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Review Article

Investigating the prospects of bacterial biosurfactants for metal nanoparticle synthesis – a comprehensive review

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Abstract: Establishing biological synthesis of nanoparticles is increasing nowadays in the field of nanotechnology. The search for an optimal source with durability, stability, capacity to withstand higher environmental conditions with excellent characteristics is yet to meet. Consequently, there is need to create an eco-friendly strategy for metal nanoparticle synthesis. One approach investigated in this review is the use of biosurfactants to enhance the synthesis biologically. In comparison with the other technologies, biosurfactants are less toxic and exhibit higher properties. This method is different from the conventional practice like physical and chemical methods. Several research studies represented that the biosurfactant influences the production of nanoparticles about 2–50 nm. In this manner, the research towards the biosurfactant has raised. This review also addressed the feasibility of biosurfactant and their benefits in the synthesis of metallic nanoparticles. The findings from this review can recommend a conceivable use of biosurfactant as a source for metal nanoparticle synthesis.

1 Introduction

The present progression in nanomaterials welcomes new items for wide applications in different fields of studies and in particular, nanomaterials for science, hardware, transport, data innovation, physics, chemistry, medicine and instrument engineering. The advancement in the field of life sciences and healthcare can be developed by nanotechnology, which makes the researchers work on the cellular and molecular levels. Nanotechnology research was increasing all over the world in the twenty-first century. The nanomaterials are usually in the range of 1–100 nm [1]. In the case of large-scale usage of nanoparticles in the field like biosensors, catalysis, drug delivery and biotechnology, the most inventive method is required. The metal nanoparticles act as biomedical agents and therapeutic agents for the various disorders. The metal nanoparticles were raise from silver, gold, platinum, palladium, titanium, copper, zinc etc. Metal nanoparticle was utilised in catalysis, sensing, electronics because they are based on properties like magnetic, catalytic, medicinal and electrical properties. Creation of nanoparticles with high monodispersity is very difficult in case of material science. Synthesis of nanoparticles has been a dynamic research region in the ongoing years because of extensive properties of the nanomaterials. In addition, these properties could provide a promising result in the biological field. The development of material science research is based on the size and composition of nanomaterials. Nanomaterials can be integrated by utilising an assortment of strategies like sol–gel, co-precipitation, laser ablation, microemulsion, electrospinning and pyrolysis [2]. The above-mentioned techniques are expensive, generates toxic substances and produce less stable nanoparticles. In addition, these techniques involve atomic, molecular and particulate processing in the medium [3]. Physical and chemical methods use high temperature and pressure and biologically toxic compounds, which creates the toxicity to the environment and human health. The most famous method is the chemical reduction method that transfers the metal salts into metal atoms by using certain reducing agents such as citrate, hydrides, ethylene glycol and hydrazine. However, all these agents have the capacity to create environmental issues [4, 5].

The major topic in various investigations is a synthesis of metallic nanoparticles using the biological material as a reducing agent. To synthesise the nanoparticles in a controlled shape and size, development of synthesis procedures is required. Thus, the environmental friendly inventive process is required to enhance the nanoparticles synthesis for industrial and medical applications. Microorganisms have a higher potential towards the synthesis of nanoparticles. Generally, two sorts of biological synthesis of metal nanoparticles have been so far been recognised. The first choice is the utilisation of every single microbial framework (all living beings) and the second alternative is to utilise the metabolites combined by various living beings (microorganisms or plants). Due to microorganisms, the nanoparticles are delivered either intracellular or extracellular [6]. The progressing research is looking for more refined conventions to determine the polydispersity and to control over size and shape of nanoparticles and a few investigations have obtained great outcomes utilising biomolecules [7, 8]. Various reports suggested that biosurfactant mediated process is developing on the biosynthesis [9, 10]. This method is particularly utilised for the metal nanoparticles. The sources needed for the nanoparticles require surfactants either chemically or biologically. However, the chemical surfactants are highly useful it brings out toxic substances to the living beings. For the fast synthesis of nanoparticles, bacterial biosurfactants (organisms delivering surfactants) are rising as a substitute hotspot due to the necessities of eco-friendly bioprocess and novel enhancer. Like above mentioned, microemulsion technique is a most promising approach in the nanoparticle synthesis which utilises oil–water–surfactant mixture. Some of the disadvantages of chemical and physical methods of nanoparticle synthesis are represented (Table 1). Biosurfactants are biological surfactants got from microbial source made generally out of sugar and unsaturated fat moieties, they have higher biodegradability and bring down harmfulness.

2 Biosurfactants

The biological method synthesis of nanoparticles plays a vital role among the research scientists. The major advantages of a biological method like cost-effectiveness, eco-friendly and so on, influences the biosynthesis of nanoparticles. Some of the organisms possess biosurfactants, which acts as a substitute for the chemical synthesis of nanoparticles [22]. Biosurfactants are the emulsifiers, which help to decrease the surface tension of the compound. It is accessible in the intracellular and extracellular part of the bacterial cell. It is comprised of hydrophobic and hydrophilic moieties, which helps in the reduction of surface tension of compounds and leads to easy degradation by the bacteria [23].

2.1 Biosurfactants classification

It consists of the non-polar group comprised of fatty acid and a polar group comprised of sugars (glycolipids like rhamnolipids, trehalolipids, mannosylerythritol lipids and sophorolipids), peptides (lipopeptides) or polysaccharides (polymeric surfactants). Based on the molecular mass of biosurfactants, they were divided into two types. They are low molecular mass biosurfactants consists of glycolipids such as rhamnolipids and sophorolipids, or high molecular mass biosurfactants consists of lipopeptides such as surfactin and polymyxin. Glycolipids contain rhamnose sugar, which is linked to the myrmicacin, which is a derivative of β-hydroxycarboxylic acid hydroxyl group [24]. Glycolipids are commercially produced from the microorganisms like *Bacillus subtilis* and *Pseudomonas aeruginosa* [25]. The disaccharide sugar in the trehalose linked to the carbon backbone to long chain fatty acids of mycolic acid. The morphology of the mycolic acid varies based on the atoms of carbons. Trehalose is produced from the organisms like *Arthrobacter* sp. and *Rhodococcus erythropolis*. Macrolactones and a free acidic group are present in the sophorolipids. From the sophorolipids, lactones are extracted which is the ester groups of hydroxyl carboxylic acids and these lactones are widely used for the various biomedical applications [26]. The microorganisms involved in the production of glycolipids are *Pseudomonas*, *Burkholderia*, *Acinetobacter*, *Mycobacterium*, *Rhodococcus*, *Nocardia*, *Candida*, *Arthrobacter* and *Corynebacterium* etc. *Aspergillus*, *Acinetobacter*, *Arthrobacter*, *Corynebacterium* and *Nocardia* have been utilised for the synthesis of phospholipids and fatty acids. Lipopeptides have reported to produce mostly by the organisms like *Bacillus, Actinoplanes*, *Aspergillus*, *Serratia* and *Streptomyces* [27, 28].

Table 1 Demerits of physical and chemical methods of nanoparticle synthesis

Method	Demerits	References
deposition of gas phase	dangerous in controlling the size of the particle	[11]
electron beam lithography	requires costly and complex machines	[12]
sol–gel method	high permeability, weak bonding,	[13]
oxidation	small size of colloids	[14, 15]
chemical coprecipitation	usage of toxic chemicals	[16]
flow injection	continuous mixing	[17]
electrochemical	recreation is not possible	[13]
aerosol/vapour phase	works under high temperature	[18]
sonochemical decomposition	not easy to understand the mechanism	[19]
supercritical fluid method	need high pressure and temperature	[20]
using nanoreactors	complicated	[21]

Table 2 Literature study about the surface tension and critical micelle concentration of various biosurfactants

Group	Surface tension, mN m^{-1}	Critical micelle concentration, mg L^{-1}	References
glycolipids	72–33.9	50	[32]
	74–38	120	[33]
	72–31.4	30	[34]
	31.1	600	[35]
	72–39.5	2.5	[36]
	72–28	35	[37]
	29.73	100	[38]
	31	50	[39]
	72–31	0.130	[40]
	33.8	37.9	[41]
phospholipids and fatty acids	31.2	400	[42]
lipopeptides and lipoproteins	36	225	[43]
	72–32	185	[44]
	71.6–30.2	56	[45]
	36	300	[46]
	30	0.12	[47]
	29	110	[48]

2.2 Characteristics of biosurfactants

Based on critical micelle concentration (CMC), hydrophilic–lipophilic balance (HLB), charge and chemical structure, the biosurfactants are characterised [29]. The efficiency of biosurfactants is determined using critical micelle concentration. For example, low critical micelle concentration indicates high efficiency, which means that low concentration of biosurfactant is required to decrease the surface tension. Usually, the CMC is lower than chemical surfactants, because of this reason biosurfactants requirement is low in case of reducing the surface tension [30]. In a study, the surface tension of water gets decreased by using rhamnolipid biosurfactant produced by *Pseudomonas aeruginosa* [31]. Hence, surface tension and interfacial tension are the major properties of biosurfactants. The list of studies, which depicts the surface tension, and critical micelle concentration of various biosurfactants are explained (Table 2). Conductivity, viscosity, density, osmotic pressure, turbidity can be characterised with the help of HLB property. The water-in-oil emulsion and oil-in-water emulsion are identified in biosurfactant by using HLB property. The environmental conditions do not affect the parameters of biosurfactants like temperature and pH. For example, a recent study suggested that lipopeptides produced by *Bacillus subtilis* was found to be more stable for about 180 days at an autoclavable temperature (121°C) and at low temperatures below −15°C. At the same NaCl concentration, more than 15% the activity of biosurfactant are more stable [49].

2.3 Upsides of biosurfactants

In a natural form, the biosurfactants can be obtained that exhibits some good characteristics like restorative properties, expanded degradability, great diminishing property and these properties are lagging in the chemical surfactants. It is highly used because of its benefits like low toxicity and high degradability. Biosurfactants can also be generated from the microbes with the help of enzymes and they play a vital role in the synthesis of biosurfactants [50]. Surfactants help to decrease the surface tension, hence its application has been raised in the industrial process containing emulsification, foaming, detergency, wetting etc. In the recovery of oil and hydrocarbons from the wastewater, it acts as an emulsifier [51]. The activity of biosurfactants varies based on the chemical composition. Several reports depicted that the bacteria have the capability to produce the surface-active agents called biosurfactants. The various properties of biosurfactants influence its application in different fields like cosmetics, pharmaceuticals, emulsifying agents in food etc. Some other applications in case of increasing the surface area and bioavailability of pollutants are heavy metal binding, bacterial pathogenesis, quorum sensing, and biofilm formation. The consequences of biosurfactants produced by bacterial strain listed (Table 3). In comparison with the chemical surfactants, the biosurfactants exhibit higher properties and they are less toxic compared to the chemical surfactants. In this manner, the research towards the biosurfactant has increased in the last decades. A few analysts investigated the bioprocess in lab scale reactors for a more noteworthy creation from known biosurfactant-creating microbes [70, 71] and others concentrated on the detachment of new species and studying the qualities of surface active products [72, 73]. In any case, while the industrial interest for surfactants has expanded almost 300% in the US industry during the most recent decade [73]. However, the surfactants used in the industries are usually synthesised by chemical method. An expanding interest of biosurfactants and the need of cost-focused bioprocess of biosurfactants for business usage, influence the scientists to create cost-effective methodologies for biosurfactant creation.

The advancement of an environmental friendly process for the synthesis of nanoparticles is developing as a vital part of nanotechnology. The most important source for the nanoparticle synthesis from biological systems are bacteria, fungi, algae and plant extracts [74, 75]. Several studies reported the production of metal nanoparticles using above-mentioned biological sources [76, 77]. Though the biological synthesis influences the system complex, it restricts the understanding about the reduction and capping process. This disadvantage can overcome easily using a microbial surfactant. They can be considered as a good appropriate method for the nanoparticle synthesis. The biosurfactants-mediated nanoparticle synthesis examined as an environmentally acceptable procedure due to its less toxicity. It is more advantageous than other methods because of its reduction in aggregate formation and provides uniform morphology among the nanoparticles. The other benefits like biodegradability, biocompatibility, availability, specificity, the effectiveness of biosurfactants at temperature, pH, and salinity influences the many authors for the generation of materials for future utilisation. In this review, we have provided a summary of available works representing the use of biosurfactants for the synthesis of metallic nanoparticles. Due to the huge applications of biosurfactants [78–80], it is a need to expand the research.

Table 3 Importance of biosurfactants produced by bacteria

Type of biosurfactant	Bacterial strain	Importance of biosurfactant	References
rhamnolipid	*Pseudomonas aeruginosa*	bioremediation of oil	[52]
		biocontrol agent	[53]
		solubilisation and mobilisation of hydrocarbons	[54]
		anti-tumour activity	[55]
		emulsifying activity and washing of hydrocarbons	[56]
	Pseudomonas. alcaligenes	mobilisation of hydrocarbons	[57]
	Pseudomonas desmolyticum	dyes solubilisation	[58]
glycolipid	*Nocardioides* sp.	induce hemolysis	[59]
	P. aeruginosa	enhanced oil recovery	[60]
	Aeromonas sp.	thermostable emulsifier of various hydrocarbons	[61]
lipopeptide	*Brevibacillus laterosporus*	antimicrobial agent	[62]
	Bacillus circulans	polyaromatic hydrocarbon solubilisation	[63]
trehalose lipid	*Rhodococcus* sp.	hemolytic activity	[64]
	Rhodococcus sp.	membrane permeabilising activity	[65]
	R. erythropolis	dissolution of hydrocarbons	[66]
sophorolipids	*Candida bombicola*	antimicrobial activity	[67]
	Wickerhamiella domercqiae	anticancer activity	[68]
	Wickerhamiella domercqiae	surface active property	[69]

3 Types of nanoparticles synthesised through bacterial biosurfactants

In connection with biotechnology and nanotechnology, a new area like bionanotechnology has raised. The aim of this new area is to understand the communication between the nanoparticle and biological systems. The current trend is to develop a technique for the production of nanoparticles in which various biological substances have used because of its benefits like renewable, less expensive and so on. The major downside in the synthesis of nanoparticles from the bacterial mass is that complex downstream process. Therefore, there is a need to introduce an ever-growing environmentally benign procedure for the synthesis of metal nanoparticles. Based on the concern, i.e. minimise the generation of waste, Anastas and Warner [81] introduced certain principles, some of them are less hazardous synthesis route, use of safe chemicals and renewable feedstocks, degradable substrates [82]. The significance of creating eco-friendly strategies for the synthesis of metal nanoparticles, researchers have started investigating based on it. This can overcome by the biosurfactant-mediated nanoparticle synthesis. It is the simplest method of synthesising the metal nanoparticles. It was noted that biosurfactants created by microorganisms can be a critical part in the synthesis of nanoparticles through aggregation and stabilisation process. The mode of action of biosurfactant is adsorbing onto metallic nanoparticles (MeNPs), surface settling the nanoparticles and avoiding consequent aggregation. The surfactant adsorption relies upon the kind of surfactant (ionic, non-ionic, polymeric, and so on.) and the thickness of the adsorbed layer [83, 84]. The research has inspected that several biosurfactants can be used as stabiliser and modifier in the synthesis of metallic nanoparticles.

3.1 Silver nanoparticles

It is generally utilised in the health care products, medical devices, optical receptors, as catalysts in chemical reactions, for biolabelling, water purification systems, antimicrobial agents in industries and so on [85–88]. The silver nanoparticles display some of the properties like catalytic property, electrical conductivity, catalytic property, magnetic property, antimicrobial activity etc. The available methodologies for the synthesis of nanoparticles are chemical reduction, photochemical reduction, aerosol approach, and electrostatic spraying approach. These are widely used techniques for the synthesis of nanoparticles. Based on the size, the application of silver nanoparticle synthesis is large. Boutonnet *et al.* [89] were the first who used reverse micelle technique to form metal nanoparticles but they used chemical surfactants, which will pollute the environment easily. This is the major drawback found in this study. Reddy *et al.* [90] investigated the utilisation of a biosurfactant, a lipopeptide biosurfactant created by *Bacillus subtilis* has exhibited for the stabilisation of silver nanoparticles. In this study, the size and morphology of nanoparticles depend on the pH and temperature of biosurfactants. This procedure gives a less complex for nanoparticle synthesis contrasted with existing frameworks. An attempt made by Das *et al.* [91] to isolate the rhamnolipid biosurfactant from *Pseudomonas aeruginosa* with an enhanced method. Synthesis of spherical shape silver nanoparticles carried out with the help of biosurfactants and then applied in microemulsion technique. Additionally, they have done antimicrobial and cytotoxic activities for both biosurfactants and synthesised nanoparticles in which the result suggested that biosurfactants show best antimicrobial activity than the silver nanoparticle. Zeta potential results from this study suggested that nanoparticle is more stable in the suspension [91]. Hence, several reports represented that rhamnolipid biosurfactants are highly useful in the synthesis of silver nanoparticles [92–94]. Moreover, some of the other researchers used the rhamnolipid biosurfactant, which was isolated from *Pseudomonas fluorescens* for the synthesis of silver nanoparticles [95]. They obtained a stable silver nanoparticle that was found to be uniform and has the capability to be stable for about 3 months. They concluded that this study is an appropriate method for green synthesis of silver nanoparticles. Kiran *et al.* [96] reported the rhamnolipid production using marine bacteria called *Brevibacterium casei*. They depicted that this biosurfactant acts as a reasonable stabiliser in Ag nanoparticles biosynthesis under solid-state fermentation. Like different perceptions detailed for rhamnolipids created nanoparticles were steady for two months and the biosurfactant acted as the best stabilisation agent. Saikia *et al.* [97] portrayed a new part of rhamnolipid in the conservation of silver nanoparticles against salt. Rhamnolipids delivered by a *Pseudomonas aeruginosa* strain utilised as a part of testing the stability of colloidal silver nanoparticles (AgNPs) regarding salt fixations (2–60 mg NaCl/mL). It was proposed that rhamnolipid might be an intense stabiliser of the AgNPs in the colloidal frame. Additionally, reports by Kasture *et al.* [98] described on utilising sophorolipids as a reducing and stabilising agent for the silver nanoparticle synthesis, which carried out at room temperature, 40, 60, 80 and 100°C. Two sorts of sophorolipids were generated on either oleic acid or linoleic acid, which may influence the fatty acid chain length of the sophorolipid molecule. At the lower temperatures, bigger particles with wide size obtained. At increasing temperatures, the silver nanoparticles with narrow size are obtained.

3.2 Gold nanoparticles

Based on the size and morphology, the physical properties of nanoparticles are determined. The gold nanoparticles exhibit the shape-dependent properties. In the synthesis of gold nanoparticles, chemical methods are not only followed but it results in environmental pollution due to the usage of toxic chemicals like borohydrate, citrate and acetylene [99]. Since gold nanoparticles are a shape dependent, stabilising agents like surfactants, thiols, amines, phosphines, phosphine oxides and carboxylates are used in the synthesis process for the control of shape and size. Nowadays, researchers focused on the synthesis of stabilised gold nanoparticles by the biological method. Recently, the demand is increasing towards the clean, non-toxic, eco-friendly synthesis of gold nanoparticles. Also hence many studies are now turned their interest into the biological microorganism. The benefits of the biological method include avoidance of toxic reagents, compatible, and so on. By seeing these benefits, biosurfactants could prove to be an appropriate method for enhancing the nanoparticle synthesis biologically. Only a few reports elucidated the synthesis of gold nanoparticles using biosurfactants. An ongoing methodology in this field is the utilisation of biosurfactant delivering microbial strain. Reddy *et al.* [100] examined the surfactant-mediated gold nanoparticle synthesis. Using the bacteria *Bacillus subtilis* lipopeptide biosurfactant generated and the changes in the structure of lipopeptide alter the shape of the gold nanoparticles in this study. They conducted the study at acid, basic and neutral conditions in which aggregation does not occur at basic and neutral conditions. The results showed that the biosurfactant-mediated gold nanoparticles are spherical in shape and very stable at basic and neutral [100]. Tomar *et al.* [101] synthesised the gold nanoparticles with the help of biosurfactant produced from *Pseudomonas aeruginosa* in which the biosurfactant acted as a capping agent. To make the gold nanoparticles synthesis more economical, more research needs to done in the biosurfactants.

3.3 Nickel nanoparticles

Nickel is an essential progress metal and nickel nanoparticles have boundless applications. Many authors are focused on the nickel nanoparticles because of its properties like catalytic activity and insulating property [102]. These enhanced properties make them a perfect for the application in battery cathode, electrochromic devices and gas sensors [103]. Due to these reasons, the nickel nanoparticles' synthesis has attracted in incredible focal point of numerous researchers. Nickel nanoparticles are widely utilised as a part of different fields and are manufactured by different physico-synthetic techniques including, i.e. sol–gel, micro-emulsion, sonochemical, vapour phase and co-precipitation methods [104–107]. Palanisamy [108] depicted that they used rhamnolipid biosurfactants for the synthesis of nanoparticles. The results show that the pH of the biosurfactant plays a vital role in the morphology of nickel nanoparticles. This study was carried out in the microemulsion technique by using biosurfactant in the dispersed in *n*-heptane hydrocarbon phase. They identified that the morphology of the nanoparticles is changing with varying pH without affecting the environment. When the pH was increased, the morphology changed to the spherical shape and when pH was decreased, the morphology changes over to flaky shape.

3.4 Zinc nanoparticles

Zinc nanoparticles contain unique properties such as UV-absorbing properties, sunscreen agents, anticancer and antibacterial activities, electronic, thermal and structural properties [109–112]. It is considered as a most important nanoparticle because of its applications in various areas like a catalyst, sensors, optoelectronic, and photoelectron devices [113]. Zinc nanoparticles have high surface area and catalytic activity and hence they are helpful in the medical and pharmaceutical fields. Some of the applications as antimicrobial agents in baby powder, calamine cream, anti-dandruff shampoos and antiseptic ointments [114]. When the size of the zinc oxide nanoparticles >100 nm, they are assumed to be biocompatible and then used for drug delivery. Several methods such as precipitation method, wet chemical synthesis, solid-state pyrolytic method, sol–gel method are refined to synthesise zinc metal nanoparticles yet many disadvantages are explained in reports like aggregation, broadening the size of the particles, poor reproducibility, need high temperature and high pressure and so on [115, 116]. Zinc nanoparticles are less toxic and more compatible when compared with the other metal nanoparticles. The interaction of zinc with the pharmaceutical compounds is less, which was reported by Sahdev *et al.* [117]. The 'biosynthesis' is an ecologically well-disposed process in science and chemical method is ending up progressively because of overall issues related with environmental contaminants [118]. To avoid the toxic waste, there is a need to develop an approach by using bacteria, algae, and fungi plant extracts [119]. During the synthesis of nanoparticles, the outcomes form microbes such as biosurfactants gets involved in the capping process [120]. Zinc oxide nanoparticles exhibit antioxidant property, which aroused the interest in synthesis [121].

In the last decades, chemical strategies have been utilised for the synthesis of zinc nanoparticles. The greater part of these strategies exhibits extreme ecological issues and natural dangers. Therefore, certain researchers reported a biological way using biosurfactants, i.e. rhamnolipids from *Pseudomonas aeruginosa* [122]. They analysed for the antioxidant property of biosurfactant mediated zinc nanoparticle and found that zinc nanoparticle is a promising antioxidant. This approach exploits the low-cost eco-friendly approach for the synthesis of nanoparticles [122]. In an attempt to synthesise zinc sulphide nanoparticles, they used biosurfactant (rhamnolipid) produced by *Pseudomonas aeruginosa* [123]. In this study, zinc sulphide nanoparticles synthesised using biosurfactants showed less degradation rate of direct brown MR textile dye. Yet the researchers concluded that ZnS nanoparticles demonstrated the best nanophotocatalyst. Narayanan *et al.* [124] utilised water-dissolvable rhamnolipids delivered by *Pseudomonas aeruginosa* for capping ZnS nanoparticles and they also represented the metal affinity, size and optical properties of the rhamnolipid ZnS nanoparticles. FT-IR spectra acquired for rhamnolipid-topped ZnS nanoparticles demonstrated an affinity between COOH of rhamnolipid and metal ions.

3.5 Cadmium nanoparticles

A cadmium nanoparticle has a wide range of applications in the field like solar energy conversion, photoelectrochemical cells and photocatalysis etc., because of its unique properties. Chemical precipitation, thermal decomposition and γ-irradiation were used for the synthesis of cadmium nanoparticles. These methods have certain downsides like the instability of nanoparticles, precipitation, broad particle size and so on [125]. Recently, the microbial synthesis of nanoparticles has been emerging alternative to the chemical and physical method [126, 127]. Still, this method also has restrictions like capping process is required for the increment of stability of the nanoparticles [128] and for this purpose bacterial biosurfactants can overcome this drawback, which could be a substitute for the conventional techniques. Singh *et al.* [115] investigated the synthesis of stable cadmium sulphide nanoparticles using surfactin produced by *Bacillus amyloliquifaciens* strain. In this study, a renewable bioresource obtained for surfactin production and applied in the nanotechnology in which it acts as a stabiliser for nanoparticle synthesis. The average yield of about 160 mg/L of surfactin was obtained, mixed with 1 Mm $Cd(NO_3)2$ in ratio 1:1. The synthesised cadmium nanoparticle was stable up to 120 days and characterised using XRD, TEM and spectroscopic studies. The results suggested that biosurfactant is a significant biocompatible and effective stabilising agent for the development of stable cadmium nanoparticles [115]. This study elucidated that biosurfactant could be utilised as a renewable source for the development of nanoparticles.

3.6 Iron nanoparticles

Nanoparticle synthesis using different organic and inorganic materials provides novel properties [129]. The essential class of nanoparticles is iron nanoparticles because it possesses technological importance. The parameters, which influence the synthesis of iron nanoparticles, are temperature, pH, the concentration of precursor etc. The behaviour of magnetic nanoparticles depends on the size of the nanoparticles. Using the external magnetic field, the iron nanoparticles can modified for its usage in target tissue [130]. The iron nanoparticles have gained the interest as they are applied in biomedical applications like cell labelling, cell targeting, and separation of cells, tissue repair, radioactive therapies, magnetic resonance imaging, magnetofection and tumour hyperthermia due to its chemical, thermal, mechanical properties [131–133]. The other important application of iron nanoparticles is magnetic storage media, solar energy transformation, electronics and catalysis. A microemulsion, thermal decomposition, co-precipitation methods, γ-ray radiation and microwave plasma synthesis are widely used for preparing magnetic nanoparticles [134–136]. The formation of aggregation and wide particle size production occurs in the above-mentioned methods. Hence, researchers are focused on the generation of magnetic nanoparticles using the biological method.

The iron nanoparticles can be synthesised using sophorolipids [137]. The acidic structures of sophorolipids were appropriate for use as surface complexing agents in the synthesis of iron oxide nanoparticles. Dynamic light scattering tests showed that sophorolipids-determined nanoparticles had amazing colloidal stability both in water and in salt-containing water. Baccile *et al.* [137] proposed that the availability of the sophorose aggregate at the surface of the nanoparticles is an imperative issue for biocompatibility properties of iron oxide nanoparticles. This study demonstrated that sophorose layer covered the iron oxide nanoparticles. A type of lipopeptide called surfactin was utilised by Liao *et al.* [138] for the stabilisation of super magnetic iron oxide nanoparticles. They found that the obtained nanoparticle is spherical in shape and dispersed easily in the aqueous phase.

4 Conclusion and future outlook

A wide assortment of microorganisms are known to create surface active compounds called biosurfactants with large ecological applications that give benefits over the chemical surfactants with high specificity, biodegradability, and biocompatibility. The investigation on the synthesis of nanoparticles will give a quick and novel indicative option for the biological method. This review represents the development of a green protocol for nanoparticle synthesis. The renewable biosurfactant-based nanoparticles have appeared to be helpful in the creation of advanced materials. Biosurfactants delivered by microorganisms is an alternative to the petroleum-based surfactants in the synthesis of advanced materials, not just for pharmaceutical and ecological applications, yet in addition to every aspect of the industry. In any case, their utilisation requires additional research to accomplish expansive scale creation and repeatability, tending to danger and security issues also. The biochemical and atomic components of biosynthesis of metallic nanoparticles should better comprehend to enhance the rate of synthesis of particles. The effect of biosurfactants on the shape, size and properties of metallic nanoparticles are required to explain the components that stimulate microbial growth to permit control of size, shape and crystallinity of the created nanoparticles. Future research on the part of biosurfactants in the biosynthesis of nanoparticles with remarkable properties is of extraordinary significance for particular applications in science, chemistry, agriculture and medicine.

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