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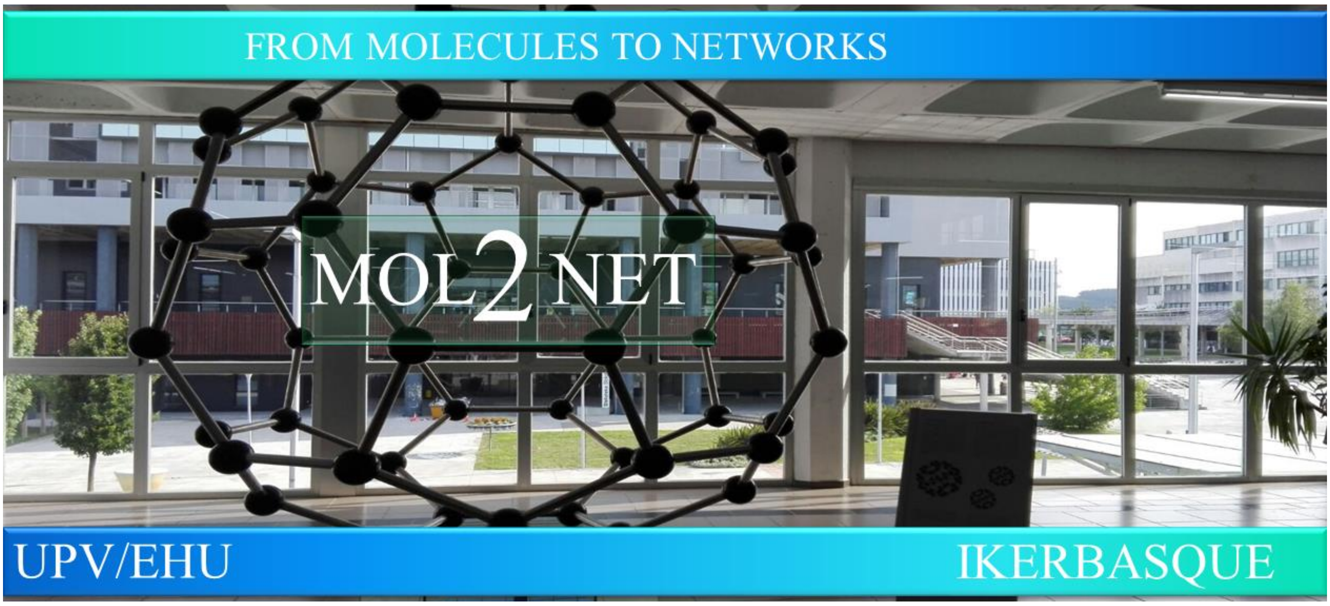

Biosynthesis of nanoparticles. A brief review for potential biomedical applications.

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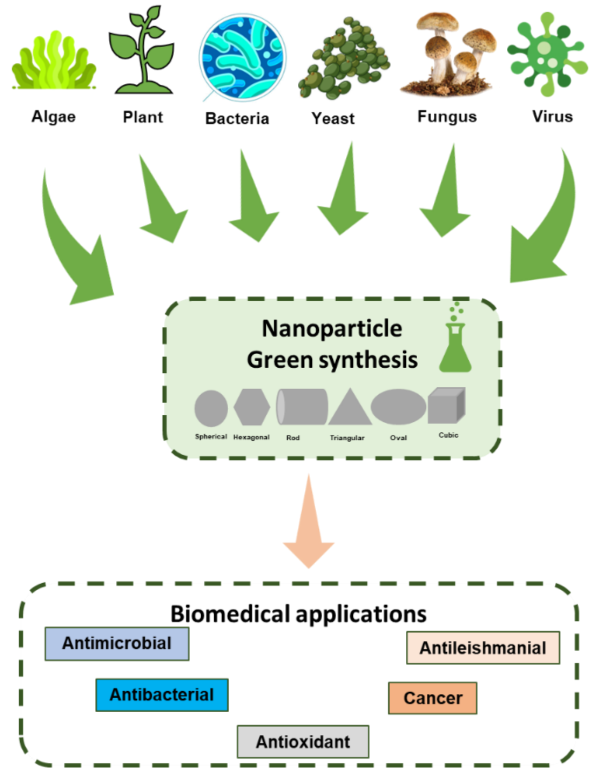
Graphical Abstract	**Abstract.**
	Recent advances in nanomaterials and nanotechnology have been attracting intense attention worldwide due to their bright prospects



in nanomedicine and other areas. The synthesis of nanoparticles (NPs) is usually done by conventional techniques that produce a lot of harmful and toxic by-products. Therefore, greener ways are needed to develop eco-friendly, clean, and less toxic nanoparticles than conventional methods. In this paper, we present a brief review of recent advances in NP biosynthesis. We include a wide variety of plant, bacterial, fungal, algal, and viral species that have been used to synthesise NPs for biomedical applications.

Introduction

Nanomaterials are made up of nanoparticles (NPs), and at least 50% of those NPs must have at least one external dimension between 1 and 100 nm [1]. In recent decades, nanomaterials have become the "wonders" of modern medicine [2]. They outperform bulk phases in biological and physicochemical properties. Their high surface reactivity due to a higher surface-to-volume ratio and their unique properties have enabled them to be employed in various applications in different fields, such as biotechnology or materials science, due to their unique properties [3]. Their unique properties make nanoparticles extremely attractive for a wide variety of applications, such as catalysis, gas and energy storage, photovoltaic, electrical, and optical devices, as well as biological and medical technologies [4-10].

Various NPs, mainly metallic nanoparticles, are used for drug delivery, the diagnosis of disorders, and other biomedical applications [11-14]. NPs are manufactured by capital- and energy-efficient physical and chemical processes using hazardous non-polar compounds and solvents [2]. In that sense, the application of green chemistry has improved safety and performance by producing them in a clean, benign, and environmentally friendly way [15,16]. Green synthesis employs more natural production processes and results in a more environmentally friendly product that reduces waste and pollution while using harmless components [2].

Bio-compounds coat the surface of NPs during green synthesis [17]. Thus, this layer enhances green NPs' biological characteristics over chemically reduced ones. Bio-compounds prevent hazardous by-products from contaminating green NPs. These dangerous chemicals adhere to NPs during physical and chemical production [18]. Bio-assisted synthesis has stayed in research because it involves a collection of connected parameters (the biological reducing agent composition and concentration, the initial precursor salt concentration, agitation speed, reaction time, pH, temperature, and light). These have an

impact on the NP properties of the formulation. Thus, optimising a biological procedure takes time and effort. The organisms' interior environments vary by species and by the individual, making techniques challenging to standardise and repeat.
In this paper, we present a brief review of recent advances in NPs biosynthesis. We include a wide variety of plant, bacterial, fungal, algal and viral species that have been used to synthesise NPs for biomedical applications.

Materials and Methods

In this study, Scopus and Web of Science (WoS) databases, the two most important international academic information sources, were utilised. Scopus data were retrieved manually from the online edition (www.scopus.com), while WoS data were extracted manually from the Web of Science Core Collection publications. In order to comprehend the evolution of biosynthesis research for biological applications, the period from 2005 to the present (December 10, 2022) was analysed for the purposes of publication. The chosen research approach for this study was a systematic review of the literature, and the study's primary phases were as follows:
Research and categorization comprise the initial phase. This phase consisted of three steps: identification, screening, and incorporation. Documents were searched, a screening of the whole output was conducted to determine whether documents may be studied in accordance with the study areas deemed intriguing and relevant, and documents were chosen for in-depth analysis.
Phase 2 consists of analysis and discussion. The results were analysed during this step. The outcomes were then analysed, and conclusions were reached.

Results and Discussion

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Table 1 presents examples of green synthesis NPs. Several species of bacteria, fungi, yeasts, algae and plants are included. In addition, several biomedical applications are shown. The most relevant biological activities where biosynthesised NPs are applied are antibacterial, antimicrobial, antifungal, antimalarial, antileishmanial, anticancer, antioxidant, etc.

Table 1. Examples of NPs synthesis using various biogenic sources and their biomedical applications.

No	Specie	NPs	Size (nm)	Shape	Application	Reference
			Bacteria			
1	*Bacillus cereus*	CuO	11–33	Spherical	Antimicrobial	[19]
2	*Shewanella oneidensis MR-1*	Fe_2O_3	30–40	Tetragonal	Anticancer	[20]
3	*Magnetospirillum* sp and *Desulfovibrio magneticus* strains	Fe_3O_4	<10	Cubic, octahedral	Antimicrobial	[21]
4	*Lactobacillus* sp.	$BaTiO_3$	20–40	Spherical	Antibacterial	[22]

No	Specie	NPs	Size (nm)	Shape	Application	Reference
5	*Bacilo índice*	Ag	–	–	Antimicrobial	[23]
6	*Klebsiella aerogenes*	CdS	20–200	–	–	[24]
7	*Pseudomonas aeruginosa*	ZnO	35–80	Spherical	Antioxidant	[25]
8	*Bacillus sp MSh1*	Se	80-220	Spherical	Antileishmanial	[26]
9	*Serratia marcescens*	Sb_2S_5	10-35	-	Antileishmanial	[27]
10	*Serratia ureilitica*	ZnO	170–250	Nano flowers	Antibacterial	[12]
Fungi						
11	*Aspergillus terreus*	ZnO	16–57	Spherical	Antibacterial/Anticancer	[28]
12	*Trichoderma harzianum*	Au	32–44	Spherical/Hexagonal	Antibacterial	[29]
13	*Fusarium oxysporum*	Ag	57.6	Spherical	Antileishmanial	[13]
14	*Fusarium oxysporum*	TiO_2 _	6–13	Spherical	Antimicrobial	[30]
15	*Aspergillus flavus*	Ag	4	Spherical	Antileishmanial	[31]
16	*Fusarium graminarum*	Ag	94	-	Antileishmanial	[32]
Yeast						
17	*Saccharomyces cerevisiae*	Ag	2–20	Spherical	Biocatalyst	[19]
18	*Saccharomyces cerevisiae*	Sb_2O_3	5–50	Hexagonal/Octahedral	Antimicrobial	[33]
Algae						
19	*Bifurcaria bifurcada/Enterobacter aerogenes*	CuO	5-45	Spherical	Antibacterial	[34]
20	*Sargassum wightii*	ZrO_2 _	4.8	Tetragonal	Antibacterial	[35]
21	*Padina tetrastromatica*	Ag	14	Spherical	Antimicrobial	[36]
22	*Gracilaria corticata*	Ag	18–44	Spherical	Antimicrobial	[37]
23	*Stoechospermum*	Au	18–93	Spherical/Hexagonal	Antimicrobial	[38]

No	Specie	NPs	Size (nm)	Shape	Application	Reference
24	*Sargassum myriocystum*	ZnO	96–110	Spherical/Rectangular	Antimicrobial	[39]
25	*Valoniopsis pachynema*	CdS	10–30	Spherical	Antimalarial/Anticancer	[19]
			Virus			
26	Hepatitis E virus	Nanoconjugates	27–34	Icosahedral	Cancer therapy	[40]
27	Potato virus X	Nanocarriers	13	Helical	Doxorubicin delivery in cancer therapy	[41]
28	Cucumber mosaic virus	Nanoassemblies	~29	icosahedral	Anticancer drug delivery	[42]
			Plant			
29	*Aloe vera*	Au/Ag	10–30	Spherical/Triangular	Cancer hyperthermia	[43]
30	*Magnolia kobus*	CuO	37–110	Spherical	Antibacterial	[44]
31	*Mentha pulegium*	Bi_2O_3	150	Monoclinic crystalline	Antibacterial	[45]
32	*Dioscorea alata*	Bi_2O_3	40–42	Nano-needle	Antifungal	[46]
33	*Moringa oleifera*	Bi_2O_3	40–57	Amorphous	Antioxidant/Antibacterial/Antifungal	[47]
34	*Gloriosa superba*	CeO_2	5–20	Spherical	Antibacterial	[48]
35	*Moringa oleifera*	SnO_2	8–10	Spherical	Antioxidant	[49]
36	*Rhamnus prinoides*	WO_3	60	Spherical	Antibacterial	[50]
37	*Medicago sativa*	FeO	2–10	Crystalline	Anticancer	[51]
38	*Morus sp*	Ag	15–20	Spherical	Antimicrobial	[52]
39	*Ocimum sanctum*	Ag	25–80	Spherical/Triangular	Antimalarial	[53]
40	*Coleus aromaticus*	TiO_2	12–33	Hexagonal	Antibacterial	[54]
41	*Rhamnus virgata*	NiO	24	Spherical	Antileishmanial	[55]
42	*Mirabilis jalapa*	Ag/ZnO	9-67	Spherical	Antileishmanial	[56]
43	*Silybum marianum*	Ag/ZnO	35	Spherical	Antileishmanial	[14]

.Conclusions

This brief review covers elements related to recent advances and avenues of NP biosynthesis. Traditional synthetic methods to synthesise NPs involve significant energy capital and harmful chemicals, which could lead to toxic products. Green synthesis is an environmentally friendly route that reduces this risk by using non-hazardous compounds. Various plant species, bacteria, fungi, algae, and viruses have been used to synthesise NPs. The most relevant biological activities where biosynthesised NPs are applied are antibacterial, antimicrobial, antifungal, antimalarial, antileishmanial, anticancer, antioxidant, etc. The production of nanomaterials is a promising topic in science; hence, the characteristics of biogenically generated NPs and their applications in the biomedical field should be studied.

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