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A review on the Green Synthesis and Biomedical Applications of TiO_2 NPs

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ABSTRACT

In this paper different types of physical and chemical methods are listed with their disadvantages. The mission is to review these methods properly and to understand why these methods are losing their presence day by day. Green synthesis method and biosynthesis has been discussed with their advantages and enhanced applications. The applications of titanium dioxide nanoparticles, their different biomedical applications are listed. Therefore this paper used various sources to collect the review articles. Green synthesis was found to be a cost effective and ecofriendly method as compared to different bottom up and top down methods. Different plant extracts are used to synthesize titanium dioxide nanoparticles which are listed in this paper. Titanium dioxide nanoparticles can be used as effective metal oxide nanoparticles for different biomedical applications and also as a smart substitute for catalytic reactions.

Keywords: Nanoparticles, Green Synthesis, Photocatalyst, Antimicrobial activity

1. INTRODUCTION

Nanotechnology is a widespread field gaining a remarkable interest among the researchers. In these recent days scientists are exploring a wide variety of metal nanoparticles and also the metal oxide nanoparticles, which are found to exhibit an excellent characteristic in them. Nanotechnology is the study of minute nanostructures. These nanostructures bearing an excellent surface morphologies and stability in them, which is the main cause for their exploration. Nanotechnology is a technical branch that works with these minute nanostructures normally bearing size which is less than 100 nm. Nanotechnology covers a broad range of research in fields including chemistry, physics, biology, molecular engineering and many more. Nowadays scientists are examining and are also employing new techniques and processes in this branch to bring out better results for the further usage of them in different streams (Rao et al., 2015). The application and usage of these nanomaterials depends totally upon their size and shapes, their orientation, stability and also upon their toxicity. Nanotechnology exhibits a widespread applications and improved benefits in many different sectors which involve pharmacology, environmental, computer science and also in many other technical sectors. Significant advantages of nanotechnology involve improved synthesis processes, choice of different solvents, choice of different reducing and capping agents, choice of various manufacturing methods and their fabrication. During the synthesis of nanomaterials of different compositions, one should take care of the risks involved in them. Mainly the risks are created because of the use of toxic chemicals, need of adverse environmental conditions, health and protection issues (Sundrarajan et al., 2011). We should also gain some knowledge about two different types of nanomaterials. Firstly we have nanocomposites; these are the nanostructure components where the minute nanomaterials are embraced into some substance, or in any medium. Another category is the mobile nanoparticles which are free in their motion and the components in them have individual identity at some step.

2. Metal And Metal Oxide Nanoparticles

In this vast area of research of nanoparticles, metal oxide and metal nanoparticles have gained substantial interest because of their anomalous properties. These metal oxide and metal nanoparticles have outstanding property of energy conduction, optical properties and they possess the ability to increase the rate of the reaction by lowering the activation energy of the product formation. The metal and metal oxide nanoparticles have extended applications and are also exploited in pharmaceuticals, textiles, in water treatment, photo catalysis and also because of excellent catalytic properties they are used as catalysts in many pharmaceutical formation reactions. These nanoparticles also have an exceptional antibacterial and antifungal property which contributes a large exploitation of them in the pharmaceutical industries (Santhoshkumar et al., 2014). These nanoparticles throw a negative impact on many other microorganisms present in the environment. The metal and metal oxide nanoparticles possess an exceptional morphology, size, shape and terminology. Biologically synthesized metal oxide nanoparticles are much more effective than other because they do not include the usage of toxic chemicals in them and are very environment friendly (Patidar et al., 2017).

Discussing about the applications and unique properties of metal and its oxide nanoparticles individually we can say that iron oxide nanoparticles are very reactive in nature and as we know that more reactivity less is the stability and therefore they are said to be unstable. Due to high magnetic property of iron oxide nanoparticles they are effectively exploited in magnetic resonance indication and also in magnetic particle indication. Iron oxide nanoparticles possess different magnetic states. Sometimes they are ferromagnetic, antiferromagnetic and also can be ferrimagnetic in nature. Now talking about silicon dioxide nanoparticles, they are highly stable and less reactive. They are very much useful in biomedical products because of their non-toxicity. Silicon oxide nanoparticles are widely used as a semiconductor for energy conduction in many devices. Zinc oxide nanoparticles are very highly resistant to corrosion. They are effective against different pathogens and microbes and possess a remarkable antibacterial and antifungal property. Zinc oxide has been efficiently used for the synthesis of rubber. These are also used in paint industry and in ceramic industries. Cerium oxide nanoparticles have very less reduction potential. Cerium oxide nanoparticles are very efficiently used in personal care and cosmetic products. These nanoparticles are also employed in the manufacturing of steel and also are a good antioxidant. Aluminium oxide nanoparticles are also very reactive in nature and hence unstable. These nanoparticles are widely used in the treatment of water and in the production of sugars. These nanoparticles are also exploited in many different chromatographic techniques. They are also useful in the manufacture of ceramics because of their remarkable property of abrasion, toughness and fire resistant. They are highly hygroscopic in nature and readily absorb moisture. Calcium oxide nanoparticles are highly employed in biofuel production and as a fire extinguisher. These nanoparticles also have an excellent antibacterial and antifungal activity and are used to cure asthma, cough and bronchitis etc.

3. Synthesis Of Metal And Metal Oxide Nanoparticles

Now talking about the production and synthesis of different metal and metal dioxide nanoparticles, these nanoparticles are mostly synthesized by various physical and chemical methods. Listing some of the methods are sol-gel method, chemical vapour deposition, hydrothermal method, laser ablation, sputtering and physical vapour deposition. The synthesis of nanoparticles by physicochemical methods is classified in bottom-up or top- down processes. There are different methods which are listed below (Nadeem et al., 2018).

4. Physical And Chemical Methods

Firstly talking about the most important and purely chemical method known as sol-gel method. Many different types of metal oxide nanoparticles have been synthesized by this process. This process involves firstly the formation of sol in which a suitable solvent is employed. In the formation of sol the solution of solids are dispersed in liquid phase. This sol acts as a starting material for the process of formation of gel, which a typical network of polymers and collectively called as a macromolecule. The process is then followed by stirring and then the product formed is separated out by ultracentrifugation or filtration. Mostly

the metal oxides involved in this process as starting material (Devi et al., 2017). Another bottom up method is pyrolysis. In this method the sample is subjected to high temperature in a furnace with high pressure. The precursor is inserted into the furnace from the bottom opening and then subjected to different temperatures at different stages. The gases are then recovered to collect the nanoparticles. Limitation of this process is that it requires high temperature but the product formed have a high yield. The next method is the hydrothermal method, in this method the products are formed by crystallization. Hydro means water; therefore water is used in this method which is kept in an autoclave with some nutrient. In this special apparatus the sample is kept at a constant high pressure and temperature is maintained to precede the reaction. Crystallization takes place and therefore crystalline phase is formed. This is a effective method for the synthesis of the nanoparticles. The major drawbacks of this process are that it involves the usage of expensive autoclaves which are somewhat difficult to handle. And also we are unable to analyze the reaction occurring inside the autoclave because the apparatus walls are totally closed (Ealias et al., 2017). In the queue the next is the spinning method. In this method the starting material of the reaction are pumped into a rotating disc, where the reaction takes place. This method is carried out inside a chamber which contains a rotating disc and the reacting temperatures are controlled inside the chamber. When the disc rotates the constituents react with each other and the oxygen inside the chamber is removed with the help of some gases like helium, neon etc. After the reaction completes the samples are collected and dried. It is a low cost and reliable method. The next chemical method for the synthesis of nanoparticles is chemical vapour deposition. In this method temperature plays a important role during the reaction of different gas molecules. The reaction forms a uniform layer over the wafer. All these method involve high temperature for the synthesis of the nanoparticles. The thin film formed is retrieved and the nanoparticles are collected. As a thin layer of gas is formed in this method the nanoparticles formed are also uniform. This method produces a high degree of purity to the nanoparticles. The apparatus should be handled carefully because the gaseous precursors are highly toxic and also volatile in nature.

Now talking about some of the physical methods for the preparation of nanoparticles. These methods come under the category of top-down methods. The foremost and most commonly used method is mechanical milling. It is the most promising method for the preparation of nanoparticles and the nanoparticles formed are of very good size and shapes. In this the sample is grounded to generate product and an inert atmosphere is created for better results. The particle size is reduced by the impact milling, as we can see in the ball mill the size reduction is done by the weight of balls circulating inside a chamber. In this method the nanoparticles formed are very fine in size. The next method is the sputtering method for the preparation of nanoparticles. This is a physical method in which nanosized particles are ejected from the surface of their own element when a beam of energetic ions are bombarded on their surface. This method is also known as physical vapour deposition technique. As the name suggests there is the deposition of a thin layer of nanoparticles. In this method temperature plays an important role to decide the morphology of nanoparticles. The thin layer formed should have a uniform thickness to obtain a high yield of products. In the queue the next method is nanolithography. This method is generally employed for fabricating the nanomaterials to a very definite microscopic size ranging between 1 to 100 nm. One can create any desired shape and size with the help of nanolithographic technique. The nanoparticles formed by this method have unusual optical, mechanical and electronic properties. There are different types of nanolithographic techniques such as ion beam lithography, magneto lithography, plasmonic lithography, stencil lithography and quantum optical lithography. Another method for synthesizing nanoparticles is thermal decomposition. As we can understand by its name that thermal means heat and the temperature at which a compound decomposes is called the decomposition. A large amount of heat is required during this technique. This heat is used to break the lattice of the compound and also the bond between them breaks down. This method proceeds with a specific temperature which is required to decompose the metal to synthesize the nanoparticles. The major drawback of this method is that this method involves the usage of high heat which is very dangerous for the workers who are working over there. The next method for effective synthesis of nanoparticles is laser ablation

method. This is the method in which nanoparticles are synthesized with the help of solvents. Different types of solvent are used in this method. This method vapourises those substances which are not commonly volatile. Mostly metal based nanoparticles are produced with this method by the irradiation of metal. This method is preceded by submerging the metal into a solution with the help of laser beam. Condensation of plasma plume takes place by laser beam. It is a purely physical method and mainly used when nanoparticles are required in colloidal state.

5. Disadvantages Of Physical And Chemical Methods

These chemical and physical methods also have some disadvantages due to which the researchers are now shifting towards the biosynthesis or green synthesis of nanoparticles. Some of these physical and chemical processes are very exothermic in nature i.e. a large amount of heat is evolved and some of them are endothermic in nature and therefore require a large amount of heat for the completion of reaction. High temperature and high pressure is required in almost all these processes (Rao et al., 2014). Therefore this is not good for the product and as well as for the staff working over there, these processes are now considered as less effective for the synthesis of nanoparticles. In some reactions temperature also affects the yield of the product. Talking about another drawback of these processes is that they are expensive and the apparatus involved are typical to handle. These apparatus require proper maintenance from time to time to function properly. Therefore because of high cost and difficult functioning of the apparatus, these processes become quite tricky. All these methods especially in chemical method, toxic chemicals and solvents are required which is a big hurdle in the large scale production of metal and metal oxide nanoparticles. These toxic chemicals sometimes cause tragedy in the working place due to spilling off the chemicals over the workers. Therefore workers working with these toxic chemicals should be very alert and careful while using them (Dobrucka., 2017).

6. Microwave Assisted Synthesis

Another method which is now proving to be an innovative method is microwave assisted method. Microwave assisted method is the process in which a chemical reaction is exposed to microwave radiation which generally heat up the material in the solvent; there may be polar molecules or different ions. This method is carried out by placing the reaction mixture into the microwave after cooling the vessel. Microwave assisted synthesis saves a lot of time and energy by targeting the main compounds present in the reaction mixture. The main advantage of microwave assisted synthesis is that it enhances the reaction rate i.e. a reaction which is normally completed in 3- 4 hours of stirring can be completed in 15-20 minutes under the microwave radiation. The nanomaterials formed by these radiations are uniformly distributed in size and shape which enhances their potential uses. These nanoparticles can be used as catalyst in many reactions to increase the reaction rates. The nanoparticles formed by this method have a high yield as compared to other process with the less requirement of time. These methods were seen to enhance the properties of different nanoparticles without usage of any harmful chemicals and adverse conditions (Ghouse et al., 2014).

7. Green Synthesis Of Nanoparticles

Because of the above listed drawbacks nowadays scientists are now looking for some alternative methods for the synthesis of nanoparticles. The main focus is to reduce the energy consumption, cost and to make the process convenient for the environment and also for the researchers and workers working on it. Nowadays researchers are synthesizing nanoparticles by green synthesis, which is a purely organic, energy efficient and environment friendly approach (Goutam et al., 2018). This process is most commonly used in today's era to eradicate the formation and usage of toxic chemicals. This is an eco- friendly method and causes no pollution and does not require any maintenance. This process involves the usage of plant extracts which acts as a reducing agent during the formation of nanoparticles. The plant extracts are easily available and are very rich in natural products. Therefore the nanoparticles formed by this green synthesis method are very much used for medical purposes and possess an excellent antibacterial and antifungal activity (Subhapriya et al., 2018). This process was mainly introduced to secure the environment by creating less toxic waste in working area whether it is in laboratory or in the industries. Green synthesis produces a high

yield of products with sustainable development. Biosynthesis of metal and metal oxide nanoparticles is also a very energy efficient and environment friendly method. In this method different microorganisms like fungi and bacteria are used for the synthesis and production of nanoparticles (Zahir et al., 2015). Bacteria are most commonly used for the synthesis of nanoparticles because of the fact that the growth of bacteria is faster and it divides gradually. Fungi are also effectively used for production of nanoparticles because they are more economic and have the ability to tolerate and handle biomass. The nanoparticles formed by this green synthesis method or by the use of microbes like bacteria and fungi are proved to be an excellent antibacterial and antifungal agent (Thakur et al., 2019). Due to this property they are used in the pharmaceutical industries for the production of different types of antibiotics and antifungal medicines. Green synthesized nanoparticles are used in cosmetic industries and also in toothpaste making. Biologically synthesized nanoparticles are very much useful in spotting diseases, imaging, in the prognosis of diseases and also in agriculture (Rajakumar et al., 2014).

Table-1 Green synthesis of TiO_2NPs by using various Plants & it application

S. No.	Plant Used	Reference	Applications
1	*Mentha arvensis*	(Ahmad et al.,2020)	These nanoparticles were found to possess good antibacterial and antifungal properties.
2	*Azadirachta indica*	(Thakur et al .,2019)	These nanoparticles were found to inhibit the growth of all the tested bacterial strains.
3	*Sesbania grandiflora*	(Srinivasan et al.,2019)	TiO_2 NPs were first time synthesized by this plant and the study was based on determining toxicity in the Zebrafish. They found that titanium dioxide nanoparticles are fatal for Zebrafish.
4	*Trigonella foenum-graecum*	(Subhapriya et al.,2018)	These nanoparticles showed an excellent antimicrobial activity against all tested pathogens.
5	*Jatropha curcus*	(Goutam et al.,2018)	These nanoparticles are widely used for the treatment of tannery waste water in-situ.
6	*Moringa oleifera*	(Patidar et al.,2017)	Nanoparticles synthesized by this plant were exploited in production of medicines because of its anti-septic, antibacterial, anti-inflammatory and antifungal property.
7	*Echinacea purpurea herba*	(Dobrucka et al.,2017)	These nanoparticles are widely used to cure the bacterial and viral infections of urinary tract, respiratory tract and also possess potential to act against tumor cells.
8	*Aloevera* Plant	(Rao et al.,2015)	*Aloe vera* is a herbal plant and therefore these nanoparticles are extensively used in the manufacture of skin care and hair care products.
9	*Psidium guajava*	(Kumar et al.,2014)	These nanoparticles were found to exhibit exceptional antibacterial and antioxidant property.
10	*Hibiscus rosa- sinesis*	(Rao et al.,2014)	These nanoparticles can be used to treat diseases like cough, asthma and also effective on heart diseases.
11	*Euphorbia prostrate*	(Zahir et al.,2015)	These nanoparticles were examined as excellent antileishmanial agents.
12	*Azadirachta indica*	(Sankar et al.,2015)	These nanoparticles are effectively used to degrade harmful dyes used in industries with the help of sunlight.
13	*Mangifera indica L.*	(Rajakumar et al.,2014)	These nanoparticles are analyzed as anti-parasitic agents and can be used to inhibit the growth of blood- feeding parasites.
14	*Nyctanthes arbor- tristis*	(Sundrarajan et al .,2011)	These nanoparticles are effectively employed in biomedical applications because they have no adverse side effects.

8. Applications

Titanium dioxide nanoparticles possess different properties which are very effectively employed in different industries and in laboratories. Titanium dioxide nanoparticles are an outstanding photo catalyst and can degrade almost all organic compounds when kept in direct contact with sunlight (Sankar et al., 2015). Due to their non-toxicity these nanoparticles are effectively used in cleaning the environment. These nanoparticles are highly resistant to corrosion and also used in the prognosis of diseases. These nanoparticles are also useful in spotting diseases, in making of surgical equipments, in production of energy and in agriculture. Titanium dioxide nanoparticles possess a characteristic of semi conduction and therefore used as a main material in solar cells and also as pigments in paint industry. They are also exploited in the areas of printing ink, in cosmetic industry and in the production of toothpaste. They also possess a unique antibacterial and antifungal property. Due to this property they are widely used in pharmaceutical industries for the production of medicines (Cabello et al., 2017). Some important applications are listed.

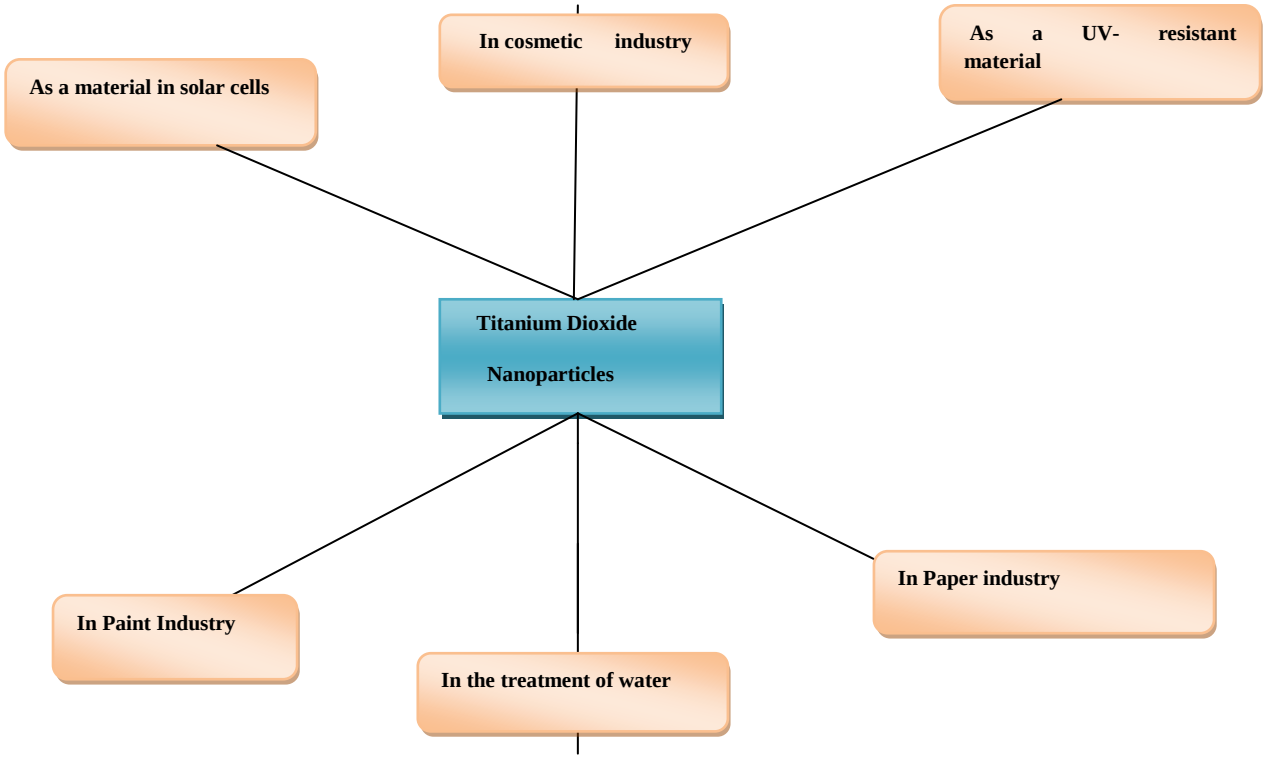

Fig.1: Applications of TiO_2 Nanoparticles

9. Biomedical Applications Of Titanium Dioxide NPs

Titanium dioxide nanoparticles are exploited in many different biomedical applications. They are widely used for drug- delivery in pharmaceutical industry, as they are the well known drug carriers. These nanoparticles have been used for the delivery of different drugs like Doxorubicin (Qin et al.; 2011), Daunorubicin (Zhang et al.; 2012) etc and also for anticancer drug delivery agents. A most important biomedical application of titanium dioxide nanoparticles is bioimaging which is very necessary in the case of drug delivery (McNamara et al., 2016). Bioimaging is a technical process with the help of which different biological activities are analyzed. Without interfering in the normal activities like respiration, digestion, bioimaging provide 3D structures of the samples in the process which is the essential condition for spotting diseases in human body. The outstanding

photocatalytic property of titanium dioxide nanoparticles are also analyzed for the treatment of different infected cells with the help of photo-induced activity (Lagopati et al., 2010). Another biomedical application is that the photoexcited titanium dioxide nanoparticles are useful for the treatment of diseases by suppressing the activity of lethal cells. These nanoparticles are excited by using ultraviolet range of light and then analyzed for further activity. Sometimes these nanoparticles are also irradiated by visible light for the treatment of different pathogens. These nanoparticles are mostly used for the inhibition of cancer cells (Wang et al., 2010). Because of the wide range of biomedical applications, biocompatibility and stability, titanium dioxide nanoparticles are used in cosmetic industries. The biosynthesized titanium dioxide nanoparticles possess antibacterial and antifungal activity against many bacterial and fungal strains. They are effective on both gram positive and gram negative bacteria. These nanoparticles act as a biosensor for the detection of different malignant cells and microorganisms which infect the human body. Due to this property they are widely used in food industries and also in health care products. Surface coatings of titanium dioxide nanoparticles are also done for effective gene delivery for the purpose of curing diseases. Titanium dioxide nanoparticles have been triggered for many biomedical applications because of its photocatalytic activity, semiconduction and less toxicity.

10. CONCLUSION

Overall, from these study reviews we concluded that there are many methods for the synthesis of nanoparticles, but green synthesis method is the most accepted approach in today's era. This is because this method is ecofriendly and requires less maintenance. Green synthesis method and biosynthesis of nanoparticles involve plant extracts and microorganisms for the synthesis of nanoparticles which is proved to be a more versatile method nowadays. Titanium dioxide nanoparticles synthesized by these methods contain excellent properties in them which are employed in different industries for different purposes. They are a clean photo catalyst and can degrade almost all organic compounds when subjected to a certain wavelength of light source. They are effectively used as UV resistant material and also as a pigment in paint industries. Therefore in this study we have listed all the physicochemical methods for the synthesis of nanoparticles. Also the disadvantages of these methods are listed to understand their absence, nowadays in the field of nanotechnology. The enhanced properties and applications of different metal and metal oxide nanoparticles are also given and also the applications of titanium dioxide nanoparticles were also listed. From this study we can clearly understand the biomedical applications, industrial applications and agricultural applications of titanium dioxide nanoparticles. Green synthesis and biosynthesis of nanoparticles are studied to study the newer trends in the field of nanoparticles. Also to conclude the study we listed some of the different plant extracts which are effectively used for the synthesis of nanoparticles. The antibacterial and antifungal properties of TiO2 nanoparticles were also studied along with other applications. A more effective, microwave assisted synthesis is also given with its enhanced applications. Overall, we concluded that the use of plant extracts and microorganisms are the most sustainable methods in the field of nanotechnology.

REFERENCES

1. Ahmad W., Jaiswal K.K., Soni S., (2020),Green synthesis of titanium dioxide (TiO_2) nanoparticles by using *Mentha arvensis* leaves extract and its antimicrobial properties, Inorganic and Nano-Metal Chemistry, DOI:10.1080/24701556.2020.1732419.
2. Cabello G., Davoglio A.R., Pereira C.E. (2017), Microwave assisted synthesis of anatase-TiO_2 nanoparticles with catalytic activity in oxygen reduction, Journal of Electro analytical Chemistry, 794:36-42.
3. Devi S.R., Dr. Venckatesh R., Dr Sivaraj R. (2014), Synthesis of titanium dioxide nanoparticles by Sol-gel Technique, International Journal of Innovative Research in Science, Engineering and Technology, 8(3):15206-15211.
4. Dobrucka R., (2017), Synthesis of titanium dioxide nanoparticles using *Echinacea purpurea herba*,

Iranian Journal of Pharmaceutical Research, 16(2):756-752.

5. Ealias M.A., Saravanakumar M P., (2017), A review on the classification, characterization, synthesis of nanoparticles and their applications, IOP Conference Series: Material Science and Engineering, doi: 10.1088/1757-899X/263/3/032019.
6. Ghouse M. S., Kumar S.Y., Jin S.J., Kim P.J., Bae S.J., Chung H.E., Kim Y.D., Jang K.E., Nawaz Khan F., Jeong D.E. (2014), Green chemical approach: Microwave assisted, titanium dioxide nanoparticles catalyzed, convenient and efficient C-C bond formation in the synthesis of highly functionalized quinolines and quinolinones, RSC Advances, 84(4):44408-44417.
7. Goutam P.S., Saxena S., Singh V., Yadav K.A., Bharagava N.R., Thapa B.K., (2018), Green synthesis of TiO_2 nanoparticles using leaf extract of *Jatropha curcus L.* for photocatalytic degradation of tannery wastewater, Chemical Engineering Journal, 336:386-396.
8. Lagopati N., Kitsiou P.V., Kontos A.I., Venieratos P., Kotsopoulou E., Kontos A.G., Dionysiou D.D., Pispas S., Tsilibary E.C., Falaras P., (2010), Photo-induced treatment of breast epithelial cancer cells using nanostructured titanium dioxide solution, Journal of Photochemistry and Photobiology A: Chemistry, 214(2-3):215-223.
9. McNamara K., Tofail A.M.S., (2016), Nanoparticles in biomedical applications, Advances in Physics: X, 2(1): 54-88.
10. Nadeem M., Tungmunnithum D., Hano C., Abbasi H.B., Hashmi S.S., Ahmad W., Zahir A. (2018), The current trends in the green synthesis of titanium dioxide nanoparticles and their applications, Green Chemistry Letters and Reviews, 11(4):492-502.
11. Patidar V., Jain P. (2017), Green synthesis of TiO_2 nanoparticles using *moringa oleifera* leaf extract, International Research Journal of Engineering and Technology, 3(04):470-472.
12. Qin Y., Sun L., Li X., Cao Q., Wang H., Tang X., Ye L., (2011), Highly water- dispersible TiO_2 nanoparticles for doxorubicin delivery: effect of loading mode on therapeutic efficacy, Journal of Material Chemistry, 21(44):18003-18010.
13. Rajakumar G., Rahuman A.A., Roopan M.S., Chung M., Anbarasan K., Karthikeyan V., (2014), Efficacy of larvicidal activity of green synthesized titanium dioxide nanoparticles using *Mangifera indica* extract against blood- feeding parasites, Parasitology Research, 114(2):571-581.
14. Rao G.K., Ashok CH., K. Rao V.K., Chakra S.CH. Tambur P. (2015), Green Synthesis of TiO_2 Nanoparticles Using *Aloe Vera* Extract, International Journal of Advanced Research in Physical Sciences, 1A(2):28-34.
15. Rao G.K., Ashok CH., Rao V.K., Chakra S.CH., Rajendar V., (2014), Green synthesis of TiO_2 nanoparticles using hibiscus flower extract, International Conference on Emerging Technologies in Mechanical Sciences, 79-82.
16. Sankar R., Rizwana K., Ravikumar V., Shivashangari K.S., (2015), Ultra-rapid photocatalytic activity of *Azadirachta indica* engineered colloidal titanium dioxide nanoparticles, Appl Nanoscience, 5:731-736.
17. Santhoshkumar T., Rahuman A.A., Jayaseelan C., Rajakumar G., Marimuthu S., Kirthi V.A., Velayutham K., Thomas J., Venkatesan J., Kim S. (2014), Green synthesis of titanium dioxide nanoparticles using *Psidium guajava* extract and its antibacterial and antioxidant properties, Asian Pacific Journal of Tropical Medicine, 12(7):968-976.
18. Srinivasan M., Venkatesan M., Arumugam V., Natesan G., Saravanan N., Murugesan S., Ramachandran S., Ayyasamy R., Pugazhendhi A. (2019), Green synthesis and characterization of titanium dioxide nanoparticles using *Sesbania grandiflora* and evaluation of toxicity in zebrafish embryos, Process Biochemistry, 80:197-202.
19. Subhapriya S, Gomathipriya P (2018), Green synthesis of titanium dioxide (TiO_2), nanoparticles by *Trigonella foenum- graecum* extract and its antimicrobial properties, Microbial Pathogenesis, 116:215-220.
20. Sundrarajan M., Gowri S. (2011), Green synthesis of titanium dioxide nanoparticles by *nyctanthes arbor-*

tristis leaves extract, Chalcogenide Letters, 8(8):447-451.

21. Thakur B.K., Kumar A., Kumar D. (2019), Green synthesis of titanium dioxide nanoparticles using *Azadirachta indica* leaf extract and evaluation of their antibacterial activity, South African Journal of Botany, 124:223-227.
22. Wang C., Cao S., Tie X., Boqiu., Wu A., Zheng Z., (2010), Induction of cytotoxicity by photoexcitation of TiO_2 can prolong survival in glioma- bearing mice, Molecular Biology Reports, 38:523-530.
23. Zahir A.A., Chauhan S.I., Bagavan A., Kamaraj C., Elango G., Shankar J., Arjaria N., Roopan M.S., Rahuman A.A., SinghN., (2015), Green synthesis of silver and titanium dioxide nanoparticles using *Euphorbia prostrate* extract shows shift from Apoptosis to $G_0\backslash G_1$ arrest followed by necrotic cell death in Leishmania donovani, Antimicrob Agents Chemother, 59(8):4782-4799.
24. Zhang H., Wang C., Chen B., Wang X., (2012), Daunorubicin- TiO2 nanocomposites as a "smart" pH-responsive drug delivery system, International Journal of Nanomedicine, 7:235-242.