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Sustainable approaches for the synthesis of biogenic platinum nanoparticles

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Abstract

Background The era of nanotechnology become widespread for research and human resource development due to its functionalized tuning with economical, eco-friendly, effective and sustainable end-products. Hence, the present review illustrates the biogenic fabrication of platinum nanoparticles (PtNPs) through the different sustainable and cheaper approaches.

Main body of the abstract Over the physicochemical-based nanotechnology, the biogenic active substances-based synthesis displayed the more promising candidature due to its non-toxic, Broad-spectrum applicability and defendable type character. The biogenic synthesis method is capable with and without capping and highly motif of reducing agents. The morphology and stability of synthesized PtNPs are mostly mediated by various experimental conditions such as pH, temperature, incubation time, concentrations of biomaterials and salts or enzymes used. Hence, the review is aiming to discuss the methodology of biogenic synthesis of PtNPs by plant stem, root, leaf, flower, fruit, extracts, algae, fungi and egg yolk. Also, we have illustrated the pharmaceutical drug model application and its adverse effect.

Short conclusion Synthesized PtNPs are open a new trend in catalyst, drug and its carrier and in cancer treatment. PtNPs are utilized as a new therapeutic agent for inhibiting the microbial pathogens with non-toxic behavior. The characterization of PtNPs could estimate the bio-sensitized properties which leads the commercial applications.

Keywords PtNPs, Biogenic synthesis, Toxicity, Bioactive product, Pharmaceutical applications

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Background

Nanomaterials influence and cover the multivariate areas like catalytical, electrical, mechanical, photo-electrical, medicinal, paint, chemical application, food industry, etc., due to their surface property, material combination, size variants, electron configuration, surface area to volume ratio, energy variation, etc. (Sana et al. 2020; Singh et al. 2023). Among it, the interest in Platinum nanoparticles (PtNPs) is its unique structural, optical and catalytic properties that make it expeditious and a promising catalyst endowed with biomedical properties (Yerpude et al. 2023).

Platinum (Pt), a priceless transition metal which has exceptional results likes, electrical and catalytic unique features and superior resistance corrosion mechanisms have been commonly applied in atomic, pharmaceutical, petrochemical, electronica and energy sector. Platinum component, as well as its Alloys have distinctive potential in dehydrogenation hydrogenation and limited oxidation catalysis, of a range of significant molecules, extremely important in several industrial processes. The different crystal surfaces of Pt may have substantially different atomic arrangements and electronic structures which lead to dramatically different response toward same reaction (Zhou et al. 2009). Pt, in a particular concentration, nanoparticles may behave as antioxidants (Zhang et al. 2010). Products that had properties like multiple anticancer activities, are being sought recently. Some studies suggested that the usage of nanoparticles in anticancer treatments produces a synergistic impact, very significant, decreases the possibility of side effects and affects patients increase in long-term prognosis (Manthe et al. 2010). The PtNPs however have a detrimental impact on cancer cells. Because of this, researchers have partly abandoned studies on the use of platinum as anticancer agent (Gu et al. 2019; Wang et al. 2022).

There are different kinds of methods like physical and chemical are employed to the synthesis of PtNPs preparation; however, eco-friendly approach is the promising approach and in now day's interest is due to the toxic behavior of nanoparticles (Agarwal et al. 2019). Biological methods can reduce the toxic effect of the particle. Biological processes are well known to have a good efficiency for generating spherical morphology, compact size and stable chemical nanoparticles (Jeyaraj et al. 2019; Gholami-Shabani et al. 2023). The plants and biological lichens are used as an option for the formulation of nanomaterials rather than dangerous chemicals by researchers because they are non-toxic, inexpensive and easily available. The plant's phytochemicals play a significant part in the production of nano-pharmaceuticals (Sana et al. 2021; Singh et al. 2022). Unlike other inorganic nanoparticles, bioactive molecules in plants help produce PtNPs. In addition, the organic PtNPs are competing with chemically synthesized nanoparticles in order to ensure adequate shape and size that the regulated reaction conditions provide better stability and it is right time to unveil the use of PtNPs as nanomedicine for vegetables. Nanoparticles synthesis for microorganisms, plants or its extracts and enzymes, proposed as possible environmentally friendly alternatives to physicochemical methods, systematic paradigm shown in Fig. 1 (Song et al. 2010; Singh et al. 2020; Muñiz-Diaz et al. 2022). Green-biogenic approaches of preparation of the platinum particle is the major aspects of this review. The current progress in biogenesis of PtNPs have been mentioned in the Table 1.

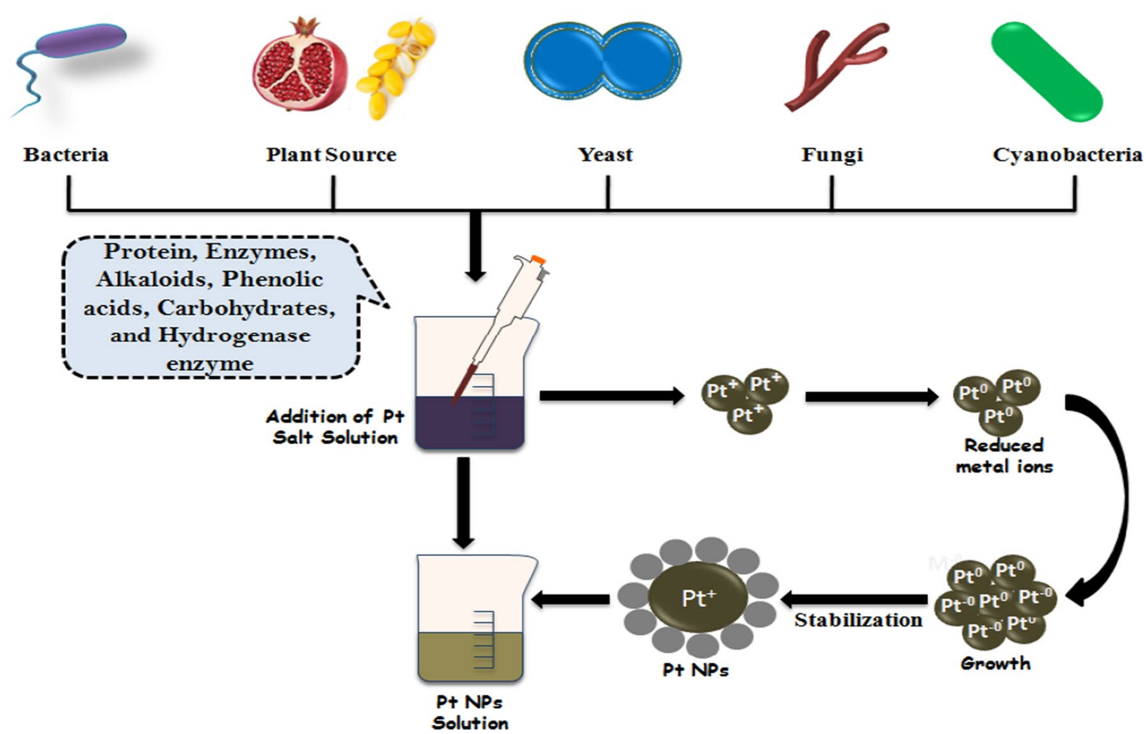

Fig. 1 A general process for the nanoparticle synthesis for algae, fungi, bacteria and Enzymes

Table 1 Biogenesis of PtNPs by various types of biomaterials

S. No.	Plant	Part used	Size (nm)	Shape	References
1.	*Azadirachta indica*	Leaves	5–50	Small and large spheres	Thirumurugan et al.(2016)
2.	*Phoenix dactylifera*	Fruit	1.3–2.6	Spherical	Sadalage et al. (2022)
3.	*Lantana camara*	Leaf	35	Spherical	Latif et al. (2019)
4.	*Prunus x yedoensis*	Gum	10–20	Circular	Guleria et al. (2022)
5.	*Camellia sinensis*	Leaf	30–60	Flower	Göl et al. (2020)
6.	*Antigonon leptopus*	Whole plant	5–190	Spherical	Ganaie et al. (2018)
7.	*Barleria prionitis*	Leaf	1–2	Spherical	Rokade et al. (2017)
8.	*B. prionitis*	Leaf	1–2	Monodispersed	Rokade et al. (2017)
9.	*Ocimun sanctum*	Leaves	23	Irregular	Soundarrajan et al. (2012)
10.	*Pinus resinosa*	Bark	6–8	Irregular	Jeyaraj et al. (2019)
11.	*Cacumen platycladi*	Whole biomass	2.4`±0.8	Spherical	Zheng et al. (2013)
12.	*Anacardium occidentale*	Leaf		Irregular and rod shaped	Sheny et al. (2013)
13.	*Diospyros kaki*	Leaf	2–20	Spheres and plates	Song et al. (2010)
14.	*Fumariae herba*	Whole herb	30	Hexagonal and pentagonal	Dobrucka (2015)
15.	*Punica granatum*	Peel	16–23	Spherical	Jha et al. (2018)
16.	*Piper betle L*	Leaf	2.1 ± 0.4	Spherical	Rajasekharreddy and Rani (2014)
17.	*Dioscorea bulbifera*	Tuber	2–5	Spherical	Ghosh et al. (2015)
18.	*Gloriosa superb*	Tuber	0.83–3	Spherical	Rokade et al. (2018)
19.	*Eichhornia crassipes*	Leaf	3.74	Spherical	Oluwafemi et al. (2016)
20.	*Quercus glauca*	Leaf	5–15	Spherical	Karthik et al. (2016)
21.	*Bacopa Monnieri*	Leaf	5–20	Spherical	Nellore et al. (2013)
22.	*Cochlospermum gossypium*	Tree Gum	2.4	Spherical	Vinod et al. (2011)
Bacteria					
1.	*Acinetobacter calcoaceticus*	Intracellular	2–3.5	Cuboidal	Gaidhani et al. (2014)
2.	*Saccharomyces boulardii*	Intracellular	80–150		Borse et al. (2015)
3.	*Plectonema boryanum* UTEX 485	Cell extract	< 300	Spherical	Brayner et al. (2007)
4.	*Calothrixv* cyanobacteria	Intracellular and extracellular	3.2		Jeyaraj et al. (2019)
5.	*Acetobacter xylinum*	bacterial cellulose (BC) matrix	6.3–9.3	Granulated	Aritonang et al. (2014)
6.	*Escherichia coli* MC4100	Cells biomass	2.3 ± 0.7	Spherical	Attard et al. (2012)
Fungi					
1.	*F. oxysporum*	Extracellular	10–50	triangle, hexagons, square, rectangles	Riddin et al. (2006)
2.	*Neurospora Crassa*	Intracellular	2–3, 4–35, 7–76 and 20–110	Quasi spherical, single crystalline and round nano-aggregates	Castro-Longoria et al. (2012)
3.	*Cordyceps sp.*	Whole fruiting body	13.34 ± 4.06 nm	spherical	Liu et al. (2022)
Algae					
1.	*Padina gymnospora*	–	25	Octahedral	Ramkumar et al. (2017)
2.	*Plectonemaboryanum UTEX 485*	Cell extract	< 300	Spherical	Lengke et al. (2006)
3.	*Halymenia dilatata*	Aqueous cell extract	15 ± 1.7	spherical	Sathiyaraj et al. (2021)

Main text

Phytochemicals approaches for green synthesis of PtNPs

Plant biomolecules-based synthesis has increased quality attention of the researcher for the synthesis of PtNPs. It is due to the seamless advantage cheaper, simple, speedy, facile, green, non- toxic and efficient. Moreover, the required form, shape and size can be generated easily by altering the parameters such as reducing agent, time, temperature and pH (Naseer et al. 2020). Plants are the richest sources of potential and novel biomolecules which make it a perfect candidate in nanotechnology application (Rawat et al 2020; Li et al. 2022; Wu et al. 2023). Moreover, phytochemical-based PtNPs are in need to be discover for multivariate uses and hence a critical review needs to done for the green synthesis of PtNPs. Remarkable studies of the synthesis *Ocimum sanctum* (Tulsi) leave extract mediated PtNPs synthesis was reported by Fahmy et al. (2020) which was accomplished at 100 °C for 1 h. Moreover, a successful PtNPs was achieved at room temperature by continuous stirring for 20 min. of the plant extract to Pt(IV) ions with the ratio of 1:9 (Fahmy et al. (2020). Similarly, Nellore et al. (2013) had reported the PtNPs by the interaction of leaf extract of *Bacopa monnieri* and Pt(IV) ions at room temperature, though the ratio was 1:4. Song et al. (2010) have described the *Diospyros kaki* (Persimmon) leaf extract-based green synthesis of PtNPs and achieved the > 90% of Pt(IV) ions reduction into PtNPs at 95 °C for 2–3 h. At same temperature (95 °C) Sheny et al. (2013) have synthesized the PtNPs by mixing the leaf powder of *Anacardium occidentale* with Pt(IV) ions.

Antimicrobial potential of green PtNPs

For PtNPs synthesis *Taraxacum laevigatum* was used to improve the bio-activity of nanoparticles. The resonance peak of the surface plasmon was seen the structure of platinum nanoparticles clearly represents 283 nm. The findings show that the genomics-synthesized particles were compatible, small and spherical in shape, dispersed (Tahir et al. 2017). These nanoparticles have been tested for the inhibition of 'gram positive' bacteria and 'gram-negative' bacteria (as *Pseudomonas aeruginosa* and *Bacillus subtilis*). The findings showed that 15 ± 0.5 mm and 18 ± 0.8 mm zone of inhibition were formed by PtNPs for *P. aeruginosa* and *B. subtilis*, respectively. The relevant consequence of this study is based on the strongest antibacterial activity of PtNPs against the multidrug resistant pathogenic bacterium *P. aeruginosa* and *B. subtilis*. It revealed the wide application of PtNPs as a good antibiotic against antibiotic defense mechanism (Hosny et al. 2022). The plant's phytochemicals play a significant role in the NPs synthesis. Organic water-soluble moieties of plants not only used to reduce but also stabilize the nanoparticles that prepared (Kharisov et al. 2014). The latest findings show that the extract of plants is more useful for metal NPs preparation over the conventional approaches because of its consistent particles with high bio-molecular concentrations, e.g., flavonoids, terpenoids, tannins, phenols, alkaloids, quinines, etc. These were accountable for metal nanoparticles reduction and stabilization (Botha et al. 2019; Gour and Jain 2019). The plant-based PtNPs have been manufactured from *Azadirachta indica* (Thirumurugan et al. 2016), *Antigone leptopus* (Selvi et al. 2020), Orange Peel extract (Karim et al. 2019) and Ajwa and Bardni dates (Aygun et al. 2020), which are used to decrease, cap and stabilize the plant growth and inhibits the phytopathogens. These synthesis are basically depending on the polyphenol mediated reduction of Pt ions which is present in the plant leaf, fruits or peel extract (Kumar et al. 2013).

Smaller and spherical nanoparticles are more successful for antimicrobial activity than the uneven formed NPs (Raza et al. 2016). Metal nanoparticles have been suggested to inhibit various mechanisms for bacteria. Prior studies indicate that released nano-particular metals within pathogenic bacteria creates OH• and O_2−• superoxide radicals. If these reactive species are more than bacterial cell scavenging capacity, causes damage to the cell (Dahiya et al. 2013). High PtNPs activity can be directly accredited to its smallest size and the uniform distribution. Current research effort reveals that the PtNPs could be an environmentally friendly, more economical solution and active antibacterial agent for bacterial pathogen inactivation (Ye et al. 2022).

Clinical potentials of green PtNPs

Developing an economically viable and environmentally friendly technique for the production of NPs is also important in the Nanobiotechnology branch. Biological synthetical method of novel PtNPs have been investigated through *neem* extract in the present study and characterized (Thirumurugan et al. 2016). A green bio-synthetic path to PtNPs synthesis with *Xanthium strumarium* extract leaf is pointed out. The synthetic methodology is very straight forward and one step rather than using a capping and removal agent. The nanoparticles also have potent cytotoxic effect on HeLa, the cancer cell lines with an IC50 were also investigated by the MTT assay as well as other biological profiles, such as *In vitro* antibacterial activity and *In vitro* antifungal activity, and show significant activity (Kumar et al. 2019). Plant crude extracts are the source of such special secondary metabolites as flavonoids and terpenoids, and these compounds plays an important role in reducing ionic to bulk metallic nanoparticles formation. Biosynthesized nanoparticles tested successfully changes involving apoptosis, genotoxicity and oxidative stress (Khan et al. 2021). Furthermore, nanoparticles are widely used in the agricultural, plant sciences and used in managing food waste (Singh et al. 2021). Plant related NPs in different areas have gained a lot of attention since, plant manufactured NPs can easily be produced without help of any special agent for capping/stabilizing and reducing agent. Metabolites of plants likes terpenoids, phenols, alkaloids, flavonoids, quinines etc. used for NPs. Material which acts as a reduction and stabilization agent and produces the Metal-NPs in an environmentally friendly manner as seen in Fig. 2.

Broad application of PtNPs

Because of the cytotoxic activity of platinum nanoparticles would be very precious in the field study of the biomedical applications and biosynthesis of PtNPs. PtNPs are also reported recently as an anticancer agent from *Punica granatum crusts* on human breast cancer cell lines (Sahin et al. 2018). The redox process to metabolize eco-friendly nano-sized particles is continuously correlated with certain primary and secondary metabolites. Different work carried out on the breast cancer cell line in human, MCF-7 has confirmed the cytotoxic effects of *Punica granatum* crusts biosynthesized PtNPs and acts as anti-tumor compound. Sphere-shaped PtNPs with size 20 nm were grown through this green synthesis method. Anti-microbial activity of synthesized PtNPs have been studied by several researchers. Keeping the same in mind, it has been revealed that PtNPs is in contrast to the bacterial negative zeta potentials which have been enhanced the antibacterial properties. Researches also indicated the potential application of PtNPs against the cancer. Membrane potential studies of PtNPs against cancer have been shown via cancer cell lines and were found significantly triggered by the increased concentration of the sample (Noah and Ndangili 2022). In all test concentrations of HeLa cell line displayed more proliferative effect in 24 h. In general, the inhibition of bacteria in combination with β-lactam drug class against antibiotic aminoglycosides class may be infringed. In this main sense, it may propose that the nanoparticles serve as an agent to use to damage the bacteria's cell wall and transmit streptomycin to the cells, and then operate upon the protein synthesizer that destroys bacteria shown in Fig. 3.

Colloidal platinum nano-structures adsorbent with organic capping agents plays key roles in many ways in the process management. Long organic capsulating chains have a hydrophobic and stereo obstacle effect, thus, stabilizing PtNPs to avoid direct contact with relatively high energy platinum surfaces (Lin et al. 2019). Because of the adsorption of capping agents, the

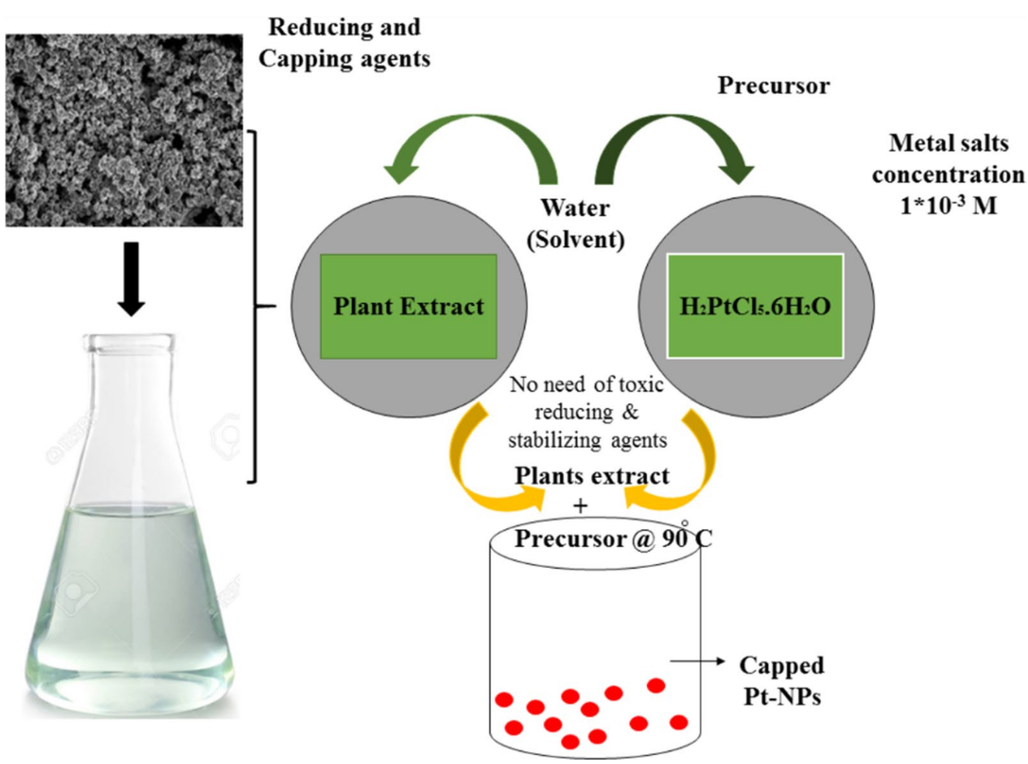

Fig. 2 Illustration of process of production of PtNPs by using the plant extract and platinum salt via environmentally friendly manner

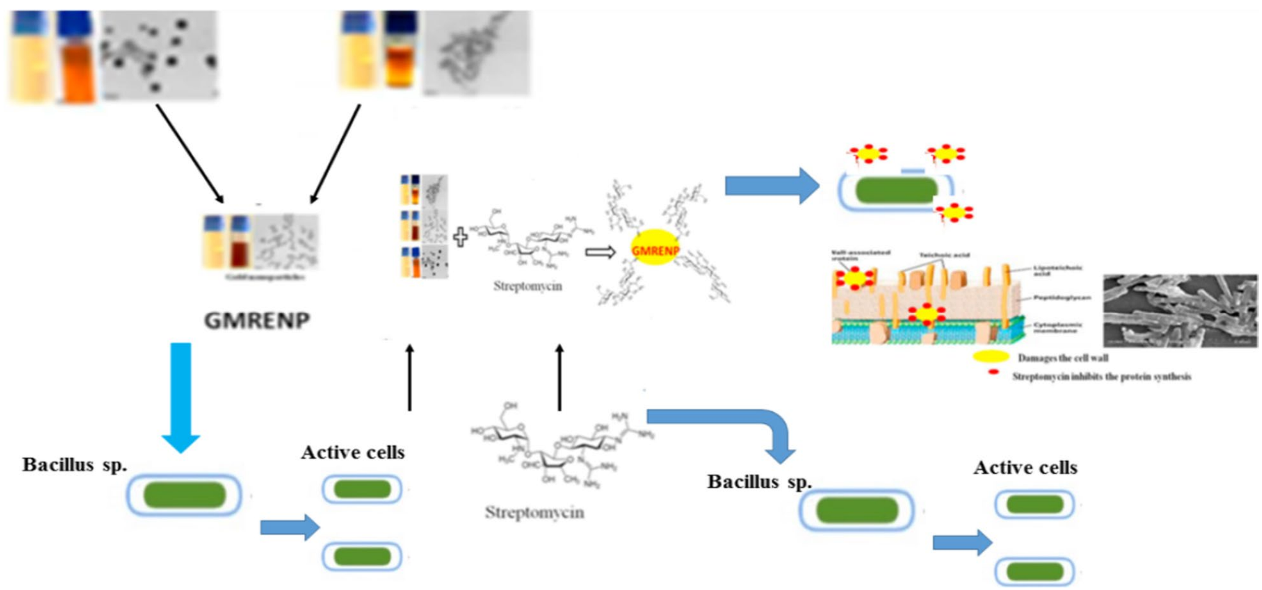

Fig. 3 Schematic description of the synergies of metal nanoparticles tagged with the antibiotics

reduction in total excess energy free prevents PtNPs from further growth and Ostwald maturation. Therefore, the morphology of the nano-crystals can be tested when capping agents adsorb very selectively on given platinum particles surfaces (Kuhn et al. 2008).

The platinum nano-crystals contain diverse electronic structures as well as nuclear configurations with different dimensions; one can assume that these surfaces absorb capping agents separately. The favored adsorption of one surface over another will lead to various development levels along different lenses. The solvent atoms will probably be more vulnerable to anisotropic growth in the less covered platinum surface region. The proper reactive interaction of guest molecules with different platinum faces, which must be balanced however choosy in desorption and adsorption, is a key criterion in choosing the right capping agent for both the shape regulation. The processing of PtNPs by plants has proved to be a feasible way to ensure the environment.

Aygun et al. (2020) have successfully synthesized the PtNPs by using the *Nigella sativa L.* (black cumin seed) extract as a reducing agent. Moreover, the results revealed its cytotoxic potential through the MDA-MB-231 breast (IC50: 36.86 μg/mL) and HeLa cervical cancer lines (19.83 μg/mL) and antibacterial potential against gram ± and gram- bacteria at the concentrations of 100 and 500 μg/ml. This inhibition was obtained by the proliferation of tested NPs. In addition, the microscopic analysis displayed that the cells morphology has been changed after 24 h during the treatment with synthetic nanoparticles with different concentrations. These findings revealed the PtNPs pharmaceutical potentials and indicating its eco-enterprising. Several researchers displayed the PtNPs synthesis by using the pomegranate and dates and indicated its impact on MCF-7 breast cancer cell line. Interestingly, the date extract PtNPs was found effective against the HepG-2 hepacellular carcinoma cell lines which is a common cancer of the colon. Previous studies have also shown that cytotoxic activity of biosynthesized PtNPs against the A549 human pulmonary adenocarcinoma (PA-1), ovarian teratocarcinoma, cell lines of Mia-Pa-Ca-2 and cell induction arrest of stage. Furthermore, the microscopic visualization of cell proliferation and morphological alteration in cytotoxic lines have proven the end application of it. Gurunathan et al. (2019) have visualize the PtNPs (conc. of 25–150 μg/mL) effect on Human Monocytic THP-1 Cell Line after the 24 h exposure and found a unique solution for the treatment of augmented oxidative DNA damage and impaired DNA integrity.

With the modernization of NPs studies, the plant derived specified compound coated PtNPs nanozymes displayed the impressive accomplishments in nanotechnology. Ma et al. (2021) developed the portable mini-drainage device with real-time monitoring assay powered by the VitaminC-coated PtNPs (AA-PtNPs) which can perform as a catalase to catalyze the breakdown of H_2O_2 to O_2. Apo-ferritin encapsulated PtNPs are also a good example of PtNPs powered nanozymes which exhibit super oxide dismutase (SOD) enzyme-like activities and also it retains the SOD derivative activity in cell culture models (Jawaid et al. 2014).

The green synthesized NPs are well known for their antimicrobial activity toward a broad range of gram negative as well as gram-positive pathogenic bacteria. Interestingly, the antimicrobial activity of PtNPs has been found massively effective on drug resistance as well as multidrug resistance (MDR) bacteria such as *Pseudomonas aeruginosa* ATCC13048, *E. coli K12*, *Enterobacter aerogenes*, etc. It is due to their unique features such as high surface area and stability against the broad range of chemicals, as well as rapid biocidal outcome toward the gram positive and gram-negative bacteria, viruses, molds, fungi and algae. It may enhance the production of "reactive oxygen species" (ROS), leading to accumulation and then loss of integrity of the cell membranes. Additionally, it can induce DNA protein kinase down-regulation, leading to oxidative stress and finally apoptosis (Fig. 4).

Though, only few of investigation has been done for the PtNPs antibacterial activity as compared to silver and copper (Zain et al. 2014). A baseline work was reported by the Gopal et al. (2013) and indicated that PtNPs with sizes less than 3 nm displayed efficient bactericidal activity against *P. aeruginosa.* The efficacy of green At-PtNPs against the gram-negative (*E. coli* and *Klebsiella pneumonia*) and gram-positive (*Bacillus subtilis* and *Staphylococcus aureus*) bacteria was determined by the zone of inhibition with the NPs concentration of concentration of 1 mg/L (Eltaweil et al. 2022). The findings showed that the zone of inhibition for *K. pneumonia* was 17 mm and zero growth was observed in *E. coli* plate which is indicating that At-PtNPs are extremely effective against *E. coli* as it completely prohibited the bacterial growth.

Platinum nanoparticles through egg yolk

With the advancement of nanoscience's and virtue-full results of Pt derived nanoparticles for clinical and commercial application. Hence, it emphasized the researches to propose the more controlled way of PtNPs synthesis with required composition, form, shapes and size for various proposes and from different higher organisms. The green synthesis of PtNPs using the quail egg yolk and a reducing agent peroxidase enzyme as well as without any reducing agents provided an eco-friendly way that has the reactive medium enriched with the high protein and vitamins content.

The pH, temperature, time and concentration of the reaction situation were optimized with the aid of quail egg yolk. The results demonstrated that at 20 °C (pH 6.0) for 4 h, the maximum PtNPs were synthesized within the size range 7–50 nm. A schematic methodology of egg yolk-based PtNPs synthesis is shown in Fig. 5.

Briefly, to prepare white, and yolk reaction medium, eggs of the quail were divided. 1.0 mL of egg yolk were added to 99 mL of distilled water and stirring at high-speed by magnetic stirrer for 30 min to obtain the homogeneous medium for reaction. Then medium was filtered which allowed the homogeneous components to be leached. Further, the egg yolk homogenate was stirred at 100 rpm with 10.0 mM of H2PtCl6 solution at normal atmospheric pressure and temperature. Formation of the

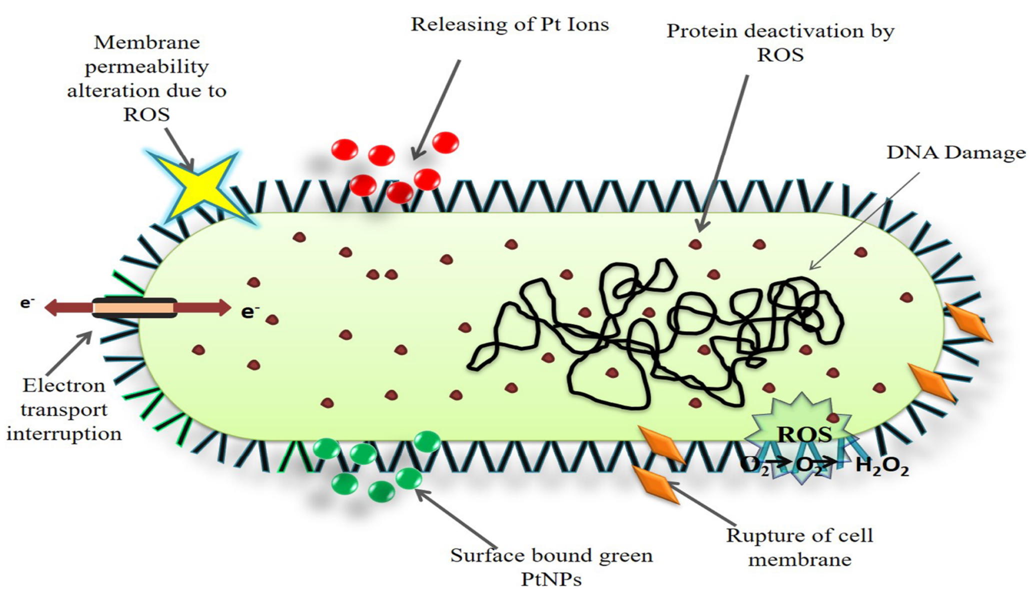

Fig. 4 ROS activity of PtNPs and interaction as well as inhibition of bacterial cell

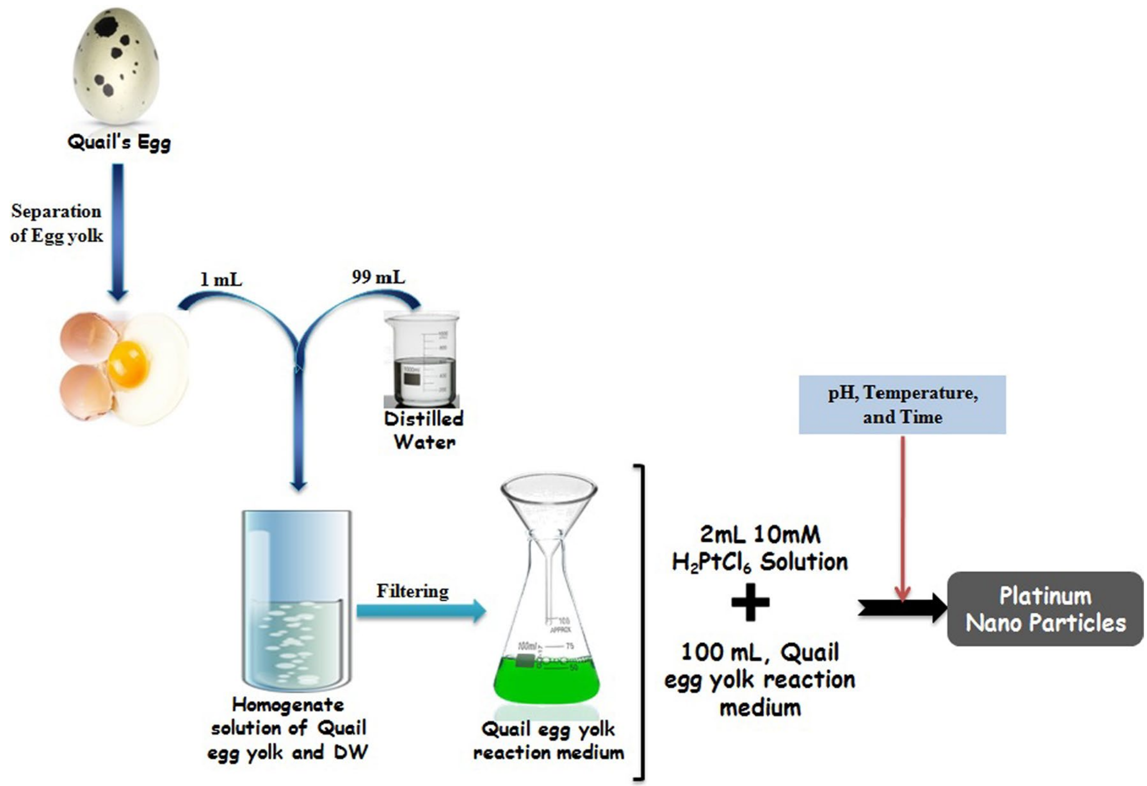

Fig. 5 Process of PtNPs synthesis through egg yolk and platinum salt

PtNPs was monitored with the scanning of reaction mixture by spectrophotometer.

The optimum reactive conditions such as metal ion concentration, reaction time, pH, temperature, etc., have determined to get maximum PtNPs by controlling the reaction parameter. Resultantly, cubic shape and sizes (7–50 nm) were observed by next generation microscopy of PtNPs that originated from quail egg yolk medium (Nadaroglu et al. 2017).

Platinum nanoparticles deposition with bio-reductive effect on algae

Algae have an exceptional aptitude to understand the metals and facilitate its uptake and accumulation and convert into more flexible forms through the hyper accumulations of heavy metal ions (Priyadarshini et al. 2019). Due to these potentials, algae are considered to be a model organism for bio-nanomaterial processing. Moreover, the algal extracts comprise of the mixture of bioactive compounds such as polyphenols, tocopherols, carotene, chlorophyll, phycocyanin, phycoerythrin, fatty acids, carbohydrates, vitamins, proteins, minerals, fats, and polyunsaturated fatty acids. Anju et al. (2020) have indicated that algae extracts are investigated for a wide number of biomolecules and metabolites that have the capability to reduce the metal ions and capped them to improve their cellular biocompatibility.

Previous research described the main active compounds of reduction and stabilizing agents for algae-based PtNPs synthesis and basically focused on the algae-mediated nanomaterial synthesis, solution of metal precursor, and metal-algae extracts reaction mixture incubation. The reaction is started when the liquid type algal extract is combined with the targeted metal precursor molar solution. Usually, the color shift in the reaction mix defines as a visible monitoring for reaction initiation and indicating the nucleation, accompanied by evolution of NPs with neighboring nucleonic particles cluster together. Resultantly, thermodynamically stable with various sized and shaped PtNPs obtained. The algae extract's bioactive portion facilitates the NPs synthesis cascade, and the regulatory factors that involved are concentration, time, temperature, and pH. Overall synthesis is accomplished by two roots, i.e., intracellular and extracellular, that keep a side the control factors. Initially the synthesis of nanoparticles was reported to be intracellular and later algae were oppressed for an extracellular synthesis mode (Fig. 6).

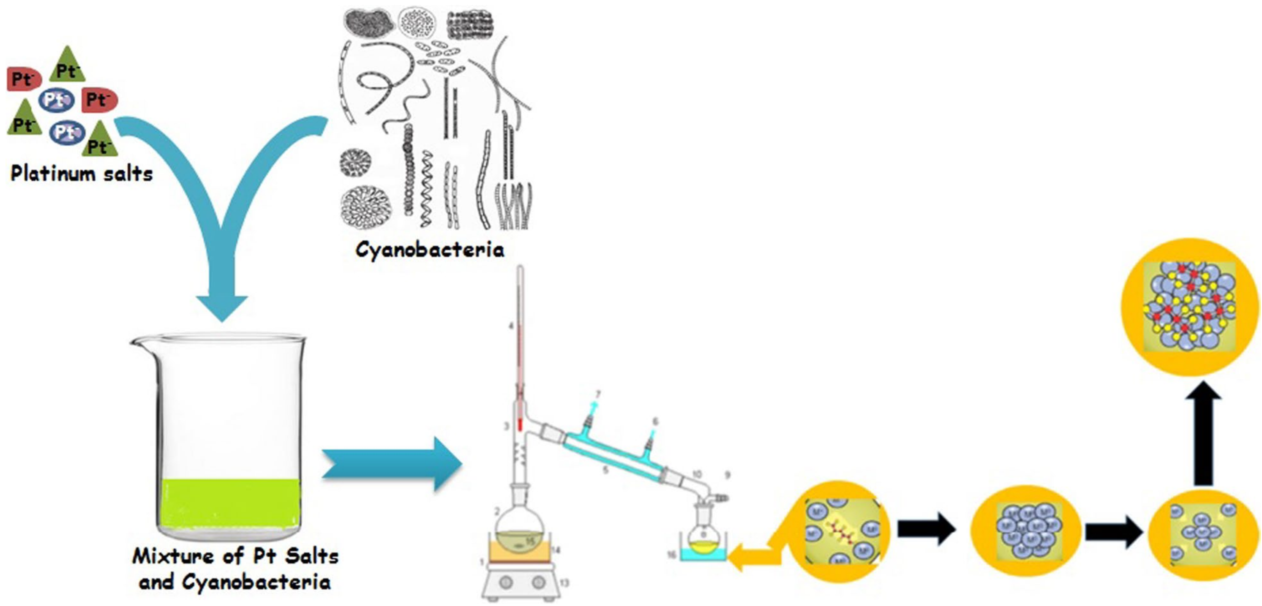

Fig. 6 Illustration of Cynobacterial species and platinum salt based Synthesis of PtNPs

Fungal mediated PtNPs synthesis

Fungi can be used with various way to synthesize the NPs such as total fungal biomass debris, cultured liquids, intracellular extracts, protein fractions, total metabolome, individual fungal metabolites. Though, biomass-based NPs needs to need to separate the synthesized NPs from the bio-objects of fungi. Other dis-advantages of this methodology are the long-time process. Interestingly, the materials derived from fungal biomass, such as cultured liquids, intracellular extract, proteins or individual metabolites can give us a perfect option for green synthesis of nanoparticles. This technique is reproducible, time saving and there is no need to destroy the fungal cells or to separate NPs from them. Though, only Ascomycota species are profoundly reported for the synthesis of Pt-based NPs nanoparticles and has been done with intracellularly as well extracellularly with the support of some enzymes or bioactive molecules. An intra- and extracellular synthesis of PtNPs from fungal cell is described in Fig. 7.

Biosynthesis of PtNPs is studied well in the Ascomycetes fungi *Fusarium oxysporum*. F. oxysporum mycelium biomass was used to produce the various shaped PtNPs such as circular, square, pentagon, hexagon, and rectangle within the size range of 10–100 nm (Riddin et al. 2006). Though, extracellular bioactive-based synthesized NPs found to be more significant. Syed and Ahmad (2012) done the reduction of platinum salt by Pt(IV)-reductase enzyme of *F. oxysporum*. The synthesized PtNPs of fungal hyphae extract and hydrogenase are showing different characteristics in the sense of size as well as in shape. The irregular shape and size range of 30–40 nm was obtained with extract and triangular, circular, pentagonal and hexagonal PtNPs with the size range of 40–60 nm were obtained with the enzyme, respectively. Further, Gupta and Chundawat (2019) synthesized the face-centered cubical shaped PtNPs (25 nm) by the using *F. oxysporum* culture filtrate which is endowed with the antimicrobial and photocatalytic potentials. Castro-Longoria (2012) has target the *Neurospora crassa* to synthesize the PtNPs by incubating the mycelium biomass with H_2PtCl_6 and obtained the extracellular PtNPs of size range 4–35 nm with spherical as well as nanoaggregates of size 20–110 nm. Sarkar and Acharya (2017) were formulated the Nano-platinum by using the fungal cultured filtrate of *Alternaria alternata* which is a common phytopathogen. The synthesized PtNPs are variable in size (50–315 nm) with irregular shape such as quasi-spherical, polygonal, rectangular, tetrahedral as well as hexagonal in morphology. The culture filtrate of model organism. *Penicillium chrysogenum* has shown the remarkable synthesis of vastly discrete non-aggregating Pt nanospheres with size range of 5–40 nm (Subramaniyan et al. 2018). Similarly, Pt nanospheres from *Saccharomyces boulardii* extract were obtained by Borse et al. (2015). It revealed that yeast cell biomass (500 mg/mL) and 0.5 mM chloroplatinic acid with the temperature 35 °C, pH 7.0 and 200 rpm needs to incubate for 36 h to achieve the significant concentration of PtNPs.

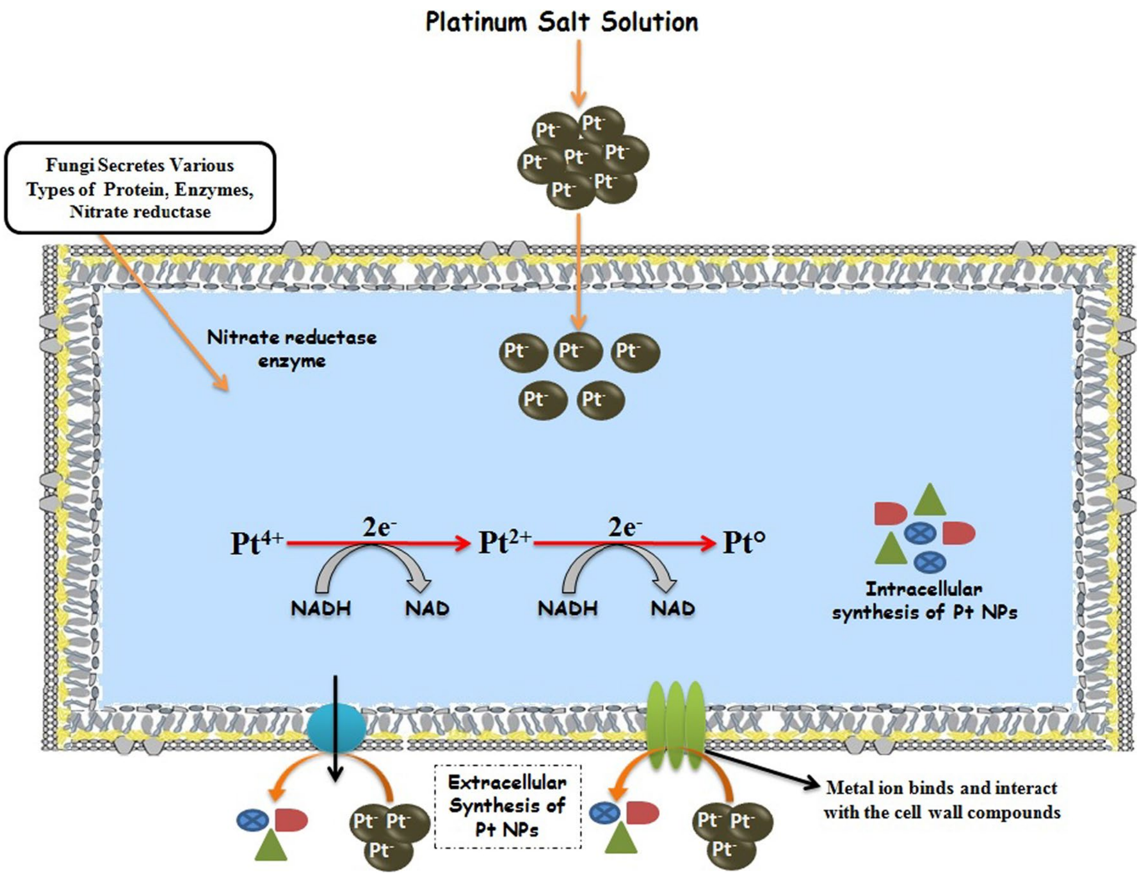

Fig. 7 Detailed process for the intracellular interaction of platinum ion and fungal metabolome and the mechanism of PtNPs synthesis

Toxicity of PtNPs

Due to the greater neoplastic patient population in recent years, substantial amounts of antineoplastic drugs based on Pt are discharged into the circumference through hospital effluents, urine patients and pharmaceuticals. Moreover, the widespread application of PtNPs in gas neutralizers for automobile drain has abruptly increased the amount of PtNPs pollution in the environment. Several species have recorded for toxic effect of cisplatin in marine organisms, such as microalgae (*Pseudokirchneriella subcapitata*), protozoans (*Tetrahymena pyriformis*), rotifers (*Brachionus calyciflorus*), crustaceans (*Daphnia magna*; *Ceriodaphnia dubia*), and fish (*Danio rerio*), which have shown their response on both inhibition in reproduction and growth (Asharani et al. 2011; Sørensen et al. 2016; Adeyemi et al. 2018; Hlavkova et al. 2018).

Koltan and Czaja (2014) have indicated that2.5 mg/kg dose of PtNPs abridged the total count of bacteria in soil and inhibited the nitrogen fixation. A recent study has revealed that PtNPs of doses 10 and 100 mg/kg has significant negative impact on the radish crops seed germination as well as root length (Kolesnikov et al. 2023).

Phytoplankton such as *C. vulgaris* are first marine food chain links which make it significant to assess the toxicity of various agents based on toxic on these species. Findings revealed that Cisplatin does have the highest rank of environmental toxicity among Platinum-based antineoplastic drugs PBADs according to a classification for chemical toxicity to the environment. *C. Vulgaris* has toxicity on all other cytotoxic agents. This has been studied in several previous research. Higher 'IC50' values of the PBADs to the algal cells as opposed to herbicides, engineered herbicides destroy the plant cells and they inhibit photosynthetic plant mechanisms (Das 2013). Microalgae are photosynthetic cells, and are highly susceptible to herbicide toxic effects compared to PBADs. Drugs based on platinum are designed to kill animal cancer cells, and their IC50s were below 1 mg/L in all the animal cell lines tested.

Different mechanisms of toxicity of PBADs in algae, human and *C. vulgaris* can occur in stable cell walls in IC50s. The results of this study have exposed that PBADs inhibit photosynthetic pigment production, cell photosynthesis and algal cell proliferation (Safi et al. 2014). Those toxic effects depended on dosage and time.

More strongly, compared with carboplatin and oxaliplatin, Cisplatin inhibited the production of photosynthetic pigments in algal cells. From the photosynthetic stains, carotenoid reduction was suggestively greater than that of chlorophylls. The intracellular mechanisms related to this are not been cleared and it needs further study. Increased MDA production was consistent with predictable toxicity of PBADs (alkylation agents). Possible methods of action PBADs contrary to human cells and are DNA and DNA impairment via cross-link formation between DNA to atoms by the add-on alkyl groups (Dasari and Tchounwou 2014). There is no proof that cytotoxic drugs, like by photosynthetic enzymes, inhibit the process of photosynthesis from algal chloroplast; in literature, the prevailing mechanism by which PBADs prevent algal cell proliferation is likely to occur. Further studies on the possible toxic mechanism of PBADs in algal cells are necessary. Several experiments have shown that cytotoxicity causing PBADs is closely linked to ROS and additional free radicals. ROS is the outgrowth of normal cell metabolism; but excessive levels of cells with adverse effects can cause oxidative stress. Reducing the antioxidant capacity (as observed in this study) in algal cells confirmed the oxidative stress induction (Choi et al. 2015).

Interestingly, size of synthesized PtNPs is the key factors on significant cytotoxicity. The PtNPs sizes ranging from to 21 nm tested on to the neural cell line displayed the cyto-compatible nature with size 5–6 nm but other sizes causes cell damage (Manikandan et al. 2013),

Depending on sizes PtNPs of size 8 nm showed no harmful effects but the PtNPs of size 1 nm in culture induced cytotoxicity to renal cells in a dose dependent manner with the same concentration range (Buchtelova et al. 2017). Alternatively, polyvinylpyrrolidone PVP PtNPs of size 6 nm caused a decline in genotoxic effects and metabolic activity and did not change primary keratinocyte morphology, and migration capacity while PtNPs of size 57 nm are less hazardous to keratinocytes than the minor ones (Konieczny et al. 2013). Hence, the reviewed research made clear that it can control or reduce the toxicity offered by PtNPs by controlling their size during their preparation, which will in turn effect their possible applications for biomedical purposes.

Conclusions

The bio-synthetic NP pathway is a reliable, environmentally friendly and more specifically on the green aspect synthetic tackle. Huge attempts are being made in the last few decades for green NP development approach. In addition, microbes and plants are efficient producers of biologically active alkaloids and useful compounds which are found to have a broad range biological-based activity, like those of antimicrobial, anticancer, antibiofueling, antimalarial, antiparasitic, and antioxidant, etc. Platinum is the most rare and costly metals. This has highest corrosion resistivity and various catalytic applications include catalytic converters for catalysts for petrochemical cracking and automotive use. The PtNPs however have a detrimental impact on cancer cells. Because of this, researchers have partly abandoned studies on the use of platinum as an agent on anticancer. This is unclear since, according to other reports, PtNPs are in very low concentration: Biological stability and tolerance. These kinds of not established part can be the forthcoming challenges will be covered. The challenging recoveries of the toxicity of the NPs with greeno-biogenic inventory part of nanotech will be the suspicious event. Through this significant focus of discussed the upcoming pharmaceutical bioactive product PtNPs through the greeno-biogenic approach with different approaches like plant products, algae, fungi, and egg yolk, etc. This greeno-biogenic PtNPs scrutiny can help the rate of the upcoming pharmacological advances. In addition, the organic PtNPs are competing with chemically synthesized nanoparticles in order to ensure adequate shape and size that the regulated reaction conditions provide better stability and it is highly important to unveil the use PtNPs as nanomedicine in biological applications. The very less studies shows, it can be great evolution in the pharmacology and nanoscience. Mainly antioxidant, antibacterial, anticancer and catalytic action are the promising studied part which needs to explore in commercial prospectives.

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UM, SN and RUT conceptualize and designed the work, YSP collected the materials, VN has revised the MS, helps in fig. designing and did the language editing, YNS, PRY and RPB has written and manuscript. All authors have read and approved the manuscript.

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