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Antifertility Potential of Plant-Mediated Bioactive Nanoparticles: Advances in Biomedical Applications

Meghraj Saini, Neha, Neha Bharti, Prity Yadav, Ashish Kumar Kansotiya, Suman Kumari and Pratap Chand Mali*

Reproductive Biomedicine and Natural Products Lab, Department of Zoology, Centre for Advanced Studies, University of Rajasthan, Jaipur – 302004, Rajasthan, India; malipc_zool@yahoo.co.in

Abstract

The application of plant-based bioactive nanoparticles in antifertility research offers a novel and promising approach to contraceptive development. This review examines the extensive potential of various medicinal plants and their bioactive compounds in nanoparticles as effective antifertility agents. Plant-based nanoparticles provide a significant advantage over traditional synthetic contraceptives due to their biocompatibility, reduced side effects, and ability to target specific tissues or cells. This review examines the various mechanisms through which these nanoparticles exert their antifertility effects, including hormonal modulation, disruption of spermatogenesis, and inhibition of fertilisation. The safety profiles, efficacy studies, and potential for integration with existing contraceptive methods are also discussed. By leveraging the inherent benefits of nanotechnology, plant-based bioactive nanoparticles hold the promise of revolutionising contraceptive technology, offering safer, more effective, and sustainable solutions to meet the growing global demand for contraceptives.

Keywords: Antifertility, Contraceptive, Medicinal Plants, Nanoparticle, Nanotechnology

1. Introduction

Overpopulation is one of the most urgent issues of our day and endangers the fragile equilibrium of global sustainability. By 2050, it is anticipated that there will be more than 9 billion people on the planet[1]. Controlling fertility is a major national and international public health priority. All aspects of life, including work, education, housing, healthcare, sanitation and the environment, are deteriorating due to the ever-increasing human population, particularly in developing and underdeveloped countries. It also exerts an inevitable impact on life-sustaining resources[2]. One of the most effective ways to manage and control population growth is by promoting the use of reversible contraceptive methods. These methods allow individuals to plan their families while retaining the option to conceive later in life. Contraception refers to the deliberate methods used to prevent pregnancy by interfering with the process of conception, which is the fertilisation of an egg by sperm. These methods work through various mechanisms, including preventing ovulation, blocking sperm from reaching the egg, or preventing a fertilised egg from implanting in the uterus. Contraceptive options are available for both males and females, of which some are listed below:-

Female contraceptive methods include:

- Birth control pills
- Intrauterine Devices (IUDs)
- Subdermal Implants
- Vaginal Sponges
- Spermicides
- Female Condoms
- Tubectomy

While many of these choices do exist, none is without downsides, which can include lack of availability, and side effects such as nausea, headache, abdominal cramping, breast tenderness, increased vaginal secretions, diminished libido, etc[3].

Most practised contraception options for males

*Author for correspondence

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- Condoms
- Vasectomy
- Coitus interruptus (withdrawal method)

Here, there are drawbacks such as limited effectiveness and irreversibility[4]. The various important contraceptive methods are shown in Figure 1. Research on the ability of plants to prevent fertility in males and females has significantly advanced. Extracts of certain plants influence fertility through various biological mechanisms. These include direct effects on sperm viability, alteration of hormone regulation, and impact on sperm movement and concentration. Their potential applications range from natural contraceptive solutions to therapeutic interventions in reproductive health[5].

The three primary ways to stop population growth are as follows:

- Stop or avoid getting pregnant
- Prevent sperm cells from fertilising the ovum [contraception] or prevent blastocyst implantation [contraception]
- Induce abortion of developing embryos using chemical or surgical means.

Numerous therapeutic plants with antifertility properties can be found in India. People who live in different places around the world have assessed the therapeutic value of plants. Several plants and their active constituents have been studied and possess potential antifertility properties, including spermicidal, anti-implantation, anti-spermatogenic, abortifacient, ecobolic and estrogenic effects. According to the World Health Organisation (WHO), traditional medicine is the sum total of the knowledge, skills, and practices based on beliefs on the theories, beliefs, and experiences indigenous to different cultures to maintain health, as well as to prevent, diagnose, improve or treat physical and mental illnesses[6]. The present study aimed to evaluate the phytochemical studies, toxicity and antifertility activities of medicinal plants on male and female animal models.

Furthermore, to manage population growth, the Indian government launched several initiatives, which

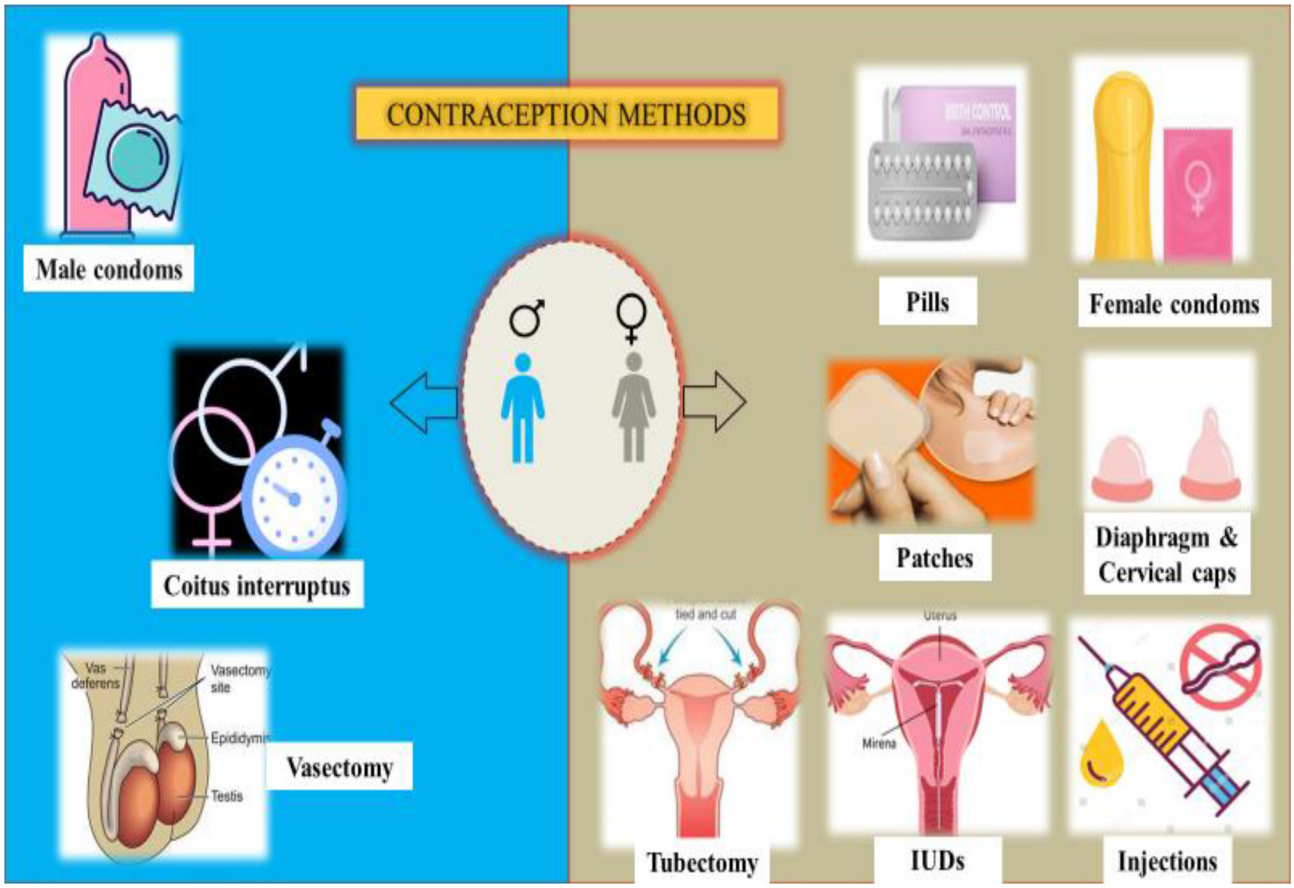


Figure 1. Methods of contraception (made with MS PowerPoint).

include the free distribution of oral contraceptive pills in government hospitals as well as the "National Family Planning Program," which was introduced in 1952, "*Hum do Hamare Do* (we two, ours two)", and "*Nasbandhi* (sterilisation)." Recent studies have documented that certain medicinal plants can interfere with male and female fertility. Furthermore, commercial oral contraceptive pills are often associated with undesirable side effects, making their use challenging for many. As a result, researchers and individuals are increasingly exploring safer and more natural alternatives, particularly those derived from medicinally important plants. Beyond physical discomfort and the risk of infections, one of the major global concerns in controlling the rate of conception remains the need for effective and accessible contraception[7].

2. Plants with Antifertility Activity

The World Health Organisation established seven centres across six countries to study plants and their byproducts and assess their potential to reduce and manage animal reproduction. Traditional systems of medicine have used medicinal plants to control fertility and the birth rate since ancient times. Many plants and their substances are also used by modern pharmacopoeia to assess and improve human fertility[8]. In particular, their effect on sex hormones is specifically useful for suppressing fertility, regularising the menstrual cycle, relieving dysmenorrhea, and treating enlarged prostate, menopausal symptoms, and breast pain (mastalgia) due to hormonal imbalance. Medicinal herbs have been reported to exhibit antifertility effects through various mechanisms of action. Furthermore, plants possessing estrogenic properties can directly control pituitary function through peripheral regulation of Luteinising Hormone (LH) and Follicle-Stimulating Hormone (FSH), reducing their production and inhibiting ovulation[9] (Table 1).

2.1 Antifertility Activity of Medicinal Plants in Males

2.1.1 Anti-Spermatogenic Activity

Plumbago zeylanica, a member of the Plumbaginaceae family, is an evergreen perennial herb growing wild or cultivated in gardens. *P. zeylanica*, also known as *Chitrak* or Leadwort, is a medicinal plant widely used in traditional medicine, especially in Ayurveda. It has a range of pharmacological properties, including antimicrobial, hepatoprotective, anticancer, antifertility, antiulcer, antifungal and wound-healing. The root of *P. zeylanica* has been reported to possess plumbagin. The roots and leaves of *P. zeylanica* are known to possess antifertility properties. Leukoderma, piles, and other skin disorders are treated with it. Its active phytoconstituents include beta sitosterol, trans-cinnamic acid, vanillic acid, plumbagin, isoshinanolone and 4-hydroxybenzaldehyde. Additionally, the number of degenerating Leydig cells increased significantly, whereas the number of Leydig cells decreased. The population of testicular cells was finally reduced. Overall, there was noticeable antifertility activity resulting from this plant in this investigation[10]. *Azadirachta indica*, or neem, is a plant that is a member of the Meliaceae family. Numerous chemical substances are present in it, including polysaccharides, azadirachtin, margosic acid, nimbine, nimbidinate, nimbidol, and nimbidin. Rats were used to test the antifertility property of *A. indica* extract, and the medication dosage was administered subcutaneously at 10mg; and the study lasted 30 days. A 50% ethanolic extract of *A. indica,* administered subcutaneously, would induce arrest of spermatogenesis after being treated for 30 days[8]. Black pepper (*Piper nigrum*) is a flowering vine belonging to the family Piperaceae. The chemical compounds in black pepper include thujone, piperin, piperettine, piperidine, piperolin A, piperolin B, terpene, volatile oil, starch, calcium, phosphorus, iron, thiamine, riboflavin, nicotinic acid, vitamin C, carotene, etc. Oral administration of *P nigrum* fruit powder at doses of 25 and 100 mg/kg body weight per day for 20 and 90 days caused dose- and duration-dependent degenerative changes in the seminiferous tubules of mice testes. This study in males shows antispermatogenic activity of this plant in mice[11]. There has been one recent investigation on the male antifertility effects of *Barleria prionitis* Linn root extract in male albino rats. Male infertility in rats was studied by administering 100 mg/d of *B. prionitis* L. root extract orally. Throughout the 60-day research, the root extract of *B. prionitis* impaired spermatogenesis through the disruption of Sertoli and Leydig cell functions. It reduced sperm quality and reproductive organ biochemical parameters, reversibly decreasing the male rat's fertility[12]. The stem of *Tinospora cordifolia* (family Menispermaceae) contains active phytoconstituents such as columbin, chasanthin, palmarin, berberine, gilion, gilosterol, tinosporin, alkaloids, tinosporic acid, and tinosporol. Traditionally used for treating wounds, fever, and tuberculosis, it also exhibits various biological activities, including antifertility, antioxidant, hypoglycemic, immunomodulatory, and cardioprotective effects. The study

indicated that the stem extract of *T. cordifolia* (Wild) had an antifertility impact in male rats. Male rats were administered 70% methanolic extract *of T. cordifolia* stem extract orally at a dose of 100 mg/kg. The trial lasted 60 days, during which time male fertility decreased and spermatogenesis was arrested entirely[13].

2.1.2 Anti-Androgenic Activity

Hibiscus rosa-sinensis is an evergreen shrub or small tree, which is a species of the Malvaceae family. It is used for various medicinal uses, like herbal medicines, cosmetics, hair dyes, etc. The 50% ethanolic extract of *Hibiscus rosa-sinensis* and the benzene and ether extracts of flowers have antifertility activity. After reviewing studies show that plant extract has an anti-spermatogenic and anti-androgenic action in rats, bats and mice[2]. *Withania somnifera*, a plant belonging to the Solanaceae family, is commonly referred to as *Ashwagandha*. The main phytochemical in it is withanolides. Male albino rats were given a 50% ethanolic extract of *W. somnifera* fruit through the oral route for 60 days at a rate of 50 mg/kg. b.wt./day. This study revealed that lowered androgen levels and testicular degeneration occurred in rats. The reduced testosterone and other androgenic contents impair spermatogenesis and sperm function, thereby decreasing male fertility[14]. According to the research, a 50% ethanolic extract of *Martynia annua* root disrupted the number of testicular and epididymal sperm and induced dose-dependent changes in the seminiferous tubules. The treatment also reduces levels of testosterone and LH in the blood after 60 days. There was no alteration in the FSH levels. It is well established and generally accepted that LH is the primary regulator of testosterone production. LH decrease was probably the principal mechanism by which the *M. annua* extract acted on the testis. Lack of LH stimulation leads to Leydig cell dysfunction in the testes, resulting in reduced testosterone production, which in turn causes a decrease in the size of the seminiferous tubules, as their maintenance is directly dependent on adequate testosterone levels[15].

2.2 Antifertility Activity of Medicinal Plants in Females

2.2.1 Anti-Ovulation Activity

Rivea hypocrateriformis, also known as Midnapore Creeper, is a robust woody climbing shrub belonging to the morning glory family (Convolvulaceae). It is found in dry subtropical forests of India. It has various uses, such as culinary and medicinal, and is also used in Ayurvedic medicine as a contraceptive and for treating cough, headache, skin diseases, malaria, burns, piles, and pain relief. The ethanolic extract of *R. hypocrateriformis* interferes with the oestrous cycle in rats, and because it inhibits steroidogenesis, the level of cholesterol increased after the extract was administered. Increases in the thickness and width of the myometrium and endometrium are indicative of the uterotrophic effect. There was a decrease in Graffian follicles and an increase in atretic follicles, suggesting an antiovulatory effect[2]. The methanolic extract of *Momordica charantia* seeds disrupted the oestrous cycle by prolonging its duration and inducing abnormal cyclicity, likely due to the interference of both ovarian and extra-ovarian hormones that impaired normal ovarian function[2]. Women in Papua New Guinea have long employed *Alstonia scholaris* Linn. (Family: Apocynaceae), also referred to as Devil's tree or *Saptaparna* tree, to cause abortions. At 250 and 500 mg/kg dosages, the hydroalcoholic extract of *A. schloris* (HAAS) demonstrated abortifacient activity of 41.67% and 61.91%, respectively. Further, HAAS generated an abnormal pattern of oestrous cycle in all treated rats. HAAS induced abnormal oestrous cycles in all treated rats and produced estrogenic effects, evidenced by: increased body weight gains, elevated uterine weight, and thickened endometrium at higher doses. These changes resemble the pharmacological profile of synthetic estrogens like Ethinylestradiol (EE), which potently alters uterine morphology and reproductive cyclicity[16].

2.2.2 Anti-Implantation Activity

*Ailanthus excelsa Roxb. (*family Simaroubaceae*)* is known as "tree of heaven," a native Indian tree with strong antifertility and abortifacient properties, traditionally used by women in South India for birth control. The anti-implantation activity was evaluated using a protocol based on the intentional anti-implantation approach described by Stella O. Olagbende-Dada (2009) in Wistar albino rats. Eighteen mature female Wistar rats, six in each of three groups, were produced through colony breeding. One group was used as a control, while two others were used as test groups. Male rats with verified fertility were kept in a 2:1 ratio with proestrous-phase rats. The female rats were examined to verify copulation the next morning. The vaginal swab was examined for significant spermatozoa aggregates. The day the spermatozoa were found in the smear was recorded as Day 1, the first day of pregnancy.

Day 11: All experimental groups had laparotomies performed under light ether anaesthesia to count the number of implantation sites in the uterine horns[17]. The onion family, Amaryllidaceae, includes the plant *Allium cepa*. It is rich in several chemical components, including myristic acid, ferulic acid, β-sitosterol, and kaempferol. Rats were studied as the test models for their antifertility action[18]. *Calotropis gigantea* Linn., a member of the Asclepiadaceae family, is traditionally used for antifertility treatments, particularly utilising its leaves and roots, which are rich in glycosides and cardenolides. It is used to treat whooping cough, cough, asthma, flatulence, and colic. This plant exhibits a range of biological activities, including wound healing, hypoglycemic, anticancer, and antifertility effects. In rats, *Calotropis gigantea* root has been shown to have antifertility effects. Albino rats were given an ethanolic extract to examine its antifertility effects; at a dose level of 250 mg/kg, the extract demonstrated potent anti-implantation activity[8]. Experimental studies confirm that oral administration of *Ocimum sanctum* leaf extract at a dose of 500 mg/kg/day for 20 days significantly reduced the number of implantation sites[19]. When *Striga orobanchioides* flavones, luteolin, and apigenin were administered to rats, it was observed that the rats' epithelial cell height, endometrial thickness, diameter, and uterine weight increased in comparison to the control rats[20].

2.2.3 *Abortifacient Activity*

Plumeria rubra L., a latex-secreting plant of the Apocynaceae family, is widely used in traditional Indian medicine. While the bark and roots are employed to treat fever, induce menstruation, relieve constipation, and manage asthma, the fruit (specifically, the pod) is traditionally used as an abortifacient in India[21]. *Balanites roxburghii* fruit ethanolic extract exerts potent abortifacient activity in rats, accompanied by increased uterine weight and structural changes in the endometrium, likely mediated through its mild estrogenic and hormonal modulatory effects[2]. The leaves of *Spondias mombin* (family Anacardiaceae) are revealed to have antifertility properties. Flavonoids, quercetin, ellagic acid, and rutin are the active ingredients. It has biological activities, including antibacterial and antioxidant properties, and treats insomnia, epilepsy, and psychosis. The authors examined the *in vivo* effectiveness of this plant extract on female rats' reproductive performance. The plant's abortifacient and anticonceptive properties were assessed. Estrogenic action was tested in ovariectomised rats. This plant's acute toxicity tests were also evaluated, and the

Table 1. List of plants that have antifertility properties

Plants Name	Common Name	Family	Part Used	Activity	Reference
Abrus precatorius	Goonj	Fabaceae	Seed	Abortifacient	[24]
Achyranthus aspera	Aaghada	Amranthaceae	Root	Antiimplantation	[24]
Aloe barbadensis	Aloe vera	Asphodelaceae	Leaf	Antiovulatory	[25]
Aegle marmelos	Bael (Golden Apple)	Rutaceae	Bark	Antiandrogenic	[26]
Balanites roxburghii Linn.	Hingan	Zygophyllaceae	Fruit	Antispermatogenic	[27]
Caesalpinia bonducella	Fever Nut	Caesalpiniaceae	Seed	Antispermatogenic	[28]
Crataeva nurvala	Varuna	Capparidaceae	Stem	Antioestrogenic	[24]
Crotalaria juncea Linn.	Sunn Hemp	Asteraceae	Seed	Antispermatogenic	[29]
Dactyloctenium aegyptium	Crowfoot Grass	Poaceae	Leaf	Antispermatogenic	[30]
Heliotropium indicum	Common Weed	Boraginaceae	Whole plant	Abortifacient	[22]
Hymenocardia acida	Large Red-Heart	Phyllanthaceae	Bark	Antiimplantation	[23]
Martynia annua	Devil's Claws	Pedaliaceae	Root	Antispermatogenic	[31]
Mentha arvensis Linn.	Pudina	Lamiaceae	Leaf	Antiandrogenic	[32]
Momordica charantia	Karla	Cucurbitaceae	Seed	Antiestrogenic	[33]
Pueraria tuberosa DC.	Vidharikand	Fabaceae	Roots	Antispermatogenic	[34]
Semecarpus anacardium Linn.	Bhilawa	Anacardiaceae	Fruit	Antispermatogenic	[35]
Jatropha curcas	Purging Nut	Euphorbiaceae	Flower	Antiestrogenic	[6]

results showed that it has no adverse effects. Despite having anticonceptive properties, this herb did not have any abortifacient properties, as evidenced by the number of pregnant animals after the third trimester. Furthermore, the extract showed no estrogenic activity. The plant's aqueous ethanol extract, however, exhibited strong anti-contraceptive properties[8]. *Derris brevipes* (Papillionaceae) at a dose level of 600 mg/kg, delivered by mouth of an alcoholic extract (ethanol) of the root, resulted in a 40% delay in implantation. The ethanolic extract of the root of *Derris brevipes* prevented the pregnant rats from giving birth, after the complete gestation period, indicating that the extract had 100% anti-implantation and abortifacient effect[22]. Female albino rats' reproductive processes are inhibited by the dilute ethanolic extract of *Hymenocardia acida* (stem bark). When the extract was taken through the oral route between days 1 and 19 of pregnancy, the number of corpora lutea and live fetuses decreased ($p<0.05$)[23].

3. Biomedicinal Activities of Herbal Nanoparticles and Their Use

Nanoparticles are particles with their size in the range of one to one hundred nanometers. Nanoparticles play an increasingly important role in fertility control. Nanoparticles offer innovative strategies to enhance or limit reproductive capabilities. Researchers are exploring their use in gene therapy to address genetic disorders affecting fertility, such as Turner's syndrome and Klinefelter's syndrome. Additionally, magnetic nanoparticles have been utilised in some studies for sperm purification. Researchers pick sound samples for *in vitro* Fertilisation (IVF) and other fertility procedures. On the contrary, specific nanoparticles, particularly those biosynthesised by plants, are being investigated for their potential antifertility effects, possibly affecting both male and female reproductive systems.

3.1 Properties of Nanoparticles

- They serve as a useful link between atomic or molecular structures and bulk materials.
- Particularly at high temperatures, nanoparticles' high surface area to volume ratio offers a powerful driving force for diffusion. Sintering can occur over short periods and at lower temperatures than larger particles.
- The interaction of the particle surface with the solvent is enough to overcome density differences, which typically cause a substance to either float or sink in a liquid, creating nanoparticle suspensions.
- Moreover, nanoparticles are small enough to contain their electrons and create quantum effects, so they frequently have surprising optical characteristics. For example, gold nanoparticles appear in the solution in dark red to black.
- Janus particles are a type of nanoparticle that is particularly useful for stabilising emulsions since it is half hydrophilic and the other half hydrophobic[36].

Encapsulation refers to the technological process of enclosing or entrapping active compounds within protective materials at the nanoscale level. This fundamental technique protects encapsulated substances from degradation, improves their bioavailability, and enables controlled release at specific target sites. Nanoencapsulation operates by creating core-shell structures where the active substance (internal phase) is surrounded by an encapsulating material (external phase), forming particles typically ranging from 10 nanometers in size. There are several ways to encapsulate nanoparticles, including dendrimers, lipid monolayers, liposomes, etc. Their (liposomal drug) distinct characteristics, such as amphiphilic nature and higher loading capacity, increase their efficacy against bacteria. Liposome-encapsulated antibiotics demonstrate substantially improved antibacterial activity compared to free drug formulations. This enhanced efficacy results from several key mechanisms that overcome bacterial resistance and improve drug delivery to infection sites[37]. In reproductive biology, nanoparticles smaller than 100nm in diameter can be employed to distribute herbal medications[38]. Herbal nanoparticles have been used to overcome obstacles to the application of herbal medicines[39]. As an advanced field, nanotechnology offers novel approaches to managing and treating disorders affecting the female reproductive system by facilitating the exact manipulation and control of biological molecules and cells. Nanodelivery systems allow medications to be delivered precisely, reducing side effects and increasing therapeutic effectiveness. Additionally, nanomaterial imaging methods improve diagnostic sensitivity and accuracy, supporting the evaluation of the development and severity of illness[40]. There are different methods of synthesis of nanoparticles shown below (Figure 2). *Bandicota bengalensis*, commonly known as the lesser bandicoot rat, Sindhi rice

rat, Bengal rat, or Indian mole-rat, is a giant rat species of Southern Asia. The potential of solid lipid nanoparticles (PSCEN stands for Papaya Seed Chloroform Extract-based Solid Lipid Nanoparticles) based on papaya seed chloroform extract as an antifertility agent in male *Bandicota bengalensis* was first formulated and examined in this work. Spherical, 300–600nm-sized nanoparticles were produced. To evaluate PSCEN's antifertility effects, adult male rats were given a diet with two distinct PSCEN concentrations (5% and 10%) for 15 days in a bi-choice setting. In the two treatment groups, the rats' mean intake of total active ingredients varied between 2.13g-3.31g and 3.92g-5.87 g/100 g body weight, respectively. There were no significant effects on body weight while, in contrast to the vehicle control group, there was a substantial rise in sperm abnormalities (%) and a significant decrease in sperm motility (%), sperm viability (%), sperm count (millions/ml), sperm mitochondrial activity (%), sperm nuclear chromatin de-condensation (%), and sperm hypo-osmotic swelling (%)[42]. Plumbagin is a naturally occurring naphthoquinone, predominantly derived from the plant *Plumbago indica Linn.*, a member of the Plumbaginaceae family. Plumbagin possesses various pharmacological properties. The antifertility potential

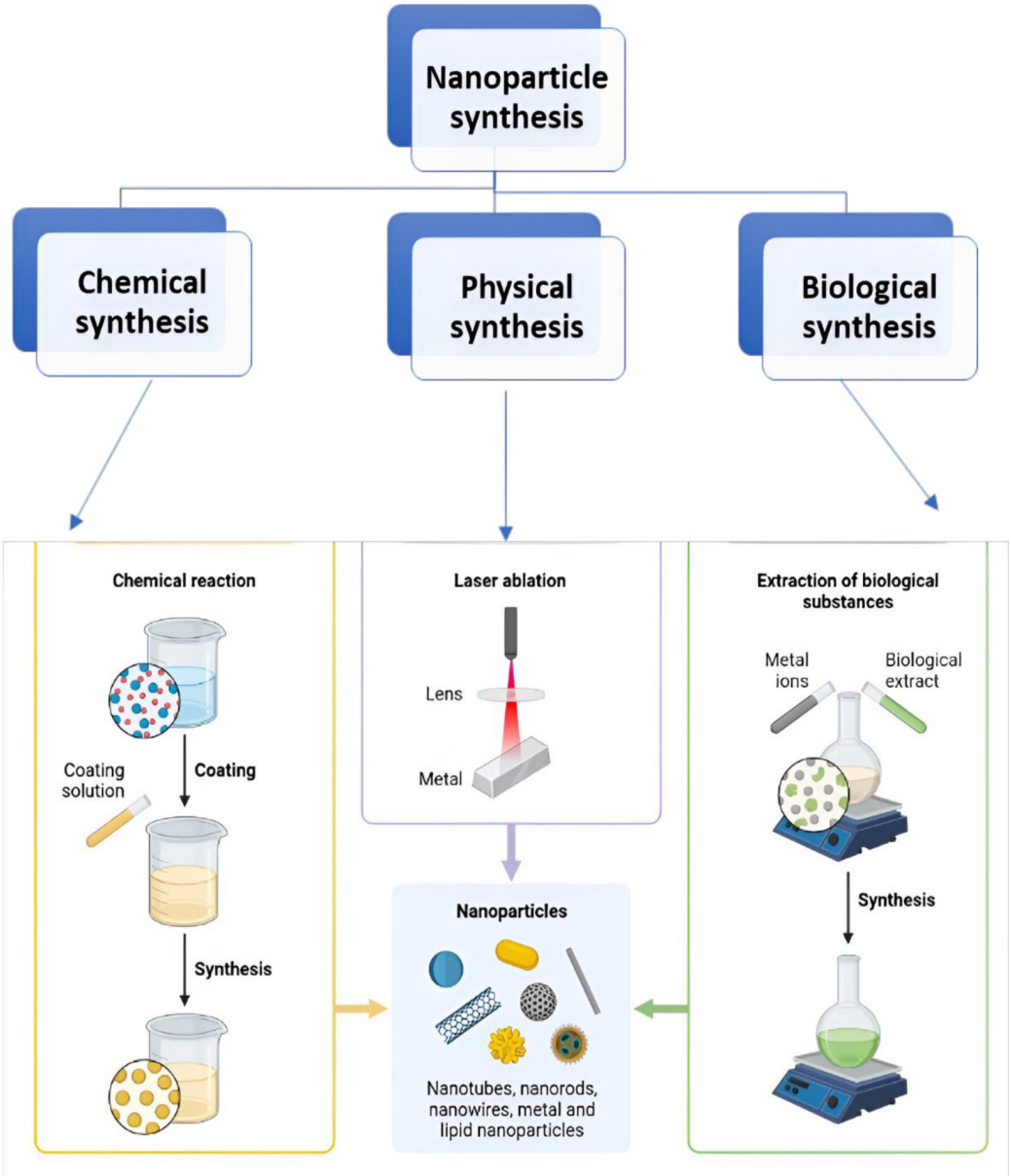


Figure 2. Types of nanoparticle synthesis (created with biorender.com)[41].

Table 2. Nanoparticles and their biological activities

Botanical Name	Family	Part Used	Used Nanoparticles	Biological Activites	Reference
Ammannia baccifera	Lythraceae	Aerial part	Ag	Antimalarial	[44]
Bergenia ciliate	Saxifragaceae	Rhizome	ZnO	Antibacterial, Anticancer	[45]
Butea monosperma	Fabaceae	Flower, Leaf, Bark	ZnO	Antibacterial	[46]
Cannabis sativa	Cannabaceae	Leaf	Au	Anti-acute leukaemia	[47]
Carica papaya	Caricaceae	Seed	Au	Anti-spermatogenic	[48]
Curcuma kwangsiensis	Zingiberaceae	Leaf	Au	Antiovarian cancer	[49]
Eruca sativa	Brassicaceae	Leaf	Se	Antioxidant	[50]
Fumaria officinalis	Papaveraceae	Leaf	Ni	Antiovarian cancer	[51]
Gymnema sylvestre	Asclepiadaceae	Leaf	Au and Ag	Antioxidant and Anticancer	[52]
Hibiscus rosa sinensis	Malvaceae	Leaf	Ag	Antimicrobial	[53]
Moringa oleifera	Moringaceae	Leaf	Fe	Antibacterial	[54]
Moringa oleifera	Moringaceae	Leaf	ZnO	Antispermatogenic	[55]
Ocimum americanum	Lamiaceae	Leaf	ZnO	Anticancer, Antimicrobial	[56]
Plumeria alba	Apocynaceae	Flower	Ag	Antioxidant	[57]
Panax Red ginseng	Araliaceae	Root	Ag & Au	Antimicrobial	[38]
Salvinia molesta	Salviniaceae	Leaf	Ag	Antimicrobial	[58]
Tecomella undulata	Bignoniaceae	Leaf	Ag	Antispermatogenic	[59]

of the plumbagin-loaded nanoparticles was evaluated in albino Wistar rats. The i*n vivo* studies demonstrated a significant decline in the reproduction rate of treated rats compared to controls. This study aimed to create a formulation of bioactive molecules (plumbagin) loaded into nanoparticles by employing experimental design to examine the formulation properties and *in vivo* antifertility activity. The number of follicles can provide important information about how the ovary functions, especially how the processes regulating and promoting folliculogenesis interact[43] (Table 2).

4. Conclusion

The use of nanoparticles synthesised using plant extracts for antifertility applications holds significant promise as a novel, sustainable, and biocompatible strategy for fertility regulation. Plant-derived nanoparticles, benefiting from the natural bioactive compounds present in plant extracts, offer several advantages, including low toxicity, biodegradability, and the potential for targeted delivery, which can enhance the specificity and effectiveness of contraceptive interventions. Studies in animal models have demonstrated the potential of these plant-derived nanoparticles to effectively modulate reproductive functions such as hormonal regulation, spermatogenesis disruption, and fertilisation inhibition. The biocompatibility and reduced side effects of natural plant extracts make them a promising alternative to synthetic contraceptives. However, further research is necessary to optimise these formulations, evaluate long-term safety, and conduct clinical trials to confirm their efficacy in humans. If successfully developed, this approach could offer a safer, eco-friendly, and more sustainable alternative to traditional synthetic contraceptives, with broad implications for both human and animal reproductive health.

5. Future Scope

The future scope of antifertility using herbal nanoparticles is quite promising. Researchers are exploring the potential of herbal nanoparticles to provide safer and more effective contraceptive options.

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