrala Sumedha REDDY[1], Vishnu Vijay KUMAR[3], Sharan Chandran M[4], G SIVASUBRAMANIAN[5,6]

AUTHOR AFFILIATIONS:
[1]Centre for Nanotechnology & Sustainability, Department of Mechanical Engineering, National University of Singapore, Singapore 117574, Singapore
[2]School of Bioscience and Technology, Vellore Institute of Technology, Vellore 632014, India
[3]Structural Engineering, Division of Engineering, New York University Abu Dhabi (NYUAD), PO Box 129188 Abu Dhabi, United Arab Emirates
[4]School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632014, India
[5]Department of Chemistry, Amrita School of Physical Sciences Coimbatore, Amrita Vishwa Vidyapeetham, India
[6]Advanced Multifunctional Materials and Analysis Laboratory (AMMAL), Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India

ABSTRACT The golden shower tree, *Cassia fistula*, is a botanical symbol of persistence, providing aesthetic appeal and sophisticated ecological dynamics. As the climate change specter looms, this paper delves into the delicate interplay between changing climatic circumstances and *Cassia fistula* phenology and phytochemistry. The tree's therapeutic effects are linked to anthraquinones, flavonoids, and saponins, which have been gathered and focused on their significant antioxidant, anti-inflammatory, and antibacterial capabilities. *Cassia fistula* has been traditionally utilized in various medical techniques to treat illnesses such as digestive issues and skin health management, demonstrating its adaptability and usefulness in herbal therapy. The review comprehensively unravels the climate-induced changes in *Cassia fistula* phenology on attribution, pharmacological advantages, and nanotechnology prospects.

KEYWORDS: *Cassia fistula*, Phenology, Antioxidant, Pharmacology, Sleep quality, Climate change, Herbal medicine

Our ecosystem consists of enumerable plants, some of which have potentially high medicinal properties, making them a base for drug formulations. Medicinal plants in Indo-China areas are considered a prime source of many pharmaceutically active compounds that are widely used as home remedies (Prakash, Kujur, and Yadav 2018). *Cassia fistula* is one such plant of medical importance whose use has been extended to ayurvedic formulations, including traditional medicines based on Chinese cultural practices (Nagpal et al. 2011). As per Ayurveda, the tree is also called "Sarvarogaprashamani," translating it to cure for all diseases (Mohanty et al. 2023).

Cassia fistula, well known as the golden shower tree or Indian laburnum, is a tropical tree belonging to the Fabaceae family and deciduous in nature and also as shown in Figure 2. This tree is renowned for its striking clusters of bright yellow, pendulous flowers that drape gracefully from its branches, creating a visually captivating and resplendent display. Native to South Asia, particularly the Indian subcontinent, *Cassia*

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Dr.Noble K Kurian, BS Abdur Rahman Crescent Institute of Science and Technology

Address correspondence to Shiva S
shivasubramanianiyer@gmail.com

Sharan Chandran M sharanchandran.m@vit.ac.in

ORCID ID https://orcid.org/0009-0009-3986-4985

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fistula is distinguished by its ornamental and fragrant blossoms, which typically bloom in the spring season. The tree's compound leaves are pinnate in structure, featuring numerous small, elliptical leaflets that create elegant foliage. The elongated, cylindrical fruit pods of *Cassia fistula*, which can reach lengths of up to two feet, are notable for their dark brown appearance. Within these pods, one can find seeds enveloped in a sweet, sticky pulp. When fully ripe, this pulp assumes a taste and texture reminiscent of tamarind, rendering it appealing for culinary purposes in various regions. *Cassia fistula* is an important source of phytochemicals involved in medicinal formulations. It is also noted for its laxative properties, hepatoprotective effects, antioxidant activity, anti-inflammatory actions, and antimicrobial potential, which have been elaborately discussed in the subsequent section.

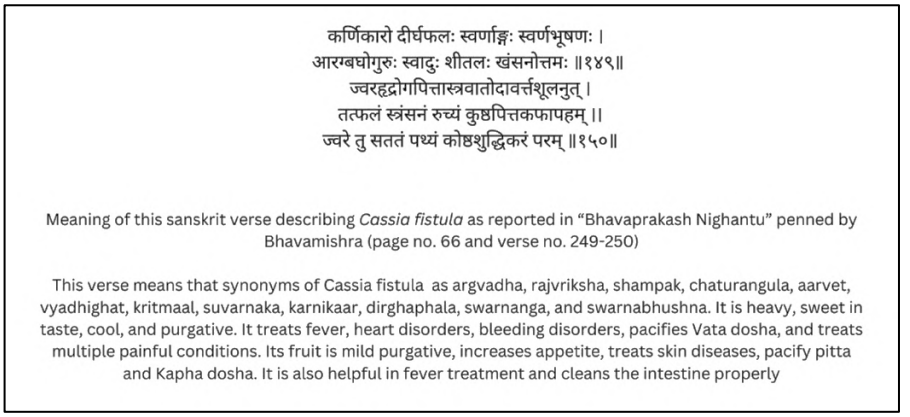


Figure 1: Quote from Bhavaprakash Nighantu describing *Cassia fistula* and its medicinal properties. The plant has been mentioned for its highly significant medicinal properties relevant to the current pharmaceutical demands.

Traditional medicine based in India is deeply rooted in various approaches, including Yoga, Ayurvedic science, Siddha medicine, and Unani, along with the field of homeopathy (Afr, Cam, and Traditional 2007). The use of the drug in the past is based on the effectiveness imparted by the plant part, which can be further studied in the present by phytochemical and pharmacological approaches aided by current scientific advancements. With more people turning towards home remedies and the ancient formulations, it is indeed of great interest to interrogate the presence of bioactive molecules and their effects on the body, especially when the plant must be reported with various bioactive molecules or phytochemicals all through the plant organs ranging from leaves, root, flowers, bark, pod, fruit, seed. In an ancient Ayurvedic text as part of Dravya Guna vijnana, Bhava Prakash Nighantu, penned by Bhava Mishra in the 16th century AD mentions the tree to be a marvel with excellent medicinal properties as a Sanskrit verse also describing the botanical properties as given in Figure 1 (Rabb Associate Professor and Rabb 2022)(M. Sharma 2023).

In Chinese medicine, the fruit of *Cassia fistula,* vernacularly known as Aleb has been utilized to enhance health prospects. Recent Chinese research has also resulted in patented advancements, such as a herbal gargle derived from *Cassia fistula* fruit, proving effective in combating bad breath and improving gastrointestinal health at the reference ID CN105030594A. Furthermore, the application of *Cassia fistula* in preparing

medicines for treating AIDS showcases its versatility. Notably, a patent(CN103156907A) on *Cassia fistula* fruit ethyl acetate extract demonstrated an impressive Human Immunodeficiency Virus I (HIV-1) protease activity inhibition rate of 83.4%. The isolation of piceatannol from *Cassia fistula* fruit, with an IC50 of 59 muM for HIV-1 protease inhibition, highlights its potential to inhibit the progression of HIV. These findings emphasize the valuable role of *Cassia fistula* in Chinese health and wellness, showcasing its adaptability in addressing diverse health concerns that have been discussed subsequently. While the Golden Shower Tree, is the national flower of Thailand, its significance also extends to China, where it is admired for its beauty and cultural symbolism. In both countries, including Thailand with its predominantly Buddhist population, this tree is associated with purity and spiritual enlightenment. In Chinese culture, flowers often carry symbolic meanings, and the Golden Shower Tree's vibrant, cascading blooms represent beauty and growth. The shared appreciation for this tree reflects the cultural connections and reverence for nature in both Thai and Chinese traditions.



Figure 2: Shows the plant parts of *Cassia fistula*, (A)Leaves, (B) Cylindrical pods, (C) Flower, and adjacently shown a complete flowering tree with significantly less leaves which are a characteristic in flowering period.

The tree is said to have originated in Southeast Asia and spread across the tropics, including the West Indies and Mexico. It may be found from sea level to a maximum elevation of 1300 meters and is commonly found in wet, tropical environments throughout subtropical zones. Usually found in better locations as well as on dry, shallow mountain slopes. The growth is acclimated to yearly temperatures ranging from 18 to 29°C and precipitation rates of 480 and 2720 mm. Although it can grow in a variety of soils with pH levels between 5.5 and 8.7, carbonate and red volcanic rock soils are thought to be preferable for it.

Table 1- Taxonomic classification

Kingdom	**Plantae**
Sub kingdom	Tracheobinota
Super Division	Spermatophyta
Division	Mangoliophyta
Class	Magnoliopsida
Sub Class	Rosidae
Order	Fabales
Family	Fabaceae
Genus	Cassia
Species	Fistula

Table 2- Vernacular names of *Cassia fistula*

Language	Vernacular name
Chinese	阿勃勒
Thai	Ratchaphruek
Sinhala	Ehela
Hindi	Amaltas
Manipuri	Chahui
Marathi	Bahava
English	Golden shower
Malayalam	Kani konna
Tamil	Konrai
Telugu	Kola Ponna
Kannada	Kakke gida
Sanskrit	Aragvadha, Suvarnaka, Kritamala, Chaturangula, Bandarlaur

Over the past two decades, India has witnessed discernible shifts in its climate, marked notably by an increase in average temperatures and alterations in rainfall patterns. Rising temperatures have manifested in more frequent and intense heatwaves, impacting various sectors, including agriculture and public health. Changes in monsoon patterns have led to regional variations in rainfall distribution and intensity, contributing to instances of flooding in some areas and drought conditions in others. These alterations in temperature and rainfall patterns have significant implications for India's agricultural landscape, influencing crop yields and contributing to uncertainties for farmers. These climate changes underscore the vulnerability of the country to the impacts of global warming and emphasize the importance of adaptive strategies to mitigate potential risks and foster resilience in the situation of evolving climatic

conditions. This climate change has profound implications for phytochemistry, the study of plant chemistry and bioactive compounds. Altered temperature and precipitation patterns affect the synthesis of secondary metabolites in plants, leading to changes in their chemical composition but yet not enough studied on *Cassia fistula* (Jamloki et al. 2021) (Qaderi, Martel, and Strugnell 2023). These metabolites, including phytochemicals such as flavonoids, alkaloids, and essential oils, play crucial roles in plant defense mechanisms and have implications for human health. Climate-induced stressors, such as heatwaves and water scarcity, can trigger the production of certain phytochemicals as part of a plant's adaptive response. Conversely, shifts in climate conditions may also lead to variations in the abundance and potency of these compounds, influencing the nutritional quality and medicinal properties of plants.

2. Phytochemistry

Each plant part exhibits beneficial therapeutic properties including anti-viral potential, antioxidant characteristics, anti-tumour potential, anti-bacterial potential, anti-fungal properties, and anti-diabetic and hepatoprotective properties. The phytochemicals have been compiled and tabulated as in Table 3.

Table 3-The phytochemistry significance of each plant part is mentioned below.

Plant part	Phytochemicals	References
Leaf	Anthraquinones, Syringaresinol Chrysophanol, Physcion, butyric acid, oxalic acid, formic acids, pectin, 3,4-di-O-caffeoylquinic acid, tannin, sennosides A & B, physcion, lignans, *Quercetin-O-hexoside, Proanthocyanidin B dimer, Apigenin-6,8-di-C- Glycoside,* Myricetin, hexoside, *Apigenin-C-hexoside-Opentoside*, Coumaric acid derivatives, chrysophanol, biflavonoids, tri-flavonoids, Physcion B2, epiafzelechin	(Jung, Ali, and Choi, n.d.; Tabrez et al. 2021; Aabideen et al. 2021; Panda, Padhi, and Mohanty 2011; Castro-lopez et al. 2018; Bahorun, Neergheen, and Aruoma 2005; Kaur, Kumar, et al. 2020; Bhakta et al. 1999)
Flower	Hentriacontanoic acid , Alkaloids, rhein , leucopelargonidin tetramer, Gibberellic acid, fistulin, kaempferol , heptacosanoic acids and triacontanoic acid	(Lavanya et al. 2016; Shelke, Yede, and Deokar 2023; Ayesha Maqsood, Ayesha Munir, and Dr. Sammia Shahid 2020; Antonisamy et al. 2019)
Bark	Fistucacidin, Oxyanthraquinone, Lupeol, flavonol, glycosides, Dihydroxyanthraquinone, catechin, Leucocyanidin, β-sitosterol	(Duraipandiyan and Ignacimuthu 2007; Kushwah et al. 2022; Rahmani 2015; Saipriya and Daisy 2012; Pandey et

		al. 2020; Daisy et al. 2010)
Root	Oxyanthraquinone, tannins, phlobaphenes, lupeol, α-amyrin, β-sitosterol, catechin	(Orwa, C.; Mutua, A.; Kindt, R.; Jamnadass, R.; Anthony 2009; Kwon et al. 2010; Tzekiat and Kang Chiang 2013; Pandey et al. 2020)
Pod	Fistulic acid, 3-formyl-1-hydroxy-8-methoxyanthraquinone, *flavone-3-O-arabinopyranoside ,* Catechins	(Naresh et al. 2018; Sakulpanich and Gritsanapan 2008)
Seed	Anthraquinone derivatives, carbohydrates, Benzyl-2-hydroxy-3,6-dimethoxy benzoate, proteins, amino acids, resinous and waxy derivatives, volatile oil, sterculic and malvalic acids,	(Bahorun, Neergheen, and Aruoma 2005; Wati, Sheetal, and Khabiruddin 2017; Kushwah et al. 2022; Saeed et al. 2020; Kuo, Lee, and Wein 2002)
Fruit	*Glycosides-Sennosides A & B, 1,8-dihydroxy-3-anthraquinone* derivative, epicatechin, fistulin, oxy anthraquinone, tannin, ceryl alcohol, volatile oil (essential oils), Chrysophanol, Rhein, resinous and waxy derivatives	*(Sakulpanich and Gritsanapan 2008; A. Sharma, Kumar, and Jaitak 2021; Mukherjee, Venkatesh, and Gantait 2010; Limtrakul et al. 2016; Rajagopal et al. 2013)*

3. Weather influence on Phenology and phytochemistry

Climate change is causing significant changes in the life cycle, distribution, and chemical makeup of the world's flora, including fragrant and medicinal plants. Climate change is causing temperature and patterns of wind to fluctuate, which is affecting plant structural changes, blooming and fruit development, the phytochemical composition, and on-site competition with other species. It is also causing natural catastrophes and human activity to effect these changes. The varying temperatures of the world and Indian mainland are given in Figure 3 and Figure 4 respectively as reported by the FAOSTAT and International Monetary Fund (IMF), Climate Change Dashboard. The annual monsoon, which is primarily responsible for India's climate, seems to be becoming harsher and more unpredictable (Brahmananda Rao, Ashok, and Govardhan 2021). To grow plants in such climates and understand how variations in temperature, moisture, and edaphic factors may affect the plants' phenology, nutrients, antioxidants, and secondary metabolite levels, it is necessary to understand the effect of higher temperatures, various precipitation levels, and different soil moisture and fertility. In a

study conducted on climate impact on the phenology of *Cassia fistula*, the shift in phenological events in response to temperature variation was significantly noted (Chauhan and Chauhan 2020)(Falga and Wang 2022). The study took place between 1965 and 2019 in Raja Balwant Singh College in the Indian state of Uttar Pradesh, where temperature was correlated to phenological events, including the abscission period, time of new leaf formations, and observations regarding the flowering period, which included initiation of bloom, full blooms, and end of blooming. Between 1965 and 2000, the dates of phenological occurrences were constant. However, after 2001, a gradual shift was seen, and this change became noticeable between 2009 and 2019. The average yearly temperature increased by a liner throughout the 1965–2008 period, ranging from 23.23º to 25.13ºC. The average annual temperature began to rise more noticeably in 2009, and this pattern of rising temperatures persisted through 2019. There has been a 0.75–1.0ºC observed temperature rise in Agra between 2009 and 2019. The change in *Cassia fistula* phenological events with the rise in the annual average temperature is correlated (Chauhan and Chauhan 2020).

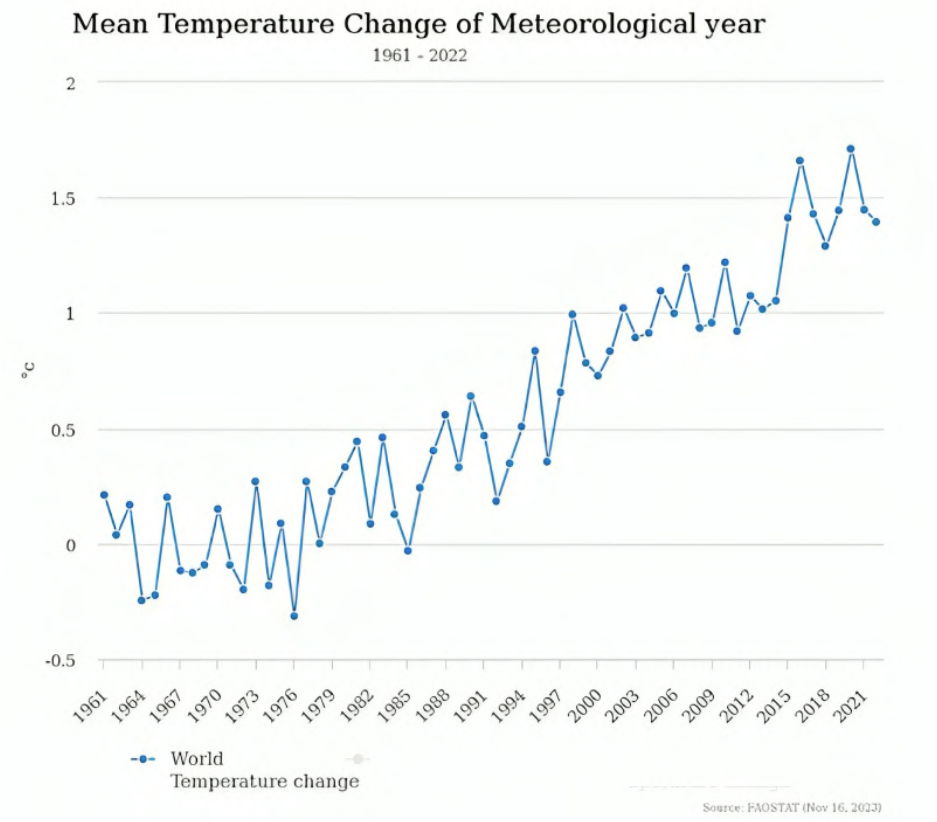


Figure 3: Mean temperature change between 1961-2022 showing total elevation in temperature around the world as adapted from Food and Agriculture Organization Corporate Statistical Database.

Climate change can impact the production of phytochemicals, the biologically active compounds found in plants, in several ways. Changes in temperature and precipitation patterns can alter the growth and development of plants, leading to changes in the concentration and composition of phytochemicals. Reports have shown that elevated atmospheric carbon dioxide levels can increase the production of certain phytochemicals, while others have found that it can decrease their synthesis (R. Sharma,

Prajapati, and Singh 2019). The effects of climate change on phytochemicals can have both positive and negative impacts on human health, agriculture, and the environment (Ebi and Loladze 2019).

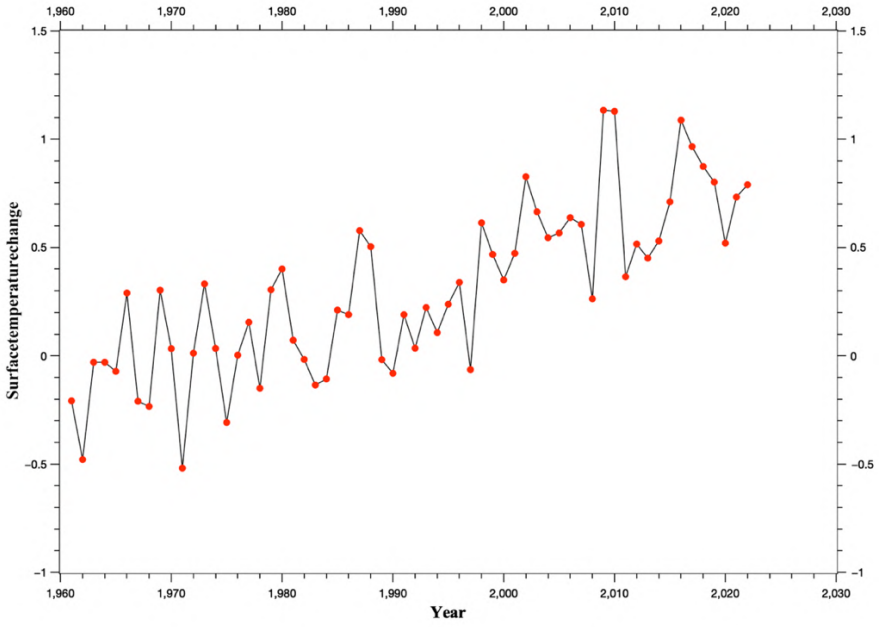


Figure 4: Graphical representation of accelerating temperature in Indian mainland till 2021 showing that the average surface temperature is increasing significantly over the last 60 years.

It is understood that the different locations and ages of the plant and atmospheric factors determine the phytochemistry of the plant, and it varies across (Hongyan Li, Tsao, and Deng 2012), but an alarming concern is changing and unpredictable climatic conditions within an area that can probably impact the availability of the plant source and the phytocompound which would aid drug development. Some floral sources that are impacted by climatic variations are noted in Aloe vera (Nagpal et al. 2011), Chokeberries (Dinu, Mazilu, and Cosmulescu 2022), and *Cassia fistula*. Experimental evidence in Aloe vera shows a correlation between phenolic content and antioxidant activity with various plant samples in *Aloe vera* and chokeberries. Similarly, rainfall was also found to impact phenological events as per a study conducted in Ota, Ogun State, Nigeria, from 2013 to 2016 for three terms (Okusanya, O. T., Shonubi, O. O., Bello, O. A. and Bamidele 2016). The monitored criteria were several plants flowering each month. There were early and late flowering plants in each year's synchronized flowering, albeit the timing of the flowers' onset and completion varied from year to year. The length of the blossoming season varies from year to year, as do the peak months. A statistical investigation revealed a substantial variation in the blossoming pattern from month to month and between two years. Each of them demonstrates a distinct variance in the species' blooming phenology. The quantity of rainfall and temperature in July and August were linked with the initiation of blooming, whereas the number of wet days and rainfall total were linked to the end.

4. Pharmacological effects of *Cassia fistula*

4.1 Anti-inflammatory activity

Various compounds in the *Cassia fistula* plant aid in the anti-inflammatory process, including quercetin, kaempferol, rutin, oleanolic acid, ursolic acid, anthraquinones, chlorogenic acid, and epicatechin (Alhawarri et al. 2021). Rhein also found *Cassia fistula* flowers have anti-inflammatory properties and were further experimented with by isolating it from flower samples collected in Chennai, India, and administering it in adult male albino Wistar rats and mice continuously (10, 20, 40 mg/kg) (Antonisamy et al. 2019). Rhein was administered via implanted cotton pellets and showcased a substantial ($p < 0.05$) decrease in the development of granulomas (20 mg/kg: 17.24%; 40 mg/kg: 36.12%) as compared to the control group. In comparison to control animals, Rhein administration resulted in decreased levels of nitrite, interleukin-6 (IL-6), interleukin-1β (IL-1β), tumour necrosis factor-α (TNF-α), malondialdehyde (MDA), and vascular endothelial growth factor (VEGF) and increased activities of catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GSH-px). The antioxidant enzymes mentioned, including CAT, SOD, and GPx, are the main defense system against oxidative implications, which are also highly produced in the administration of the rhein (Ighodaro and Akinloye 2018). According to Western blotting results reported in the study, after 6 hours in the paw edema model, Rhein also increased the expression of nuclear factor erythroid 2–related factor 2 (Nrf2), heme oxygenase (HO)-1, peroxisome proliferator-activated receptor gamma (PPAR)-γ, and heat shock protein (HSP)–72 and also decreased the expression of carrageenan-induced cyclooxygenase (COX)-2 and inducible nitric oxide synthase (iNOS) (Antonisamy et al. 2019).

A triterpenoid with anti-inflammatory qualities is oleanolic acid, which is also found in *Glycyrrhiza glabra* (Leite et al. 2022), *Hippophae rhamnoides* (Tanwar et al. 2018), *Astragalus membranaceus* (Kim et al. 2014), *Terminalia chebula* (Bag et al. 2013) and *Artemisia annua* (Han et al. 2022). This study assessed how oleanolic acid affects secretory phospholipase 2 (sPLA2), an important enzyme involved in inflammatory responses. In dependence on the concentration, oleanolic acid suppressed the sPLA2 activities of the venoms of *Vipera russelli, Naja naja,* and human synovial fluid (HSF) (Dharmappa Raju Venkatesh; Nataraju, Angaswamy; Mohamed, Riyaz; Shivaprasad, Holenarasipura V.; Vishwanath, Bannikuppe S. 2009). According to these investigations, there is direct contact with the enzyme, and the sPLA2-oleanolic acid complex forms. The compound that developed caused sPLA2 to be irreversibly inhibited. Oleanolic acid prevented sPLA2-induced mouse paw edema. Many medicinal herbs that contain oleanolic acid are known to possess anti-inflammatory qualities, which are explained by the compound's inhibition of sPLA2 activity (Cunningham, Yao, and Lucena 2008; Giordanetto et al. 2016; Maher, Yassine, and Sofiane 2015; Church et al. 2001). The capacity of ursolic acids found in *Cassia fistula* has the potential to inhibit the activation of nuclear factor kappa B(NF-κB), which has been linked to anti-inflammatory activity (Checker et al. 2012). Given that NF-κB is known to control inflammatory genes in concert with NF-AT (nuclear factor of activated T cells) and AP-1 (activator protein-1), Before allogenic transplantation done in the study, treating immune cells with ursolic acids greatly lowered the serum levels of pro-inflammatory cytokines IFN-γ and IL-6 and also postponed the occurrence of acute graft-versus-host illness in mice. Even when the post-mitogenic stimulation was added, ursolic acid therapy suppressed T cell activation,

indicating its potential use as an anti-inflammatory medication (Checker et al. 2012).

4.2 Antioxidant property

According to research (Singh et al. 2023), with several *Cassia fistula* sections, *Cassia fistula* bark had a high concentration of total phenolics and protein, whereas *Cassia fistula* leaves had a high content of ascorbic acid, carotenoids, and carbohydrates. Strong hydrogen-donating and metal-chelating properties, together with potent free radical scavenging activity, are reported to be responsible for *Cassia fistula*'s antioxidant properties, and the allied pharmacological benefits are shown in Figure 5 (Singh et al. 2023; Bhalodia, Acharya, and Shukla 2011). The study reported by them also suggests that the bark of the plant is a valuable source of natural antioxidants and nutraceuticals for use in food and pharmaceutical products. Quercetin, Kaempferol, Rutin, chlorogenic acid, oleanolic acid, ursolic acid, and anthraquinones are the known compounds to impart antioxidant effect and these molecules are also found in *Allium cepa* (Higashi, Tsuge, and Sawada 2013), *Vitis vinifera* (Castillo-Muñoz et al. 2007), berries, citrus fruits and cherries (Erlund et al. 2006; Johnson et al. 2011).

Hepatocellular carcinoma ranks third in terms of cancer-related mortality and is a serious worldwide health concern (Naganuma 2000; Chohan et al. 2020). Antioxidants derived from herbal sources have been shown to dramatically lower oxidative stress. Aglycone dietary flavonoids, including kaempferol present in *Cassia fistula*, can interact with pleiotropic human body proteins (Atrahimovich, Avni, and Khatib 2021). The quantity of thiobarbituric acid reactive compounds in the liver improved after kaempferol 3-O-β-d-(2,6-di-O-α-l-rhamnopyranosyl) galactopyronoside pretreatment in mice, also suggesting that kaempferol reduces liver damage due to oxidative stress(Zang et al. 2017; Alkandahri et al. 2023; Aftab et al. 2019). Apart from anti-inflammatory and antioxidant activity, pharmacological effects, including anti-depressive benefits (Gao et al. 2019), anxiolytic (Vissiennon et al. 2012), and anticancer properties (Imran et al. 2019), are exhibited by kaempferol.

4.3 Antifungal activity

Mycoses, or fungal infections, can affect any area of the body and are caused by a variety of fungi, some of which include *Candida albicans* (Turner and Butler 2014), *Microsporum gypseum* (Souza et al. 2016), and *Aspergillus niger* (Rodríguez et al. 2006). Fungal infections can be systemic, affecting internal organs, or superficial, infecting the epidermal layer, nails, and mucous membranes (Pathakumari, Liang, and Liu 2020). Antifungal activity of extract of *Cassia fistula* leaves against the above-said pathogen has been tested by standard disk diffusion and a concentration-dependent antifungal activity was revealed with a greater zone of inhibition with 200mg/ml concentration (Ag 2014). Like human cholesterol, ergosterol is a sterol that is found on the cell membranes of fungi and functions to preserve the integrity of the cell membrane (Bell 2006). Antimicrobial substances such as β-sitosterol, fucosterol, stigmasterol, ergosterol, betulinic acid, α-amyrin, and friedelin were found in *Cassia fistula* oil after gas chromatography in conjunction with mass spectrometry (GC-MS) study. Inhibition of ≥63.8% ergosterol biosynthesis in the candida cell wall by oil was reported and a strong correlation with the ergosterol content decremented within the cell wall was observed(Irshad et al. 2013).

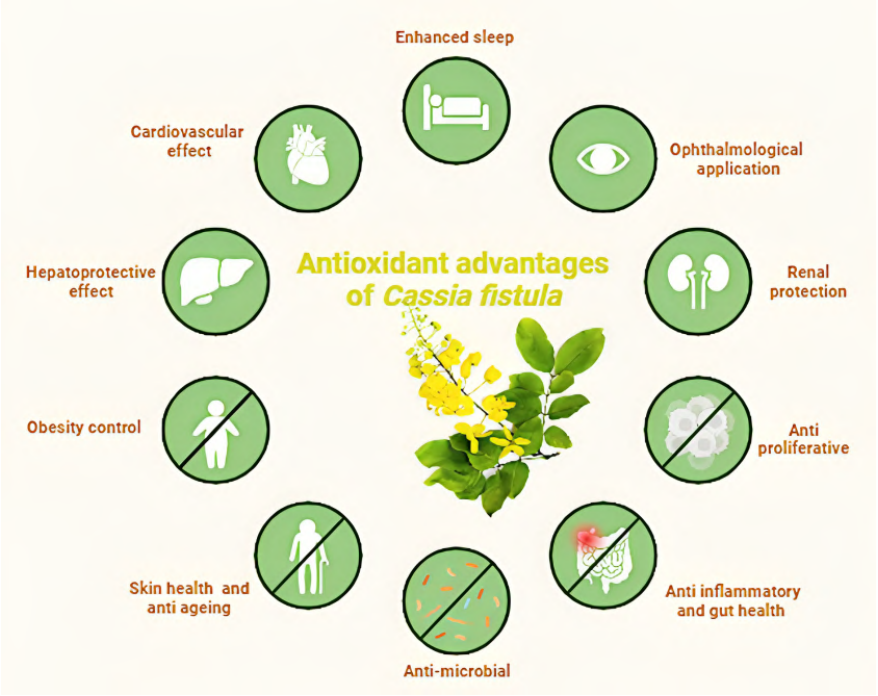


Figure 5: Antioxidant benefits of *Cassia fistula*

4.4 Anti-bacterial property

Antibiotics have been recognized as one of the most crucial instruments in the fight against bacterial illnesses since their discovery (Vaishampayan and Grohmann 2022). Though there has been an alarming increase in microbial resistance to antimicrobial agents in recent years because of the widespread and improper use of antibiotics, this is a major factor in the search for novel medications with lower resistance and fewer adverse effects. Traditional folklore medication mentions the usage of *Cassia fistula* plant extracts for leprosy, caused by *Mycobacterium leprae* (Jothy et al. 2011; Duraipandiyan and Ignacimuthu 2007; DeFilipps and Krupnick 2018). A study was conducted in Iran, to scrutinize the in vitro antibacterial activity of methanolic and ethanolic extracts of the Iranian native *Cassia fistula*. The results showcased strong antibacterial effects against extracts from *Cassia fistula* that were efficient against *K. pneumoniae, S. aureus, B. cereus, S. epidermidis,* and *E. coli*. Higher sensitivity was reported against the strains of *K. pneumoniae* and *E. coli* (Seyyednejad et al. 2014). The reports suggested that the phytocompounds as a strong candidate to fight microbial diseases also with suppressing side effects and fighting antibiotic resistance (Seyyednejad et al. 2014; Khameneh et al. 2021; Huanbutta and Sittikijyothin 2018). 2-Nonanone, Spiro[5.5]undec-8-en-1-one and imidazole are some notable compounds providing antimicrobial effects. The quantity of phenolic components in the plant extracts determines their antibacterial action. Elevated levels of the phenolic group in *Cassia fistula* aerial parts suggested that these elements could be the active substances causing the antibacterial action (Seyyednejad et al. 2014). The climatic implications on total phenolic composition already discussed would affect the pharmacological industry and potentially reduce the potentiality of the fight against increased resistance (Kumar et al. 2017).

4.5 Wound healing and skin health maintenance

Wound healing is an integral part of healthcare management and ranges of wounds exist more severe from minor cuts. *Cassia fistula* with strong antimicrobial properties would aid in wound protection and also support wound closure by stimulating collagen synthesis (Limtrakul et al. 2016). A study of wound healing potential on infected albino rats administered with formulated ointment on infected wounds showcased enhanced wound closure and improvised tissue regeneration compared to the control models. The results of the biochemical examination of granulated tissue in the study, which included the DNA, protein, collagen, hexosamine, and uronic acid apart from the expression of matrix metalloproteinases corresponded favorably with the findings, indicating that *Cassia fistula* is effective in treating infected wounds (Senthil Kumar et al. 2006). Oxidative damage on skin imposed by air and UV sunlight, *Cassia fistula* extract has potential application in skin lightning applications as discussed. Collagenase and gelatinases are examples of matrix metalloproteinases (MMPs) that are involved in the breakdown of extracellular matrix (ECM). The tensile strength of the skin is lost because of MMP-induced ECM breakdown. Tyrosinase inhibitors have been researched for the treatment of hyperpigmentation. The rate-limiting enzyme tyrosinase transforms tyrosine over melanin. Thus, tyrosine inhibitors are important skin-lightening agents by blocking and the effect has been also found to be imparted by *Cassia fistula* flower extract (Limtrakul et al. 2016).

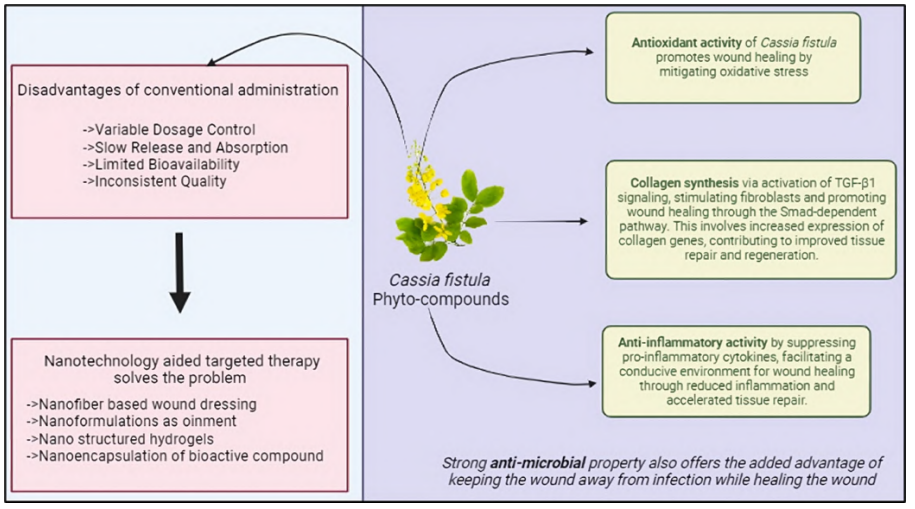


Figure 6: Image depicting the challenges of conventional application of bioactive plant ingredients and a nanotechnology-based solution for overcoming the challenges. The image also describes wound healing activity of *Cassia fistula* and the mechanisms.

4.6 Anti-proliferative property

Anti-proliferative and apoptogenic effects of hexane leaf extract were done on cancer cell lines of HeLa, MG-63, IMR-32, and PC-3 by MTT assay (Kaur, Pandit, et al. 2020). Apoptotic effects were also observed by methodologies including Scanning Electron Microscope (SEM) and confocal analysis. Treatment with the extract demonstrated dose-dependent chromatin condensation, membrane blebbing, and DNA breakage along apoptotic body formation. Using the Annexin V-FITC/PI double labeling experiment, the study report also observed a notable rise in the number of reactive

oxygen species, mitochondrial depolarization, cell arrest in the G0/G1 phase, and induction of phosphatidylserine externalization in HeLa cells. The main phytoconstituents considered responsible for the pharmacological activity were epicatechin (Kaur, Kumar, et al. 2020), ellagic acid (Ilavarasana, Mallika, and Venkataraman 2004), and kaempferol (Saeed et al. 2020). The study also included semi-quantitative RT-PCR analysis of the n-hexane fraction treatment in HeLa cells, revealing an increase in the expression levels of the genes p53, Bad, and caspase-3, and downregulation of the Bcl-2 gene (Kaur, Kumar, et al. 2020; Kaur, Pandit, et al. 2020). Factor p53 is activated when DNA damage results in cell growth arrest. This process permits DNA repair and cellular death to preserve the integrity of the genome (Aly et al. 2019; Zhang, Yin, and Sui 2018).

4.7 Anti-diabetic potential and Insulin mimetic activity

Diabetes is a serious health issue that affects large numbers of people globally (Complications 2008) and the anti-diabetic properties of *Cassia fistula* fruits have been reported in ancient literature (AYUSH 2019; Akhila and Aleykutty 2015). Tests were conducted on glucose-overloaded hyperglycemic rats to understand the antihyperglycemic potential of many floral extracts from *Cassia fistula,* including petroleum ether (60-80°), chloroform, acetone, ethanol, aqueous and crude aqueous extracts, and two fractions of ethanol extract (Jarald et al. 2013). The hypoglycemic efficacy of fractions was evaluated at two different dosage levels. The extracts and fraction of *Cassia fistula* were tested for their antidiabetic properties in an alloxan-induced diabetic model at two dosage levels of 200 and 400 mg/kg, respectively, to validate their usefulness in higher models. Additionally, the study also focussed on biochemical markers including haemoglobin, glycosylated haemoglobin, high and low density lipoprotein, glucose, urea, creatinine, serum cholesterol, and serum triglyceride (Jarald et al. 2013). Triterpenoid chemicals from *Cassia fistula* also have been found to be involved in the regulation of skeletal muscle and liver carbohydrate metabolic enzymes and activated IRS-1/Akt-mediated insulin signalling pathways to moderate hyperglycemia (Indu, Vijayalakshmi, and Selvaraj 2021; Raddatz G 2007).

The naturally occurring substance streptozotocin, which is generated from *Streptomyces achromogenes*, is especially harmful to the beta cells in animals pancreas that produce insulin and is a DNA alkylation agent (Abdollahi and Hosseini 2014). Rats with diabetes administered with streptozotocin had lower blood glucose levels when the methanol-based stem extract was also supplemented. For six weeks, male Wistar rats with diabetes caused by streptozotocin (60 mg/kg) were given several dosages of catechin (5, 10, 20 mg/kg) to evaluate its impact on plasma glucose levels while fasting. The plasma glucose was considerably lowered when compared to the control. Without affecting plasma insulin or C-peptide levels, oral treatment of catechin (20 mg/kg) significantly enhanced tissue glycogen and glucose oxidation. The levels of the modified enzymes glucose kinase, glucose-6 phosphatase, glycogen synthase, and glycogen phosphorylase were nearly returned to normal by catechin. Following treatment with catechin, GLUT4 mRNA and protein expression were also reported to be increased. According to this experimental study's findings, catechin has hypo-glycemic, glucose-oxidizing, and insulin-mimetic properties; as a consequence, it may find use in the treatment of diabetes (Daisy et al. 2010; Pitchai and Manikkam 2012; Einstein, Mohd

Rais, and Mohd 2013).

4.8 Hepatoprotective properties

Numerous incidents, such as exposure to drugs, some medicines, excessive alcohol use, viral infections, and specific medical disorders, can result in liver toxicity, also known as liver damage (Sijamhodžić et al. 2019). Hepatoprotective property is aided by the phytocompounds in *Cassia fistula* and also by antioxidant and anti-inflammatory activity (Ahirwar et al. 2010; Zang et al. 2017). By administering paracetamol in rats to cause hepatotoxicity, the n-heptane extract of *Cassia fistula* leaves was tested for its hepatoprotective properties. At 400 mg/kg body weight, the extract showed a substantial protective effect when taken orally, as evidenced by a decrease in the levels of bilirubin, alkaline phosphatase (ALP), and transaminases (SGOT and SGPT) in the blood. The results obtained were like those of a typical hepatoprotective medication (Bhakta et al. 1999; Wasu and Muley 2009).

4.9 Larvicidal activity

Every year, almost 390 million people contract dengue, and hundreds of millions more contract zika, chikungunya, and yellow fever, as per the World Mosquito Programme website. The fatalities of these mosquito-borne diseases are fatal, and necessary control can be adopted by preventing mosquito breeding and using larvicides (Benelli, Jeffries, and Walker 2016). Larvicides are substances that are specifically designed to target and kill the larvae of insects, such as mosquitoes before they mature into adults. Mosquito larvae are a significant concern as they can develop into disease vectors, transmitting diseases such as malaria, dengue fever, and Zika virus (Dahmana and Mediannikov 2020). Methanolic extract of *Cassia fistula* contains various phytochemicals, including flavonoids and tannins, which have been found to affect the hatchability of *Culex quinquefasciatus* and *Anopheles stephensi.* The mean percent ovicidal activity was measured 120 hours after treatment. The percentage of hatchability was directly correlated with the eggs and negatively correlated with the extract concentration (Govindarajan, Jebanesan, and Pushpanathan 2008). Ethyl acetate extract of *Cassia fistula* flowers having, rhein (1,8-dihydroxyanthraquinone-3-carboxylic acid) was tested against the lepidopteron pests *Spodoptera litura* and *Helicoverpa armigera*, and the results supported strong larvicidal properties (Duraipandiyan, Ignacimuthu, and Gabriel Paulraj 2011).

4.10 Gastrointestinal benefits

The clinical condition known as constipation is caused by ineffective colonic impulsion and/or excessive resistance to the growth of colonic materials. Around 20% of people worldwide experience persistent constipation (Liu 2011). It is among the most prevalent issues among children and the aged. In the field of paediatric gastroenterology, it was discovered to be the second most often reported condition. Cisapride is frequently used to relieve constipation in children (Müller-Lissner 1987). Although lactulose and polyethylene glycol 3350 are alternative therapies, polyethylene glycol 3350 has already been proven to be more successful (Voskuijl et al. 2004). Yogurt, both supplemented and non-supplemented, can improve the frequency of bowel movements and lessen discomfort in the abdomen (Guerra et al. 2011). However, cisapride has been largely

discontinued, including in Canada and the United States, due to safety concerns and potential adverse effects. One of the main disadvantages of cisapride is its association with serious cardiac side effects, particularly its impact on the QT interval.

Cassia fistula, being a potent herbal and non-toxic medicinal source, is potentially a laxative agent. Chrysophanol, rhein, aloe-emodin, and chrysoobtusin are only a few of the anthraquinone derivatives that give different species of Cassia their laxative qualities—other species of Cassia include *Cassia augustifolia* (Reddy et al. 2015) and *Cassia alata (*Oladeji et al. 2020). Because of many anthraquinone derivatives, including rhein, chrysophanol, aloe-emodin, and chrysoobtusin, cassava has laxative qualities (Lombardi et al. 2020). Cassia species also have sennosides, which are anthranoid derivatives that are laxative (Morales et al. 2009). There are ongoing studies on the possibility of *Cassia fistula* fruit pulp polysaccharide as a prebiotic, and it supports the study because of its increased resistance against the α-amylase and digestive acids (Costa Silva et al. 2019). The polysaccharide has been found to withstand hydrolysis in an acidic environment, which is a crucial component in figuring out a prebiotic's potential (Moumita and Das 2022). The polysaccharide also induced nitric oxide production which plays an important role in the immune system by inhibiting viral and parasitic growth (Dawood et al. 2021). On the other hand, elevated nitric oxide levels inhibit the growth of lymphocytes and harm other normal host cells. *Cassia fistula* polysaccharides' effects of two-way adjustment on nitric oxide generation suggest that this technique might be used to inhibit nitric oxide production and activate macrophages (Dawood et al. 2021; Silva 2021).

4.11 Anti-Rheumatic activity

Research on *Cassia fistula*'s anti-rheumatic properties is not as solid as that of certain other herbs or drugs that are frequently prescribed for rheumatoid arthritis. However, according to some research and as discussed already, *Cassia fistula* has antioxidant (Deepika Priyadharshini and Sujatha 2012) and anti-inflammatory qualities (Kim et al. 2014), which is important when it comes to rheumatic disorders. For instance, rheumatoid arthritis can cause joint cartilage to be destroyed (Ostrowska et al. 2018). By inhibiting the enzymes responsible for cartilage deterioration, compounds found in *Cassia fistula* may provide cartilage tissue with protection (Ongchai et al. 2019).

4.12 Cardiovascular activity

Compounds from *Cassia fistula* have been involved with the metabolism of lipids. Studies on several plants in the Cassia genus have revealed possible benefits in decreasing cholesterol. In a study on cardiovascular effects, rats were given isoproterenol, a substance that causes cardiotoxicity, for two days in a row. When the *Cassia fistula* methanolic extract was given, it was discovered that, according to in vitro research, the extract significantly reduced lipid peroxidation and increased antioxidant levels in cardiac tissues. The extract reduced the activity of the enzyme's alanine transaminase and aspartate transaminase in the blood and eliminated the levels of triglycerides and total cholesterol. Histopathology studies and 2,3,5-Triphenyltetrazolium chloride staining further demonstrated *Cassia fistula* extract's ability to prevent isoproterenol-induced myocardial infarction (Kushwah et al. 2022; Majagi 2010).

4.13 Sleep-Enhancing benefits

In today's digitally driven and stress-laden society, sleep deprivation has become a prevalent concern with far-reaching implications for public health (Chattu et al. 2019). The widespread integration of digital technologies, such as smartphones and computers, has significantly altered sleep patterns, with individuals often succumbing to the temptation of late-night screen exposure (Fuller et al. 2017). The constant connectivity to social media, emails, and work-related tasks, coupled with the pressure to meet high-performance expectations, contributes to heightened stress levels that further disrupt sleep quality and duration. The blue light emitted by screens can interfere with the body's natural production of melatonin, a hormone crucial for regulating sleep-wake cycles, exacerbating the challenge of achieving restful sleep (Blume, Garbazza, and Spitschan 2019). The relentless demands of modern life, coupled with the pervasive influence of digitalization, create a perfect storm for sleep deprivation, adversely affecting overall well-being, cognitive function, and long-term health. In some cases, sleeping pills also Is being prescribed for age-old individuals experiencing chronic sleep deprivation to provide short-term relief and improve overall well-being. The long-term hazardous effect of sleeping pills and temporary short-term difficulties can be covered by opting for traditional herbal methodologies (Fitzgerald and Vietri 2015).

Compounds found in *Cassia fistula* can affect the brain's serotonin levels. One neurotransmitter that is essential for controlling mood and sleep-wake cycles is serotonin. The compounds, however, are poorly understood. The study reported in mice showed a proportional advantage over sleep duration with the concentration administered (Vafaei et al. 2011). Flavonoids, as discussed already for their antioxidant property, scavenge on superoxide and peroxynitrite. They also aid in the restoration of tetrahydrobiopterin (BH4) levels [129] and suppress the Nuclear factor kappa B (NF-Kb) (Ye and Zhou 2023). The possible effect to explain the restoration by flavonoids would be the antioxidant activity, which is important for maintaining the stability of BH4. Oxidative stress, including autooxidation otherwise, can lead to the oxidation of BH4 to its inactive form, dihydrobiopterin (BH2) (Fanet et al. 2020; M. Channon 2012). The phytocompounds might also be stabilizing the enzyme dihydrofolate reductase (DHFR), which is responsible for converting BH2 back to BH4 (Crabtree, Hale, and Channon 2011). By enhancing the stability of these enzymes, flavonoids may contribute to maintaining optimal BH4 levels (Hao Li and Zhang 2023).

Moving towards the pathway, BH4 is a necessary cofactor of the enzyme phenylalanine hydroxylase (PAH), which changes phenylalanine (Phe) into tyrosine (Tyr) (Eichwald et al. 2023; Knerr 2016). This information was discovered in 1958. Ten years later, its function was revealed as a cofactor for enzymatic reactions that were catalysed by two other enzymes that are involved in the hydroxylation of aromatic amino acids: tryptophan 5-hydroxylase (TPH), which converts tryptophan to serotonin (Richard et al. 2009), and tyrosine hydroxylase, which converts Tyr to 3,4-dihydroxyphenylalanine (L-DOPA)(Kobayashi and Nagatsu 2012). In addition, alkylglycerol monooxygenase (AGMO) requires BH4 to operate (Fanet et al. 2020). In the 1990s, research showed that it functions as a cofactor for nitric oxide synthases (NOS), which produce nitric oxide (NO). Melatonin and serotonin production depend on the levels of tetrahydrobiopterin (Sarma, Borah, and Das 2015). In addition to helping regulate sleep and wakefulness,

serotonin and melatonin also influence pain, well-being, and sexual desire (Portas, Bjorvatn, and Ursin 2000) and is represented in Figure 7.

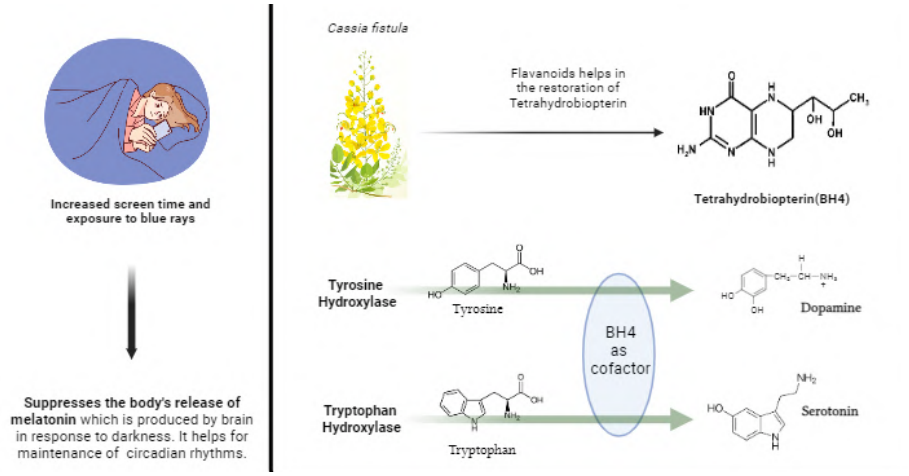


Figure 7: Graphical information on the consequence of blue rays from the electronic device and the mechanism of action of BH4 in sleep-inducing activity by the production of dopamine and serotonin

4.14 Anti-tussive benefits

Cassia fistula is not commonly associated with antitussive (cough-suppressing) benefits. While it has been traditionally used in various cultures for its medicinal properties, scientific evidence specifically supporting its efficacy as an antitussive is limited. The plant contains mucilage (Gaikwad, Patil, and Killedar 2023), a substance with a soothing effect on irritated mucous membranes. This soothing action aided by mucilage might have potentially provided relief for symptoms associated with coughing (Lataran et al. 2023; Ameri et al. 2015).

4.15 Antiviral properties

In the pursuit of effective antiviral therapeutics, *Cassia fistula*, emerges as a promising candidate due to its rich pharmacological composition. Packed with anthraquinones, flavonoids, and saponins, this plant showcases potential antiviral mechanisms, including the inhibition of key viral enzymes and modulation of host immune responses (Naresh et al. 2018). Experimental studies have explored its efficacy against various viruses, demonstrating inhibitory effects on herpes simplex virus (HSV), potential activity against influenza viruses, and promising antiviral properties against the Dengue virus. Amid the global challenge of viral infections, *Cassia fistula* holds relevance in the context of COVID-19. It is speculated to interfere with the ACE2 receptor, crucial for SARS-CoV-2 entry, suggesting a potential preventative role against COVID-19 infections. Additionally, its anti-inflammatory properties may mitigate the cytokine storm associated with severe viral infections, while antioxidant compounds may alleviate oxidative stress, contributing to the recovery process. While preclinical evidence is encouraging, the imperative for rigorous clinical trials remains, aiming to establish the efficacy, safety, and clinical significance of *Cassia fistula* in treating viral infections, including its potential role in the ongoing global battle against COVID-19.

Innate immunity relies heavily on the human IFIT protein (interferon induced protein with tetratricopeptide repeats) (Vladimer, Górna, and Superti-Furga 2014; Diamond and Farzan 2013; Mears and Sweeney 2018). Normally, IFIT1 protein expression is quiet; however, it can be substantially increased following treatment with interferons or viral infections (Xue, Zhao, and Liu 2022). By preventing several phases of viral replication, translation, and the assembly of new viral proteins, the IFIT1 protein does, in fact, exhibit a wide range of antiviral action. Treatment for viral disorders may benefit from altering the expression of the IFIT1 protein and also has been confirmed in norovirus infection (Mears et al. 2019).

A study was conducted by Naresh et al (Naresh et al. 2018) to unravel the effect of anthraquinones and its antiviral activity. The anthraquinones was derived from *Cassia fistula* pod extract by Soxhlet method and further anthraquinones were separated. The results of the investigation demonstrated a considerable induction of IFIT1 antiviral protein by the *Cassia fistula* pod rich in anthraquinones extract (Naresh et al. 2018). The extract's IFIT1 induction was shown by RT-PCR and Western blot. Consequently, the current study's confirmation that the extract induces IFIT1 protein which may provide crucial information for the creation of antiviral medications derived from anthraquinones that cause *Cassia fistula (*Naresh et al. 2018).

The work by Ravi et al. is based on a sophisticated structural bioinformatics procedure, and the main analytical method used to establish the antiviral action against SARS COVID-19 was molecular dynamic simulation. Procyanidin B2's molecular dynamic modelling, used in the study, made a compelling case for the possibility that the molecule may be a potent COVID19 protease inhibitor, preventing the virus from multiplying within the host (Mostafa et al. 2022).

5. Future perspectives with Nanotechnology

Nanotechnology, the manipulation of matter at the nanoscale, has emerged as a transformative field with applications spanning medicine, agriculture, electronics, and materials science. *Cassia fistula* possesses noteworthy medicinal properties, as already discussed elaborately, featuring antioxidant, anti-inflammatory, and antimicrobial attributes attributed to its rich content of bioactive compounds. The intersection of nanotechnology with *Cassia fistula* holds promise for innovative applications, particularly in the realm of drug delivery, where nanoparticles can enhance the bioavailability and targeted release of the plant's medicinal components. This convergence opens avenues for the development of novel formulations with improved therapeutic efficacy and reduced side effects. Additionally, the antioxidant and antimicrobial properties of *Cassia fistula* could inspire the creation of specialized nanoparticles for combating oxidative stress-related conditions and microbial infections, including skin infections. While specific applications may still be in the early stages of exploration, the amalgamation of nanotechnology and *Cassia fistula* presents an exciting frontier for potential advancements in medicine and related fields in the form of nano formulations (Kamaraj et al. 2023; Muruganandham et al. 2023).

Nano formulations of *Cassia fistula*, through encapsulation of its bioactive compounds within nanoparticles, offer a ground-breaking approach to wound healing (Abaid et al. 2023). These formulations not only enhance the stability and shelf life of the plant's therapeutic constituents but also enable a controlled and sustained release at the

wound site (Bonifácio et al. 2014). This controlled release contributes to reduced inflammation, promoting an environment conducive to accelerated tissue repair and collagen synthesis. Additionally, incorporating *Cassia fistula* extracts into nanofiber-based wound dressings provides a physical barrier, supports a moist wound environment, and enhances absorption into the wound bed, optimizing contact with damaged tissues (Rezvani Ghomi et al. 2022)(Vijay Kumar et al. 2019). The inherent antimicrobial properties of *Cassia fistula* further aid in preventing infections, ensuring a cleaner and more efficient healing process (Bhakta et al. 1998). This innovative application of nanotechnology harnesses the plant's natural healing potential, offering a sustainable and effective strategy for wound care.

The integration of nanotechnology for the development of nano-pesticides using *Cassia fistula* holds promise for efficient and targeted agricultural pest management. The synthesis of silver nanoparticles using plant extracts has become a viable substitute for conventional chemical synthesis techniques (Ahmed et al. 2016). Ag-nanoparticles from *Cassia fistula* leaf extract were evaluated in research for their potential as nano-pesticidal agents against tomato phytopathogens (Danish et al. 2022). The average diameter of the spherical silver nanoparticles in the study revolved around the *Cassia fistula* leaf exhibited a variation between 10 and 20 nm in particle size. *Pseudomonas syringae*, a bacterial pathogen, was found to be inhibited in the study by increasing dosages of biosynthesized silver nanoparticles. At 400 µg ml-1, the bacterial shape was changed, cellular viability was decreased, and cellular death was reported. Moreover, the nanoparticles inhibited *P. syringae's* synthesis of exopolysaccharides and biofilm formation. Strong antifungal efficacy against the most common fungal infections was also portrayed, and the antifungal property, as discussed already, is exhibited. The sensitivity of the fungi under test at 400 µg ml-1 was reported as follows: *Fusarium oxysporum* (76%) > *R. solani* (65%) > *Sarocladium oryzae* (39%). Additionally, 400 µg ml-1 enhanced larval mortality and reduced egg-hatching of Meloidogyne incognita by 65% and 82%, respectively, concerning control. Additionally, pot tests were also carried out using tomatoes (*Solanum lycopersicum*), which served as a model crop to evaluate the effectiveness of phytopathogens. On the other hand, compared to tomatoes challenged with pathogens, 100 mg kg-1 was found to enhance the root length, dry biomass, total chlorophyll, carotenoid, peroxidase (POD), and phenylalanine ammonia-lyase (PAL) activity. The work executed by (Danish et al. 2022) would provide crucial guidance for the synthesis of effective nano-control agents, which would help regulate lethal phytopathogens that significantly reduce agricultural production.

A nanoprobe utilizing *Cassia fistula* demonstrates considerable promise for sensor applications, particularly in the detection of hydrogen peroxide (H_2O_2) (Farrokhnia et al. 2017). Its distinctive material properties enable precise and efficient H_2O_2 detection, highlighting its potential for advancing sensor technologies in fields such as environmental monitoring or biomedical diagnostics. The antioxidant capabilities and cytocompatibility of the biogenic *Cassia fistula* silver nanoparticle on erythrocytes and HEK-293 cells were investigated (Eze, Jayeoye, and Tola 2021). The effective production of stable, widely distributed nanoparticles was facilitated, according to the results. It showed strong reducing and radical scavenging properties against NO., DPPH., and $ABTS^{\cdot}+$. The study also reported the compatibility with HEK-293 cells and human erythrocytes (Eze, Jayeoye, and Tola 2021). Outstanding surface plasmonic and

biological properties were also taken into consideration while assessing their potential for H2O2 sensing. With a linearity of 10–200 µM and a detection limit of 3.0 µM for H2O2, the sensor, as reported, showed good analytical performance and was successfully used to detect H2O2 in human plasma (Eze, Jayeoye, and Tola 2021).

In envisioning the future perspectives of *Cassia fistula*-based drug development and nanoformulations, it is evident that the plant's rich pharmacological profile holds tremendous potential for innovative therapeutics. Continued research in this direction may unravel novel applications, paving the way for the development of targeted and efficient antiviral drugs. Nano formulations, leveraging advancements in nanotechnology, present an exciting avenue for enhancing the delivery and efficacy of *Cassia fistula*-derived compounds, ensuring controlled release and optimal therapeutic outcomes. Beyond *Cassia fistula,* nanotechnology holds promise in revolutionizing various aspects of pharmaceuticals, from drug delivery systems to diagnostics, offering a plethora of opportunities for advancing healthcare. However, as we delve into these scientific frontiers, it is imperative to consider the sustainability of botanical resources like *Cassia fistula*. Climate change poses a significant threat, altering phenology and impacting the availability of medicinal plants. A holistic approach to mitigate climate change, incorporating sustainable practices, afforestation efforts, and eco-friendly technologies, is essential to ensure the continued abundance and efficacy of *Cassia fistula*. The symbiosis between scientific innovation, environmental conservation, and climate action is crucial to harness the full potential of *Cassia fistula* for the well-being of both human health and the planet.

6. Conclusion and Future perspectives

To summarize, the use of *Cassia fistula* in numerous research applications, particularly the production of improved pharmaceuticals, is a promising option for scientific investigation. The unique features of this botanical resource have proven to be invaluable in medicinal chemistry, demonstrating its potential for developing innovative medications with improved therapeutic advantages. According to a growing amount of research, *Cassia fistula* extracts have significant antibacterial, anti-inflammatory, and antioxidant effects, emphasizing their importance in the pharmaceutical industry. Most prominent is the recipient of the much-needed sleep that today's generation finds difficult to obtain. Furthermore, the need to reduce climate change is closely related to the conservation of biodiversity, especially *Cassia fistula.*

As climate change accelerates, preserving the genetic diversity of medicinal plants becomes crucial for ensuring a stable supply of bioactive compounds. For *Cassia fistula*, in situ conservation strategies, such as protecting natural habitats and integrating the species into community forest programs, play a vital role. Additionally, ex situ methods like seed banks, botanical gardens, and tissue culture propagation ensure its genetic diversity and future availability. Public awareness campaigns and the involvement of local communities in sustainable harvesting practices further support its preservation while maintaining its cultural and medicinal significance. Additionally, protecting these species helps to maintain ecological balance and resilience in the face of environmental threats. As a result, efforts to improve the pharmaceutical sector through the exploration of *Cassia fistula* must be accompanied by a commitment to conservation. Sustainable practices and conservation efforts are critical for preserving the natural

habitats of these significant plant resources. By doing so, we not only ensure the ongoing availability of effective therapeutic chemicals but also help the larger global effort to protect biodiversity and resist climate change. Finally, the convergence of medicinal research, environmental conservation, and climate action provides a comprehensive approach to creating a healthier and more sustainable future, with nanotechnology helping to improve chances.

Future research should focus on conducting rigorous clinical trials to validate the safety and efficacy of *Cassia fistula* in modern therapeutic applications including supplements and wellness products. Additionally, exploring regulatory frameworks for standardizing its use in herbal formulations can bridge the gap between traditional knowledge and contemporary medicine which is a significant gap.

Authorship Contributions and Declaration

Conceptualization and methodology: SS, VVK, VSR, SCM; Investigation: SS; Analysis; SS, VVK; Writing: SS, VVK; Revise: VVK, VSR, SCM, GS. All authors have read and agreed to the final version of the manuscript, and no conflict has been raised. All the data utilized in the study is publicly available.

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