molecules

MDPI

Review

Bactericidal Properties of Plants-Derived Metal and Metal Oxide Nanoparticles (NPs)

Sin-Yeang Teow [1,*], Magdelyn Mei-Theng Wong [1], Hooi-Yeen Yap [1], Suat-Cheng Peh [1,2] and Kamyar Shameli [3]

1 Department of Medical Sciences, School of Healthcare and Medical Sciences, Sunway University, Jalan Universiti, Bandar Sunway, Subang Jaya 47500, Selangor Darul Ehsan, Malaysia; magdelyn.w@gmail.com (M.M.-T.W.); 17084351@imail.sunway.edu.my (H.-Y.Y.); pehsc@sunway.edu.my (S.-C.P.)

2 Anatomical Pathology Department, Sunway Medical Centre, Jalan Lagoon Selatan, Bandar Sunway, Subang Jaya 47500, Selangor Darul Ehsan, Malaysia

3 Department of Environment and Green Technology, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur 54100, Malaysia; kamyar@utm.my

* Correspondence: ronaldt@sunway.edu.my; Tel.: +60-3-7491-8622 (ext. 7369)

Received: 27 April 2018; Accepted: 15 May 2018; Published: 06 June 2018

Abstract: Nanoparticles (NPs) are nano-sized particles (generally 1–100 nm) that can be synthesized through various methods. The wide range of physicochemical characteristics of NPs permit them to have diverse biological functions. These particles are versatile and can be adopted into various applications, particularly in biomedical field. In the past five years, NPs' roles in biomedical applications have drawn considerable attentions, and novel NPs with improved functions and reduced toxicity are continuously increasing. Extensive studies have been carried out in evaluating antibacterial potentials of NPs. The promising antibacterial effects exhibited by NPs highlight the potential of developing them into future generation of antimicrobial agents. There are various methods to synthesize NPs, and each of the method has significant implication on the biological action of NPs. Among all synthetic methods, green technology is the least toxic biological route, which is particularly suitable for biomedical applications. This mini-review provides current update on the antibacterial effects of NPs synthesized by green technology using plants. Underlying challenges in developing NPs into future antibacterials in clinics are also discussed at the present review.

Keywords: antibacterial; nanoparticles; green synthesis; biomedical applications; plants

1. Nanoparticles and Green Technology

Nanoparticles (NPs), also known as nanomaterials, are small on a molecular scale and have various physical and chemical properties. Some examples of NPs are made up of metals ions such as Au, Ag, Pd, Pt, Zn, Fe, and Cu, and metal oxides such as Ag_2O, NiO, ZnO, CuO, FeO, and CeO_2. The advancement of nanotechnology has also given rise to the development of various nanocomposites, which are multiphase solid materials consisting of multiple types of NPs and polymers to improve single-metal biological effects and overcome structure-function related issues [1]. Multiple biological actions of the NPs such as antibacterial [2,3], antioxidant [2,4], anticancer [5,6], antifungal [5,7], antiviral [8,9], antiparasitic [10,11] and anti-inflammatory activities [12,13] have been associated with their highly diverse chemistry-rich characteristics [14]. There are myriad ways of synthesizing NPs, including physical (e.g., vapor deposition [15], sputter deposition [16], electric arc deposition [17], ion beam technique [18], molecular beam epitaxy [19], melt mixing [20]), chemical (e.g., co-precipitation [21], sol-gel [22], microemulsions [23], sonochemical synthesis [24] UV-initiated

photoreduction [25]), and biological (e.g., synthesis using plant extracts [26], microorganisms [26], algae [27], fungi [28], animals [29] or agricultural waste [30], enzymes [31]) methods as well as hybrid methods [32] (Figure 1). There are advantages and limitations for each synthetic method, and the choice of method is selected based on the downstream applications.

Due to their small size and improved cell-penetrating features, NPs are extremely useful in various biomedical applications including sensing [33,34], imaging [33,35], diagnostics [36,37], drug/compound delivery system [38,39], bioconjugation [40,41], hyperthermia [42,43], and biological therapies [33,36] (Figure 1). In the past few years, NPs have been widely used to improve sensing and imaging techniques mainly due to their remarkable localization capability [33]. Some other additional advantages using NPs include flexibility in surface modification of NP [44], easy control of size [45], and production of highly degradable NPs in vivo [46]. Moreover, NPs are widely used in bio-conjugation and combination with drugs and compounds as well as in facilitating their delivery to target [47]. In a review paper authored by Werengowska-Ciećwier et al., bioconjugation of various drugs and NPs as well as their detailed chemistry have been described [47]. The same review also discussed the application of NPs in drug delivery system for targeted therapies. The potential use of NPs in hyperthermia mainly in cancer cell killing have been extensively explored [48,49]. The use of magnetic hyperthermia is one of the hot approaches [48,50]. Using magnetic NPs, heat generation can be controlled and specifically target and kill cancer cells while limiting damage to the surrounding normal tissue [50,51]. As chemo- and radiotherapies are standard cancer treatments, it is anticipated that the use of NPs in combination with current treatments could enhance the treatment outcome while reducing side effects of chemo-and radio-therapies [51]. Similarly, NPs have also been shown to be effective against other infectious diseases such as *Pseudomonas aeruginosa* [52] and *Escherichia coli* [53] infections in addition to cancers. This highlights the important role of NPs in medical and biomedical application in short future.

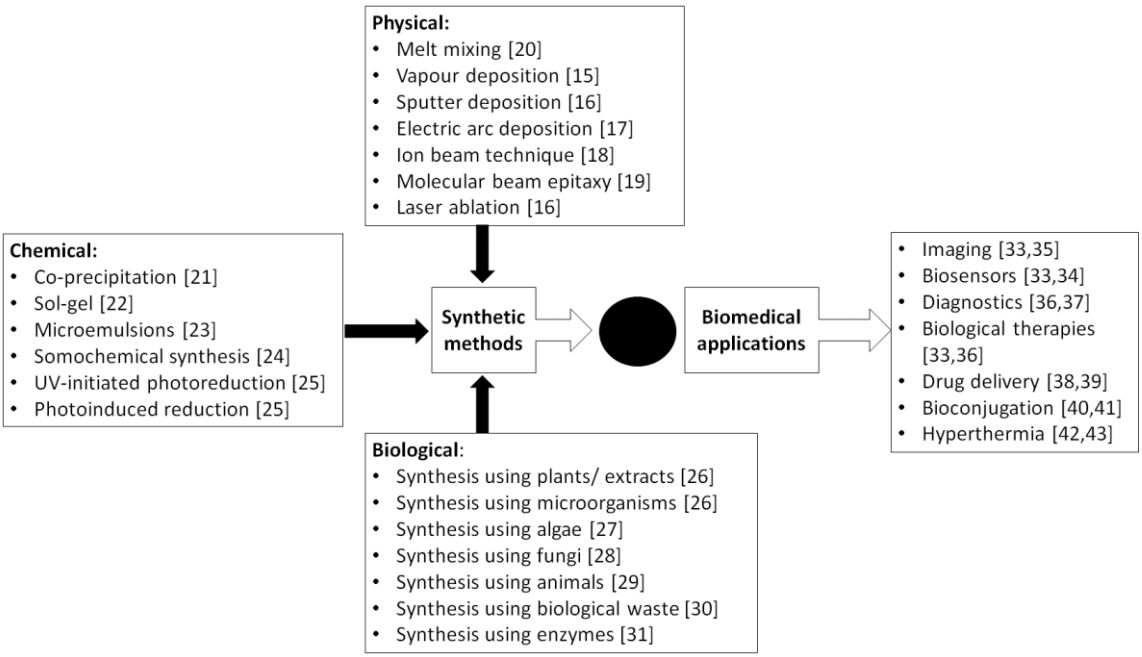

Figure 1. Current synthetic methods of nanoparticles (NPs) and their biomedical applications. The core methods used for NPs construction are divided into physical, chemical, and biological methods. The generated NPs can be utilized in various biomedical applications including imaging, biosensors, diagnostics, biological therapies, drug delivery, bioconjugation, and hyperthermia.

Generally, synthesis of NPs by biological routes has several advantages over both physical and chemical methods. First, the process is relatively simple, easy to scale up, efficient, and it consumes lesser energy **[26]**. Second, green technology is environmentally friendly as it uses lesser toxic chemicals and generating safer products and byproducts [54]. The green method is suitable and applicable for production of food, pharmaceuticals, and cosmetics [55]. Comparatively, the green method produces NPs that are generally less toxic, the end products being more suitable for a wide range of biomedical applications [26,56]. Chemical and physical methods can be very costly and usually involve the use of toxic and hazardous chemicals which tend to be more toxic to human cells. Additionally, the green method does not strictly require high temperature, pressure, and energy [57]. However, several parameters such as pH, chemical concentration, reaction time and reaction temperature are critical to consistently produce biologically functional NPs [58–61]. Furthermore, unlike using microbial system, generation of NPs from plants do not have to maintain microbial culture hence reducing the costs for microorganism isolation and culture media preparation [54]. The NPs generated from plants generally have size ranging from 1 to 100 nm (Table 1). There are also relatively large NPs that have sizes ranging from 100 to 500 nm [2,62,63]. NPs generated by all type of methods result in impurities that mainly cause toxicity to the human cells. These impurities can be removed by dialysis and filtering. The plant-derived NPs are less toxic, as shown from toxicity testing across several mammalian cell lines such as NIH3T3 [4], HEK293 [3], and primary cells such as peripheral blood mononuclear cells (PBMCs) [63] and rat aortic vascular smooth muscle cells (VSMCs) [4].

There is an extensive list of NPs possessing various biological actions as mentioned above. However, the focus of this review emphasizes the NPs' antibacterial activities. This short review provides updates on the recent NPs with promising antibacterial activity synthesized by green technology using whole plant or other extracts of plants such as leaves [5,63], fruits [64,65], roots [66,67], barks [62,68], seeds [69,70], rhizomes [71,72], peels [73,74], flowers [75], and callus [76,77]. Here, we also discuss the challenges of adopting NPs for clinical applications.

Table 1. Antibacterial effects of nanoparticles synthesized by green method using plants against various bacteria reported in PubMed-indexed publications from 2016 to 2017.

Nanoparticles	Size (nm)	Source	Scientific Name	Common Name	Target Bacteria	References
Ag-NPs	26–28	Leaves	*Coleus aromaticus*	Cuban oregano	*Escherichia coli* (*E. coli*), *Staphylococcus aureus* (*S. aureus*)	[78]
	12.46	Leaves	*Salvinia molesta*	Kariba weed	*E. coli*, *S. aureus*	[79]
	70.7–192.02	Leaves	*Aloe vera*	Aloe	*Pseudomonas aeruginosa* (*P. aeruginosa*), *Streptococcus epidermidis* (*S. epidermidis*)	[63]
	5–50	Leaves	*Mentha pulegium*	Pennyroyal	*E. coli*, *S. aureus*, *Streptococcus pyogenes* (*S. pyogenes*)	[5]
	5–40	Leaves	*Cucurbita pepo*	Summer squash	*E. coli*, *S. aureus*, *Bacillus cereus* (*B. cereus*), *Listeria monocytogenes* (*L. monocytogenes*), *Salmonella typhi* (*S. typhi*), *Salmonella enterica* (*S. enterica*)	[80]
	112.6	Crude	*Ammania baccifera*	Monarch redstem	*S. aureus*, *P. aeruginosa*, MRSA	[81]
	10–70	Oil cake	*Cocos nucifera*	Coconut	*Aeromonas* sp., *Acinetobacter* sp., *Citrobacter* sp.	[82]
	3.2–16	Seeds	*Pimpinella anisum*	Aniseed	*K. pneumonia*, *P. aeruginosa*, *S. typhi* *Streptococcus pyogenes* (*S. pyogenes*), *Acinetobacter baumannii* (*A. baumannii*)	[69]
	2–25	Crude	*Matricaria camomilia*	Camomile	*E. coli*, *S. aureus*, *Bacillus subtilis* (*B. subtilis*), *P. aeruginosa*	[83]
	50	Crude	*Salvadora persica* L.	Toothbrush tree	*E. coli*, *S. aureus*	[84]
	25	Rhizomes	*Zingiber officinale*	Ginger	*E. coli*, *S. aureus*, *K. pneumonia*	[71]
	20	Leaves	*Gloriosa superba*	Flame lily	*E. coli*, *B. subtilis*	[85]
	5–25	Leaves	*Parkia roxburghii*	Tree bean	*E. coli*, *S. aureus*	[86]
	10–20	Tubers	*Dioscorea alata*	Yams	*E. coli*, *Staphylococcus auricularis* (*S. auricularis*)	[87]
	35–42.5	Powder	*Theobroma cacao*	Cacao	*E. coli*, *S. aureus*, *Staphylococcus epidermidis* (*S. epidermidis*), *P. aeruginosa*	[88]
	10–50	Leaves	*Adathoda vasica Linn*	Vasaka	*Vibrio parahaemolyticus* (*V. parahaemolyticus*)	[89]
	14.63	Crude	*Eleutherococcus senticosus*	Siberian ginseng	*E. coli*, *S. aureus*, *V. parahaemolyticus* *Bacillus anthracis* (*B. anthracis*)	[90]
	20–30	Seeds	*Coffea arabica*	Arabian coffee	*E. coli*, *S. aureus*	[70]
	20–100	Leaves	*Sonneratia apetala*	Sonneratia mangrove	*Shigella flexneri* (*S. flexneri*), *E. coli*, *S. aureus*, *Vibrio cholera* (*V. cholera*), *S. epidermidis*, *B. subtilis*	[62]
	50–400	Bark	*Heritiera fomes*	Sundari	*E. coli*, *S. aureus*, *V. cholera*, *S. epidermidis*, *B. subtilis*	[62]

Table 1. *Cont.*

Nanoparticles	Size (nm)	Source	Scientific Name	Common Name	Target Bacteria	References
	3–6	Crude	*Allium sativum* L.	Garlic	*E. coli*, *E. faecalis*, *Bacillus cereus* (*B. cereus*), *S. flexneri*	[91]
	3–22	Crude	*Zingiber officinale* Rosc.	Ginger	*E. coli*, *E. faecalis*, *B. cereus*, *S. flexneri*	[91]
	3–18	Crude	*Capsicum frutescens* L.	Cayenne pepper	*E. coli*, *E. faecalis*, *B. cereus*, *S. flexneri*	[91]
	10–20	Roots	*Salvadora persica* L.	Toothbrush tree	*E. coli*, *S. aureus*, *P. aeruginosa*, *Micrococcus luteus* (*M. luteus*)	[92]
	5–30	Crude	*Rumex dentatus*	Toothed dock	*P. aeruginosa*, *Bacillus thuringiensis* (*B. thuringiensis*)	[93]
	49	Flowers	*Millettia pinnata*	Karanja	*E. coli*, *P. aeruginosa*, *Proteus vulgaris* (*P. vulgaris*), *S. aureus*, *K. pneumonia*	[75]
	16.4	Seeds	*Pongamia pinnata*	Seashore Mempari	*E. coli*	[94]
	5–60	Rhizomes	*Dryopteris crassirhizoma*	Japanese fern	*P. aeruginosa*, *B. cereus*	[72]
	1–69	Leaves	*Ficus religiosa*	Peepul tree	*E. coli*, *B. subtilis*, *S. typhi*, *Pseudomonas fluorescens* (*P. fluorescens*)	[95]
	12–38	Powder	*Styrax benzoin*	Benzoin gum	*E. coli*, *P. aeruginosa*, *S. aureus*	[96]
	6.4–27.2	Callus	*Taxus yunnanensis*	Himalayan yew	*E. coli*, *S. aureus*, *S. paratyphi*, *B. subtilis*	[76]
	10–20	Ginseng berry	*Panax ginseng*	Meyer berries	*E. coli*, *S. aureus*	[4]
	45.26	Corn leaves	*Zea mays* L.	Maize	*E. coli*, *S. aureus*, *S. typhimurium*, *L. monocytogenes*, *B. cereus*	[97]
	20–80	Shoot tip	*Caesalpinia mimosoides* Lam.	Mimosa thorn	*E. coli*, *L. monocytogenes*	[98]
	37	Leaves	*Coriandrum sativum*	Coriander	*Propionibacterium acnes* (*P. acnes*)	[99]
	22.89	Aerial parts	*Artemisia tournefortiana*	-	*E. coli*, *B. subtilis*, *S. pyogenes*, *P. aeruginosa*	[100]
	20	Leaves	*Derris trifoliata*	Common derris	*E. coli*, *S. aureus*, *S. enterica*, *Vibrio parahaemolyticus* (*V. parahaemolyticus*)	[101]
	121	Roots	*Rheum palmatum*	Chinese Rhubarb	*S. aureus*, *P. aeruginosa*	[66]
	12.46	Leaves	*Salvinia molesta*	Giant salvinia	*E. coli*, *S. aureus*	[102]
	32.5	Roots	*Decalepis hamiltonii*	Indian Sarsaparilla	*E. coli*, *S. aureus*, *P. aeruginosa*, *B. cereus*, *B. licheniformis*	[67]

Table 1. *Cont.*

Nanoparticles	Size (nm)	Source	Scientific Name	Common Name	Target Bacteria	References
	16	Crude	*Heterotheca inuloides*	Mexican arnica	*E. coli*, *S. aureus*	[103]
	10–30	Fruit juices	*Vitis vinifera* and *Solanum lycopersicum*	Grape and tomato	*Pseudomonas septica* (*P. septica*), *S. aureus*, *M. luteus*, *Enterobacter aerogenes* (*E. aerogenes*), *B. subtilis*, *S. typhi*	[104]
	2.1–45.2	Callus	*Artemisia annua*	Sweet wormwood	*Arthrobacter arilaitensis* (*A. arilaitensis*), *Staphylococcus equorum* (*S. equorum*), *Microbacterium oxydans* (*M. oxydans*)	[77]
	15.2	Bark	*Crataeva nurvala*	Ayurveda	*P. aeruginosa*	[105]
	6–8	Fruit	*Tamarindus indica*	Tamarind	*P. aeruginosa*, *S. aureus*, *M. luteus*, *Enterobacter aerogenes* (*E. aerogenes*) *B. subtilis*, *B. cereus*, *S. typhi*	[106]
	12–80	Callus	*Nicotiana tabacum*	Tobacco	*E. coli*, *Agrobacterium rhizogenes* (*A. rhizogenes*)	[107]
	410–450	Leaves	*Lantana camara*	Verbanaceae	*E. coli*, *S. aureus*, *P. aeruginosa*	[2]
	25–40	Crude	*Actinidia deliciosa*	Kiwi fruit	*P. aeruginosa*	[6]
	15–28	Stem bark	*Ficus krishnae*	Krishna fig	*E. coli*, *S. aureus*, *S. typhimurium*	[68]
	2–15	Callus	*Catharanthhus roseus*	Madagascar periwinkle	*E. coli*	[108]
	28	Leaves	*Convolvulus arvensis*	Field bindweed	*E. coli*	[109]
	25	Leaves	*Artemisia vulgaris*	Common wormwood	*E. coli*, *S. aureus*, *P. aeruginosa*, *K. pneumonia*, *Haemophilus influenza* (*H. influenza*)	[110]
	20	Leaves	*Costus afer*	-	*E. coli*, *S. aureus*, *P. aeruginosa*, *K. pneumonia*, *B. subtilis*	[111]
	23–42	Leaves	*Exocoecaria agallocha*	Blinding tree	*P. aeruginosa*, *S. aureus*, *S typhi*, *B. cereus*	[112]
	10–80	Aerial parts	*Anthemis atropatana*	-	*E. coli*, *S. aureus*, *P. aeruginosa*, *S. pyogenes*	[113]
	40–60	Leaves	*Arbutus unedo*	Strawberry tree	*E. coli*, *S. epidermis*, *B. subtilis*, *P. aeruginosa*	[114]
	88.8	Leaves	*Cicer arietinum*	Chickpea	*E. coli*, *P. aeruginosa*	[115]
	5–30	Leaves	*Taraxacum officinale*	Dandelion	*Xanthomonas axonopodis* (*X. axonopodis*), *Pseudomonas syringae* (*P. syringae*)	[116]
	20–44.49	Leaves	*Prosopis cinerraria*	Khejri tree	*E. coli*, *K. pneumonia*, *S. epidermidis*	[117]
	15–25	Leaves	*Croton bonplandianum*	Bantulasi	*E. coli*, *S. aureus*	[118]

Table 1. *Cont.*

Nanoparticles	Size (nm)	Source	Scientific Name	Common Name	Target Bacteria	References
Au-NPs	5–10	Ginseng berry	*Panax ginseng*	Meyer berries	*E. coli*, *S. aureus*	[4]
	5–25	Leaves	*Parkia roxburghii*	Tree bean	*E. coli*, *S. aureus*	[71]
	10–75	Leaves	*Ginkgo biloba Linn*	Ginkgo tree	*Brevibacterium linens* (*B. linens*)	[119]
	3–37	Leaves	*Nigella arvensis*	Love-in-a-mist	*E. coli*, *S. aureus*, *P. aeruginosa*, *Serratia marcescens* (*S. marcescens*), *B. subtilis*, *S. epidermidis*	[120]
	25	Fruit	*Dimocarpus longan*	Longan	*S. aureus*, *B. subtilis*, *E. coli*	[64]
	5–25	Leaves	*Cerasus serrulata*	Japanese cherry	*E. coli*, *S. aureus*	[121]
	7–20	Crude	*Actinidia deliciosa*	Kiwi fruit	*P. aeruginosa*	[6]
	8–25	Peel	*Citrus maxima*	Pomelo	*E. coli*, *S. aureus*	[122]
	20–30	Crude	*Coptis chinensis*	Gold thread	Drug-resistant *E. coli*	[123]
Ag_2O-NPs	42.7	Roots	*Ficus benghalensis*	Banyan	*Streptococcus mutans* (*S. mutans*), *Lactobacilli* sp.	[124]
NiO-NPs	9.69	Crude	*Moringa oleifera*	Drumstick tree	*S. aureus*, *S. pneumonia*, *Escherichia hermannii* (*E. hermannii*), *E. coli*	[125]
	10–20	Leaves	*Eucalyptus globulus*	Blue glum	*E. coli*, *S. aureus*, MRSA, *P. aeruginosa*	[126]
ZnO-NPs	20.06	Leaves	*Prunus x yedoensis Matsumura*	Yoshino cherry	*B. linens*, *S. epidermidis*	[127]
	400–500	Leaves	*Sonneratia apetala*	Sonneratia mangrove	*S. flexneri*	[62]
	47.27	Leaves	*Laurus nobilis*	Bay tree	*S. aureus*, *P. aeruginosa*	[128]
	50	Fruit	*Rosa canina*	Dog rose	*E. coli*, *L. monocytogenes*, *P. aeruginosa*	[65]
	-	Leaves	*Lobelia leschenaultiana*	Lobelia	*P. aeruginosa*, *Shigella sonnei* (*S. sonnei*), *P. vulgaris*, *V. parahaemolyticus*	[129]
	27–85	Fruit, seed, and pulp	*Citrullus colocynthis* L.	Schrad	MRSA, *P. aeruginosa*, *E. coli*, *B. subtilis*	[130]
Cu-NPs	21–30	Leaves	*Terminalia catappa*	Tropical almond	*E. coli*	[131]
	18.9–32.09	Leaves	*Prosopis cineraria*	Khejri tree	*E. coli*, *K. pneumonia*, *S. epidermidis*	[117]
CuO-NPs	30 –222.5	Leaves	*Seidlitzia rosmarinus*	Keliab	*E. coli*, *S. aureus*	[132]

Table 1. *Cont.*

Nanoparticles	Size (nm)	Source	Scientific Name	Common Name	Target Bacteria	References
Pt-NPs	2–7	Crude	*Taraxacum laevigatum*	Red-seeded dandelion	*P. aeruginosa*, *B. subtilis*	[133]
FeO-NPs	-	Peel	*Punica granatum*	Pomegranate	*P. aeruginosa*	[134]
Pd-NPs	5	Leaves	*Sapium sebiferum*	Chinese tallow tree	*S. aureus*, *P. aeruginosa* *Bacillus subtilis*	[135]
	30	Seeds	*Phyllanthus emblica*	Indian Gooseberry	*S. aureus*, *P. aeruginosa*, *B subtilis* *Proteus mirabilis*	[136]
	27	Peel	*Moringa oleifera*	Horseradish tree	*E. coli*, *S. aureus*	[73]
CeO_2-NPs	45	Peel	*Moringa oleifera*	Horseradish tree	*E. coli*, *S. aureus*	[74]
	24	Leaves	*Olea europaea*	Olive	*E. coli*, *S. aureus*, *K. pneumonia*, *P. aeruginosa*	[137]
Ce_2O_3-NPs	8.6–10.5	Crude	*Euphorbia amygdaloides*	Wood spurge	*Pediococcus acidilactici* (*P. acidilactici*)	[138]
Pectin/Ag-NPs	20–80	Shoot tip	*Caesalpinia mimosoides* Lam.	Mimosa thorn	*E. coli*, *L. monocytogenes*	[98]
Ag/Ag_2O-NPs	8.2–20.5	Leaves	*Eupatorium odoratum*	Christmas bush	*E. coli*, *S. typhi*, *S. aureus*, *B. subtilis*	[139]
Ag/Au-NPs	10	Leaves	*Gloriosa superba*	Flame lily	*E. coli*, *B. subtilis*	[85]
Chitosan/Ag-NPs	378–402	Crude	*Rumex dentatus*	Toothed dock	*P. aeruginosa*, *B. thuringiensis*	[140]
Chitosan/CeO_2-NPs	3.61–24.4	Leaves	*Sida acuta*	Common wireweed	*E. coli*, *B. subtilis*	[141]
PCL/Cur/GLE-Ag-NPs	200	Leaves	*Vitis vinifera*	Grape	*E. coli*, *S. aureus*, *P. aeruginosa*, *B. subtilis*, *S. enterica*	[93]
GLE-Ag-NPs	30	Leaves	*Vitis vinifera*	Grape	*E. coli*, *S. aureus*, *P. aeruginosa*, *B. subtilis*, *S. enterica*	[93]
Cellulose/Cu-NPs	20–40	Leaves	*Terminalia catappa*	Tropical almond	*E. coli*	[131]
Ag-MnO_2-NPs	5–40	Leaves	*Cucurbita pepo*	Summer squash	*E. coli*, *S. aureus*, *B. cereus*, *L. monocytogenes*, *S. typhi*, *S. enterica*	[142]

2. Bactericidal Properties and Synergistic Enhancement of Common Antibiotics

NPs derived from plants that show promising antibacterial activities have high potential to be developed into future antibacterials mainly due to their low toxic effects [143]. NPs have been previously reported to inhibit gram-positive bacteria such as *Staphylococcus* spp. [4,5], *Streptococcus* spp. [113,124], and *Bacillus* spp. [114,120], and gram-negative bacteria such as *Escherichia* spp. [97,122], *Pseudomonas* spp. [6,68], *Salmonella* spp. [68,104], *Shigella* spp. [97,129], *Proteus* spp. [75,136], and *Vibrio* spp. [101,129]. More promisingly, NPs have also been shown to inhibit antibiotic-resistant bacteria such as Methicillin-resistant *S. aureus* (MRSA) [81,130] and drug-resistant *E. coli* [123]. Table 1 summaries the antibacterial action of NPs reported in PubMed-indexed journals in the past two years (2016–2017). A total of 107 articles was obtained from Pub-Med search engine through National Center for Biotechnology Information (NCBI) website using four keywords (nanoparticles, green synthesis, plant, and antibacterial) [144]. Out of the 107, 17 articles have been excluded as they do not contain relevant information for this review. These articles included retracted papers, review papers, and other non-plant-derived NP research papers. The remaining 90 articles are reviewed, and the information is tabulated in Table 1 and categorized based on the type of NPs. Since there are various synthetic methods to generate NPs as mentioned in Section 1, the protocol of constructing the NPs tabulated in Table 1 is different from one to another even though they are derived from the same part of extracts. Overall, the most reported NPs are Ag-NPs, Au-NPs, followed by other metal/metal oxide-based NPs and nanocomposites. Most of the NPs have size of less than 100 nm except for a few NPs as shown in Table 1 [2,62,63,81]. From Table 1, it is also shown that most of the NPs were produced from the plant's leaves rather than other parts of the plants, regardless of type of NPs.

Table 2 shows both gram-positive and gram-negative bacterial species that have been targeted by various NPs, and the frequency of bacterial species being studied is tabulated. Gram-negative species that have been targeted the most are *E. coli* followed by *P. aeruginosa*, whereas gram-positive species that are mostly targeted are *S. aureus* followed by *B. subtilis* and *B. cereus*. Comparatively, the type and total number of gram-negative bacterial species that are being targeted are more than gram-positive species. This highlights the potential of NPs as antibacterial agents since they could effectively permeate and kill gram-negative bacterial species which are notorious of their difficult-to-penetrate multilayer membranes [145]. This notion can be further supported by recent finding by Acharya et al. which showed a potent killing of AgNPs towards *K. pneumonia* [146]. FE-SEM analysis demonstrated that the NPs overlaid with *K. pneumonia* with damaged cell surfaces and disrupted cells due to the interaction with NPs. Similarly, it has also been shown by SEM that AgNPs damaged *E. coli* by causing a large leakage on cell membrane and the bacteria were disorganized to several parts [147]. The potent antibacterial killings of NPs demonstrate their potential to be developed into antibacterials against gut-related bacteria (e.g., *E. coli*, *P. aeruginosa*, *B. cereus*, *K. pneumoniae*, *S. flexneri*, and *S. typhi*) and skin infection–related bacteria (*S. aureus*). The collective findings from Table 2 also show that Ag-NPs are the most bactericidal NPs against the gut bacteria such as *E. coli*, *P. aeruginosa*, *B. cereus*, *K. pneumoniae*, *S. flexneri*, *S. pyogenes*, *S. typhi*) and skin-related bacteria such as *S. aureus* and *S. epidermidis*. Followed by Ag-NPs, Au-NPs were reported to be effective in killing *E. coli* and *S. aureus*. Interestingly, Table 2 shows that some specific types of NPs were more effective against a particular bacterial type compared to others. For example, ZnO-NPs was effective against *P. aeruginosa* while Pd-NPs was effective against *S. aureus*.

Table 2. Gram-negative and gram-positive bacterial species targeted by NPs synthesized from plants via green technology.

Gram-Negative Species	Ag	Au	Cu	Pt	Pd	Ag_2O	NiO	ZnO	CuO	FeO	CeO_2	Ce_2O_3
E. coli	46	6	2	-	1	-	2	2	1	-	2	-
Drug-resistant *E. coli*	-	1	-	-	-	-	-	-	-	-	-	-
E. hermannii	-	-	-	-	-	-	1	-	-	-	-	-
P. fluorescens	1	-	-	-	-	-	-	-	-	-	-	-
P. aeruginosa	23	2	-	1	2	-	1	4	-	1	1	-
P. syringae	1	-	-	-	-	-	-	-	-	-	-	-
P. septica	1	-	-	-	-	-	-	-	-	-	-	-
K. pneumoniae	6	-	1	-	-	-	-	-	-	-	1	-
P. vulgaris	1	-	-	-	-	-	-	1	-	-	-	-
P. mirabilis	-	-	-	-	1	-	-	-	-	-	-	-
S. flexneri	4	-	-	-	-	-	-	1	-	-	-	-
S. sonnei	-	-	-	-	-	-	-	1	-	-	-	-
S. paratyphi	1	-	-	-	-	-	-	-	-	-	-	-
S. typhi	6	-	-	-	-	-	-	-	-	-	-	-
S. typhimurium	2	-	-	-	-	-	-	-	-	-	-	-
S. enterica	2	-	-	-	-	-	-	-	-	-	-	-
V. parahaemolyticus	3	-	-	-	-	-	-	1	-	-	-	-
V. cholera	2	-	-	-	-	-	-	-	-	-	-	-
Aeromonas sp.	1	-	-	-	-	-	-	-	-	-	-	-
Acinetobacter sp.	1	-	-	-	-	-	-	-	-	-	-	-
A. baumannii	1	-	-	-	-	-	-	-	-	-	-	-
Citrobacter sp.	1	-	-	-	-	-	-	-	-	-	-	-
E. aerogenes	2	-	-	-	-	-	-	-	-	-	-	-
A. rhizogenes	1	-	-	-	-	-	-	-	-	-	-	-
H. influenza	1	-	-	-	-	-	-	-	-	-	-	-
X. axonopodis	1	-	-	-	-	-	-	-	-	-	-	-
S. marcescens	-	1	-	-	-	-	-	-	-	-	-	-
Lactobacilli sp.	-	-	-	-	-	1	-	-	-	-	-	-

Table 2. *Cont.*

Gram-Positive Species	Ag	Au	Cu	Pt	Pd	Ag_2O	NiO	ZnO	CuO	FeO	CeO_2	Ce_2O_3
S. aureus	35	6	-	-	3	-	2	1	1	-	2	-
S. epidermidis	5	1	1	-	-	-	-	1	-	-	-	-
MRSA	1	-	-	-	-	-	1	1	-	-	-	-
S. pyogenes	4	-	-	-	-	-	-	-	-	-	-	-
S. mutans	-	-	-	-	-	1	-	-	-	-	-	-
S. pneumonia	-	-	-	-	-	-	1	-	-	-	-	-
B. thuringiensis	1	-	-	-	-	-	-	-	-	-	-	-
B. cereus	9	-	-	-	-	-	-	-	-	-	-	-
B. subtilis	11	2	-	1	2	-	-	1	-	-	-	-
B. licheniformis	1	-	-	-	-	-	-	-	-	-	-	-
B. anthracis	1	-	-	-	-	-	-	-	-	-	-	-
E. faecalis	3	-	-	-	-	-	-	-	-	-	-	-
L. monocytogenes	3	-	-	-	-	-	-	1	-	-	-	-
M. luteus	3	-	-	-	-	-	-	-	-	-	-	-
P. acnes	1	-	-	-	-	-	-	-	-	-	-	-
A. arilaitensis	1	-	-	-	-	-	-	-	-	-	-	-
M. oxydans	1	-	-	-	-	-	-	-	-	-	-	-
B. linens	-	1	-	-	-	-	-	1	-	-	-	-
P. acidilactici	-	-	-	-	-	-	-	-	-	-	-	1

In addition to exhibiting antibacterial effects, NPs derived from plants can also serve as carriers to deliver antibacterial molecules or drugs to the target cells either via conjugation or nanoemulsions, hence synergistically enhance the antibacterial effect [97,139]. For example, Kalita and coworkers demonstrated that a gold NP was able to enhance the bacterial killing effects of Amoxicillin against both gram-positive (*Staphylococcus* spp. And *Bacillus* spp.) and gram-negative bacteria (*E. coli*) [139]. Patra and colleagues reported the potential of silver NP synthesized from corn leaves of *Zea mays* in foodborne pathogenic bacterial killings when used in combination with Kanamycin and Rifampicin [97]. More interestingly, the NP was able to reverse the development of antibiotics resistance by killing MRSA clinical isolates *in vitro* and *in vivo* using murine MRSA infection models [148]. The exact mechanism of NPs' synergism with antibiotics remains exploratory. It could be due to (a) generation of additional bactericidal Ag+ ions by NPs [149], (b) generation of bactericidal hydroxyl radicals by NPs [150], and (c) effective blocking of the efflux pump for drug-resistant bacterial killing [143]. This synergistic effect could ultimately help in reducing the dosage of antibacterials that may potentially toxic to host system.

The exact mechanisms of NPs against various bacteria remain unknown. There have been several studies supporting the possible mechanisms of bactericidal effects including (a) attachment of large number of NPs on bacterial surface that interrupts respiration and other permeability-dependent functions [97], (b) generation of electrostatic attraction between negatively charged bacterial cells and the positively charged NPs [151], (c) inactivation and degradation of bacterial essential proteins [152], and (d) breakage or damage of bacterial genes following the efficient penetration of NPs [153]. For example, it has been shown that silver NPs permeated into bacterial cells and resulted in significant DNA damages by interacting with sulphur- and phosphorus-containing compounds [154,155]. Similarly, it has also been shown that silver NPs released highly reactive Ag+ ions and radicals for the antibacterial effects [156]. These ions have also been reported to interact with sulphur-containing proteins in the bacterial cell wall that caused multiple functionality impairs [152]. Raffi and colleagues also showed that the silver NPs could inactivate the bacterial enzymes and generate toxic hydrogen peroxide leading to bacterial cell death [157].

3. Plant-derived Nanoparticles as Future Antibacterials

To date, numerous NPs have been approved by either Food and Drug Administration (FDA) in United States, or European Medicines Agency (EMA) in the European Union for various clinical applications including imaging (e.g., Resovist), iron-replacement therapy for anaemia treatment (e.g., Vifor), delivery of anticancer drugs (e.g., Onivyde and MEPACT) [158,159], vaccines for viral diseases (e.g., Epaval against hepatitis A and Inflexal V against influenza) [160,161], fungal infection (e.g., AmBisome) [162], and so on. However, none of the currently approved NPs are used for controlling bacterial infection [163]. The only liposomal NP formulations that is undergoing clinical trial is CAL02, which has been designed for bacterial pneumonia management [163]. In this section, we discuss the potential challenges of developing NPs into clinically approved antimicrobial agents. Table 3 summaries some of the limitations and challenges of using plant-derived NPs for antimicrobials development. Undoubtedly, the nano-scale size of NPs has facilitated the cell-penetrating capacity including crossing blood-brain barrier (BBB) [164,165], hence improving the target specificity and biological activity. However, the small size may be one of the challenges in the clinical trials. It has been reported that NPs have poor stability and bioavailability under physiological conditions when they are administered into host system [166]. Studies have shown that NPs have been targeted and degraded by various enzymes and proteins from human blood before reaching to target sites [167,168]. These significantly reduced the biological functions of NPs. To overcome this limitation, several modification methods have been adopted such as conjugation with stabilizer (e.g., serum albumin) [169,170], synthesis of stable nanoemulsions [169,170], modification of surface chemistry and functionalization [171], and development of composite NPs [172]. In addition to size, it has also been reported that the NPs' shape and morphology could determine their biological actions and toxicity

profile [172–174]. Some NPs have high tendency to form aggregates as a result of the particle surface chemistry. This may cause unwanted toxicity and drastically limit the access of NPs into the target cells [175]. Toxicity is also attributed to several characteristics of NPs (e.g., chemistry, retention rate, biodistribution, stability, and specificity), mode of administration, and target sites [176].

There are numerous limitations for NPs productions for biomedical application (summarized in Table 3). As the biological functions of NPs highly depend on their shape, size, permeability, and physicochemical properties, manufacturing NPs in industrial scale must strictly adhere to the tight-controlled, consistent, and reproducible standard operating procedure (SOP) and Good Manufacturing Practice (GMP). Another challenge is the heterogeneity of diseases in human. The clinical effect of NPs on infected humans could be very complicated as different individuals present varied profiles (mainly due to the individual's immunity) even though they have been infected from the same source. This will require detailed and organized planning to validate the clinical value of NPs. Following the increase of potential NPs, the experimental design that requires high throughput setup for biological screening is also increasingly demanding. This is also closely linked with automation that allows cost-effective NPs production and, computing and modelling technology that would predict NPs' efficacies or toxicities on target cells. The improvement in high throughput screening and computation will surely boost the development of nanotechnology in biomedical applications.

From an industrial point of view, the chosen synthesis method of NPs-based antibacterials must be compatible for large-scale production. As most NPs possess complex chemical make-up and arrangement of components, retaining these key characteristics in the process of scaling up remains a huge challenge in the manufacturing field. Secondly, the production method has to consistently produce high quality (e.g., size, uniformity, and physicochemical properties) of NPs. The formulation process must be recorded meticulously to ensure high-level of reproducibility. The advancement of modern technology contributed from large high-tech companies and academia will continuously support the production of high-quality NPs in a consistent and timely fashion.

Table 3. Challenges of developing nanoparticles into clinically used antibacterial agents.

Structural Challenge	
Size	Smaller size enhances the cell penetration, but may have decreased stability or bioavailability
Shape	Certain shape of NPs may improve the functionality due to total surface exposure area
Aggregate	NPs that form aggregate increase the overall particle size, hence limiting the cell permeation and may increase toxicity
Biological Challenge	
Biodistribution	Poor dispersion due to limited entry (e.g., skin barrier)
Bioavailability	Poor bioavailability results in rapid loss of function
Specificity	High specificity results in less off-target effects and more effective
Clearance	High retention rate ensures the high efficiency
Toxicity	Accumulation of toxic materials may damage the host
Technological Challenge	
Heterogeneity of human disease	Variation within disease may complicate treatment
Scale-up	Optimization of NPs synthesis and production with uniform size without aggregates in controlled and consistent fashion
Throughput	Synthesis of NP is multistep and laborious which does not allow high-throughput optimization
Prediction	Prediction using computer modelling on NP efficiency is extremely challenging

Table 3. *Cont.*

Industrial Challenge	
Quantity	Large scale production may result in inconsistent size and physicochemical properties of NPs
Processes	Reproducible and consistent manufacturing processes requires modern technology and instrumentation
Quality	Continuous production of high level uniformity and functionality of NPs

4. Conclusions and Future Perspectives

This mini-review provides a recent update on the NPs derived from plants that possess promising antibacterial action. Antibacterial NPs produced from green technology have great potential to be developed into future antibacterials and are able to synergistically enhance the efficacy of antibiotics. While the exact mechanisms remain unknown, a great effort is currently underway to produce a highly potent and robust NPs for clinical use. Understanding the bactericidal mechanism of NPs is also important to control and overcome the emerging issue of bacterial resistance to NPs [177]. As highlighted above, the limitations and potential challenges need to be overcome to maximize the use of NPs to clinical applications. Uniformity, stability, specificity, and toxicity of NPs are the main biological properties in deciding the fate of NPs in clinical application. From an industrial perspective, the development of sustainable process and modern instrumentation is crucial to produce a practical amount of NPs for clinical use [178]. The advancement of nanotechnology and biotechnology are anticipated to boost the use of NPs in biomedical applications in the future.

Author Contributions: All authors participated in the literature search, interpretation of the articles reviewed, and review of manuscript. All authors have read and approved the paper.

Acknowledgments: We would like to thank Sunway Internal Research Grant 2018 (INT-2018-SHMS-SIHD-01) from Sunway University and National Cancer Council Malaysia (MAKNA) Cancer Research Award (CRA) 2016 (EXT-SIDS-SIHD-MAKNA-2017-01) for partly supporting this work. We also thank Sunway Research Grant 2018 (SRC/002/2017/FR and SRC/003/2017/FR) from Sunway Medical Centre for partly supporting this work. Hooi-Yeen Yap is a recipient of Sunway University Master's Degree by Research Scholarship.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zare, Y.; Shabani, I. Polymer/metal nanocomposites for biomedical applications. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *60*, 195–203. [CrossRef] [PubMed]
2. Shriniwas, P.P.; Subhash, T.K. Antioxidant, antibacterial and cytotoxic potential of silver nanoparticles synthesized using terpenes rich extract of *Lantana camara* L. leaves. *Biochem. Biophys. Rep.* **2017**, *10*, 76–81.
3. Okafor, F.; Janen, A.; Kukhtareva, T.; Edwards, V.; Curley, M. Green synthesis of silver nanoparticles, their characterization, application and antibacterial activity. *Int. J. Environ. Res. Public Health* **2013**, *10*, 5221–5238. [CrossRef] [PubMed]
4. Jiménez Pérez, Z.E.; Mathiyalagan, R.; Markus, J.; Kim, Y.; Kang, H.M.; Abbai, R.; Seo, K.H.; Wang, D.; Soshnikova, V.; Yang, D.C. Ginseng-berry-mediated gold and silver nanoparticle synthesis and evaluation of their in vitro antioxidant, antimicrobial, and cytotoxicity effects on human dermal fibroblast and murine melanoma skin cell lines. *Int. J. Nanomed.* **2017**, *12*, 709–723. [CrossRef] [PubMed]
5. Kelkawi, A.H.A.; Abbasi Kajani, A.; Bordbar, A.K. Green synthesis of silver nanoparticles using *Mentha pulegium* and investigation of their antibacterial, antifungal and anticancer activity. *IET Nanobiotechnol.* **2017**, *11*, 370–376. [CrossRef] [PubMed]
6. Naraginti, S.; Li, Y. Preliminary investigation of catalytic, antioxidant, anticancer and bactericidal activity of green synthesized silver and gold nanoparticles using *Actinidia deliciosa*. *J. Photochem. Photobiol. B Biol.* **2017**, *170*, 225–234. [CrossRef] [PubMed]

7. Ahmad, T.; Wani, I.A.; Lone, I.H.; Ganguly, A.; Manzoor, N.; Ahmad, A.; Ahmed, J.; Al-Shihri, A.S. Antifungal activity of gold nanoparticles prepared by solvothermal method. *Mater. Res. Bull.* **2013**, *48*, 12–20. [CrossRef]
8. Cagno, V.; Andreozzi, P.; D'Alicarnasso, M.; Silva, P.J.; Mueller, M.; Galloux, M.; Goffic, R.L.; Jones, S.T.; Vallino, M.; Hodek, J.; et al. Broad-spectrum non-toxic antiviral nanoparticles with a virucidal inhibition mechanism. *Nat. Mater.* **2018**, *17*, 195–203. [CrossRef] [PubMed]
9. Park, S.; Park, H.H.; Kim, S.Y.; Kim, S.J.; Woo, K.; Ko, G. Antiviral properties of silver nanoparticles on a magnetic hybrid colloid. *Appl. Environ. Microbiol.* **2014**, *80*, 2343–2350. [CrossRef] [PubMed]
10. Soflaei, S.; Dalimi, A.; Ghaffarifar, F.; Shakibaie, M.; Shahverdi, A.R.; Shafiepour, M. In vitro antiparasitic and apoptotic effects of antimony sulfide nanoparticles on *Leishmania infantum*. *J. Parasitol. Res.* **2012**, *2012*, 1–7. [CrossRef] [PubMed]
11. Rahul, S.; Chandrashekhar, P.; Hemant, B.; Bipinchandra, S.; Mouray, E.; Grellier, P.; Satish, P. In vitro antiparasitic activity of microbial pigments and their combination with phytosynthesized metal nanoparticles. *Parasitol. Int.* **2015**, *64*, 353–356. [CrossRef] [PubMed]
12. De Araújo Júnior, R.F.; de Araújo, A.A.; Pessoa, J.B.; Freire Neto, F.P.; da Silva, G.R.; Leitão Oliveira, A.L.; de Carvalho, T.G.; Silva, H.F.; Eugênio, M.; Sant'Anna, C.; et al. Anti-inflammatory, analgesic and anti-tumor properties of gold nanoparticles. *Pharmacol. Rep.* **2017**, *69*, 119–129. [CrossRef] [PubMed]
13. Laroui, H.; Sitaraman, S.V.; Merlin, D. Gastrointestinal delivery of anti-inflammatory nanoparticles. *Methods Enzymol.* **2012**, *509*, 101–125. [PubMed]
14. Wang, E.C.; Wang, A.Z. Nanoparticles and their applications in cell and molecular biology. *Integr. Biol. Quant. Biosci. Nano Macro* **2014**, *6*, 9–26. [CrossRef] [PubMed]
15. Raula, J.; Kuivanen, A.; Lähde, A.; Jiang, H.; Antopolsky, M.; Kansikas, J.; Kauppinen, E.I. Synthesis of L-leucine nanoparticles via physical vapor deposition at varying saturation conditions. *J. Aerosol Sci.* **2007**, *38*, 1172–1184. [CrossRef]
16. Ayyub, P.; Chandra, R.; Taneja, P.; Sharma, A.K.; Pinto, R. Synthesis of nanocrystalline material by sputtering and laser ablation at low temperatures. *Appl. Phys. A* **2001**, *73*, 67–73. [CrossRef]
17. Sharma, R.; Sharma, A.K.; Sharma, V. Synthesis of carbon nanotubes by arc-discharge and chemical vapor deposition method with analysis of its morphology, dispersion and functionalization characteristics. *Cogent Eng.* **2015**, *2*, 1094017. [CrossRef]
18. Perez-Rodriguez, A.; Garrido, B.; Bonafos, C.; Lopez, M.; Gonzalez-Varona, O.; Monrante, J.R.; Montserrat, J.; Rodriguez, R. Ion beam synthesis of compound nanoparticles in SiO2. *J. Mater. Sci. Mater. Electron.* **1999**, *10*, 385–391. [CrossRef]
19. Wang, H.-C.; Liao, C.-H.; Chueh, Y.-L.; Lai, C.-C.; Chen, L.-H.; Tsiang, R.C.-C. Synthesis and characterization of ZnO/ZnMgO multiple quantum wells by molecular beam epitaxy. *Opt. Mater. Express* **2013**, *3*, 237–247. [CrossRef]
20. Bikiaris, D.N.; Papageorgiou, G.Z.; Pavlidou, E.; Vouroutzis, N.; Palatzoglou, P.; Karayannidis, G.P. Preparation by melt mixing and characterization of isotactic polypropylene/SiO2 nanocomposites containing untreated and surface-treated nanoparticles. *J. Appl. Polym. Sci.* **2006**, *100*, 2684–2696. [CrossRef]
21. Petcharoen, K.; Sirivat, A. Synthesis and characterization of magnetite nanoparticles via the chemical co-precipitation method. *Mater. Sci. Eng. B* **2012**, *177*, 421–427. [CrossRef]
22. Sui, R.; Charpentier, P. Synthesis of metal oxide nanostructures by direct Sol–Gel chemistry in supercritical fluids. *Chem. Rev.* **2012**, *112*, 3057–3082. [CrossRef] [PubMed]
23. Malik, M.A.; Wani, M.Y.; Hashim, M.A. Microemulsion method: A novel route to synthesize organic and inorganic nanomaterials: 1st nano update. *Arab. J. Chem.* **2012**, *5*, 397–417. [CrossRef]
24. Xu, H.; Zeiger, B.W.; Suslick, K.S. Sonochemical synthesis of nanomaterials. *Chem. Soc. Rev.* **2013**, *42*, 2555–2567. [CrossRef] [PubMed]
25. Omrani, A.A.; Taghavinia, N. Photo-induced growth of silver nanoparticles using UV sensitivity of cellulose fibers. *Appl. Surf. Sci.* **2012**, *258*, 2373–2377. [CrossRef]
26. Singh, P.; Kim, Y.J.; Zhang, D.; Yang, D.C. Biological synthesis of nanoparticles from plants and microorganisms. *Trends Biotechnol.* **2016**, *34*, 588–599. [CrossRef] [PubMed]
27. Castro, L.; Blázquez, M.L.; Muñoz, J.A.; González, F.; Ballester, A. Biological synthesis of metallic nanoparticles using algae. *IET Nanobiotechnol.* **2013**, *7*, 109–116. [CrossRef] [PubMed]
28. Zielonka, A.; Klimek-Ochab, M. Fungal synthesis of size-defined nanoparticles. *Adv. Nat. Sci. Nanosci. Nanotechnol.* **2017**, *8*, 043001. [CrossRef]

29. Das, R.K.; Pachapur, V.L.; Lonappan, L.; Naghdi, M.; Pulicharla, R.; Maiti, S.; Cledon, M.; Dalila, L.M.A.; Sarma, S.J.; Brar, S.K. Biological synthesis of metallic nanoparticles: Plants, animals and microbial aspects. *Nanotechnol. Environ. Eng.* **2017**, *2*, 18. [CrossRef]
30. Ghosh, P.R.; Fawcett, D.; Sharma, S.B.; Poinern, G.E.J. Production of high-value nanoparticles via biogenic processes using aquacultural and horticultural food waste. *Materials* **2017**, *10*, 852. [CrossRef] [PubMed]
31. Pundir, C.S. *Enzyme Nanoparticles: Preparation, Characterisation, Properties and Application*, 1st ed.; William Andrew: Waltham, MA, USA, 2015; ISBN 978-0-323-38913-6.
32. Iravani, S.; Korbekandi, H.; Mirmohammadi, S.V.; Zolfaghari, B. Synthesis of silver nanoparticles: Chemical, physical and biological methods. *Res. Pharm. Sci.* **2014**, *9*, 385–406. [PubMed]
33. Bogart, L.K.; Pourroy, G.; Murphy, C.J.; Puntes, V.; Pellegrino, T.; Rosenblum, D.; Peer, D.; Lévy, R. Nanoparticles for imaging, sensing, and therapeutic intervention. *ACS Nano* **2014**, *8*, 3107–3122. [CrossRef] [PubMed]
34. Charbgoo, F.; Ramezani, M.; Darroudi, M. Bio-sensing applications of cerium oxide nanoparticles: Advantages and disadvantages. *Biosens. Bioelectron.* **2017**, *96*, 33–43. [CrossRef] [PubMed]
35. Nune, S.K.; Gunda, P.; Thallapally, P.K.; Lin, Y.Y.; Forrest, M.L.; Berkland, C.J. Nanoparticles for biomedical imaging. *Expert Opin. Drug Deliv.* **2009**, *6*, 1175–1194. [CrossRef] [PubMed]
36. Baetke, S.C.; Lammers, T.; Kiessling, F. Applications of nanoparticles for diagnosis and therapy of cancer. *Br. J. Radiol.* **2015**, *88*, 20150207. [CrossRef] [PubMed]
37. Fortina, P.; Kricka, L.J.; Graves, D.J.; Park, J.; Hyslop, T.; Tam, F.; Halas, N.; Surrey, S.; Waldman, S.A. Applications of nanoparticles to diagnostics and therapeutics in colorectal cancer. *Trends Biotechnol.* **2007**, *25*, 145–152. [CrossRef] [PubMed]
38. De Jong, W.H.; Borm, P.J.A. Drug delivery and nanoparticles: Applications and hazards. *Int. J. Nanomed.* **2008**, *3*, 133–149. [CrossRef]
39. Singh, R.; Lillard, J.W. Nanoparticle-based targeted drug delivery. *Exp. Mol. Pathol.* **2009**, *86*, 215–223. [CrossRef] [PubMed]
40. Couto, C.; Vitorino, R.; Daniel-da-Silva, A.L. Gold nanoparticles and bioconjugation: A pathway for proteomic applications. *Crit. Rev. Biotechnol.* **2017**, *37*, 238–250. [CrossRef] [PubMed]
41. Chen, L. Surface Functionalization and Bioconjugation of Nanoparticles for Biomedical Applications. Ph.D. Dissertation, University of Western Ontario, London, ON, Canada, 2013.
42. Thiesen, B.; Jordan, A. Clinical applications of magnetic nanoparticles for hyperthermia. *Int. J. Hyperth.* **2008**, *24*, 467–474. [CrossRef] [PubMed]
43. Beik, J.; Abed, Z.; Ghoreishi, F.S.; Hosseini-Nami, S.; Mehrzadi, S.; Shakeri-Zadeh, A.; Kamrava, S.K. Nanotechnology in hyperthermia cancer therapy: From fundamental principles to advanced applications. *J. Control Release* **2016**, *235*, 205–221. [CrossRef] [PubMed]
44. Schrittwieser, S.; Reichinger, D.; Schotter, J. Applications, surface modification and functionalization of nickel nanorods. *Materials* **2017**, *11*, 45. [CrossRef] [PubMed]
45. Kang, S.; Shi, S.; Nikles, D.E.; Harrell, J.W. Easy control of the size and composition of FePt nanoparticles with improved synthesis. *J. Appl. Phys.* **2008**, *103*, 07D503. [CrossRef]
46. Guerrero-Cázares, H.; Tzeng, S.Y.; Young, N.P.; Abutaleb, A.O.; Quiñones-Hinojosa, A.; Green, J.J. Biodegradable polymeric nanoparticles show high efficacy and specificity at DNA delivery to human glioblastoma in vitro and in vivo. *ACS Nano* **2014**, *8*, 5141–5153. [CrossRef] [PubMed]
47. Werengowska-Ciećwierz, K.; Wiśniewski, M.; Terzyk, A.P.; Furmaniak, S. The chemistry of bioconjugation in nanoparticles-based drug delivery system. *Adv. Condens. Matter Phys.* **2015**, *2015*. [CrossRef]
48. Williams, H.M. The application of magnetic nanoparticles in the treatment and monitoring of cancer and infectious diseases. *Biosci. Horiz. Int. J. Stud. Res.* **2017**, *10*, hzx009. [CrossRef]
49. Chatterjee, D.K.; Diagaradjane, P.; Krishnan, S. Nanoparticle-mediated hyperthermia in cancer therapy. *Ther. Deliv.* **2011**, *2*, 1001–1014. [CrossRef] [PubMed]
50. Bañobre-López, M.; Teijeiro, A.; Rivas, J. Magnetic nanoparticle-based hyperthermia for cancer treatment. *Rep. Pract. Oncol. Radiother.* **2013**, *18*, 397–400. [CrossRef] [PubMed]
51. Shetake, N.G.; Balla, M.M.S.; Kumar, A.; Pandey, B.N. Magnetic hyperthermia therapy: An emerging modality of cancer treatment in combination with radiotherapy. *J. Radiat. Cancer Res.* **2016**, *7*, 13–17.

52. Park, H.; Park, H.; Kim, J.A.; Lee, S.H.; Kim, J.H.; Yoon, J.; Park, T.H. Inactivation of *Pseudomonas aeruginosa* PA01 biofilms by hyperthermia using superparamagnetic nanoparticles. *J. Microbiol. Methods* **2011**, *84*, 41–45. [CrossRef] [PubMed]
53. Singh, S. , Barick, K.C. And Bahadur, D. Inactivation of bacterial pathogens under magnetic hyperthermia using Fe3O4–ZnO nanocomposite. *Powder Technol.* **2015**, *269*, 513–519. [CrossRef]
54. Parveen, K.; Banse, V.; Ledwani, L. Green synthesis of nanoparticles: Their advantages and disadvantages. *AIP Conf. Proc.* **2016**, *1724*, 020048.
55. Kuppusamy, P.; Yusoff, M.M.; Maniam, G.P.; Govindan, N. Biosynthesis of metallic nanoparticles using plant derivatives and their new avenues in pharmacological applications—An updated report. *Saudi Pharm. J. SPJ Off. Publ. Saudi Pharm. Soc.* **2016**, *24*, 473–484. [CrossRef] [PubMed]
56. Makarov, V.V.; Love, A.J.; Sinitsyna, O.V.; Makarova, S.S.; Yaminsky, I.V.; Taliansky, M.E.; Kalinina, N.O. 'Green' nanotechnologies: Synthesis of metal nanoparticle using plants. *Acta Nat.* **2014**, *6*, 35–44.
57. Sabri, M.A.; Umer, A.; Awan, G.H.; Hassan, M.F.; Hasnain, A. Selection of suitable biological method for the synthesis of silver nanoparticles. *Nanomater. Nanotechnol.* **2016**, *6*, 29. [CrossRef]
58. Amin, G.; Asif, M.H.; Zainelabdin, A.; Zaman, S.; Nur, O.; Willander, M. Influence of pH, precursor concentration, growth time, and temperature on the morphology of ZnO nanostructures grown by the hydrothermal method. *J. Nanomater.* **2011**, *2011*, 5. [CrossRef]
59. Kumari, M.; Mishra, A.; Pandey, S.; Singh, S.P.; Chaudhry, V.; Mudiam, M.K.R.; Shukla, S.; Kakkar, P.; Nautiyal, C.S. Physico-chemical condition cptimization during biosynthesis lead to development of improved and catalytically efficient gold nano particles. *Sci. Rep.* **2016**, *6*, 27575. [CrossRef] [PubMed]
60. Liu, H.; Zhang, H.; Wang, J.; Wei, J. Effect of temperature on the size of biosynthesized silver nanoparticle: Deep insight into microscopic kinetics analysis. *Arab. J. Chem.* **2017**. [CrossRef]
61. Mansouri, S.S.; Ghader, S. Experimental study on effect of different parameters on size and shape of triangular silver nanoparticles prepared by a simple and rapid method in aqueous solution. *Arab. J. Chem.* **2009**, *2*, 47–53. [CrossRef]
62. Thatoi, P.; Kerry, R.G.; Gouda, S.; Das, G.; Pramanik, K.; Thatoi, H.; Patra, J.K. Photo-mediated green synthesis of silver and zinc oxide nanoparticles using aqueous extracts of two mangrove plant species, *Heritiera fomes* and *Sonneratia apetala* and investigation of their biomedical applications. *J. Photochem. Photobiol. B Biol.* **2016**, *163*, 311–318. [CrossRef] [PubMed]
63. Tippayawat, P.; Phromviyo, N.; Boueroy, P.; Chompoosor, A. Green synthesis of silver nanoparticles in aloe vera plant extract prepared by a hydrothermal method and their synergistic antibacterial activity. *PeerJ* **2016**, *4*, e2589. [CrossRef] [PubMed]
64. Khan, A.U.; Yuan, Q.; Wei, Y.; Khan, G.M.; Khan, Z.U.H.; Khan, S.; Ali, F.; Tahir, K.; Ahmad, A.; Khan, F.U. Photocatalytic and antibacterial response of biosynthesized gold nanoparticles. *J. Photochem. Photobiol. B Biol.* **2016**, *162*, 273–277. [CrossRef] [PubMed]
65. Jafarirad, S.; Mehrabi, M.; Divband, B.; Kosari-Nasab, M. Biofabrication of zinc oxide nanoparticles using fruit extract of Rosa canina and their toxic potential against bacteria: A mechanistic approach. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *59*, 296–302. [CrossRef] [PubMed]
66. Arokiyaraj, S.; Vincent, S.; Saravanan, M.; Lee, Y.; Oh, Y.K.; Kim, K.H. Green synthesis of silver nanoparticles using *Rheum palmatum* root extract and their antibacterial activity against *Staphylococcus aureus* and *Pseudomonas aeruginosa*. *Artif. Cells Nanomed. Biotechnol.* **2017**, *45*, 372–379. [CrossRef] [PubMed]
67. Rashmi, V.; Sanjay, K.R. Green synthesis, characterization and bioactivity of plant-mediated silver nanoparticles using *Decalepis hamiltonii* root extract. *IET Nanobiotechnol.* **2017**, *11*, 247–254. [CrossRef] [PubMed]
68. Kanjikar, A.P.; Hugar, A.L.; Londonkar, R.L. Characterization of phyto-nanoparticles from *Ficus krishnae* for their antibacterial and anticancer activities. *Drug Dev. Ind. Pharm.* **2018**, *44*, 377–384. [CrossRef] [PubMed]
69. Alsalhi, M.S.; Devanesan, S.; Alfuraydi, A.A.; Vishnubalaji, R.; Munusamy, M.A.; Murugan, K.; Nicoletti, M.; Benelli, G. Green synthesis of silver nanoparticles using *Pimpinella anisum* seeds: Antimicrobial activity and cytotoxicity on human neonatal skin stromal cells and colon cancer cells. *Int. J. Nanomed.* **2016**, *11*, 4439–4449. [CrossRef] [PubMed]
70. Dhand, V.; Soumya, L.; Bharadwaj, S.; Chakra, S.; Bhatt, D.; Sreedhar, B. Green synthesis of silver nanoparticles using *Coffea arabica* seed extract and its antibacterial activity. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *58*, 36–43. [CrossRef] [PubMed]

71. Chitra, K.; Manikandan, A.; Antony, S.A. Effect of poloxamer on *Zingiber officinale* extracted green synthesis and antibacterial studies of silver nanoparticles. *J. Nanosci. Nanotechnol.* **2016**, *16*, 758–764. [CrossRef] [PubMed]
72. Lee, J.H.; Lim, J.M.; Velmurugan, P.; Park, Y.J.; Park, Y.J.; Bang, K.S.; Oh, B.T. Photobiologic-mediated fabrication of silver nanoparticles with antibacterial activity. *J. Photochem. Photobiol. B Biol.* **2016**, *162*, 93–99. [CrossRef] [PubMed]
73. Surendra, T.V.; Roopan, S.M.; Arasu, M.V.; Al-Dhabi, N.A.; Rayalu, G.M. RSM optimized *Moringa oleifera* peel extract for green synthesis of *M. oleifera* capped palladium nanoparticles with antibacterial and hemolytic property. *J. Photochem. Photobiol. B Biol.* **2016**, *162*, 550–557. [CrossRef] [PubMed]
74. Surendra, T.V.; Roopan, S.M. Photocatalytic and antibacterial properties of photosynthesized CeO2 NPs using *Moringa oleifera* peel extract. *J. Photochem. Photobiol. B Biol.* **2016**, *161*, 122–128. [CrossRef] [PubMed]
75. Rajakumar, G.; Gomathi, T.; Thiruvengadam, M.; Devi Rajeswari, V.; Kalpana, V.N.; Chung, I.M. Evaluation of anti-cholinesterase, antibacterial and cytotoxic activities of green synthesized silver nanoparticles using from *Millettia pinnata* flower extract. *Microb. Pathog.* **2017**, *103*, 123–128. [CrossRef] [PubMed]
76. Xia, Q.H.; Ma, Y.J.; Wang, J.W. Biosynthesis of silver nanoparticles using *Taxus yunnanensis* callus and their antibacterial activity and cytotoxicity in human cancer cells. *Nanomaterials* **2016**, *6*, 160. [CrossRef] [PubMed]
77. Xia, Q.H.; Zheng, L.P.; Zhao, P.F.; Wang, J.W. Biosynthesis of silver nanoparticles using *Artemisia annua* callus for inhibiting stem-end bacteria in cut carnation flowers. *IET Nanobiotechnol.* **2017**, *11*, 185–192. [CrossRef] [PubMed]
78. Vilas, V.; Philip, D.; Mathew, J. Essential oil mediated synthesis of silver nanocrystals for environmental, anti-microbial and antioxidant applications. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *61*, 429–436. [CrossRef] [PubMed]
79. Verma, D.K.; Hasan, S.H.; Banik, R.M. Photo-catalyzed and phyto-mediated rapid green synthesis of silver nanoparticles using herbal extract of *Salvinia molesta* and its antimicrobial efficacy. *J. Photochem. Photobiol. B Biol.* **2016**, *155*, 51–59. [CrossRef] [PubMed]
80. Krishnaraj, C.; Ji, B.J.; Harper, S.L.; Yun, S.I. Plant extract-mediated biogenic synthesis of silver, manganese dioxide, silver-doped manganese dioxide nanoparticles and their antibacterial activity against food- and water-borne pathogens. *Bioprocess Biosyst. Eng.* **2016**, *39*, 759–772. [CrossRef] [PubMed]
81. Jadhav, K.; Dhamecha, D.; Bhattacharya, D.; Patil, M. Green and ecofriendly synthesis of silver nanoparticles: Characterization, biocompatibility studies and gel formulation for treatment of infections in burns. *J. Photochem. Photobiol. B Biol.* **2016**, *155*, 109–115. [CrossRef] [PubMed]
82. Govarthanan, M.; Seo, Y.S.; Lee, K.J.; Jung, I.B.; Ju, H.J.; Kim, J.S.; Cho, M.; Kamala-Kannan, S.; Oh, B.T. Low-cost and eco-friendly synthesis of silver nanoparticles using coconut (*Cocos nucifera*) oil cake extract and its antibacterial activity. *Artif. Cells Nanomed. Biotechnol.* **2016**, *44*, 1878–1882. [CrossRef] [PubMed]
83. Parlinska-Wojtan, M.; Kus-Liskiewicz, M.; Depciuch, J.; Sadik, O. Green synthesis and antibacterial effects of aqueous colloidal solutions of silver nanoparticles using chamomile terpenoids as a combined reducing and capping agent. *Bioprocess Biosyst. Eng.* **2016**, *39*, 1213–1223. [CrossRef] [PubMed]
84. Miri, A.; Dorani, N.; Darroudi, M.; Sarani, M. Green synthesis of silver nanoparticles *using Salvadora persica L.* And its antibacterial activity. *Cell. Mol. Biol.* **2016**, *62*, 46–50. [PubMed]
85. Gopinath, K.; Kumaraguru, S.; Bhakyaraj, K.; Mohan, S.; Venkatesh, K.S.; Esakkirajan, M.; Kaleeswarran, P.; Alharbi, N.S.; Kadaikunnan, S.; Govindarajan, M.; et al. Green synthesis of silver, gold and silver/gold bimetallic nanoparticles using the *Gloriosa superba* leaf extract and their antibacterial and antibiofilm activities. *Microb. Pathog.* **2016**, *101*, 1–11. [CrossRef] [PubMed]
86. Paul, B.; Bhuyan, B.; Purkayastha, D.D.; Dhar, S.S. Photocatalytic and antibacterial activities of gold and silver nanoparticles synthesized using biomass of *Parkia roxburghii* leaf. *J. Photochem. Photobiol. B Biol.* **2016**, *154*, 1–7. [CrossRef] [PubMed]
87. Pugazhendhi, S.; Sathya, P.; Palanisamy, P.K.; Gopalakrishnan, R. Synthesis of silver nanoparticles through green approach using *Dioscorea alata* and their characterization on antibacterial activities and optical limiting behavior. *J. Photochem. Photobiol. B Biol.* **2016**, *159*, 155–160. [CrossRef] [PubMed]
88. Chowdhury, N.R.; MacGregor-Ramiasa, M.; Zilm, P.; Majewski, P.; Vasilev, K. Chocolate' silver nanoparticles: Synthesis, antibacterial activity and cytotoxicity. *J. Colloid Interface Sci.* **2016**, *482*, 151–158. [CrossRef] [PubMed]

89. Latha, M.; Priyanka, M.; Rajasekar, P.; Manikandan, R.; Prabhu, N.M. Biocompatibility and antibacterial activity of the *Adathoda vasica Linn* extract mediated silver nanoparticles. *Microb. Pathog.* **2016**, *93*, 88–94. [CrossRef] [PubMed]
90. Abbai, R.; Mathiyalagn, R.; Markus, J.; Kim, Y.; Wang, C.; Singh, P.; Ahn, S.; Farh, M.E.; Yang, D.C. Green synthesis of multifunctional silver and gold nanoparticles from the oriental herbal adaptogen: Siberian ginseng. *Int. J. Nanomed.* **2016**, *11*, 3131–3143.
91. Otunola, G.A.; Afolayan, A.J.; Ajayi, E.O.; Odeyemi, S.W. Characterization, antibacterial and antioxidant properties of silver nanoparticles synthesized from aqueous extracts of *Allium sativum*, *Zingiber officianale*, and *Capsicum frutscens*. *Pharmacogn. Mag.* **2017**, *13*, S201–S208. [CrossRef] [PubMed]
92. Shaik, M.R.; Albalawi, G.H.; Khan, S.T.; Khan, M.; Adil, S.F.; Kuniyil, M.; Al-Warthan, A.; Siddiqui, M.R.; Alkhathlan, H.Z.; Khan, M. "Miswak" based green synthesis of silver nanoparticles: Evaluation and comparison of their microbicidal activities with the chemical synthesis. *Molecules* **2016**, *21*, E1478. [CrossRef] [PubMed]
93. El-Sherbiny, I.M.; El-Shibiny, A.; Salih, E. Photo-induced green synthesis and antimicrobial efficacy of poly (ε-caprolactone)/curcumin/grape leaf extract-silver hybrid nanoparticles. *J. Photochem. Photobiol. B Biol.* **2016**, *160*, 355–363. [CrossRef] [PubMed]
94. Beg, M.; Maji, A.; Mandal, A.K.; Das, S.; Aktara, M.N.; Jha, P.K.; Hossain, M. Green synthesis of silver nanoparticles using *Pongamia pinnata* seed: Characterization, antibacterial property, and spectroscopic investigation of interaction with human serum albumin. *J. Mol. Recognit.* **2016**, *30*. [CrossRef] [PubMed]
95. Nakkala, J.R.; Mata, R.; Sandras, S.R. Green synthesized nano silver: Synthesis, physiochemical profiling, antibacterial, anticancer activities and biological in vivo toxicity. *J. Colloid Interface Sci.* **2017**, *499*, 33–45. [CrossRef] [PubMed]
96. Du, J.; Singh, H.; Yi, T.H. Antibacterial, anti-biofilm and anticancer potentials of green synthesized silver nanoparticles using benzoin gum (*Styrax benzoin*) extract. *Bioprocess Biosyst. Eng.* **2016**, *39*, 1923–1931. [CrossRef] [PubMed]
97. Patra, J.K.; Baek, K.H. Antibacterial activity and synergistic antibacterial potential of biosynthesized silver nanoparticles against foodborne pathogenic bacteria along with its anticandidal and antioxidant effects. *Front. Microbiol.* **2017**, *8*, 167. [CrossRef] [PubMed]
98. Shankar, S.; Tanomrod, N.; Rawdkuen, S.; Rhim, J.W. Preparation of pectin/silver nanoparticles composite films with UV-light barrier and properties. *Int. J. Biol. Macromol.* **2016**, *92*, 842–849. [CrossRef] [PubMed]
99. Sathishkumar, P.; Preethi, J.; Vijayan, R.; Mohd Yusoff, A.R.; Ameen, F.; Suresh, S.; Balagurunathan, R.; Palvannan, T. Anti-acne, anti-dandruff and anti-breast cancer efficacy of green synthesized silver nanoparticles using *Coriandrum sativum* leaf extract. *J. Photochem. Photobiol. B Biol.* **2016**, *163*, 69–76. [CrossRef] [PubMed]
100. Baghbani-Arani, F.; Movagharnia, R.; Sharifian, A.; Salehi, S.; Shandiz, S.A.S. Photo-catalytic, anti-bacterial, and anti-cancer properties of phyto-mediated synthesis of silver nanoparticles from *Artemisia tournefortiana Rchb* extract. *J. Photochem. Photobiol. B Biol.* **2017**, *173*, 640–649. [CrossRef] [PubMed]
101. Kumar, V. A.; Ammani, K.; Jobina, R.; Subhaswaraj, P.; Siddhardha, B. Photo-induced and phytomediated synthesis of silver nanoparticles using *Derris trifoliata* leaf extract and its larvicidal activity against *Aedes aegypti*. *J. Photochem. Photobiol. B Biol.* **2017**, *171*, 1–8. [CrossRef] [PubMed]
102. Li, X.; Xu, H.; Chen, Z.; Chen, G. Biosynthesis of nanoparticles by microorganisms and their applications. *J. Nanomater.* **2011**, *2011*. [CrossRef]
103. Morales-Luckie, R.A.; Lopezfuentes-Ruiz, A.A.; Olea-Mejia, O.F.; Liliana, A.F.; Sanchez-Mendieta, V.; Brostow, W.; Hinestroza, J.P. Synthesis of silver nanoparticles using aqueous extracts of *Heterotheca inuloides* as reducing agent and natural fibers as templates: *Agave lechuguilla* and silk. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *69*, 429–436. [CrossRef] [PubMed]
104. Zia, M.; Gul, S.; Akhtar, J.; Haq, I.U.; Abbasi, B.H.; Hussain, A.; Naz, S.; Chaudhary, M.F. Green synthesis of silver nanoparticles from grape and tomato juices and evaluation of biological activities. *IET Nanobiotechnol.* **2017**, *11*, 193–199. [CrossRef] [PubMed]
105. Ali, S.G.; Ansari, M.A.; Khan, H.M.; Jalal, M.; Mahdi, A.A.; Cameotra, S.S. *Crataeva nurvala* nanoparticles inhibit virulence factors and biofilm formation in clinical isolates of *Pseudomonas aeruginosa*. *J. Basic Microbiol.* **2017**, *57*, 193–203. [CrossRef] [PubMed]

106. Jayaprakash, N.; Vijaya, J.J.; Kaviyarasu, K.; Kombaiah, K.; Kennedy, L.J.; Ramalingam, R.J.; Munusamy, M.A.; Al-Lohedan, H.A. Green synthesis of Ag nanoparticles using Tamarind fruit extract for the antibacterial studies. *J. Photochem. Photobiol. B Biol.* **2017**, *169*, 178–185. [CrossRef] [PubMed]
107. Shkryl, Y.N.; Veremeichik, G.N.; Kamenev, D.G.; Gorpenchenko, T.Y.; Yugay, Y.A.; Mashtalyar, D.V.; Nepomnyaschiy, A.V.; Avramenko, T.V.; Karabtsov, A.A.; Ivanov, V.V.; et al. Green synthesis of silver nanoparticles using transgenic *Nicotiana tabacum* callus culture expressing silicatein gene from marine sponge *Latrunculia oparinae*. *Artif. Cells Nanomed. Biotechnol.* **2017**, 1–13. [CrossRef] [PubMed]
108. Osibe, D.A.; Chiejina, N.V.; Ogawa, K.; Aoyagi, H. Stable antibacterial silver nanoparticles produced with seed-derived callus extract of *Catharanthus roseus*. *Artif. Cells Nanomed. Biotechnol.* **2017**, 1–8. [CrossRef] [PubMed]
109. Hamedi, S.; Shojaosadati, S.A.; Mohammadi, A. Evaluation of the catalytic, antibacterial and anti-biofilm activities of the *Convolvulus arvensis* extract functionalized silver nanoparticles. *J. Photochem. Photobiol. B Biol.* **2017**, *167*, 36–44. [CrossRef] [PubMed]
110. Rasheed, T.; Bilal, M.; Iqbal, H.M.N.; Li, C. Green biosynthesis of silver nanoparticles using leaves extract of *Artemisia vulgaris* and their potential biomedical applications. *Colloids Surf. B Biointerfaces* **2017**, *158*, 408–415. [CrossRef] [PubMed]
111. Elemike, E.E.; Fayemi, O.E.; Ekennia, A.C.; Onwudiwe, D.C.; Ebenso, E.E. Silver nanoparticles mediated by *Costus afer* leaf extract: Synthesis, antibacterial, antioxidant and electrochemical properties. *Molecules* **2017**, *22*, E701. [CrossRef] [PubMed]
112. Bhuvaneswari, R.; Xavier, R.J.; Arumugam, M. Facile synthesis of multifunctional silver nanoparticles using mangrove plant *Excoecaria agallocha* L. for its antibacterial, antioxidant and cytotoxic effects. *J. Parasit. Dis. Off. Organ Indian Soci. Parasitol.* **2017**, *41*, 180–187. [CrossRef] [PubMed]
113. Dehghanizade, S.; Arasteh, J.; Mirzaie, A. Green synthesis of silver nanoparticles using *Anthemis atropatana* extract: Characterization and in vitro biological activities. *Artif. Cell Nanomed. Biotechnol.* **2018**, *46*, 160–168. [CrossRef] [PubMed]
114. Skandalis, N.; Dimopoulou, A.; Georgopoulou, A.; Gallios, N.; Papadopoulos, D.; Tsipas, D.; Theologidis, I.; Michailidis, N.; Chatzinikolaidou, M. The effect of silver nanoparticles size, produced using plant extract from *Arbutus unedo* on their antibacterial efficacy. *Nanomaterials* **2017**, *7*, E178. [CrossRef] [PubMed]
115. Arya, G.; Sharma, N.; Ahmed, J.; Gupta, N.; Kumar, A.; Chandra, R.; Nimesh, S. Degradation of anthropogenic pollutant and organic dyes by biosynthesized silver nanocatalyst from *Cicer arietinum* leaves. *J. Photochem. Photobiol. B Biol.* **2017**, *174*, 90–96. [CrossRef] [PubMed]
116. Saratale, R.G.; Benelli, G.; Kumar, G.; Kim, D.S.; Saratale, G.D. Bio-fabrication of silver nanoparticles using the leaf extract of an ancient herbal medicine, dandelion (*Taraxacum officinale*), evaluation of their antioxidant, anticancer potential, and antimicrobial activity against phytopathogens. *Environ. Sci. Pollut. Res. Int.* **2018**, *25*, 10392–10406. [CrossRef] [PubMed]
117. Jinu, U.; Gomathi, M.; Saiqa, I.; Geetha, N.; Benelli, G.; Venkatachalam, P. Green engineered biomolecule-capped silver and copper nanohybrids using *Prosopis crineraria* leaf extract: Enhanced antibacterial activity against microbial pathogens of public health relevance and cytotoxicity on human breast cancer cells (MCF-7). *Microb. Pathog.* **2017**, *105*, 86–95. [CrossRef] [PubMed]
118. Kumar, V.; Mohan, S.; Singh, D.K.; Verma, D.K.; Singh, V.K.; Hasan, S.H. Photo-mediated optimized synthesis of silver nanoparticles for the selective detection of Iron(III), antibacterial and antioxidant activity. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2017**, *71*, 1004–1019. [CrossRef] [PubMed]
119. Velmurugan, P.; Shim, J.; Bang, K.S.; Oh, B.T. Gold nanoparticles mediated coloring of fabrics and leather for antibacterial activity. *J. Photochem. Photobiol. B Biol.* **2016**, *160*, 102–109. [CrossRef] [PubMed]
120. Chahardoli, A.; Karimi, N.; Sadeghi, F.; Fattahi, A. Green approach for synthesis of gold nanoparticles from *Nigella arvensis* leaf extract and evaluation of their antibacterial, antioxidant, cytotoxicity and catalytic activities. *Artif. Cells Nanomed. Biotechnol.* **2018**, *46*, 579–588. [CrossRef] [PubMed]
121. Karthik, R.; Chen, S.M.; Elangovan, A.; Muthukrishnan, P.; Shanmugam, R.; Lou, B.S. Phyto mediated biogenic synthesis of gold nanoparticles using *Cerasus serrulata* and its utility in detecting hydrazine, microbial activity and DFT studies. *J. Colloid Interface Sci.* **2016**, *468*, 163–175. [CrossRef] [PubMed]
122. Yuan, C.G.; Huo, C.; Gui, B.; Cao, W.P. Green synthesis of gold nanoparticles using *Citrus maxima* peel extract and their catalytic/antibacterial activities. *IET Nanobiotechnol.* **2017**, *11*, 523–530. [CrossRef] [PubMed]

123. Khan, F.U.; Chen, Y.; Khan, N.U.; Ahmad, A.; Tahir, K.; Khan, Z.U.; Khan, A.U.; Khan, S.U.; Raza, M.; Wan, P. Visible light inactivation of *E. coli*, cytotoxicity and ROS determination of biochemically capped gold nanoparticles. *Microb. Pathog.* **2017**, *107*, 419–424. [CrossRef] [PubMed]
124. Manikandan, V.; Velmurugan, P.; Park, J.H.; Chang, W.S.; Park, Y.J.; Jayanthi, P.; Cho, M.; Oh, B.T. Green synthesis of silver oxide nanoparticles and its antibacterial activity against dental pathogens. *3 Biotech* **2017**, *7*, 72. [CrossRef] [PubMed]
125. Ezhilarasi, A.A.; Vijaya, J.J.; Kaviyarasu, K.; Maaza, M.; Ayeshamariam, A.; Kennedy, L.J. Green synthesis of NiO nanoparticles using *Moringa oleifera* extract and their biomedical applications: Cytotoxicity effect of nanoparticles against HT-29 cancer cells. *J. Photochem. Photobiol. B Biol.* **2016**, *164*, 352–360. [CrossRef] [PubMed]
126. Saleem, S.; Ahmed, B.; Khan, M.S.; Al-Shaeri, M.; Musarrat, J. Inhibition of growth and biofilm formation of clinical bacterial isolates by NiO nanoparticles synthesized from *Eucalyptus globulus* plants. *Microb. Pathog.* **2017**, *111*, 375–387. [CrossRef] [PubMed]
127. Velmurugan, P.; Park, J.H.; Lee, S.M.; Yi, Y.J.; Cho, M.; Jang, J.S.; Myung, H.; Bang, K.S.; Oh, B.T. Eco-friendly approach towards green synthesis of zinc oxide nanocrystals and its potential applications. *Artif. Cells Nanomed. Biotechnol.* **2016**, *44*, 1537–1543. [CrossRef] [PubMed]
128. Vijayakumar, S.; Vaseeharan, B.; Malaikozhundan, B.; Shobiya, M. *Laurus nobilis* leaf extract mediated green synthesis of ZnO nanoparticles: Characterization and biomedical applications. *Biomed. Pharmacother.* **2016**, *84*, 1213–1222. [CrossRef] [PubMed]
129. Banumathi, B.; Vaseeharan, B.; Ishwarya, R.; Govindarajan, M.; Alharbi, N.S.; Kadaikunnan, S.; Khaled, J.M.; Benelli, G. Toxicity of herbal extracts used in ethno-veterinary medicine and green-encapsulated ZnO nanoparticles against *Aedes aegypti* and microbial pathogens. *Parasitol. Res.* **2017**, *116*, 1637–1651. [CrossRef] [PubMed]
130. Azizi, S.; Mohamad, R.; Mahdavi Shahri, M. Green microwave-assisted combustion synthesis of zinc oxide nanoparticles with *Citrullus colocynthis* L. schrad: Characterization and biomedical applications. *Molecules* **2017**, *22*, E301. [CrossRef] [PubMed]
131. Muthulakshmi, L.; Rajini, N.; Nellaiah, H.; Kathiresan, T.; Jawaid, M.; Rajulu, A.V. Preparation and properties of cellulose nanocomposite films with in situ generated copper nanoparticles *using Terminalia catappa* leaf extract. *Int. J. Biol. Macromol.* **2017**, *95*, 1064–1071. [CrossRef] [PubMed]
132. Rezaie, A.B.; Montazer, M.; Rad, M.M. Photo and biocatalytic activities along with UV protection properties on polyester fabric through green in-situ synthesis of cauliflower-like CuO nanoparticles. *J. Photochem. Photobiol. B Biol.* **2017**, *176*, 100–111. [CrossRef] [PubMed]
133. Tahir, K.; Nazir, S.; Ahmad, A.; Li, B.; Khan, A.U.; Khan, Z.U.H.; Khan, F.U.; Khan, Q.U.; Khan, A.; Rahman, A.U. Facile and green synthesis of phytochemicals capped platinum nanoparticles and in vitro their superior antibacterial activity. *J. Photochem. Photobiol. B Biol.* **2017**, *166*, 246–251. [CrossRef] [PubMed]
134. Irshad, R.; Tahir, K.; Li, B.; Ahmad, A.; Siddiqui, R.A.; Nazir, S. Antibacterial activity of biochemically capped iron oxide nanoparticles: A view towards green chemistry. *J. Photochem. Photobiol. B Biol.* **2017**, *170*, 241–246. [CrossRef] [PubMed]
135. Tahir, K.; Nazir, S.; Li, B.; Ahmad, A.; Nasir, T.; Khan, A.U.; Shah, S.A.; Khan, Z.U.; Yasin, G.; Hameed, M.U. *Sapium sebiferum* leaf extract mediated synthesis of palladium nanoparticles and in vitro investigation of their bacterial and photocatalytic activities. *J. Photochem. Photobiol. B Biol.* **2016**, *164*, 164–173. [CrossRef] [PubMed]
136. Dinesh, M.; Roopan, S.M.; Selvaraj, C.I.; Arunachalam, P. *Phyllanthus emblica* seed extract mediated synthesis of PdNPs against antibacterial, haemolytic and cytotoxic studies. *J. Photochem. Photobiol. B Biol.* **2017**, *167*, 64–71. [CrossRef] [PubMed]
137. Maqbool, Q.; Nazar, M.; Naz, S.; Hussain, T.; Jabeen, N.; Kausar, R.; Anwaar, S.; Abbas, F.; Jan, T. Antimicrobial potential of green synthesized CeO2 nanoparticles from *Olea europaea* leaf extract. *Int. J. Nanomed.* **2016**, *11*, 5015–5025. [CrossRef] [PubMed]
138. Nadaroglu, H.; Onem, H.; Alayli Gungor, A. Green synthesis of Ce2O3 NPs and determination of its antioxidant activity. *IET Nanobiotechnol.* **2017**, *11*, 411–419. [CrossRef] [PubMed]
139. Elemike, E.E.; Onwudiwe, D.C.; Ekennia, A.C.; Sonde, C.U.; Ehiri, R.C. Green synthesis of Ag/Ag_2O nanoparticles using aqueous leaf extract of *Eupatorium odoratum* and its antimicrobial and mosquito larvicidal activities. *Molecules* **2017**, *22*, E674. [CrossRef] [PubMed]

140. El-Sherbiny, I.; Salih, E.; Reicha, F. New trimethyl chitosan-based composite nanoparticles as promising antibacterial agents. *Drug Dev. Ind. Pharm.* **2016**, *42*, 720–729. [CrossRef] [PubMed]
141. Senthikumar, R.P.; Bhuvaneshwari, V.; Ranjithkumar, R.; Sathiyavimal, S.; Malayaman, V.; Chandarshekar, B. Synthesis, characterization and antibacterial activity of hybrid chitosan-cerium oxide nanoparticles: As a bionanomaterials. *Int. J. Biol. Macromol.* **2017**, *104*, 1746–1752. [CrossRef] [PubMed]
142. Ahmed, S.; Ahmad, M.; Swami, B. L.; Ikram, S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *J. Adv. Res.* **2016**, *7*, 17–28. [CrossRef] [PubMed]
143. Gupta, A.; Saleh, N.M.; Das, R.; Landis, R.F.; Bigdeli, A.; Motamedchaboki, K.; Campos, A.R.; Pomeroy, K.; Mahmoudi, M.; Rotello, V.M. Synergistic antimicrobial therapy using nanoparticles and antibiotics for the treatment of multidrug-resistant bacterial infection. *Nano Futures* **2017**, *1*, 015004. [CrossRef]
144. National Center for Biotechnology Information (NCBI). Bethesda (MD): National Library of Medicine (US), National Center for Biotechnology Information. Available online: https://www.ncbi.nlm.nih.gov/ (accessed on 20 April 2018).
145. Zgurskaya, H.I.; Löpez, C. A.; Gnanakaran, S. Permeability barrier of gram-negative cell envelopes and approaches to bypass it. *ACS Infect. Dis.* **2015**, *1*, 512–522. [CrossRef] [PubMed]
146. Acharya, D.; Singha, K.M.; Pandey, P.; Mohanta, B.; Rajkumari, J.; Singha, L.P. Shape dependent physical mutilation and lethal effects of silver nanoparticles on bacteria. *Sci. Rep.* **2018**, *8*, 201. [CrossRef] [PubMed]
147. Das, B.; Dash, S.K.; Mandal, D.; Ghosh, T.; Chattopadhyay, S.; Tripathy, S.; Das, S.; Dey, S.K.; Das, D.; Roy, S. Green synthesized silver nanoparticles destroy multidrug resistant bacteria via reactive oxygen species mediated membrane damage. *Arab. J. Chem.* **2017**, *10*, 862–876. [CrossRef]
148. Kalita, S.; Kandimalla, R.; Sharma, K.K.; Kataki, A.C.; Deka, M.; Kotoky, J. Amoxicilin functionalized gold nanoparticles reverts MRSA resistance. *Mater. Sci. Eng. C Mater. Biol. Appl.* **2016**, *61*, 720–727. [CrossRef] [PubMed]
149. Deng, H.; McShan, D.; Zhang, Y.; Sinha, S.S.; Arslan, Z.; Ray, P.C.; Yu, H. Mechanistic study of the synergistic antibacterial activity of combined silver nanoparticles and common antibiotics. *Environ. Sci. Technol.* **2016**, *50*, 8840–8848. [CrossRef] [PubMed]
150. Hwang, I.S.; Hwang, J.H.; Choi, H.; Kim, K.J.; Lee, D.G. Synergistic effects between silver nanoparticles and antibiotics and the mechanisms involved. *J. Med. Microbiol.* **2012**, *61*, 1719–1726. [CrossRef] [PubMed]
151. Sondi, I.; Salopek-Sondi, B. Silver nanoparticles as antimicrobial agent: A case study on *E. coli* as a model for gram-negative bacteria. *J. Colloid Interface Sci.* **2004**, *275*, 177–182. [CrossRef] [PubMed]
152. Reidy, B.; Haase, A.; Luch, A.; Dawson, K.A.; Lynch, I. Mechanisms of silver nanoparticle release, transformation and toxicity: A critical review of current knowledge and recommendations for future studies and applications. *Materials* **2013**, *6*, 2295–2350. [CrossRef] [PubMed]
153. Guzman, M.; Dille, J.; Godet, S. Synthesis and antibacterial activity of silver nanoparticles against gram-positive and gram-negative bacteria. *Nanomed. Nanotechnol. Biol. Med.* **2012**, *8*, 37–45. [CrossRef] [PubMed]
154. Swamy, M.K.; Sudipta, K.M.; Jayanta, K.; Balasubramanya, S. The green synthesis, characterization, and evaluation of the biological activities of silver nanoparticles synthesized from *Leptadenia reticulate* leaf extract. *Appl. Nanosci.* **2015**, *5*, 73–81. [CrossRef]
155. Ramseh, P.S.; Kokola, T.; Geetha, D. Plant mediated green synthesis and antibacterial activity of silver nanoparticles using *Emblica officinalis* fruit extract. *Spectrochimica Acta A Mol. Biomol. Spectrosc.* **2015**, *142*, 339–343. [CrossRef] [PubMed]
156. Ovington, L.G. The truth about silver. *Ostomy/Wound Manag.* **2004**, *50*, 1S–10S.
157. Raffi, M.; Hussain, F.; Bhatti, T.M.; Akhter, J.I.; Hameed, A.; Hasan, M.M. Antibacterial characterization of silver nanoparticles against *E. coli* ATCC-15224. *J. Mater. Sci. Technol.* **2008**, *24*, 192–196.
158. Carnevale, J.; Ko, A.H. MM-398 (nanoliposomal irinotecan): Emergence of a novel therapy for the treatment of advanced pancreatic cancer. *Future Oncol.* **2016**, *12*, 453–464. [CrossRef] [PubMed]
159. Ando, K.; Mori, K.; Corradini, N.; Redini, F.; Heymann, D. Mifamurtide for the treatment of nonmetastatic osteosarcoma. *Expert Opin. Pharmacother.* **2011**, *12*, 285–292. [CrossRef] [PubMed]
160. Bovier, P.A. Epaxal: A virosomal vaccine to prevent hepatitis A infection. *Expert Rev. Vaccines* **2008**, *7*, 1141–1150. [CrossRef] [PubMed]

161. Herzog, C.; Hartmann, K.; Künzi, V.; Kürsteiner, O.; Mischler, R.; Lazar, H.; Glück, R. Eleven years of inflexal V—A virosomal adjuvanted influenza vaccine. *Vaccine* **2009**, *27*, 4381–4387. [CrossRef] [PubMed]
162. Boswell, G.W.; Buell, D.; Bekersky, I. AmBisome (liposomal amphotericin B): A comparative review. *J. Clin. Pharmacol.* **1998**, *38*, 583–592. [CrossRef] [PubMed]
163. Anselmo, A.C.; Mitragotri, S. Nanoparticles in the clinic. *Bioeng. Transl. Med.* **2016**, *1*, 10–29. [CrossRef] [PubMed]
164. Grabrucker, A. M.; Ruozi, B.; Belletti, D.; Pederzoli, F.; Forni, F.; Vandelli, M.A.; Tosi, G. Nanoparticle transport across the blood brain barrier. *Tissue Barriers* **2016**, *4*, e1153568. [CrossRef] [PubMed]
165. Saraiva, C.; Praça, C.; Ferreira, R.; Santos, T.; Ferreira, L.; Bernardino, L. Nanoparticle-mediated brain drug delivery: Overcoming blood-brain barrier to treat neurodegenerative diseases. *J. Control Rel.* **2016**, *235*, 34–47. [CrossRef] [PubMed]
166. Moore, T.L.; Rodriguez-Lorenzo, L.; Hirsch, V.; Balog, S.; Urban, D.; Jud, C.; Rothen-Rutishauser, B.; Lattuada, M.; Petri-Fink, A. Nanoparticle colloidal stability in cell culture media and impact on cellular interactions. *Chem. Soc. Rev.* **2015**, *44*, 6287–6305. [CrossRef] [PubMed]
167. Sanfins, E.; Augustsson, C.; Dahlbäck, B.; Linse, S.; Cedervall, T. Size-dependent effects of nanoparticles on enzymes in the blood coagulation cascade. *Nano Lett.* **2014**, *14*, 4736–4744. [CrossRef] [PubMed]
168. Lohcharoenkal, W.; Wang, L.; Chen, Y.C.; Rojanasakul, Y. Protein nanoparticles as drug delivery carriers for cancer therapy. *BioMed Res. Int.* **2014**, *2014*. [CrossRef] [PubMed]
169. Gupta, A.; Eral, H.B.; Hatton, T.A.; Doyle, P.S. Nanoemulsions: Formation, properties and applications. *Soft Matter* **2016**, *12*, 2826–2841. [CrossRef] [PubMed]
170. Jaiswa, M.; Dudhe, R.; Sharma, P.K. Nanoemulsion: An advanced mode of drug delivery system. *3 Biotech* **2015**, *5*, 123–127. [CrossRef] [PubMed]
171. Sperling, R.A.; Parak, W.J. Surface modification, functionalization and bioconjugation of colloidal inorganic nanoparticles. *Philos. Trans. Ser. A Math. Phys. Eng. Sci.* **2010**, *368*, 1333–1383. [CrossRef] [PubMed]
172. Albanese, A.; Tang, P.S.; Chan, W.C. The effect of nanoparticle size, shape, and surface chemistry on biological systems. *Annu. Rev. Biomed. Eng.* **2012**, *14*, 1–16. [CrossRef] [PubMed]
173. Khodashenas, B.; Ghorbani, H.R. Synthesis of silver nanoparticles with different shapes. *Arab. J. Chem.* **2015**. [CrossRef]
174. Moreno-Vega, A.; Gómez-Quintero, T.; Nuñez-Anita, R.; Acosta-Torres, L.; Castaño, V. Polymeric and ceramic nanoparticles in biomedical applications. *J. Nanotechnol.* **2012**, *2012*. [CrossRef]
175. Woźniak, A.; Malankowska, A.; Nowaczyk, G.; Grześkowiak, B.F.; Tuśnio, K.; Slomski, R.; Zaleska-Medynska, A.; Jurga, S. Size and shape-dependent cytotoxicity profile of gold nanoparticles for biomedical applications. *J. Mater. Sci. Mater. Med.* **2017**, *28*, 92. [CrossRef] [PubMed]
176. Yildrimer, L.; Thanh, N.T.; Loizidou, M.; Seifalian, A.M. Toxicology and clinical potential of nanoparticles. *Nano Today* **2011**, *6*, 585–607. [CrossRef] [PubMed]
177. Panáček, A.; Kvítek, L.; Smékalová, M.; Večeřová, R.; Kolář, M.; Röderová, M.; Dyčka, F.; Šebela, M.; Prucek, R.; Tomanec, O.; Zbořil, R. Bacterial resistance to silver nanoparticles and how to overcome it. *Nanotechnology* **2018**, *13*, 65–71. [CrossRef] [PubMed]
178. Stark, W.J.; Stoessel, P.R.; Wohlleben, W.; Hafner, A. Industrial applications of nanoparticles. *Chem. Soc. Rev.* **2015**, *44*, 5793–5805. [CrossRef] [PubMed]