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Use of Neem Tree in the Pharmaceutical Industry

Rohan Deshmukh, Dr. Sarika Nikam

[1]B. Pharm Final year, [2]Asst. Professor, D.Y. Patil college of Pharmacy Akurdi Pune. India.

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ABSTRACT

Neem (*Azadirachta indica*) is an evergreen tree predominantly found in the Indian subcontinent and recognized its medicinal properties for centuries. Various parts of the tree, including its bark, leaves, seeds, flowers, and oil, with bioactive compounds with significant therapeutic potential. This paper examines the pharmaceutical applications of neem, highlighting its key bioactive components, health benefits, and possible contributions to drug development.

Keywords: Azadirachta indica, Antimicrobial, Hepatoprotective, Nimbin.

INTRODUCTION

More than two millennia, neem cornerstone of regular medicine, especially in Ayurveda. Its diverse pharmacological properties have sparked significant interest in the pharmaceutical industry. Neem is mostly known for its uses and for various health conditions, with microbial infections, diabetes, cancer, and cardiovascular diseases[6].

The pharmaceutical sector acknowledges neem's antimicrobial, anti-inflammatory, and antioxidant properties. Several components of the tree—its leaves, bark, seeds, and flowers—are utilized in modern medicine to produce pharmaceutical formulations[5].

This study investigates neem's contribution to pharmaceutical advancements, emphasizing its active constituents, therapeutic applications, also progress in the development of neem-based medicinal products.

This paper aims to examine the use of neem in the pharmaceutical industry, highlighting its active components, therapeutic uses, and the progress made in formulating neem-based drugs and treatments.

Bioactive Compounds in Neem

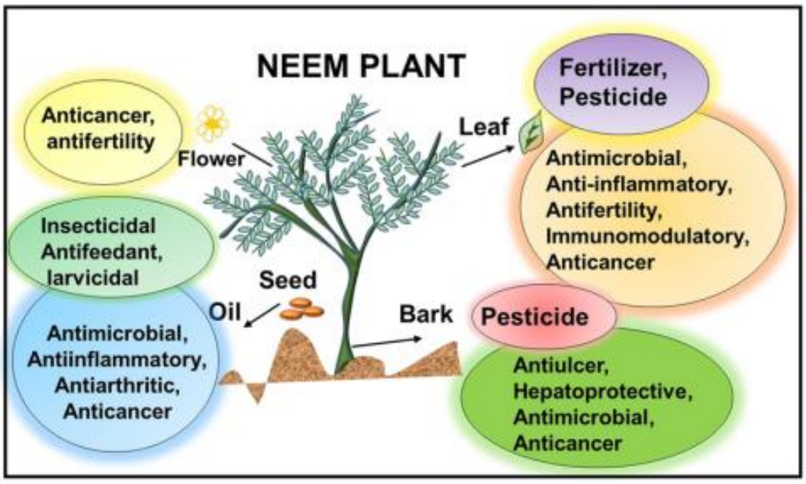

Fig.1 Bioactive compound

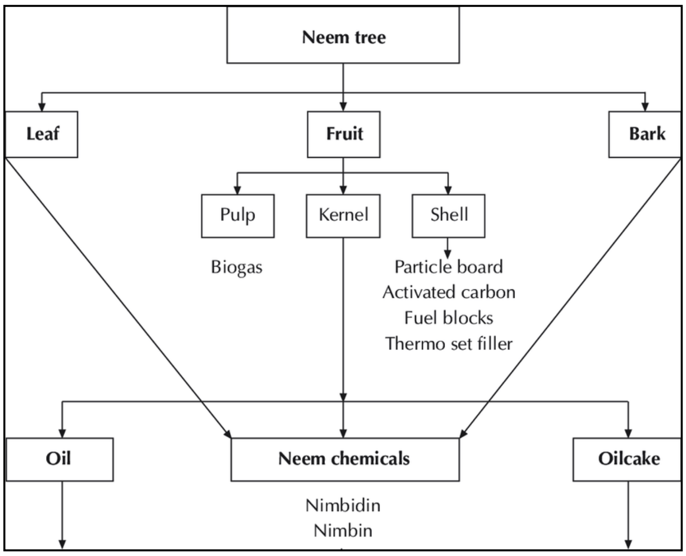

Fig.2 Neem tree Chemistry

Taxonomic	
Biological/ Scientific Name	*Aloe barbadensis miller.*
Domain	Eukaryota
Kingdom	Planta
Phylum	Spermatophyta
Subphylum	Angiospermae
Class	Monocotyledonae
Order	Asparagales
Family	Liliaceae or Asphodelaceae.
Genus	Aloe Linn.

Fig.3 Updated taxonomical review of Aloe vera plant

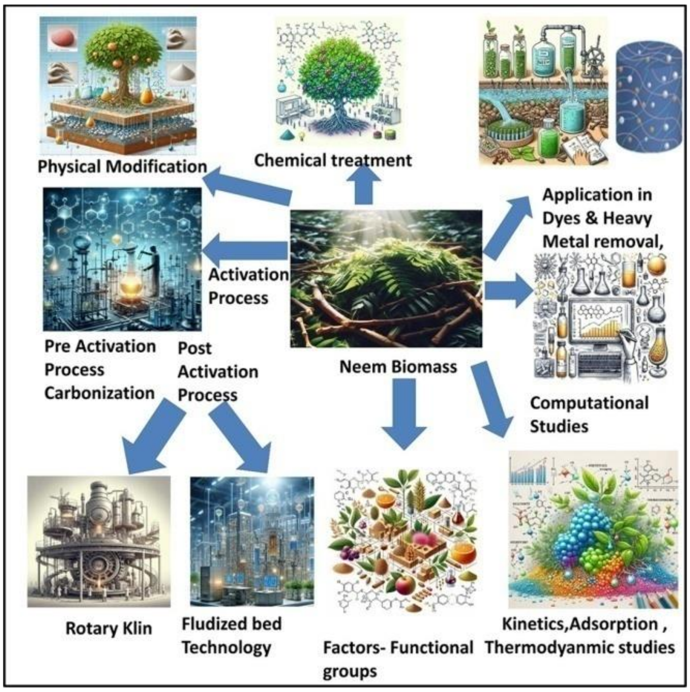

Fig 4. Neem Chemical treatment

Chemical composition of various parts of Neem tree					
S.No.	**Source**	**Seed (%)**	**Wood (%)**	**Leaf (%)**	**Bark (%)**
1	Fiber	8–26	–	11.40–23.08	59.33
2	Fat	2–13	1	–	–
3	Oil	40–45	–	–	0.02
4	Moisture	9.5	12–20	59.4	3.33
5	Ash	5–18	3	7.73–18.37	4.31–9.67
6	Cellulose	27.86–29.50	38–70	–	68.42
7	Lignin	5.64–5.96	14.63	10–15	13.58

Neem contains a variety of bioactive compounds[1] primarily located in its seeds, leaves, flowers, and bark. These include:

1. **Azadirachtin**: A well-documented compound with potent insecticidal, antifungal, antimicrobial, and anticancer properties.

2. **Nimbin**: A flavonoid known for its anti-inflammatory, antipyretic, and antidiabetic activities.

3. **Nimbidin**: xhibits strong anti-inflammatory, antibacterial, and hepatoprotective effects.

Salannin: Functions as an insecticide and possesses antimicrobial and antioxidant properties.

Quercetin: A flavonoid with notable anti-inflammatory, anticancer, and antioxidant benefits.

Vitamin E and Carotenoids: Found in neem oil, these compounds contribute to antioxidant activity and skin health.

These compounds work synergistically to enhance the therapeutic properties of neem in treating a variety of health conditions**.**

Therapeutic Applications of Neem in the Pharmaceutical Industry

Antimicrobial and Antifungal Properties:

Neem is comm.only incorporated into pharmaceutical formulations due to its powerful antimicrobial properties. It is effective against bacteria, fungi, and viruses, making it a valuable ingredient in treatments for wounds, oral infections, and various skin conditions. Additionally, its antibacterial effects make it a popular choice in cosmetic products such as dandruff treatments, eczema creams, and acne solutions[8].

Anti-inflammatory and Analgesic Effects:

Neem contains bioactive compounds like nimbin and nimbidin, which exhibit potent anti-inflammatory and pain-relieving effects. These properties make neem beneficial in managing diseases like arthritis and gout.

Antidiabetic Properties:

Scientific research supports neem's role in regulating blood sugar levels by improving insulin sensitivity and reducing oxidative stress. Neem leaf extracts are tested for their potential to complement conventional diabetes treatments.

Anticancer Potential:

Preliminary studies suggest that neem-derived compounds, particularly azadirachtin, may have anticancer properties. Azadirachtin is responsible to inhibit cancer cells in certain cancer types. Further research is ongoing to explore neem's potential in cancer treatment[11].

1. **Hepatoprotective and Detoxifying Effects**:

Neem is responsible for its ability to protect liver function and prevent damage. Its hepatoprotective effects make it useful in treating liver disorders like hepatitis and cirrhosis. Neem is also incorporated into detoxification treatments due to its antioxidant and liver-supporting benefits.

2. **Antiviral and Immunomodulatory Effects**:

Neem is recognized for its immune-boosting properties, which contribute to its antiviral applications. Research indicates that neem extracts may strengthen immune responses, help in treating the viral infections.

3. **Skin Care and Cosmeceuticals**:

Neem is generally used in the cosmetic industry due to its antimicrobial and skin-repairing properties. It is a ingredient in skin care products such as creams, lotions, and soaps, designed to treat acne, eczema, psoriasis, and fungal infections.

Pharmaceutical Products Derived from Neem

Neem's medicinal properties is responsible development of several pharmaceutical formulations,[8] including:

- **Neem Oil**: Used in dermatology for treating infections and skin disorders.
- **Neem Capsules/Tablets**: Standardized neem extracts used for conditions like diabetes, hypertension, and detoxification.
- **Topical Creams and Ointments**: Effective in managing acne, eczema, and fungal infections.
- **Herbal Teas and Decoctions**: Neem leaves are brewed into teas known for their detoxifying and immune-enhancing properties.
- **Neem-based Mouthwash**: Incorporated for its antibacterial benefits in maintaining oral hygiene.

Neem (*Azadirachta indica*) is bioactive compounds like azadirachtin, nimbin, nimbidin, and limonoids, which make it valuable for medicinal, agricultural, and industrial applications. Here are some useful chemical reactions involving neem extracts[9]:

1. Neem Oil Saponification (Soap Making)

- **Reaction:** Neem oil (fatty acids) reacts with sodium hydroxide (NaOH) to form soap.

• **Equation:** Neem oil+NaOH→Soap+Glycerol\text{Neem oil} + NaOH \rightarrow \text{Soap} +\text{Glycerol}Neem oil+NaOH→Soap+Glycerol

- **Use:** Antibacterial neem soap.

2. Neem-Based Pesticide (Neem Oil Emulsion)

- **Reaction:** Neem oil is emulsified with soap or detergent to improve solubility in water.

- **Equation:**Neem oil+Surfactant+H2O→Emulsified Neem Pesticide\text{Neem oil} + \text{Surfactant} + H_2O \rightarrow \text{Emulsified Neem Pesticide}Neem oil+Surfactant+H2O→Emulsified Neem Pesticide

- **Use:** Natural insecticide.

3. Neem Leaf Extract with Silver Nitrate (Nanoparticle Synthesis)

- **Reaction:** Neem leaf extract is a lowering agent for silver nitrate ($AgNO_3$), forming silver nanoparticles.

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- **Equation:**AgNO3+Neem extract→Ag(nanoparticles)+by-productsAgNO_3 + \text{Neem extract} \rightarrow Ag \text{(nanoparticles)} + \text{by-products}AgNO3+Neem extract→Ag(nanoparticles)+by-products

- **Use:** Antimicrobial silver nanoparticles.

4. **Neem Alkaloid Isolation (Bitter Compounds)**

- **Reaction:** Neem bark or leaf extracts are treated with acidic or alkaline solutions to extract alkaloids like nimbin and nimbidin.

- **Equation:**Neem extract+HCl/NaOH→Purified Alkaloids\text{Neem extract} + HCl/NaOH \rightarrow \text{Purified Alkaloids}Neem extract+HCl/NaOH→Purified Alkaloids

- **Use:** Pharmaceutical applications.

5. Neem-Based Mosquito Repellent

- **Reaction:** Neem oil is mixed with camphor and ethanol to create an effective repellent.

- **Equation:**Neem oil+Camphor+Ethanol→Mosquito Repellent\text{Neem oil} + \text{Camphor} + \text{Ethanol} \rightarrow \text{Mosquito Repellent}Neem oil+Camphor+Ethanol→Mosquito Repellent

- **Use:** Natural alternative to chemical repellents.

Neem in Agroforestry

In agroforestry systems, the preferred tree species should have local utility, be easily marketable, and offer good economic value. While Neem is not typically regarded as the ideal agroforestry species, it has proven to be suitable in various regions of India. In semi-arid conditions at the Indian Grassland and Fodder Research Institute, Jhansi, Neem, and other tree species, contributed to increasing silvicultural productivity to 8.5 tonnes per hectare. Studies indicate that in the arid zone of the Thar Desert, fodder production can be enhanced from 0.5 to 3.6 tonnes per hectare by integrating suitable grasses and legumes with Neem and other tree species.

Neem as a Timber Tree

The neem tree is a large, evergreen species that typically grows between 15 to 20 meters tall, with a semi-straight to straight trunk ranging from 30 to 80 cm in diameter. It features a broad, spreading crown and has a long lifespan of up to 100 years. Neem holds significant economic value compared to other multipurpose tree species in India. While its primary use is seed production for oil extraction, it is harvested for timber after 35 to 40 years. The sapwood is greyish-white, while the heartwood has a reddish to reddish-brown hue, resembling mahogany. Neem wood is aromatic, moderately heavy, and highly durable, offering natural resistance to insect attacks. It seasons well, even when sawn wet, and is easy to work with, though it does not polish well. Common applications of neem wood include construction, such as house building, posts, beams, and door/window frames. Additionally, it is used for making furniture, carts, axles, yokes, ship and boat components, helms, oars, oil mills, cigar boxes, carved images, toys, and various agricultural implements[3].

Challenges and Future Prospects

Despite neem's vast potential in pharmaceuticals, several challenges hinder its widespread adoption. Standardizing neem extracts is crucial, as bioactive compound concentrations may vary due to factors like geographical location and harvesting techniques. Furthermore, sustainable cultivation and large-scale production of neem require careful planning[10].

Additionally, extensive clinical trials are necessary to validate neem's therapeutic efficacy. Although traditional practices and preclinical studies suggest its effectiveness, large-scale human studies are essential to confirm its safety and potential pharmaceutical applications.

Moreover, there is a need for more rigorous clinical trials to substantiate the therapeutic claims associated with neem[4]. While traditional use and preclinical studies support its effectiveness, large-scale human studies are essential to ensure its safety and efficacy in pharmaceutical products.

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Industrialized applications

Neem plays a crucial role in addressing health conditions such as heart disease, cancer, and diabetes. Research in these areas has led to the development of innovative, patentable technologies with potential clinical and commercial applications.

One of the remarkable uses of Neem is its role as a natural male contraceptive, offering a non-invasive alternative to vasectomy. Studies indicate that injecting 50µl of Neem oil into the vas deferens of rats effectively induces infertility for up to nine months without affecting libido or androgen levels (Talwar, Upadhyay, & Dhawan, 1996). Neem oil has also been integrated into vaginal creams with spermicidal effects, serving as a contraceptive measure. A formulation composed of 89:10:1 organic carrier, Neem oil, and reetha extract has been found to prevent pregnancy for up to three months without disrupting ovulation. Research on Bonnet monkeys suggests that only one in six females conceived after 50 mating cycles, with Neem creams influencing TNF-α and γ-interferon levels, thereby primarily affecting placental implantation[15`] (Asif, 2013; Talwar et al., 1993). Unlike conventional oral contraceptives, Neem-based options do not interfere with hormonal regulation. Additionally, Khillare et al. demonstrated that a 3 mg dose of Neem extract could eliminate 100% of sperm (1 million in vitro). Histological studies confirmed strong spermicidal properties, particularly when 100 mg of dried Neem leaf powder was soaked in distilled water for 24 hours. Lower concentrations primarily impacted sperm motility by inhibiting ATPase activity (Khillare & Shrivastav, 2003).

Neem is also widely recognized for its antifungal, insecticidal, and antibacterial properties (Barnette & Walter, 1997; Locke et al., 1993; Locke et al., 1995). The key bioactive compound[7], Azadirachtin, disrupts mitochondrial oxidative phosphorylation, interfering with the respiratory chain. Additionally, other components such as nimbidin, nimbin, nimbolide, gedunin, mahmoodin, margolone, and cyclic trisulfide contribute to Neem's antimicrobial capabilities (Al Akeel et al., 2017; Heyman et al., 2017; Khamis Al-Jadidi & Hossain, 2015; Shah et al., 2016). Neem-based pest control solutions are extensively utilized in agriculture and residential environments, with the market valued at $16.2 billion and expected to exceed $27 billion by 2025 (GLOBE NEWSWIRE, 2019). Furthermore, the antimicrobial properties of Neem are being researched for applications in medical, residential, and industrial surface coatings, particularly in epoxy resins and plastic-based coatings (Forim & Fernandes Da, 2017; Lisec, 2011).

Neem has also been extensively studied for its potential in managing diabetes. Research by Chauhan et al. demonstrated that Neem functions as a beta-cell stimulant, promoting native insulin production [13] (Chauhan et al., 2006; Pushpangadan & Prakash, 2006). Recent studies have shown that aqueous extracts of Neem aid in glycemic control by reducing acid phosphate activity while increasing 5′-nucleotidase levels, an effect linked to nimbidin (Puri, 1999). Additionally, Neem extract has been encapsulated into pill formulations, which enhance blood antioxidant activity, inhibit LDL oxidation, and prevent foam cell formation—key factors in cardiovascular disease. These formulations also contain tannins, which help alleviate oxidative stress and may support weight management (Mazed & Sayeeda, 2011; Naguib, 2004; Tripp et al., 2012). Collectively, these findings highlight Neem's role in improving overall health and quality of life.

Neem's anti-cancer properties have contributed to the development of novel drugs aimed at inhibiting tumor growth and metastasis. Plant cells derived from *Azadirachta indica* have been identified as sources of 17β-hydroxy-17α-methyl-5α-androst-1-en-3-one and 17β-hydroxy-17α-methyl-5α-androstan-3-one, compounds that suppress the proliferation of the NCI-H460 cancer cell line through IL-2 interaction (Saifullah et al., 2012; Saifullah et al., 2013). Neem-based formulations have also been explored as topoisomerase I and II inhibitors, alkylating agents, and microtubule inhibitors for cancer treatment (Thompson et al., 2014; Thompson et al., 2016). In early 2010, Japanese researchers developed a combination of Neem, Ganoderma spores, Wanirin, Chaga enzymes, and rice to prevent the metastatic spread of colon cancer (Tanaka, 2019)[15].

These versatile applications of Neem extracts highlight their immense potential in clinical and commercial domains, providing natural and effective solutions in medicine, agriculture, and industry.

Neem biomass: activation process

The activation process of biomass commonly involves the creation of activated products derived from neem. Activated carbon is a porous substance that effectively absorbs pollutants, poisons, and odors. The neem biomass activation method consists of four key steps: sample collection and preparation, carbonization, activation, post-activation treatment, and sieving. Collection and preparation involve collecting neem biomass, which can include neem leaves, seeds, and parts of the neem tree, followed by cleaning. In this cleaning step, wash the neem biomass to remove dirt, dust, and any other contaminants[10]. Lastly, the biomass must be dried thoroughly to reduce moisture content, which is important for effective carbonization and activation. For the carbonization process, chopping and heating is being carried out . Grind or chop the dried neem biomass into smaller pieces to ensure even carbonization. Subject the biomass to high temperatures (typically 400–600 °C) to carbonize the material. This step decomposes the organic matter and forms a char. Next, is the cooling step, which allow the carbonized material to cool down in an inert atmosphere to prevent oxidation. Physical activation involves using steam or carbon dioxide at high temperatures (700–1000

°C) to develop the porous structure of the carbonized material. The activation process creates a network of pores, enhancing the surface area and adsorption capacity. Whereas, chemical Activation involves the chemical agents like phosphoric acid (H_3PO_4) or potassium hydroxide (KOH) used for activation].The biomass is impregnated with the chemical agent before carbonization[4]. This method typically requires lower temperatures (400–600 °C) and can produce a more developed porous structure. At last, post-activation treatment, wash the activated carbon to remove any residual chemicals or ash. After washing, dry the activated carbon thoroughly. Sieve the dried activated carbon to obtain particles of the desired size and store the activated carbon in a dry, airtight container to maintain its effectiveness. displays the flow diagram illustrating the activation procedure. Different types of structural and functional groups can be included in a material based on the source of the material and the method used to activate it[2].

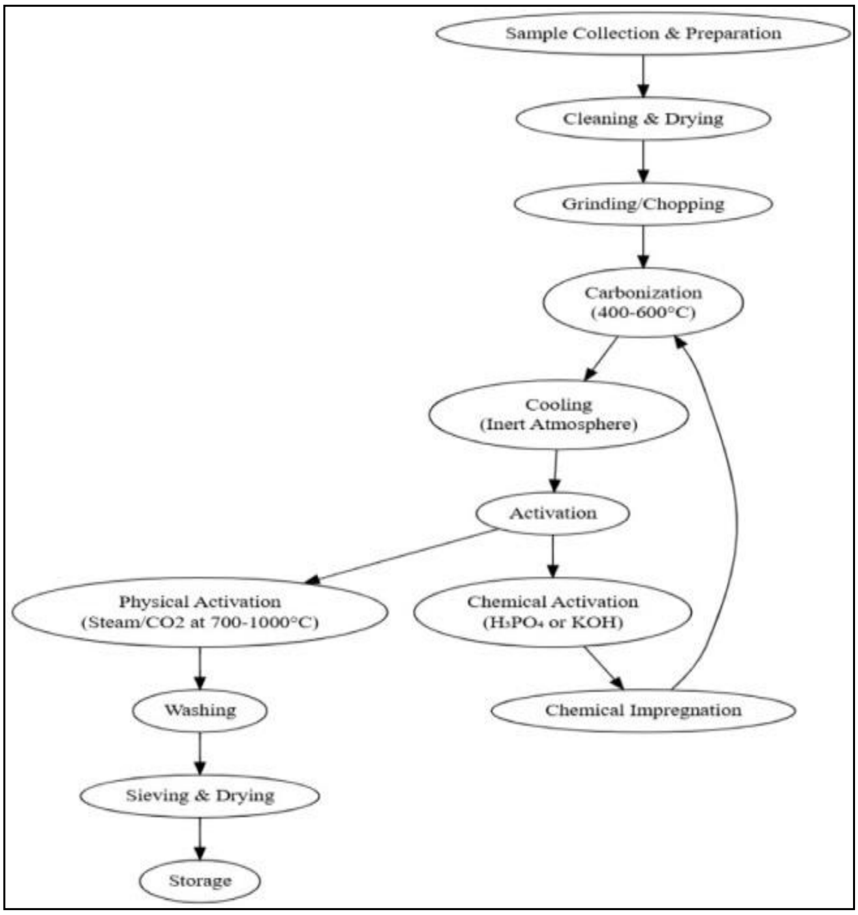

Fig.5

Chemistry of Neem Compounds

Natural compounds present in neem are triterpenes or limonoids. New limonoids are still being discovered in neem. Azadirachtin, salannin, meliantriol and nimbin are well known (Naik et al., 2014). The bitterconstituent, the nimbin contains an acetoxy, a lactone, an ester, a methoxy and an aldehyde group. Nimbidin contains sulphur.

3.1. Bark

The bark exudes a clean bright amber coloured gum which is collected in small tears or fragments. It contains a bitteralkaloid named "margosine". Leaves also bitter principles but in small quantity which are much more soluble in water. This substance is a hydrate of the resin. Seeds contain 10% to 31% of a yellow bitter fixed oil with a strong disagreeable acrid taste. The volatilefatty acids present in the bark consist a mixture of stearic and oleic acids along little amount of lauric acid. Trunk bark yields 0.04% nimbin, 0.001 nimbinin, 0.4% nimbidin, andessential oil 0.02%. Tetracyclic triterpenoids and their derivatives have been isolated from the stem bark along with tricyclic diterpenoids).

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3.2. Flowers

Flowers have been found to contain a flavonoid. Nimbicetin is identical to kaempferol. In the dried bark the same bitter components as in the seed oil have been found and in the pericarp of the fruit a bitter principle bakayanin was found.3.3. Neem oil Neem oil contains Sulphur 0.427%; a very bitter yellowish substance obtained from the alcoholic extract of the oil, which is supposed to be an alkaloid; resins; glucosides and fatty acids

3.4. Seeds

Meliacins found in the seeds include gedunin,

7-desacetylgedunin, desace-tylnimbin and azedarachtin.The seed oil mainly contains nimbidin, nimbin and nimbinin, which also occur in the stembark (Ara et al., 1989).

3.5. Toddy

The toddy or sap contains glucose, sucrose, gums and louringmatte

Fluidized bed technology

fluidized bed technology is used in the industrial production of carbon materials, which involves several key steps, each aimed at optimizing the activation process to produce high-quality activated carbon.In a carbonization reactor utilizing a fluidized bed, the material is introduced into a vertical column and subjected to heating in inert gas, such as nitrogen or argon, from 400 °C to 600 °C. An inert gas is used to prevent oxidation during the heating process[6]. The solid particles are made to behave like a fluid by the upward movement of the inert gas. This guarantees consistent heating and carbonization of the particles. Following carbonization, the bed is cooled within an inert environment to inhibit the carbonized material from undergoing oxidation with atmospheric oxygen. The carbonized material undergoes exposure to steam at 700 °C to 1000 °C. When steam or CO_2 comes into contact with carbon, it undergoes a chemical reaction, forming a structure of small holes, resulting in activated carbon with a large surface area.

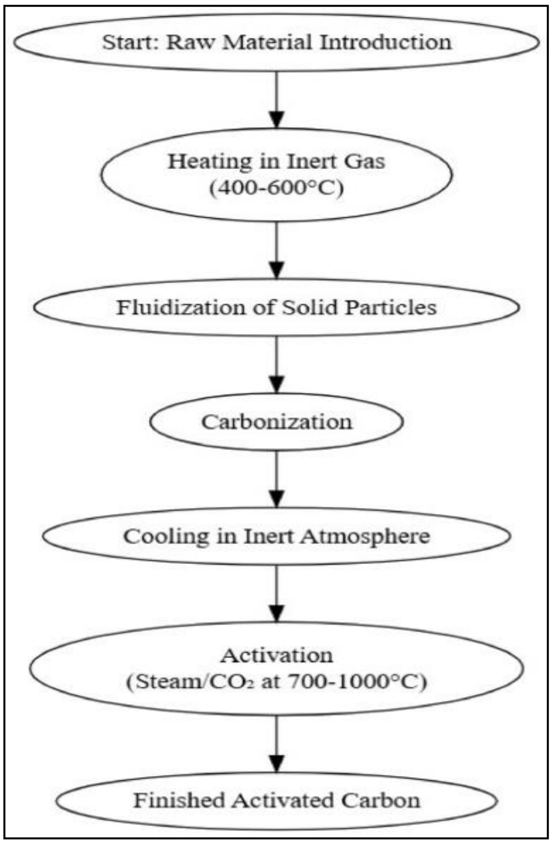

Fig.6

Within a fluidized bed reactor, the carbonized material is made to flow like a fluid through the upward movement of steam or CO_2. This guarantees consistent activation and prevents the creation of aggregates or uneven activation.

Flow diagram of the Fluidized Bed Technology for producing activated carbon from neem biomass, showing steps from raw material introduction to activation with steam or CO_2.

Rotary kiln

A rotary kiln is a cylindrical furnace that rotates on its axis to subject materials to high temperatures for thermal treatment. It is widely employed in various industries for a multitude of applications, including the production of cement, lime, and activated carbon. The design of the rotary kiln allows for continuous processing and efficient heat transfer, making it well-suited for a wide range of industrial activities[9]. In this technique, raw materials are fed into the kiln through a hopper situated at one end. In the context of creating activated carbon, this term refers to carbonized material that necessitates further activation. The kiln rotates slowly around its horizontal axis. The kiln's rotation ensures consistent mixing and thorough exposure of the material to the heat source. The kiln is heated by burning fuels such as natural gas, coal, or oil in a separate chamber[1]. The substance receives heat through the processes of convection, conduction, and radiation. As the material moves through the kiln, it passes through several temperature zones, which enable specific reactions or processes to occur[14]. The production of activated carbon requires activation temperatures that vary between 700 °C and 1000 °C. Activated carbon is created by either physically or chemically activating it, leading to the development of a porous framework. The treated material is expelled from the kiln at the opposite end from where it was initially inserted. Usually, a cooler is placed at the end where the material is released in order to decrease its temperature before it is gathered or further processed (Rafsanjani et al., 2013).

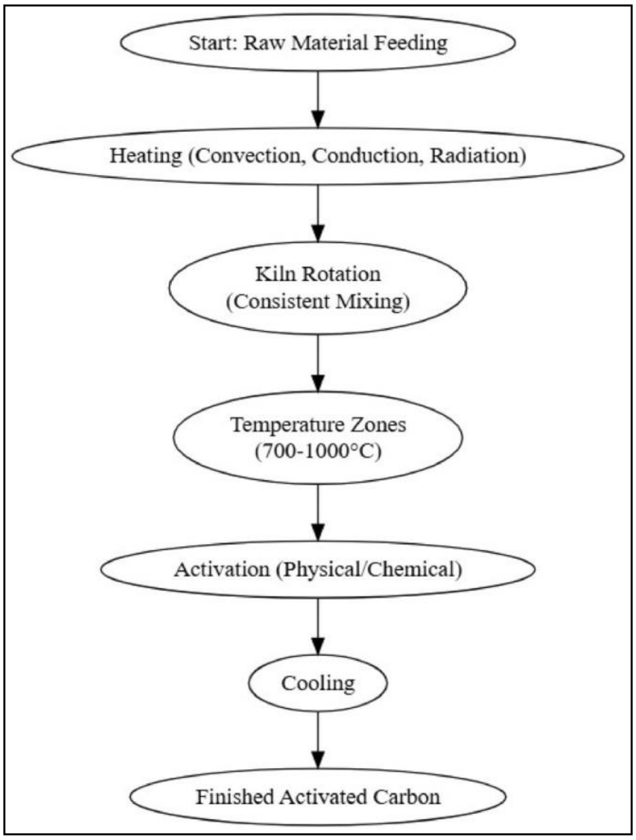

Fig. 7. Flow diagram of the Rotary Kiln Technology for activated carbon production from neem biomass, detailing the process from feeding raw materials to activation through heating and rotation.

Methods for modifying the surface of adsorbents

Neem biomass-derived adsorbents can be modifications to achieve maximum adsorption effectiveness. The neem biomass is subjected to physical modification by processes such as cutting, grinding, and heat treatment[6]. Chemical alterations entail employing acid, base, and salt impregnation techniques to introduce functional groups. Generally, most investigations on surface

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modification involve the integration of oxygen into the carbon network structure[9]. As a result, the activated carbon experienced a modification in its surface characteristics. Chemical treatments consist of applying acid compounds to alter the surface.

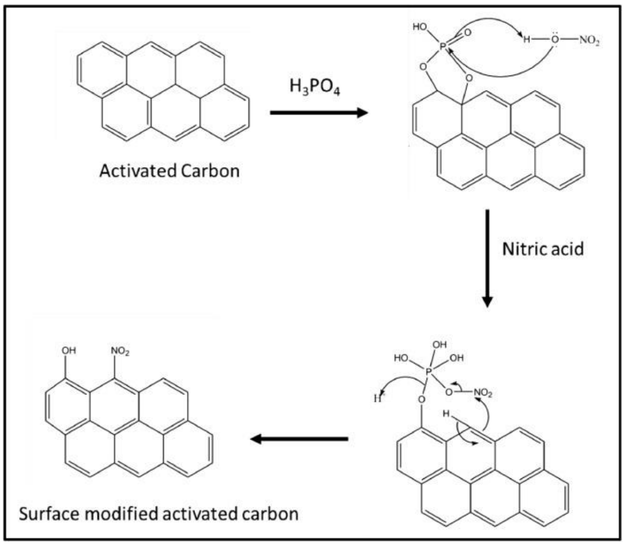

Fig. 8. Chemical modification of activated carbon/Neem absorbent.

Chemical alteration of activated carbons generated from neem biomass

The technique of chemically altering neem biomass-derived adsorbents involves using acid or base activating agents to alter the surface. This approach utilizes functional groups that give unique features to the adsorbents, Strong acidic or basic activating agents can be used to change the chemicals in adsorbents made from NEEM biomass. The concept of chemical modification is to alter the acidity or alkalinity of the adsorbent's surface[4].The chemical modification introduces functional groups that generate distinctive properties in adsorbents, which aid in the adsorption of specific pollutants. Activated carbons made from neem biomass can have their surface changed with acids such as nitric acid (HNO3), phosphoric acid (H3PO4), ammonium persulfate (NH3)2SO4, potassium hydroxide (KOH), zinc chloride (ZnCl2), potassium carbonate (K2CO3), hydrochloric acid (HCl), sulfuric acid (H2SO4), and others (Azhagapillai et al., 2021)[2]. The flow diagram for neem biomass activated carbon surface modification methods and the mechanism of surface modification is illustrated in , Nitric, sulfuric, and phosphoric acids are the most frequently employed acids in the modification of biomass activated carbon surface oxidation. During oxidation, acryl groups from carboxylic, lactone, and phenolic acids are added to the activated carbon's surface (Azhagapillai et al., 2021). Gas-phase oxidants can also be employed to accomplish the surface oxidation of activated carbon[8]. Steam, carbon dioxide, and air are the gas phase oxidants that are most frequently employed in biomass-activated carbon surface oxidation. These oxidants require a high level of energy (temperature). The energy required for aqueous oxidation is reduced due to the fact that it takes place at moderate temperatures. In general, the generation of strong acid functionalities, such as carboxylic groups, is a consequence of low-temperature oxidation. But the hydroxyl and carbonyl groups that form on the surface of the biomass-activated carbon are caused by oxidation at high temperatures, the same way they are in gas phase oxidation (Rehman et al., 2019) . The acid treatment adds negative charges to the surface of biomass-activated carbon. This makes it a beneficial place for positively charged ions, like metals and cationic pollutants, to interact with it electrostatically. The surface structure of methylene blue makes it more likely to stick to high-PH environments. This is true even though cationic dyes can stick to acid-modified activated carbons (Rehman et al., 2019). A test using activated carbon that had been changed with nitric and phosphoric acid showed that nitric acid was better at getting rid of basic yellow 28 dye than phosphoric acid[14]. According to Pego et al.(2019)the activation process of neem biomass resulted in the collapse of pores, which consequently led to a lower percentage of color removal. A.R. Karim et al.(2024). In a different study, oxidation and nitrogenation altered activated carbon, increasing the amount of oxygen and nitrogen on its surface. This made the modified activated carbon better at absorbing organic dyes. It's because of the surface charge interactions between the adsorbent and pollutants, as well as the effect of solution pH, that acid-modified adsorbents are able to selectively remove pollutants[11]. When activated carbons are made in an alkaline environment, they have more oxygenated basic complexes on their positively charged surfaces. This process promotes the adsorption of negatively charged pollutants. NaOH, KOH, NH3, or other basic components are used to modify activated carbon in an alkaline manner. Nevertheless, NaOH and KOH are the most frequently employed (Srivastava et al., 2021). When activated carbon is treated with alkali, its surface is less likely to absorb water, which makes it less effective at removing metal ions. The neem leaf adsorbent that has been changed by citric acid has surface changes that can be seen at the 200 nm level (Hatiya et al., 2022). The phosphoric acid-modified neem leaf adsorbent's highly uneven surface is visible at a 10 µm scale (Thomas and Alexander, 2019). If the neem flower was chemically changed with cetyltrimethylammonium bromide, a cationic surfactant (Kumar et al., 2023), the following changes were seen:

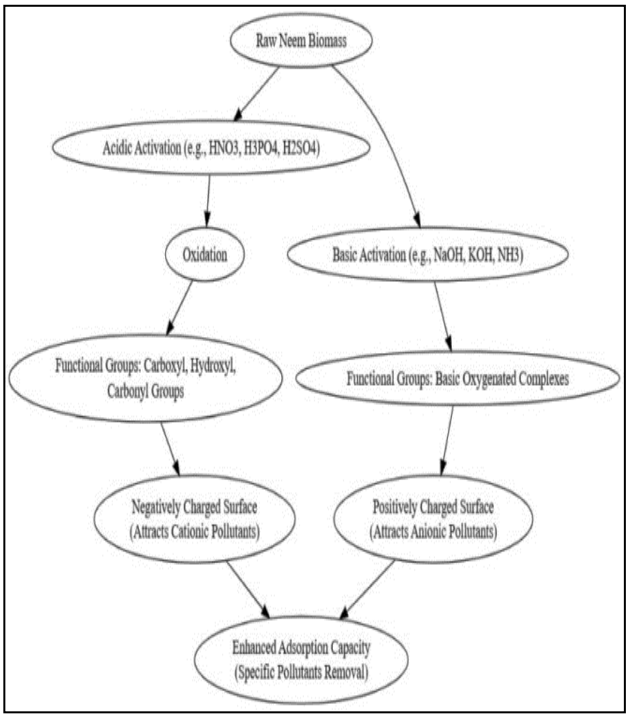

Fig. 9. Flow Diagram of Neem Biomass Surface Modification; Flowchart showing the acidic and basic activation methods used to modify neem biomass surfaces, resulting in improved adsorption of specific pollutants.

Conclusion

Neem holds immense potential in the pharmaceutical field due to its vast array of bioactive compounds and their therapeutic applications. From antimicrobial and anti-inflammatory properties to its effectiveness in managing diabetes and cancer, neem provides a natural and holistic approach to healthcare. However, to maximize its benefits, further research, standardization, and clinical validation are essential.

With the increasing demand for plant-based medicines, neem continues to be a promising candidate for future pharmaceutical innovations. Its broad spectrum of medicinal applications, including skincare, immune support, and chronic disease management, reinforces its importance in the healthcare industry.

While neem has been used for centuries in traditional medicine, not all its extracts may lead to pharmaceutical-grade drugs due to factors like variability in composition and potential toxicity. Despite this, neem remains a crucial component in complementary medicine. The need for improved standardization in processing neem extracts highlights the importance of continued research into its bioactive compounds and their potential therapeutic applications.

Studies suggest neem's anti-cancer and anti-diabetic properties largely stem from its anti-inflammatory and antioxidant effects. By reducing oxidative stress and modulating immune responses, neem contributes to the prevention and management of various diseases. Its compounds, such as limonoids, help alleviate inflammation and pain through natural biological pathways. Furthermore, regulating immune cell activity and inflammatory mediators may play a role in preventing conditions like cancer and diabetes. Addressing oxidative stress and metabolic imbalances through neem-based treatments presents a promising area for future research and clinical applications.

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