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A Review on Nano-sponges of plant '*Moringa oleifera*'

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ABSTRACT:

Nano sponge is a form of a nanoparticle, commonly a manufactured carbonised polymer. They can be more porous in structure, pores being roughly 1.0-2.0 nanometers in dimension, and could therefore targeted so to absorb small quantity of materials or poison. In medical sector, nano sponge is mostly utilized as targeted systems of drug delivery, detoxifying techs or damage control actions following an accident. By carrying out operations like cleaning water or deposits of metals, they can also be utilized in environmental applications to recover ecosystems because of its diminutive dimensions. They could swiftly navigate inside materials such as water or blood precisely locating and eliminating undesired substances. Although they are frequently made artificially from naturally occurring elements. Frequently added to nano sponges so to enhance their effectiveness when administered intravenously.

A variety of chemicals having antifungal, antiviral, antibacterial and also antioxidant qualities can be found in medicinally active plant Moringa oleifera. Extracts of Moringa may therefore be able to manage fungal infections. Significant antifungal qualities are exhibited behalf of Moringa oleifera. Research has found that, extracts from its leaves and seeds are particularly efficient on a variety of fungal species such as Candida albicans, Aspergillus flavus and Rhizopus stolonifera. Flavonoids (apigenin, quercetin, luteolin, myricetin and kaempferol), lignans (secoisolariciresinol, isolariciresinol, medioresinol and epipinoresinol, glycosides), and also phenolcarboxylic acids and their some derivatives (coumaroylquinic, caffeoylquinic and feruloylquinic acids) are primary phenolic compounds get in moringa leaves. Those bioactive compounds are reasons for the antifungal effect.

This review is done so that, enlightened nano tech utilized for formulating novel drug delivery as nano-sponges, by using the Moringa plant.

Keywords: Antifungal, Bioactive compounds, Fungal species, Moringa, Nano-sponges, etc.

Introduction: (Moringa Plant)

Moringa oleifera [1] is a fast-growing, deciduous tree with an open, spreading crown that is usually umbrella-shaped. It is distinguished by its feathery, tripinnate compound leaves, fragrant white to cream-colored flowers in drooping panicles, and long, pod-like fruits that are often referred to as "drumsticks" and contain many winged seeds. The bark is whitish-gray, and depending on the climate and growing conditions, the tree can grow to a height of 5–12 meters.[2]

Native to Northern India, Moringa oleifera is a short-lived, drought-resistant tree that grows quickly and is widely used in South and Southeast Asia. In the tiny plant family Moringaceae, also known as the bottle tree, horseradish, or drumstick family, Moringa is the only genus of blooming tropical and subtropical species.[3]

The medical plant Moringa oleifera possesses antifungal, antiviral, antibacterial, and antioxidant qualities.[4] There are likely more and more varied applications for Indian moringa than for any other plant, and new use are being suggested annually. Moringa's many applications fall into the following general categories: foods for human, animal, and fish consumption; human and veterinary medications; agricultural applications in soil remediation, as plant growth stimulants, biopesticides, and bee fodder; biofuels; and water and wastewater treatment.[5]

The herbal plant Moringa uses nanotechnology to create antifungal nano-sponges that can be applied to humans.[6] As a new medication delivery technology, it has several applications.

Etymology:

"Murungai," which means "twisted pod" in Tamil, is the source of the genus name Moringa, referring to the juvenile fruit. The Latin terms ferre, which means "to bear," and oleum, which means "oil," are the sources of the specific name oleifera.

Taxonomy:

- **Kingdom**: Plantae
- **Sub-kingdom**: Tracheobionta
- **Super division**: Spermatophyta
- **Division**: Magnoliophyta
- **Class**: Magnoliopsida
- **Sub-class**: Dilleniidae
- **Order**: Capparales
- **Family**: Moringaceae
- **Genus**: *Moringa*
- **Species**: *oleifera*

Synonyms:

- *Guilandina moringa* L.
- *Hyperanthera moringa* (L.) Vahl
- *Moringa pterygosperma* Gaertn. nom. illeg.

Other features of the moringa plant:

It is a short-lived, drought-tolerant tree that grows quickly. It originated in Asia and has now spread to many other regions of the world. Its triangular, long, thin seedpods have a horseradish-like flavor.[7] It may be cultivated anywhere on the plains and can withstand temperatures ranging from 19 to 28 degrees Celsius.

Botanical Description:

Leaves:

It depicts a number of small, oval-shaped, tripinnately complex leaves that alternate along with a dark green upper and a paler underside. Each pinnate of Moringa's alternating, 7–60 cm long, tripinnately compound leaves comprises 4-6 pairs of dark green, elliptical–obovate, 1-2 cm long leaflets.[8]

Appearance:

Since the leaves are the compound, they have been separated into multiple smaller, feather-like leaflets that are oblong or elliptic in shape and positioned on the stem.

Nutritional profile:

Considered a "superfood" due to their high content of protein, vitamins A and C, calcium, potassium, iron, and various B vitamins.[9]

Culinary uses:

Fresh leaves may be consumed as a vegetable, incorporated into salads, prepared in curries, or desiccated and pulverized for use in smoothies or soups.

Medicinal properties:

Historically employed to treat many ailments such as anemia, dermatological conditions, gastrointestinal disorders, and inflammation, owing to its antioxidant, antifungal, and anti-inflammatory attributes.[10]

Growing circumstances:

Moringa trees exhibit drought resistance and flourish in tropical and subtropical climes.

Flowers:

Five unequal petals, ranging in color from white to cream, are arranged in axillary panicles on this aromatic bisexual plant. The fragrant, white blooms of the moringa tree (Moringa oleifera) have a somewhat pleasant flavor. They have both male and female organs at the same time since they are hermaphrodites.

Appearance:

The blossoms measure roughly 2 cm in width and 1 to 1.5 cm in length. They feature five yellowish-white petals that are uneven and have tiny veins. Bright yellow pollen envelops thin stamens surrounded by petals. Clusters of the blooms may droop or stretch out.

Taste:

The blossoms have a mildly pleasant flavor and a fresh, green scent. When cooked, they acquire a flavor akin to a hybrid of asparagus and mushrooms.

Uses:

Traditional medicine has utilized the blossoms to cure cancers, muscular ailments, and to boost sexual desire. The blossoms provide a good source of nectar for honey-producing bees.[11]

Other facts:

The flowers have both male and female components since they are hermaphrodites. On thin, hairy stalks, the blooms are borne. Delicate flower clusters adorn the branches of the moringa tree. The flowers are zygomorphic and pentamerous.

Fruits (pods):

Long, slender, three-valved pods with numerous winged seeds that are green when immature and brown when fully grown. The fruit of the moringa plant is a drumstick-shaped capsule that is also referred to as a pod. The fruit is green while it is young and turns brown as it grows.

Appearance:

The pod hangs downward, is three-sided, and ranges in length from 10 to 60 cm. When the fruit reaches maturity, it splits open along each angle. There are 15–20 spherical, fatty seeds in the fruit. Three paper-like wings, up to 2.5 cm long, encircle the seeds.

Seeds:

The spherical, dark brown seeds have a diameter of roughly 1 cm. Both wind and water spread the seeds.

Uses:

The fruit is eaten as a vegetable. The fruit is used for traditional medicine.[12]

Other features:

Moringa is a deciduous tree with a rootstock that looks like horseradish. The moringa plant has white to cream-colored blooms that are around 2.5 cm across. The moringa may bloom at any time of year. The moringa plant has numerous health benefits, including the capacity to boost immunity, reduce blood sugar, and reduce the risk of chronic diseases.[13]

Bark:

Young shoots frequently have a purplish or greenish-white hairy look, and the bark is corky and whitish-gray. Thick cork surrounds the whitish-gray bark of the moringa tree (Moringa oleifera). Traditional medicine has utilized the bark to cure a number of ailments. **Characteristics:**

Young shoots have hairy, purple or greenish-white bark. The bark includes octacosanoic acid, 4-hydroxymellin, β-sitosterol, β-sitostenone, vanillin, and moringine. Antibacterial, antifungal, anti-inflammatory, and antioxidant qualities are all present in the bark.[14]

Uses:

The bark has been used to treat stomach issues, anemia, diabetes, and other conditions. The bark has been used to treat wounds and skin infections.[15] The bark can be beaten into a fiber for production of ropes or mats. The bark and gum can be used in tanning hides.

Other uses of the Moringa tree:

Vitamin C, calcium, potassium, omega-3 fatty acids, and protein are all found in abundance in the seeds. The roots can be ground to make a paste that tastes like horseradish. The pods alleviate joint pain and treat hepatitis. The leaves have been useful for patients suffering from insomnia and treating wounds. The leaves are also used in the cosmetic industry.

Root system:

Deep, taproot system. The moringa tree (*Moringa oleifera*) has a large taproot that anchors the tree in the soil. The tree also has lateral roots that extend from the base.[16]

Taproot:

The taproot of the moringa tree can reach depths of 10 to 15 feet. The taproot anchors the tree firmly in the soil.

Lateral roots:

The lateral roots of the moringa tree can extend up to 30 feet from the base. The lateral roots provide stability and access to nutrients.

Other root characteristics:

The moringa tree does not have a very extensive lateral system of roots. The moringa roots typically have a brownish to beige color and are about the thickness of a finger. The moringa roots are known for their pungent, spicy taste and pleasant aroma.

Other moringa tree characteristics:

The moringa tree is a small to medium evergreen or deciduous tree that can grow to a height of 10-12 m. The moringa tree has a spreading open crown, typically umbrella-shaped.[17] The moringa tree has a corky and grey bark. The moringa tree has fragile and drooping branches, with a feathery foliage.

Medicinal properties of Moringa Plant:

Antifungal properties are found in the drumstick tree *Moringa oleifera*. Antifungal activity has been demonstrated by extracts from the plant's leaves, seeds, and roots.[18]

Working against fungi:

Inhibits germination: The steroid ring in the fruit of moringa can inhibit the germination of spores.

Damages cell structure: Moringa leaf extracts can damage the surface and ultra-structure of fungal cells.

Deactivates fungi: Moringa nanoparticles have the ability to deactivate fungi.

Moringa's other medicinal properties:

Antibacterial: Both gram-positive and gram-negative bacteria can be killed by Moringa.[19]

Antiviral: Moringa leaf extracts have shown antiviral activity against foot and mouth disease.

Anti-inflammatory: Moringa has anti-inflammatory properties.[20]

Antioxidant: Moringa has antioxidant properties.[21]

Antihypertensive: Moringa has antihypertensive properties.[22]

How to use moringa:

- Moringa leaves can be used to treat skin fungal and bacterial complaints.
- Moringa seeds can be used to treat arthritis.
- Moringa seeds can also be used to treat rheumatism, gout, cramps, and boils.
- Moringa leaves can be used to treat high blood pressure.

Toxicological Studies:

The Moringa plant has been the subject of toxicological research, which has demonstrated that it has the potential to cause adverse effects such as harm to the liver and kidneys, anemia, and fetal abnormalities.[23] However, some studies have shown that Moringa is relatively safe for human consumption.[24]

Acute toxicity:

In one study, Moringa leaf extract was non-lethal at doses up to 6400 mg/kg, but higher doses caused lethargy and reduced locomotion.[25]

In another study, Moringa leaf extract caused mild anemia and moderate hepato-nephrotoxicity in mice.[26]

Long-term toxicity:

In one study, long-term consumption of Moringa leaf extract may cause nephrotoxicity.

In another study, pregnant rats were given Moringa oleifera, which resulted in fetal resorption and decreased maternal weight gain.[27]

Other adverse effects:

- Moringa can cause diarrhea, insomnia, and lithiasis.
- Moringa can interact with commonly used drugs.
- Moringa can cause harm due to the presence of unknown contaminants.

Safety:

While Moringa can cause adverse effects, some studies have shown that it is relatively safe for human consumption.

When taking Moringa for an extended period of time, exercise caution.

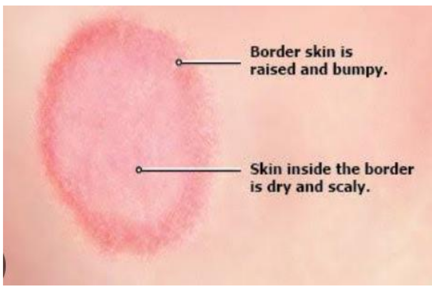
More research is needed to standardize Moringa extracts so that results between studies can be compared.

Fungal Infections treated by Moringa:

It has been demonstrated that Moringa bark extract, seeds, and leaves have antifungal properties. Moringa extracts can be used to treat a variety of fungal infections, including those that cause skin diseases, soil-borne diseases, and crop diseases.[28]

Skin diseases:

Moringa extracts have been shown to be effective against dermatophytes that cause skin diseases like tinea and ringworm.



(Ringworm infection)

(Tinea)

The extracts can be used to develop anti-skin disease agents. Moringa has been used in traditional medicine to treat skin diseases like atopic dermatitis and psoriasis.[29] Moringa has also been shown to help heal skin wounds and reduce oxidative stress.

Other Skin diseases:

Dermatitis atopy Topical application of moringa leaf extract can help with atopic dermatitis by regulating Th1/Th2/Th17 balance.

Psoriasis:

Topical application of moringa can help reduce epidermal thickness, which is a characteristic of psoriasis.

Additional skin benefits:

Skin wounds: Moringa may help heal skin wounds faster by reducing oxidative stress.

Skin inflammation: Moringa seed oil may help reduce skin inflammation.

UVB-induced oxidative stress: Moringa stem extracts can help protect skin from oxidative stress caused by UVB radiation.

Soil-borne diseases:

Moringa extracts have been shown to be effective against soil-borne fungi like Rhizoctonia, Pythium, and Fusarium. Moringa extracts have been shown to be effective against Fusarium dry rot in potatoes.[30]

Moringa extracts can also be used to control other fungal diseases and improve the shelf life of crops.[31]

(Fusarium dry rot in potatoes)

Moringa can be utilized as a biofungicide due to its antifungal properties.[32],[33]

Moringa treat diseases spread by soil:

Inhibits mycelial growth: Moringa extracts can inhibit the growth of soil-borne fungi like Fusarium solani and Rhizoctonia solani.

Reduces disease severity: Moringa seed extract can reduce the severity of powdery mildew disease.

Prevents fungal production: Moringa seed extract can prevent E. betae from producing its conidiophores and conidia.

Other uses of Moringa:

- Moringa can also be used to control the Rhizopus pathogen, which causes food spoilage and losses.
- Food-borne pathogens like Salmonella typhi, Salmonella paratyphi, and Escherichia coli have been shown to be inhibited by moringa. Moringa leaves are rich in zeatin, a cytokinin that enhances crop growth.[34]

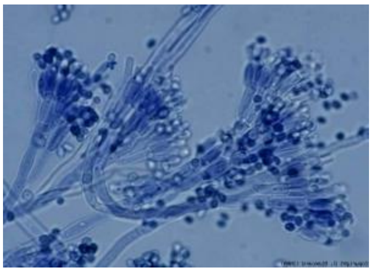
Potential of moringa:

Moringa has potential to be a sustainable solution for disease prevention, malnutrition, and providing safe-drinking water.

Other fungal infections:

Moringa extracts have been shown to be effective against 1) Alternaria spp., 2) Penicillium sp., 3) Candida albicans,[35] 4) Aspergillus niger,[36] 5) Candida albicans and 6) Candida flavus.

(1)



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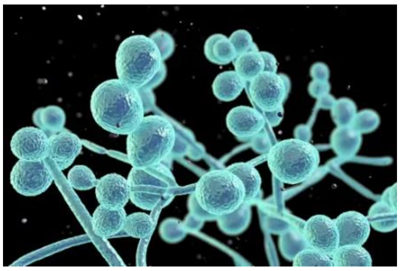

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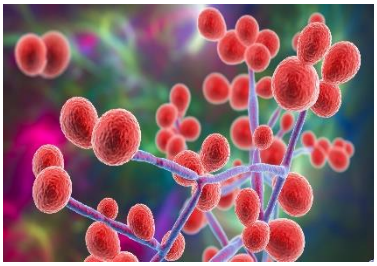


(5)

How moringa extract works and other potential uses:

Working:

Quercetin, b-sitsterol, caffeoylquinic acid, and kaempferol are antifungal compounds found in moringa extracts.[37] Moringa extracts can also inhibit the growth of fungi by damaging their surface and ultra-structure.

Moringa extract works primarily through its potent antioxidant properties, containing compounds like flavonoids and phenolic acids which neutralize free radicals, combat oxidative stress, and protect cells from damage; this mechanism contributes to potential benefits like reducing inflammation, supporting immune function, and potentially aiding in managing blood sugar levels and cholesterol due to its bioactive components.

Potential uses:

Antioxidant power:

The main mechanism of action is attributed to its high concentration of antioxidants like quercetin, chlorogenic acid, and other phenolic compounds, which scavenge harmful free radicals in the body.[38]

Effects on inflammation: Moringa's phytochemicals can also help reduce inflammation by modulating inflammatory pathways.

Potential for blood sugar regulation:

Studies suggest moringa may help manage blood sugar levels by improving insulin sensitivity, potentially benefiting individuals with diabetes.

Cardiovascular benefits:

Some research indicates that moringa may have positive effects on heart health by potentially lowering cholesterol levels and supporting healthy blood pressure.

Gastroprotective activity:

Moringa extracts have shown potential to protect the stomach lining and reduce the risk of ulcers due to their anti-ulcer properties.

Nanoparticles:

Introduction:

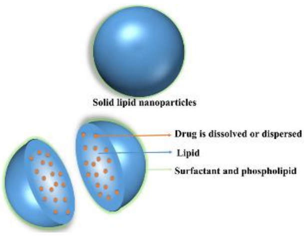
Nanoparticles are materials that are measured in nanometers, i.e. 10^{-9} m. They have many applications in medicine, electronics, and manufacturing.

Moringa oleifera nanoparticles are made from the extract of the moringa tree, which is known for its health benefits. The nanoparticles can be used for a variety of applications, including medicine, water treatment, and food production.[39]

"Nanotechnology is the study of manipulating materials at the atomic and molecular levels to create new materials and devices".

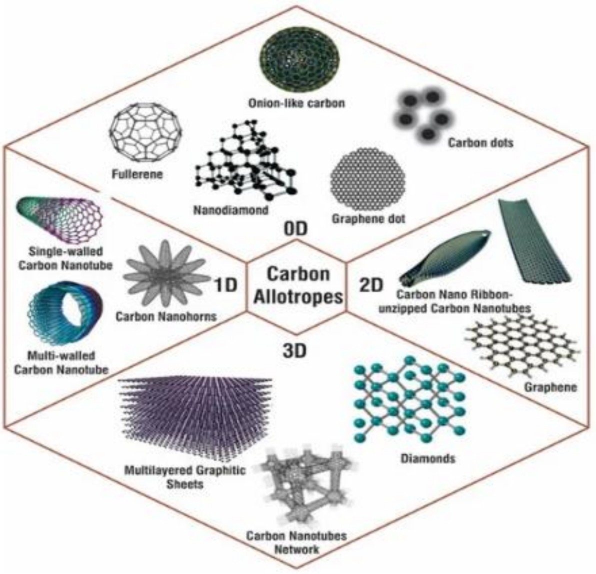
Types of nanoparticles:

1) Solid lipid nanoparticles: Made of lipids, these nanoparticles remain solid at room temperature.

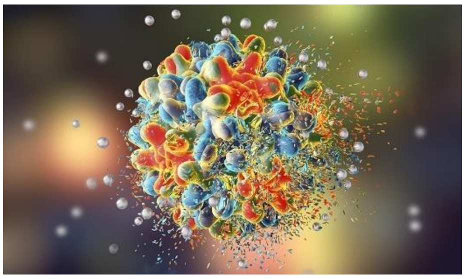


2) Carbon nanomaterials:

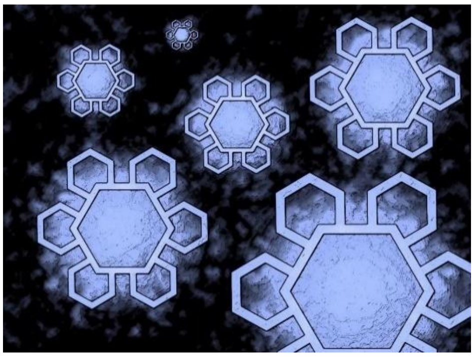
Used in the manufacturing of baseball bats and other sports equipment.



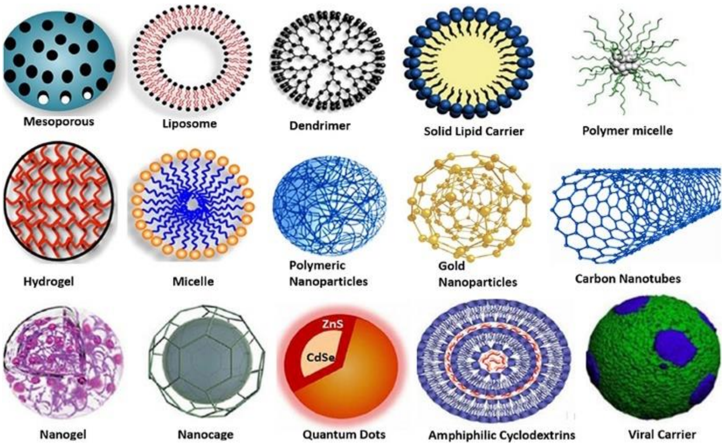
3) Biomedical nanoparticles: Used to deliver drugs and genes to treat cancer and other diseses.[40]



4) Ceramic nanomaterials: Used to strengthen composites.



5) Metal nanoparticles: Such as gold and silver, these nanoparticles have vivid colours.



6) Metal oxide nanoparticles: Used in optoelectronics, solar cells, catalysis, and energy conversion.

Applications of nanoparticles:

Nanomedicine: Used to develop nanoscale agents for treating diseases.[41]
Nanoelectronics: Used to create new materials and devices.[42]
Agricultural sectors: Used in the development of new agricultural products.
Biomaterials: Used in the development of new biomaterials.[43]
Energy production: Used in the development of new energy production technologies.
Consumer products: Used in the development of new consumer products.
Benefits of nanoparticles:
Nanoparticles have many benefits, including in medicine, manufacturing, and environmental applications.

Medicine:

Delivery of drugs:
Nanoparticles can carry drugs to treat tuberculosis and other diseases. Additionally, cancer and neurodegenerative diseases can be treated with them.[44]
Dental applications:
Nanoparticles can improve the strength of dental materials, prevent tooth decay, and whiten teeth.
Pacemakers:
Nanoparticles can be used to create pacemakers that work more closely with the lungs to improve heart function.
Manufacturing:
Prosthetics: Nanoparticles can improve the strength, weight, and biocompatibility of prosthetics.
Fabrics: Nanoparticles can make fabrics more stain-, water-, and flame-resistant.
Wind turbines: Nanoparticles have the potential to make wind turbines lighter and stronger. **Fuel economy:** Nanoparticles have the potential to boost fuel economy.

Environmental applications:

Catalytic converters: In automotive catalytic converters, nanoparticles can be used to reduce pollutants.
Degreasers and stain removers: Nanoparticles can be used to make better household products.

Air purifiers and filters: Nanoparticles can be used to make better air purifiers and filters.

Nanoparticles can also be used to detect tumors and monitor therapy.

Nanoparticle Synthesis methods:

Nanoparticles can be made using various methods including: sol-gel synthesis, chemical precipitation, hydrothermal synthesis, microemulsion, chemical vapor deposition, thermal breakdown, solvent evaporation, and biological synthesis; with the most common approach being "bottom-up" chemical methods where nanoparticles are formed from basic atoms and molecules in a solution.[45]

Nanoparticle synthesis methods:

1) Sol-gel method:

A widely used technique where precursors are dissolved in a solvent to form a gel, which is then heated to produce nanoparticles.

2) Chemical precipitation:

A fast and efficient method where metal ions in solution are reduced to form nanoparticles by adding a precipitating agent.

3) Hydrothermal synthesis:

Involves growing crystals of nanoparticles under high temperature and pressure conditions in a closed system.

4) Microemulsion method:

Utilizes a mixture of oil, water, and surfactant to create a stable dispersion for producing nanoparticles with controlled size.

5) Chemical vapor deposition (CVD):

A gas-phase reaction where nanoparticles are deposited on a substrate by introducing precursor vapors.

6) Solvent evaporation technique:

Dissolving a polymer in a solvent, adding a drug, and then evaporating the solvent to create polymeric nanoparticles.

The "solvent evaporation method" for nanoparticle synthesis involves dissolving a polymer and desired substance (like a drug) in a volatile organic solvent, then allowing the solvent to evaporate, causing the polymer to precipitate and form nanoparticles around the dissolved substance; essentially, the solvent is removed, leaving behind the nanoparticles made from the polymer matrix encapsulating the desired material.

Key points:

Widely used:

This is a common technique for creating polymeric nanoparticles, particularly for drug delivery applications due to its relative simplicity and ability to control particle size.

Process steps:

- Utilize a suitable volatile organic solvent to dissolve the drug and polymer. Add the solution to an aqueous phase (often with a surfactant to stabilize the emulsion).
- Slowly evaporate the organic solvent, causing the polymer to precipitate and form nanoparticles.

Factors affecting particle size:

- Polymer concentration
- Solvent volatility
- Stirring rate
- Surfactant type and concentration

Synonyms:

Nanoprecipitation method and Solvent displacement method.

Other important aspects:

Top-down vs. Bottom-up:

While most nanoparticle synthesis methods are considered "bottom-up" (building from small components), some techniques like mechanical milling can be considered "top-down" (breaking down larger materials).

Controlling particle size and shape:

Factors like reaction temperature, concentration of reactants, and the use of capping agents can influence the size and morphology of the resulting nanoparticles.

Biological synthesis:

Utilizing organisms like bacteria or plants to produce nanoparticles through bioreduction of metal ions, considered a more environmentally friendly approach.

Nano sponges:

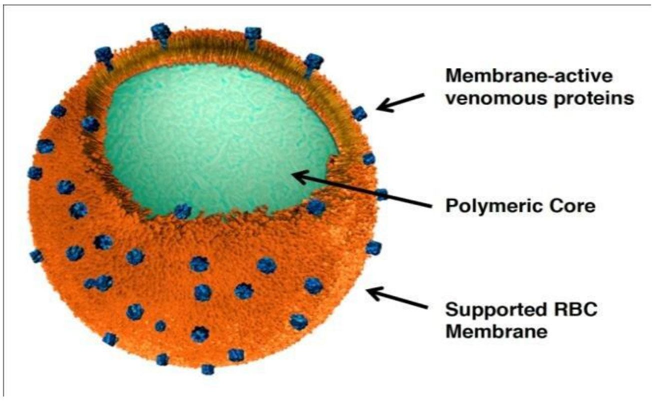
Nanosponges are microscopic, sponge-like particles that are used to deliver drugs, clean up toxins, and repair damaged tissue.[46] They are made of polymers and have pores that are about 1–2 nanometers in size.[47]

Uses:

Drug delivery: Nanosponges can deliver drugs that have low bioavailability, control the release of drugs, and reduce drug toxicity.[48]

Detoxification: Nanosponges can soak up toxins and pathogens from the bloodstream, such as snake venom and toxins from bacterial infections.

Environmental applications: Nanosponges can purify water and metal deposits.[49]
Tissue repair: Nanosponges can be used as a way to control damage after an injury.[50]



Working:

- Nanosponges are made of polymers and have a mesh-like structure with cavities that can hold medications.[51]
- Nanosponges are small enough to move quickly through substances like water or blood.
- Nanosponges can be made to be sturdy up to high temperatures.

Synthesis:

Nanosponges can be synthesized using a solvent method, where a polymer is mixed with a polar aprotic solvent and then crosslinked.
Nanosponges are synthesized using a variety of techniques, including cross-linking, solvent methods, and microwave-assisted synthesis.[52] The method of synthesis depends on the type of polymer used and its concentration.

Synthesis techniques:

Cross-linking:

Cyclodextrins are treated with cross-linking agents to form nanosponges.

Solvent methods:

Nanosponges can be synthesized using solvent condensation, emulsion solvent diffusion, and other solvent-based methods.

Microwave-assisted synthesis:

Cyclodextrins are reacted with cross-linkers in polar aprotic solvents to form nanosponges.

Ultrasound-assisted synthesis:

Nanosponges with uniform spherical sizes can be synthesized using ultrasound-assisted methods.[53]

Properties of nanosponges:

- Nanosponges have a porous structure, high surface area, and a cross-linked three-dimensional network.
- They can be synthesized as neutral or acidic materials.
- They can be utilized in environmental remediation as adsorbents. They can be used in medical research to reduce brain swelling, treat sepsis, and treat ischemic strokes.

Characterization of nanosponges:

Fourier Transform Infrared Spectroscopy (FTIR) can be used to confirm the cross-linking reaction.

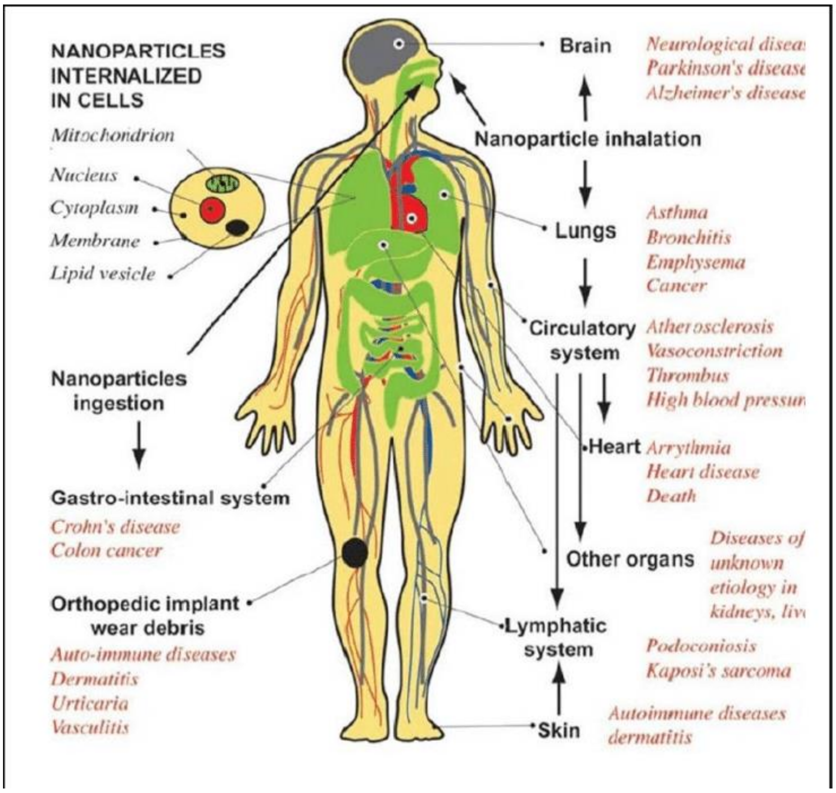
Toxicological Studies of nanoparticles:

These studies are crucial for assessing the safety of nanomaterials used in various applications and developing strategies to mitigate potential risks.[54]
Toxicological studies of nanoparticles, also known as **nanotoxicology**, investigate the adverse effects of nanoparticles on living organisms,[55] examining how their unique size and properties can lead to potential toxicity through mechanisms like oxidative stress, inflammation, genotoxicity, and disruption of cellular functions, depending on factors like particle size, shape, surface chemistry, and route of exposure.[56]

Key aspects of nanoparticle toxicology:

Mechanisms of toxicity:

Oxidative stress: Nanoparticles can generate reactive oxygen species (ROS) which damage cellular components like proteins, lipids, and DNA, leading to cell death or dysfunction.[57]



Inflammation: Nanoparticles can trigger immune responses by activating inflammatory cells and releasing pro-inflammatory cytokines.
Genotoxicity: Some nanoparticles can directly interact with DNA, causing mutations or DNA damage.[58]
Cellular disruption: Nanoparticles can disrupt cell membranes, interfere with cellular signaling pathways, and disrupt organ function.
Factors affecting toxicity:
Particle size: Because of their larger surface area and potential for deeper tissue penetration, smaller nanoparticles typically have a higher level of toxicity.[59]
Shape: Nanoparticle shape (e.g., fibers, spheres) can influence their interaction with cells and potential toxicity.
Surface chemistry: The chemical composition of the nanoparticle surface can significantly impact its interactions with biological systems.
Route of exposure: Inhalation, ingestion, or dermal contact can lead to different patterns of toxicity.

Commonly studied nanoparticles:

Metal nanoparticles: Silver nanoparticles, gold nanoparticles, copper oxide nanoparticles
Carbon nanotubes: Single-walled carbon nanotubes (SWCNTs), multi-walled carbon nanotubes (MWCNTs)
Metal oxides: Titanium dioxide, zinc oxide

Methods for studying nanoparticle toxicity:

In vitro studies:
Using cell cultures to assess cytotoxicity, cell viability, oxidative stress markers, inflammatory responses, and genotoxicity.
In vivo studies:
Animal models to evaluate systemic toxicity, organ accumulation, and tissue damage following nanoparticle exposure.
Biodistribution studies:
Tracking the movement of nanoparticles within the body using techniques like imaging modalities to identify accumulation sites.

Important considerations in nanoparticle toxicology:

Standardized testing protocols:
The need for standardized methods to accurately compare toxicity across different nanoparticles and studies.
Exposure assessment:
Understanding the potential routes of human exposure to nanoparticles in different environments.

Safety concerns and mitigation strategies:

Developing strategies to minimize potential toxic effects of nanoparticles through surface modifications or design considerations.[60]

The primary safety concerns regarding nanoparticles include their potential for inhalation, skin absorption, and ingestion due to their small size, which can lead to toxicity in various organs depending on the nanoparticle type; mitigation strategies focus on proper handling practices like wearing personal protective equipment (PPE), using contained systems like fume hoods or glove boxes, and implementing strict cleanup procedures to minimize exposure to airborne nanoparticles.

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