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Chapter

Perspective Chapter: *Brassica* Species Mediated Green Synthesis of Nanoparticles and Its Potential Biological Applications

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Abstract

Nanotechnology is a recent technology which is developing rapidly and it has a wide range of potential applications. It is the atomic-level tailoring of materials to achieve unique features that may be controlled for the intended purposes. Nanomaterials can be prepared via several physico-chemical methods but bioreduction of bulk to nanomaterials via green synthesis has developed as a viable alternative to physico-chemical methods in order to overcome their limitations. Plant-mediated nanomaterial synthesis has been found to be environmentally friendly, less costly, and safe with no use of chemicals for medicinal and biological applications where the nanoparticles purity is of major concern. Plant extract is used for the reduction of materials from bulk into nano scale instead of other toxic reducing agents used in chemical methods. The phytochemicals present the extract of plant not only facilitate the synthesis of nanomaterials but act as stabilizing and capping agent, also the shape and size of nanoparticles can be tailored by changing the nature and concentration of plant extract. The present chapter focuses on the green synthesis of nanoparticles mediated by various *Brassica* species and their potential medicinal and biological applications.

**Keywords:** green synthesis, *brassica* mediated nanoparticles, biological activities, size, morphology

1. Introduction

The word nano comes from a Greek word which means “dwarf”. The term nanotechnology is described as to synthesize measure and observe materials at nanometer range. A nanometer (nm) is one billionth part of a meter or $10^{-9}$ m. So, nanotechnology is the field that includes the synthesis, fabrication and application of nanomaterials or nanoparticles where nanomaterials or nanoparticles can be defined as the materials or particles having at least one dimension in size range of 1–100 nm.
The applications of nanoparticles in different fields submerged nanotechnology with numerous other fields such as chemistry, physics, biotechnology, materials sciences, medicine, and engineering as a result new fields such as nano-chemistry, nanophysics, nanobiotechnology, nanomedicine, and nanoengineering etc. has emerged recently [1]. Nanotechnology is gaining prominence rapidly because of its wide range application in a number of other areas such as information technology, energy, environmental science, food packing, cosmetics, medicine and many more. Among them, the most important use of nanotechnology, however, is in medicine and health care [2].

2. Nanoparticles

A “nanoparticle” is a particle having a size in at least one dimension ranging from 1 nm to 100 nm. Looking at it another way, nanoparticles have the similar description as the ultrafine or airborne particles and may be categorized as a subclass of colloidal particles depending on their size [3]. A lot of research work has been done in the development of novel and efficient methods to synthesize the nanoparticles of controlled and desired shape, size and morphology. Depending on the method of synthesis several shapes and sizes of nanoparticles have been observed including nanospheres, nano-cubes, nanorods, nanowires, nanotubes, nano-stars etc. which are often surface functionalized in order to be utilized in desired applications. Furthermore due to their unique size and shape they have been used prominent sensing materials, studying the biological processes and for the treatment of several diseases [4].

3. Classification of nanoparticles

The advancement of nanotechnology enables researchers and scientists to prepare nanoparticles of different sizes and shapes. Nanoparticles of different sizes and shapes exhibit unique chemical and physical properties depending upon the method of their synthesis. The broad classification of nanoparticles is based upon their nanometer range dimensions.

3.1 Zero dimensional particles

Zero dimensional particles are referred to the particles having all three dimensions within nanometer range. The size of zero dimensional ranges from few tens to few hundreds of nanometers. Due to such small size they have very high surface area to volume ratio as compared to bulk materials. It is for this reason that they have unique and improved physico-chemical properties [5].

3.2 One dimensional particles

One dimensional particles are those having two dimension within nanometer range and one dimension out of nanometer range. Nanorods, nanowires and nanotubes are the most common examples of one dimensional nanoparticles. The outer layer of one dimensional nanoparticles are composed of single of multiple atoms with the inner diameter of few nanometers. They are extremely light weighted and strong materials with enhanced thermal and electrical properties [6].
3.3 Two dimensional particles

Two dimensional particles referred to those having only one dimension in nanometer range while two of their dimensions are out of nanometer range. Nanosheets are the best examples of two dimensional particles. Two dimensional nanosheets are extremely thin with the highest surface area having excellent mechanical, chemical and optical properties allowing them to be utilized in a wide range of applications [7].

4. Synthesis of nanoparticles

As discussed earlier that the method of synthesis of nanoparticle is the key factor responsible for their unique size and shape. Nanoparticles can be synthesized by chemical, physical or mechanical methods. Generally the methods of synthesis of nanoparticles are classified into two broad categories i.e. Top down and bottom up methods (Figure 1).

4.1 Top-down methods

Top down method referred to the strategy of going from bulk to tiny. In top down methods nanoparticles come into their unique morphology via breakdown of bulk materials into smaller particles. Lithography and sputtering are the most widely used top down methods to synthesize nanoparticles. Other examples include
electrochemical explosion, photoirradiation, ultrasonication, laser ablation, mechanical milling and chemical etching etc.

4.2 Bottom-up methods

The bottom up approach generally referred to going to large from small. In bottom up methods the nanoparticles take their ultimate structure via merging of small building blocks. Examples of bottom up methods for the synthesis of nanoparticles include sol-gel method, co-precipitation method, chemical reduction method, hydrothermal/solvothermal method, biological/green synthesis methods etc. [8].

5. Green synthesis of nanoparticles

A wide number of physico-chemical methods have been discovered over the past 50 years for the synthesis of nanoparticles having desired size and shapes. The need for nanoparticles is increased due to its wide range of applications in almost every area of modern time. This increasing demand of nanoparticles also poses threat to environment as the synthesis of nanoparticles by various physico-chemical methods utilizes several hazardous chemicals. As a result scientists developed a much safer method known as green synthesis of nanoparticles. Green synthesis of sometimes referred to biological or biogenic synthesis of nanoparticles is basically bottom up approach in which the precursor metal salts undergo reduction resulting in the synthesis of nanoparticles. The phenomenon of green synthesis of similar to chemical reduction method with the benefit of replacement of toxic reducing agent by the natural products extracts (Figure 2). The natural product extract is devoid of hazardous chemicals and has inherent stabilizing, capping properties, and growth inhibiting, making this technique eco-friendly, non-toxic, cost-effective, and ideally suited for biological and medicinal applications. Plants, algae, fungi, and bacteria etc. can be used for this purpose where the nature of biomolecules at various concentrations and in various combinations with precursor salts influences the size and structure of NPs [9].

5.1 Green synthesis of nanoparticles using Brassica genus

Brassica is genus consist of 37 flowering plants in the mustard and cabbage family (Brassicaceae). Among them majority of species are agricultural corps. The genus Brassica is native to temperate Asia and Europe, and is particularly prevalent in the Mediterranean region; nonetheless, several species have been reported invasive in places beyond their natural range. Broccoli, sprouts, cabbage, brussels, rape, kale, kohlrabi, rutabaga, cauliflower, turnip and brown mustard are all economically significant members. It is among the most frequently produced plant genera in the world, with vegetables high in minerals and vitamins that are beneficial to the human diet. Plant extracts (flower, leaf, root, and seed) have recently been widely researched as a biological method for the production of nanoparticles (mostly silver and gold nanoparticles). Some plants have also been shown to have the ability of in vivo synthesis of nanoparticles. Plant-derived chemicals of different types exhibit potential biological activities. The phytochemistry of the genus Brassica has been researched, and the following substances have been identified: proteins, steroids, carbohydrates, phenols, terpenoids, flavanoids, quinones, coumarines, phlobatannins, tannins, saponins, vitamins and different minerals. These phytochemicals are responsible for the synthesis and stabilization of
metal nanoparticle [10]. Extensive study has recently been conducted on plant mediated reduction of metal nanoparticles and the function of phytochemicals in this technique. A great number of articles on the green synthesis of nanoparticles utilizing phytochemical enriched plant extracts have been published. The extract of broccoli has been utilized for the bio-reduction of various metal precursors to synthesize the corresponding metallic nanoparticles. Osuntokun J. et al., reported the synthesis of CuO nanoparticles using aqueous extract of broccoli having size of 30–40 nm [11]. Similarly the synthesis of gold and silver nanoparticles were reported having particle size of 24–38 nm and 38–45 nm respectively [12]. Recently selenium nanoparticles with anti-carcinogenic properties were synthesized having an average particles size of 10–28 nm [13]. The phytochemical screening of broccoli extract showed that the active compound responsible for the synthesis of nanoparticles were alkaloids, phenolic compounds, saponins, flavonoids and ascorbic acid. The extract of other species of brassica genus is extensively studied for the synthesis of various metallic nanoparticles in literature. Some of the species of genus brassica have the potential for in-vivo synthesis of nanoparticles. For this purpose the plant is grown on the surface or land having certain metal ions, the plant extracts metal from land through their hyper cumulating capacity and then through their reducing capacity they reduce metal ions into metal nanoparticles in various organs and tissues. This approach is known as phytominning and the accumulated metal is recovered after different steps of harvesting. Some of brassica species are known to be better hyper accumulators such as Brassica juncea. B. juncea accumulated about silver ions and synthesized
about 2–25 nm silver nanoparticles when grown silver containing land [14]. Furthermore the mechanism of reduction of metal ions into metal nanoparticles and organs responsible for the storage of reduced metal nanoparticles were also investigated in B. juncea plants. Gold nanoparticles were synthesized by in vivo method where B. juncea were grown on the solutions AgNO$_3$ and HAuCl$_4$. In case of gold the reduction Ag$^{3+}$ ions to Au$^0$ nanoparticles and in case of the silver the reduction Ag$^+$ ions and Ag$^0$ nanoparticles were investigated and the sites of their responsible for their reduction were investigated. The major amounts of nanoparticles were found in the leaf area which showed that the reduction of metal ions into metal nanoparticles mainly occurred in chloroplasts (the regions of high contents of glucose and fructose). Glucose and fructose were found to be the sugars with high reducing properties and the amount of these sugar had a directly relation to the amount of nanoparticles synthesized [15]. Having high reducing properties these glucose can be used for synthesis of nanoparticles in conventional chemical methods by replacing the toxic reducing agent with glucose. The synthesis of metal nanoparticles using other extract of organs of Brassica genus such as roots, seeds, flowers etc. having potential biological activities has also been reported in literature which will be discussed in the coming sections.

5.2 Potential biological activities of brassica genus mediated synthesized nanoparticles

Green synthesized nanoparticles being safe and economic having a wide range of applications in the area of health and medicine. The extract used for the reduction of metal ions into metal nanoparticles and also act as capping agent has an important role in their applications. The extract its-self have biological properties and depending on the extract used for synthesis and capping of nanoparticles the applications of prepared nanoparticles varies. Different species of genus Brassica has been reported in literature for the synthesis of metal nanoparticles and used for different biological activities. The detailed discussion of different biological applications of Brassica genus mediated nanoparticles is present in the coming sections.

5.2.1 Antifungal activity

Green synthesized nanoparticles have gained popularity in recent years because of their applications to control and treat several human and plants diseases, and due to their nanosized dependent unique chemical and physical properties they are found to be very effective materials in the area of medicine and biology. Initially Brassica rapa L. leaf extract was used for the synthesis of silver nanoparticles which were employed for the antifungal activity against a wide range of wood rotting pathogens such as Gloeophyllum abietinum, G. trabeum, Chaetomium globosum, and Phanerochaete sordida. This was the first study regarding the application of green synthesized nanoparticles for the treatment of plant disease. The results indicated that prepared nanoparticles were effective to protect soft and hand wood against pathogenic fungi [16]. Gold nanoparticles were synthesized using the extract of Brassica oleracea specie of genus Brassica which act as antifungal agent against human pathogenic fungi. The prepared gold nanoparticles were found to be effective antifungal agent against Aspergillus niger, Aspergillus flavus, and Candida albicans. The results showed the gold nanoparticles prepared using extract of B. oleracea exhibited enhanced antifungal activity as compared to the previously prepared using extract of other plants. The mechanism of such great antifungal activity of prepared gold nanoparticles was also investigated, as the
nanoparticles had a very small size, i.e. 12–22 nm, which was 275 times smaller than the size of fungi, making them more likely to adhere to the cell wall of fungi and resulting in death of human pathogenic fungi [17]. Copper nanoparticles being relatively economic than silver and gold nanoparticles but exhibits excellent antimicrobial, antibacterial, antifungal and anticancer activities. Copper nanoparticles prepared using the aqueous extract of *B. oleracea* var. italic were found to be very efficient against human pathogenic fungi such as *Aspergillus niger* and *Candida Albicans* by disc diffusion method. The phytochemical screening showed that polyphenols, gluco- sinolates, flavonoids, minerals and vitamins were present in the aqueous extract of *B. oleracea* var. italic which was responsible for the reduction of copper ions into copper nanoparticles [18]. Zinc oxide nanoparticles (ZnO NPs) have a broad range of applications and they have been extensively studied for antibacterial and antifungal properties. Zinc nanoparticles were prepared using the extract of *Brassica oleracea var. italic* and their antimicrobial and antifungal efficiency against *Staphylococcus aureus* and *Escherichia coli* and *Aspergillus niger* and *C. albicans*. ZnO-NPs synthesized *B. oleracea var. italic* extract were found to be effective against both the fungal stains [19]. Several studies have shown that nanoparticles prepared via *Brassica* genus species extracts have excellent antifungal characteristics and have the potential to be used as an antibacterial agent against a variety of microbiological species.

5.2.2 Antibacterial activity

Using various extraction solvents such as ethanol, methanol, acetone, chloroform, and water, the antibacterial activity of *Brassica* plants against Gram-positive and Gram-negative bacteria was examined. When compared to other extracts, methanolic extracts were found to be more effective at controlling the development of all bacteria [20]. Antibacterial properties of four *Brassica* species were investigated, specifically *Brassica cretica Lam.* (broccoli) and three *B. oleracea* variants (portuguese galega, Portuguese tronchuda and red cabbage). They applied different ratios of bioactive substances such as phenolic compounds and organic acids (2.5–25 mg/ml) to prevent common foodborne bacterial infections (*E. coli* O 157: H7, *Salmonella typhimurium*, *Listeria monocytogenes*, *Bacillus cereus*, and *Staphylococcus aureus*). A solution of INT was used to estimate the minimal inhibitory concentration (MICINT) based on metabolic respiratory activity (2-p-iodophenyl-3-p-nitrophenyl- 5-phenyl tetrazolium chloride) [21]. Silver and gold nanoparticles synthesized from plant and vegetable extracts of the genus *Brassica* have become extremely popular because of their antibacterial qualities. The nanoparticles are even being considered as antibacterial agents of the future. Various researchers have thoroughly made consistent the production of antibacterial nanoparticles using green technology, however the induced generation of metal nanoparticles in living plants is poorly understood in this study. Tamileswari et al. (2015) described the production of silver nanoparticles using *B. oleracea* (cauliflower) and *B. oleracea capitata* (cabbage), as well as their antibacterial efficacy against pathogenic microorganisms. Sridhara et al. found that silver nanoparticles synthesized from cauliflower broth had full antibacterial action against two human pathogens, *E. coli* (*E. coli*) and *S. aureus* (*S. aureus*), at a concentration of 50 mg/liter (2013) [22]. Silver nanoparticles synthesized from broccoli were found to be effective in antibacterial activity when combined with silver nanoparticles and antibiotics in a prior study. The antibacterial efficacy of gold nanoparticles derived from *B. oleracea* (broccoli) flower bud aqueous extracts was investigated using the disc diffusion method and human pathogenic bacteria (*S. aureus* and *Klebsiella pneumonia*). When compared to
traditional antibiotics, gold nanoparticles were found to have the best antibacterial action (Gentamicin and Fluconazole). The sensitivity zone for all the studied microorganisms increased as the concentrations of gold nanoparticles (10, 25, and 50 g/ml) were raised [17]. These silver nanoparticles were tested for antibacterial efficacy against four human pathogens: Klebsiella pneumoniae, E. coli, Staphylococcus saprophyticus, and B. cereus. Gram negative (−ve) bacteria include K. pneumonia and E. coli, while gram positive (+ve) bacteria include S. saprophyticus and B. cereus, and biosynthesized silver nanoparticles demonstrated a distinct zone of inhibition. Antibacterial activity of the ethanolic crude extract and synthesized nanoparticles was studied in this work the Agar disc diffusion method was used, which measured the inhibition zone of the test microorganisms. The antibacterial potential of ethanolic crude extract and copper nanoparticles against E.coli, S.aureus, and P.aeruginosa was demonstrated by extract of Brassica oleracea var. acephala. It was also found to have antifungal properties against C. albicans. When comparing the two samples, copper nanoparticles demonstrated the greatest inhibition zone against the test organisms. This was because nanoparticles had higher antibacterial activity than the crude extract. As a result, this research suggests that copper nanoparticles generated from the leaf extract have wide antibacterial efficacy against these harmful species [23].

5.2.3 Antioxidant activity

Due to the presence of a variety of oxidants and varied ways to scavenge them, determining the antioxidant capacity of fruits and vegetables is a difficult task. There is no one assay that can evaluate the biological samples’ overall antioxidant potential. As a result, various tests are used to obtain a conclusive picture of the antioxidant capacity of the materials. For the evaluation of antioxidant capacity in plant samples, the ferric reducing antioxidant potential (FRAP) and 1,1-diphenyl-2-28 picrylhydrazyl radical (DPPH) tests are the most used assays. During physiological homeostasis, organisms continuously produce large levels of molecules, many of which are reactive, known as reactive oxygen species (ROS). The oxidants that are produced can interact with proteins, lipids, and nucleic acids, among other biological components. Proteins are, indeed, oxidants’ primary targets. Lipid peroxidation, on the other hand, is caused by free radicals such hydroxyl, alkoxyl, and peroxyl, particularly in polyunsaturated fatty acids. Antioxidant molecules are receiving a lot of attention these days to prevent diseases caused by oxidative stress. Polyphenols have been related to anticancer, antiaging, neuroprotective, antidiabetic, and cardioprotective properties because of their excellent structural chemistry for free radical scavenging activities. Furthermore, ascorbic acid and its oxidation product, dehydroascorbic acid, have been linked to a lower risk of cancer, cardiovascular disease, and diabetes in humans [24]. Copper nanoparticles, have a low redox potential and are more likely to oxidize when exposed to air. Microwave aided pyrol, hydrothermal technique, thermal reduction, and other methods are commonly used to make them. However, these methods are not inexpensive and require the use of toxic chemical solvents. As a result, ecologically friendly synthetic methods are preferred. The leaf extract binds to the copper nanoparticles, B. oleracea has a high antioxidant capacity [23]. The metabolic & antioxidant properties of synthesized copper oxide nanoparticles using Solanum lycopersicum & B. oleracea were studied. The amount of copper oxide nanoparticles accumulated in the two species of plants was dosage dependent, and the results revealed that tomato plants accumulated nanoparticles more actively than cauliflower plants, probably due to differences in root architecture [25].
5.2.4 Anticancer activity

Pharmaceutical companies have periodically produced a significant number of commercial anticancer medicines. Because these treatments have such a high rate of side effects, natural effective drugs with the fewest negative effects are in demand. According to a study, the active component 2-pyrrolidinone found in the leaves of *B. oleracea* has anticancer properties. This chemical was projected to be useful in the creation of novel anticancer drugs that could stop cancer cells from growing in vitro. In HeLa (IC50 2.5 g/ml at 24 h and 1.5 g/ml at 48 h) and PC-3 cancer cells (IC50 3.0 g/ml at 24 h and 2.0 g/ml at 48 h), this compound inhibited the proliferator cells, resulting in a considerable decrease in cell proliferation, cell viability, and significant induction of apoptosis [26]. In vitro studies were conducted on HCT116 colorectal cancer and H1299 non-small-cell lung carcinoma cells using ethanolic extracts of mustard (*B. juncea*) leaves. The release of vascular endothelial cell growth factor & basic fibroblast growth factor was significantly suppressed in both cell lines after treatment with mustard leaves extract. This study discovered that mustard leaves extract had anticancer properties in vitro against colon (IC50 253 g/ml at 72 h and 153 g/ml at 96 h) & lung cancers (IC50 700 g/ml at 72 h and 130 g/ml at 96 h), but the findings need to be confirmed in vivo [27]. Nanoparticles could be a more active and lucrative source of novel cancer treatments in the current context. As a result, biologically synthesized nanoparticles have recently received a lot of attention as chemotherapeutic agents. Mayilsamy and Krishnaswamy (2016) looked at the anticancer properties of silver nanoparticles made from *B. rapa chinensis* L., as well as their in vivo experiments in mice. Treatment with a methanolic extract of *B. rapa chinensis* leaves resulted in a rise in hemoglobin content and RBC, as well as a decrease in WBC count. The histological evaluation of control animals revealed aberrant growth, but treatment with nanoparticles resulted in hepatocyte growth that was practically normal. Many scientists and researchers have recently worked on silver nanoparticles and examined their anticancer activity in lung and liver cancer cells as well as HEPG-2 cells and gold nanoparticles against HL-60 cells [28, 29]. Ethanolic crude extract and copper nanoparticles were tested in vitro against the HeLa cervical cancer cell line at various doses. The samples had a high level of cytotoxicity when tested on the HeLa cell line. The results showed that ethanolic crude extract and copper nanoparticles effectively inhibited HeLa cell proliferation, with an IC 50 value of 170.6622 (g/ml) for the crude extract and 119.0805 (g/ml) for the nanoparticles. The fact that the percent toxicity increased as the concentration of copper nanoparticles grew suggests that synthesized copper nanoparticles could be useful in medicine as an anticancer drug. The vitality of cancer cells decreases as the concentration of the samples increases, whereas cytotoxicity against HeLa cell lines increases as the concentration of the samples increases [23].

5.2.5 Cytotoxic activity

Cytotoxicity tests, which include plant extracts or physiologically active chemicals derived from plants, are a valuable first step in identifying the potential toxicity of a test drug. For the effective development of a pharmaceutical or cosmetic product, minimal to no toxicity is required, and cellular toxicity studies play a critical role in this regard [30]. Using AgNO3 solution as a precursor and *B. rapa* var. *japonica* leaf extract as a reducing and capping agent, silver nanoparticles (AgNPs) were successfully synthesized from Ag + reduction. The goal of this research was to synthesize AgNPs that were less toxic. On PC12 cells, crystalline phased *Brassica* AgNPs were
less toxic than Com AgNPs. Brassica AgNPs’ lower cytotoxic activity could be related to their stability, which was attributed to the presence of a capping agent on AgNPs given by Brassica rap var. japonica. As a result, Brassica AgNPs could be a good choice for safe application in consumer products because they are simple and inexpensive [31]. The 70 percent aqueous ethanolic extract of B. rapa and silver nanoparticles were studied for chemical components and cytotoxic effects. The ethanolic extract included silver nanoparticles that were less than 20 nm in size. The two extracts (ethanolic extract and its nanoparticles) were tested for cytotoxicity against HELA cells (human cervical cancer cell line) and M-NFS-60 cells (human Mouse Myelogenous Leukemia carcinoma) using Doxorubicin as the control medication. Brassica extract showed to be less toxic to both cell lines [32]. First, Ag-NPs were successfully synthesized by reducing Ag + with AgNO3 solution and B. rapa var. nipposinica/japonica leaf extract as reducing and capping agents. There were no further chemical reductants or stabilizing agents used in the synthesis process. Following tests were done to conform the production of Ag-NPs to lower toxicity. The cytotoxicity of Brassica AgNPs was compared to that of commercial AgNPs by using PC12 cell system. Commercial Ag-NPs reduced cell viability to 23% (control: 97%) and increased lactate dehydrogenase activity in PC12 cells at three ppm, whereas Brassica Ag-NPs showed no cytotoxicity on both parameters up to a concentration level of 10 ppm. The lower cytotoxicity of green produced Ag-NPs will be beneficial for safely use of Ag-NP in consumer products [33]. Greenly synthesized silver nanoparticles (Ag-NPs) have shown promising effect on different cell lines including cytotoxicity and anticancer potential. As a result, Ag-NPs were synthesized from AgNO3 reduction using B. rapa var. japonica (Bj) leaf extract as a reducing and stabilizing agent in a prior study. The Ag-NPs were spherical in form and ranged in size from 15 to 30 nm. They had a phase-centered cubic structure and could effectively limit the growth of various bacteria. In this work, we wanted to see if Ag-NPs have an autophagy-regulated lethal effect on human epithelial colorectal adenocarcinoma cells, like we did in the prior one (Caco-2 cells). Brassica silver nanoparticles (Brassica Ag-NPs)-induced NF-B mediated autophagy in Caco-2 cells was accelerated by the Bj leaf aqueous extract. According to results the Ag-NPs reduced Caco-2 cell viability by producing oxidative stress and DNA damage [34]. High-quality gold nanoparticles (AuNPs) were produced using aqueous Chinese lettuce (CL) leaf extract as a reducing agent in this study. According to FTIR studies, the excellent stability of AuNPs can be linked to the presence of CL leaf extract on particle surfaces. AuNPs concentrations ranging from 0 to 2 g/ml, but no significant variations in cell viability were observed; however, A549 cell proliferation was severely reduced in a dose-dependent manner at doses more than 4 g/ml. The viability of cells was 90% after 48 hours of treatment with AuNPs, according to cytotoxicity data. After 48 hours of therapy, a healthy nucleus was found with decreased chromatin condensation. These studies indicate that AuNPs had no negative effects on A549 cells’ chromatin or DNA. AuNPs eventually caused necrosis and apoptosis in A549 cells, according to the results of the apoptosis experiment [35]. The green approach of nanoparticle synthesis, which is both environmentally and biologically friendly, is a new topic that has emerged as a viable alternative to traditional methods such as physical and chemical synthesis. The green synthesis of magnetic iron oxide nanoparticles (IONPs) from iron (III) chloride was described in this study employing B. oleracea aqueous peel extract. The MTT assay was used to investigate the cytotoxic effects of IONPs on the MCF-7 breast cancer cell line. The polydispersity index of IONPs was found to be 0.265, and the mean particle size was 675 25 nm. The effective
synthesis of nanoparticles is supported by characterization results, and nanoparticles’ dose-dependent lethal effects on MCF-7 cells make them a promising chemotherapeutic agent for breast cancer treatment [36].

6. Future perspectives

According to previous research Brassica species have potential biomedical properties because different species of Brassica genus were found to have several significant phytochemicals like phenols, alkaloids, carbohydrates, tannins, saponin, flavonoids, proteins etc. Owing to these biologically important phytochemicals the extract of Brassica species exhibits strong biomedical application. Several potential biological activities of different Brassica species have been discovered such as antioxidant activity, antibacterial activity, antifungal activity, antidiabetic activity, anticancer activity, anti-inflammatory activity, antinoceptive activity, antiviral activity, anti-hyperlipidemic activity, antiobesity, antihyperglycemic activity and antidepressant activity [37].

On the other hand Brassica species mediated nanoparticles have been explored less as compared to the pure extract of different Brassica species. These kind of nanoparticles are used against few activities such as antibacterial, antifungal, anticancer, and antioxidant activities with enhanced performance as discussed earlier but still there is a plenty of room in exploration of brassica mediated nanoparticles against the remaining biological activities. In future the Brassica mediated nanoparticles can used for these activities with enhanced performance and which can act as potential materials in the treatment of such critical diseases.

7. Conclusions

Brassica species have some potential phytochemicals which not only act as reducing agents but also act as capping agents owing to the stability of prepared nanoparticles. Several species of Brassica genus and different parts of each plant has been used for the synthesis of nanoparticles of different metals such as gold, silver, copper, zinc, iron and selenium. The particles prepared using extract of various species of nanoparticles were found to be safer as compared to prepared by conventional chemical methods with enhanced biological properties. Recent studies showed that the Brassica species mediated nanoparticles have strong antifungal, antibacterial, anticancer and antioxidant activities. However, more study is required for the extension of biomedical applications of these nanoparticles because the pure extract of several species of Brassica genus has been explored for having metabolites with profound biological properties. Further, due to absence of toxic chemicals in this method synthesis these kind of nanoparticles can be used for other biomedical, environmental and electrochemical purposes.

Acknowledgements

The authors acknowledge their respective institutions for providing all facilities used in this study.
Conflict of interest

The authors have no conflicts of interest to declare. All co-authors have seen and approved the contents of the manuscript and have no financial interest to report. We certify that the submission is original work and not under review in another publication.

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