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RESEARCH ARTICLE

Biosynthesized nanoparticles from aloe vera: A brief review towards membrane technology

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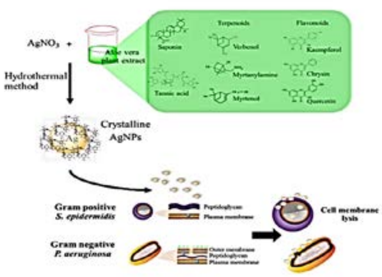
Graphical abstract



Abstract

Nanomaterial has become an interesting additive in membrane technology field. The nano size of these materials provide high surface area which then enhanced membrane properties such as anti - fouling, photocatalytic and anti-bacterial. This review gathers and compares the method of nanoparticles' biosynthesis using aloe vera as a reducing agent. Recent articles revealed that various plant, bacterial and fungus were used to produce nanomaterial through biosynthesis route. Aloe vera is abundant plant in Malaysia and most tropical climate country. The plant has many unique characteristics and was well known for its antioxidant, anti-inflammatory, anti-diabetic, sunburn relief, immune boost, anti-ageing and anticancer properties. In many of the studies related to biosynthesis, the nanoparticles produced were characterized by TEM, SEM, AAS, UV–VIS, FTIR, AFM, EDX, XRD techniques and was tested via anti–microbial assay. In this review, it can be concluded that biosynthesized nanoparticles added membrane value as it is eco-friendly, simple, cost effective and harmless. The incorporation of biosynthesized nanoparticles in membrane as additive has improved the membrane properties and characteristic (e.g. membrane fluxes were improved as well as its rejection and anti-fouling performance was also improved).

Keywords: Biosynthesis, nanoparticles, aloe vera, membrane

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INTRODUCTION

Nowadays, the convergence of nanotechnology and membrane technology has attracted most researchers. The incorporation of nanoparticles (NPs) as additive has significant effects in membrane's properties as well as performances. Currently, the use of additive in nanoscale range can be considered as it provides large surface area and resulted in better characteristic and performance of the membranes. As an example, membrane incorporated nanomaterial was enhanced in terms of the anti – fouling, photocatalytic and anti – bacterial properties (Nasrollahi *et al.*, 2018; Mollahosseini *et al.*, 2012; Damodar *et al.*, 2009; Akar *et al*., 2013; Behboudi *et al.*, 2018a, 2018b, 2016; Faizah *et al.*, 2013; Sawada *et al.*, 2012). Cao *et al.*, (2006) studied the effect of titanium dioxide nanoparticle size on the performance of PVDF membrane and reported the smaller nanoparticles could improve the antifouling property of the PVDF membrane significantly. NPs has been integrated in membrane for application of wound dressing, water treatment, gas separation, protien separation and fabrication of omniphobic membrane (Ghaemi, Daraei *et al.*, 2018; Livari *et al.*, 2012; Molki *et al*., 2018; Silva *et al*., 2017; Nasrollahi *et al.*, 2018; Chen *et al.*, 2018).

For years, researchers studied green technologies to preserve the environment from toxin, pollution and extreme climate change. According to review by Agarwal *et al.*, 2017 various efforts had been carried out to synthesize zinc oxide NPs using different sources like bacteria, fungus, algae, plants and others. Plants are most preferred source of NPs synthesis because they lead to large - scale production and produced stable, various shape and size of nanoparticles (Qu *et al.*, 2011). Extract of various plants or parts of plants have been used as reductant and as capping agents during biosynthesis of nanoparticles and polyphenols found in plant material often play a key role in these processes (Kharissova *et al.*, 2013; Zare *et al.*, 2017; Sharma *et al.*, 2016; Gnanadesigan *et al.*, 2011; Karnan and Selvakumar, 2016; Azizi *et al.*, 2015; Ambika and Sundrarajan 2015; Vijayakumar *et al.*, 2018; Dobrucka and Długaszewska 2016; Nagajyothi *et al.*, 2013; Bhuyan *et al.*, 2015; Fu and Fu 2015). The techniques involved are simple, environmental friendly and generally one-pot processes.

The aloe vera plant is classified as a succulent plant which consists of a stem, greyish green thick leaves and contains a lot of water. It has thorns along the edge of the leaves and the leaf cuticle was covered with wax (Abdul Kadir *et al.*, 2017). In Malaysia, the plant is known as "*lidah buaya*" and belongs to Lily family of Aloe barbadensis group. The aloe vera plant has many unique characteristics and is well known for its antioxidant, anti–inflammatory, antidiabetic, sunburn relief, immune boost, anti–ageing and anticancer properties (Maan *et al.*, 2018). According to Moghaddasi & Verma, (2011) there are active chemical constituents potentially contain in some part of aloe vera such as the gel and latex leaf lining. The gel contains polysaccharides (glicomannan and acemannan), carboxypeptidase, magnesium, zinc, calcium, glucose, cholestrol, salicylic acid, prostaglandin precursors (gamma - linolenic acid [GLA]), vitamins A, C, E, lignins, saponins, plant sterols and amino acids. Meanwhile, the latex leaf lining contains anthraquinone glycosides such as aloin, aloe-emodin and barbaloin. Phenolic compound is the second mostly found in aloe vera and the main active constituent is aloine.

Research by López *et al.*, (2013) had discovered that there were 18 phenolic constituents from the leaf and aloe vera flower which are sinapic acid, quercitrin, kaempferol, apigenin, gallic acid (not available in leaf skin), protocatechuic, catechin, vanillic acid, epicatechin, syringic acid, chlorogenic acid, gentisic acid, caffeic acid, coumaric acid, ferulic acid, rutin, miricetin and quecetin (not available in flower). They also found that the presence of these phenolic constituents was related to the antioxidant and anti-mycoplasmic activities in which give good motivation to use aloe vera leaf and flowers in the health food and pharmaceutical industries.

In spite of all the advantages of aloe vera plant, there were few bio-synthesized nanoparticles could be produced such as zinc oxide, copper oxide, silver, gold, iron, tin oxide, cerium oxide and indium oxide via redox reaction with suitable precursor. Gowri *et al.*, (2013) synthesized tin oxide from aloe vera extract. The biomolecules of aloe vera plant extract induced the metal salts to form to their corresponding hydroxides. Besides that, aloe vera also been functionalized with zinc oxide nanoparticles and improved the anti-bacterial properties of the NPs (Qian *et al.*, 2015). In this review we discussed a few techniques of biosynthesized nanoparticles from aloe vera plant and their characterization.

BIOSYNTHESIS OF METAL OXIDE

There were several steps to synthesize NPs from aloe vera plant. Basically, the procedure consist of pre-treatment step, biosynthesis and characterization of the NPs. Precursor was involved and plant extract acted as reducing agent in producing the desired NPs.

Zinc oxide

Intensive study was carried out by Gunalan *et al.*, (2011, 2012b) to produce zinc oxide NPs by using aloe vera extract as reducing agent. There were two different processes to treat aloe vera plant to obtain the extract by hot (boiling) and cold treatment. Different concentration of aloe vera extract was reacted with the zinc nitrate precursor and kept under vigorous stirring at 150 ^{o}C for 5 – 6 hours. The mixture was coolled at room temperature and the supernatant was discarded. Pale white solid product obtained was centrifuged twice at 4500 rpm for 15 min after washing and dried at 80 ^{o}C for 7 – 8 hours. In term of antimicrobial activity, the growth inhibition was higher in biosynthsized ZnO NPs compared to chemical ZnO NPs against bacterial strains (*Staphylococcus aureus, Serratia marcescens, Proteus mirabilis* and *Citrobacter freundii*) and fungal strains (*Aspergillus flavus, Aspergillus nidulans, Trichoderma harzianum* and *Rhizopus stolonifera*). This antibacterial properties that owned by the aloe vera affected the synthesized particles in this work. Besides, smaller particles attributed to be higher surface area and enhanced bioactivity, which prove of effective anti microbial agent against pathogenic microorganism.

Research by Jeeva *et al.,* (2012) almost similar with the previous author. The ZnO NPs was produced with the aid of zinc nitrate as precursor and aloe vera extract. The extract also was obtained using both hot and cold treatment apporach. However, the biosynthesis was carried out in much lesser temperature. The antimicrobial activity was carried out against *Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Salmonella typhi and Staphylococcus aureus.* The preliminary antibacterial activity study results indicate that biosynthesized ZnO NPs via hot pre-treatment (ZnO-AH) shows most activity against gram-negative, *Klebsiella pneumoniae* (8.33±1.87) while biosynthesized ZnO NPs via cold pre-treatment (ZnO-AC) and ZnO NPs chemically synthesized (ZnO-C) showed most activity against gram-negative, *Pseudomonas aeruginosa* (ZnO-AC 16.00±0.26; ZnO-C 19.00±0.68) compared to other five strains. It has been suggested that the electrostatic interactions between the bacteria surface and nanoparticles may be responsible for the inhibitory effect. The presence of ZnO nanoparticles leads to damage to the membrane wall of the bacteria (Yamamoto *et al.,* 2000).

Most of research on biosynthesis of zinc oxide used zinc nitrate as precursor. However, Ali *et al.*, (2016) synthesized zinc oxide NPs with the aid of zinc sulphate precursor. It consists of two major steps which is; pre-treatment and biosynthesis zinc oxide NPs. 20 g of aloe vera was blended with 100 ml autoclaved DI water. The blended aloe vera was kept under water bath 60^{o}C for 10 min and cooled at room temperature. The extract then filtered through Whatman filter paper no 1 and kept the stock solution at 4 ^{o}C for further use. For the biosynthesis part, 40 ml of aloe vera extract in $ZnSO_4$ (0.25 M) in ratio of 1:4 (v/v) with total mixture 200 ml. The reaction was carried out under stirring for 3 hours at 60 ^{o}C. After that, mixture was centrifuged at 4500 rpm for 10 min. The precipitate was washed and dried at 80 ^{o}C in vacuum ovum for 24 h. The antimicrobial test for this biosynthesized nanoparticles against *Escherichia coli, Pseudomonas auruginosa* and *Staphylococcus aureus.* The results also demonstrated biosynthesized zinc oxide NPs induced inhibition in the order as *Escherichia coli* > *Pseudomonas aeruginosa* > *Staphylococcus aureus*. Greater sensitivity of *Escherichia coli* cells to biosynthesized zinc oxide NPs is most likely due to stronger cell proliferation and interaction with cellular components gram-positive *Staphylococcus aureus* cells.

Copper oxide

The biosynthesis of copper oxide has been carried out by Gunalan *et al.*, (2012a) using copper sulphate as precursor. Different concentrations of the aloe vera extract was diluted with distilled water and was reacted with copper sulphate precursor. The reaction time was longer than zinc oxide synthesis from the previous study, which is 7 hours at 130 ^{o}C. The resulting NPs was centrifuged, washed and dried in oven at 100 ^{o}C for 6 hours. The produced NPs has average sizes between 15 to 30 nm. The NPs image was clearly shown by SEM and TEM analysis with well dispersed and spherical shape distribution. It can be conclude that the shape of NPs was not change with the increasing aloe vera extract concentration but cause the increasing of NPs size.

Silver

Yuvasree *et al*., (2013) synthesized silver NPs by the aid of silver nitrate as precursor. In this procedure, there was no involvement of heat in the biosynthesis process and the reaction was carried out in dark room for 24 hours. The color of the mixture was observed from pale brown to yellowish brown which indicate the formation of silver NPs. The solution was centrifuged and supernatant was collected and analysed for further characterization. The biosynthesized silver NPs were tested against *Escherichia coli, Pseudomonas spp* and *Bacillus spp*. Zones of 11 mm and 10 mm were observed for *Escherichia coli* and *Bacillus Species* respectively. For *Pseudomonas spp* it was 8 mm of inhibition area. The presence of antimicrobial properties has been proved with the appearance of inhibition zones.

Silver nitrate precursor was commonly used as the aid to produce silver NPs. Ibrahim *et al.,* (2014) carried out similar procedure by reacting 5 ml of aloe vera extract and 5 ml of 10^{-2} M silver nitrate precursor. Before that, the precursor was treated with 2.5 ml of 30% ammonia solution which facilitates the formation of soluble silver complex [Ag $(NH_3)_2$] which then facilitates the reduction process. The formation of silver NPs was indicated with the color change to faint yellow after 24 hours of reaction. The resulting NPs was tested for antimicrobial properties by testing with against bacteria *Escherichia coli* and *Staphylococcus aureus* and fungi *Candida albican, Aspergillus niger* and *Pencillium sp*. The result show the biosynthesized Ag NPs inhibit 20 – 30 mm towards *Escherichia coli* and *Staphylococcus aureus*. However no significant effect toward fungi *Candida albican, Aspergillus niger* and *Pencillium sp.*

According to previous study, the reaction time for biosynthesis of silver NPs was 24 hours. but Medda *et al.*, (2015) had applied longer time reaction which is 48 hours. The aloe vera leaf was undergoes the standard pre – treatment to obtain the aloe vera extract. The plant was cleaned, grinded and heated with 100 ml of distilled water for 12 minutes. Meanwhile, the precursor was prepared by adding 1.575g of silver nitrate into 1000 ml of distilled water. After that, 10% of aloe vera extract was mixed with the silver nitrate solution in 1:9 ratios and kept in room temperature for 48 hours for the development of reddish brown colour. The resulting NPs then were tested for antimicrobial activity against *Aspergillus sp* and *Rhizopus sp* using disc diffusion method and show better inhibition zone than the aloe vera extract alone. The SEM analysis show the NPs shape and the dynamic light scattering (DLS) technique was used to analyze he nanoparticle size.

Tippayawat *et al*., (2016) explained the steps in producing silver nanoparticles with the aids of silver nitrate as precursor using hydrothermal method. As pre-treatment, 50 g of aloe vera had been risen with DI water and finely cut into small pieces. Then, it was boiled in 50 ml of DI water for 20 min and allowed to cold. The solution was filtered and stored in fridge at 4 ^{o}C for further use. For biosynthesis, 0.3M of $AgNO_3$ was dissolved in 20 ml of DI water and mixed with 20 ml of aloe vera extract. The mixture was stirred under vigorous stirring at room temperature for 30 min. Added the mixture in Teflon-lined vessel of 100 ml capacity and heated and manipulate the time of reaction (6h, 12h) and temperature condition (100, 150, 200 ^{o}C). After cooled at room temperature, the grey precipitate was collected by filtration and washed with DI water several times. The resulting particles was dried at 60 ^{o}C for 6 h. The biosynthesized Ag NPs were found to be effective against gram possitive bacteria, *Streptococcus epidermidis* and gram negative bacteria *Pseudomonas aeruginosa* using agar well diffusion method. As illustrated in Fig 1, the hydrothermal method combines various organic compound in aloe vera extract such as saponin, tannin, terpenoids and flavonoids with $AgNO_3$ to produce Ag NPs. The free silver ion was responsible for antibacterial activity as it bind with he thiol groups of enzymes and be toxic to the gram possitive and negative bacteria. They also found that the nanoparticle size was significantly affected by the temperature of biosynthesis process. The nanoparticles size was increased with higher temperature used.

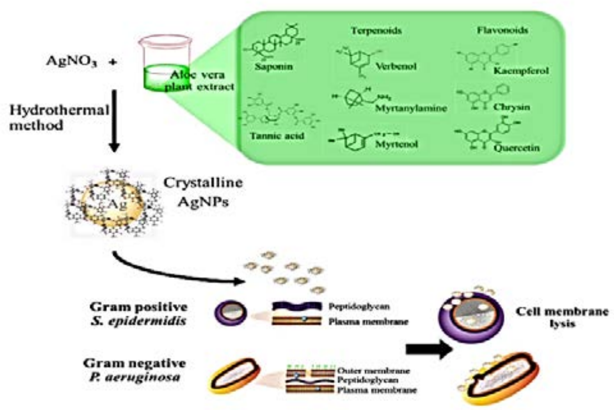

Fig 1 Schematic diagram of bacterial inactivation mechanism disrupted by biosynthesized Ag NPs (Adapted from Tippayawat *et al.*, 2016).

In other hand, Yadav *et al.,* (2016) produced two types of nanoparticles which were silver and iron with the aids of silver nitrate and ferric chloride respectively. 2 ml leaf extract react with 20 ml of 1 mM of silver nitrate under continuous stirring for 20 min. The mixture was incubated 24 h at room temperature. The colour change from colorless to pale yellow and finally reddish brown was the proof of AgNPs formation in this biosynthesis procedure. Meanwhile, for biosynthesis of Fe NPs, the ratio of reducing agent and precursor (ferric chloride) was 1:1 portion and mixed together in clean flask. The mixture was centrifuge at 12000 rpm for 15 min. Consequently, the precipitate was dispersed in double distilled water to remove any heavy-handed biological materials with constant stirring at 50 – 60 °C. Finally, the resulting NPs were lypholized to obtain a fine powder. The antimicrobial properties of both Ag NPs and Fe NPs was observed against 9 types of bacteria, which were *Escherichia coli, Proteus mirabilis, Klebsiella pneumoniae, Pseudomonas aeruginosa, Shigella flexneri, Serratia marcescens, Salmonella typhi, Enterococcus faecalis* and *Staphylococcus aereus.* The inhibition zones and minimum inhibitory concentration values of silver and iron NPs against different bacterial strains showed that silver nanoparticles were more effective against *Proteus mirabilis, Shigella flexneri* and *Staphylococcus aureus* strains while iron NPs were efficiently against *Proteus mirabilis, Klebsiella pneumonia, Pseudomonas aeruginosa* and *Salmonella typhi* strains. Against *Escherichia coli* both silver and iron NPs showed almost similar response. Overall, the silver NPs have higher antibacterial potential as it has ability to release silver ion more specifically.

Logaranjan *et al.*, (2016) also synthesized silver NPs with the aids of silver nitrate. The procedure was quite similar with previous research by undergoes the pre-treatment and biosynthesis steps. 5 ml of 10 mM of silver nitrate was added to 5 ml of aloe vera solution in 50 ml conical flask. The mixture was diluted with 1% of ammonia to adjust the pH. The reaction was carried in room temperature. From the observation, the colour change to orange yellow and the produced NPs was in spherical shape. In other hand, the author also applied microwave irradiation in their methodology, which involve repeating heating and cooling step. The purpose of the step was to obtain a unifrom-sized octahedral shape silver NPs. It is suggested that aloe vera gel plays important rule to regulate the size and shape of the silver NPs. In term of microbial activity, the produced NPs was observed against five types of bacteria which were *Staphylococcus aureus, Bacillus cereus, Micrococcus luteus, Escherichia coli* and *Klebsiella pneumoniae.* The biosynthesized Ag NPs show better antimicrobial properties compared to aloe vera extract, Ag NPs by chemical method and $AgNO_3$ against *Staphylococcus aureus, Bacillus cereus, Micrococcus luteus, Escherichia coli* and *Klebsiella pneumoniae.*

Gold

The unique properties of gold such as chemical inertness and resistance to surface oxidation make gold as a material of choice in nano-range technologies and application (Kumar *et al.,* 2016). Gold and silver NPs were synthesized by Chandran et al., (2006) by using tetrachloroauric acid and silver nitrate as precursor respectively. The aloe vera extract was prepared by boiling the aloe vera leaves. Both gold and silver NPs was reacted with 2 ml of aloe vera extract and 0.001 M of precursor. The synthesis was carried out successfully and it has found that the size of the gold nanotriangles was varied from 50 to 350 nm by manupulating the amount of aloe vera extract. The nanoparticles size increase is aligned with aloe vera extract concentration and the carbonyl compounds in aloe vera extract are believed to be responsible for the formation of the single crystalline gold NPs.

In other hand, biosynthesized gold NPs produced by Muralikrishna, Pattanayak, and Nayak, (2014) applied different parameter condition. The amount of aloe vera extract was increased up to 10 ml and reacted with 0.001 M of precursor in 1 hour instead of 30 hours from previous study. The experiment was carried in room temperature and the color of mixture had change from light yellow to dark brown. The particle size analysis (PSA) was conducted by laser diffraction and it show polydispersity at 0.419 indexing and effective diameter around 441.4 nm. Their finding also agreed with the previous study which state that the concentration of aloe vera extract and metal ions plays an important role to produce desirable size of biologically synthesized gold NPs.

Indium oxide

Indium oxide was used in various application such as solar cells, panel displays, organic light emitting diode, photocatalysts, architectural glasses, field emission and semiconductor gas sensors. It has interesting properties such as high transparency to visible light, high electrical conductance and strong interaction between certain poisonous gas molecules and its surface. Maensiri *et al.,* (2008) produced biosynthesized indium oxide nanoparticles with the aids of indium (III) acetylacetonate as precursor and aloe vera extract was prepared by boiling. The precursor was directly dissolved in the extract and reacted for few hours until dried at 60 ^{o}C. The author compared the synthesized NPs by calcination at 400, 500 and 600 ^{o}C and the morphology and size of In_2O_3 materials were affected by the calcination temperature. In this work, they demand that aloe vera extract enhance the calcination effect toward enhancing particle size as the size of NPs was increased with the calcine temperature. The biosynthesis route of In_2O_3 NPs is a simple and ultilized cheap precursor which suitable for scale up procedure.

Titanium dioxide

Titanium dioxide is widely use in paints, printing ink, rubber, paper, cosmetics, sunscreen, car materials, cleaning air products, industrial photocatalytic processes and decomposing organic matters in wastewater due to their unique properties (Vijayaraghavan and Ashokkumar, 2017). Titanium dioxide is also known as photocatalyst in which has almost similar band gap energy with zinc oxide of 3.2 eV and only absorbs ultraviolet region (wavelenght < 390 nm because of the wide band gap (Lee and Abd Hamid 2015; Vargas Hernandez et al. 2017). An interesting study has been reported by Marimuthu *et al.* (2013) which biosynthesized titanium dioxide using *Calotropis gigantea* plant extract against *Rhipicephalus microplus* and *Haemaphysalis bispinosa.* Both parasite were known as vector of infectious agents lethal to cattle. Titanium dioxide NPs also has been synthesized using aloe vera extract. Nithya *et al.*, (2013) produced titanium dioxide NPs using aloe vera extract and metatitanic acid as precursor. The aloe vera gel was boiled for 10 minutes and the filtered broth was kept for further experiment. 100 ml of 0.005M $TiO(OH)_2$ was added with 20 ml of the extract and stirred for 24h. The precipitate formed was confirmed by color change to light green. The obtained precipitate was dried in oven at 120 ^oC for 1 h. During drying, complete conversion of $TiO(OH)_2$ to TiO_2 took place. The nanoparticles size was determined by AFM and the average particle size was calculated by Scheer's equation.

Cerium oxide

Besides zinc oxide, silver, gold, indium oxide and titanium dioxide, cerium oxide also can be synthesized using aloe vera extract as reducing agent. Cerium oxide was used in biomedical industry, extensively use in industrial application and commercial products. Cerium oxide NPs also have ability to absorb ultraviolet radioation and often used as alternative for zinc oxide and titanium oxide NPs in cosmetics. Priya *et al.*, (2014) studied the synthesis of cerium oxide by using cerium (III) nitrate hexahydrate as precursor. 40 ml of distilled water was added into 0.1 M of cerium (III) nitrate hexahydrate and stirred until homogenized. 10 ml of aloe vera extract was added into the mixture and stirred for 30 mins. The solution was heated on a hot plate at 80 ^oC till the supernatant got evaporated. The obtained product was pound into fine powder and calcinated at 600 ^oC for 2 hours. There were no peak observed in XRD plotted graft before the calcination. However, the peak was clearly seen after the calcination and confirmed the particles as cerium oxide. Meanwhile, the PSA was carried out via DLS technique. An amount of nanoparticles was dispersed in distilled water and ultrasonification to obtain homogeneous distribution of nanoparticles.

The detail parameter and condition of each technique is listed in Table 1. Meanwhile, the information of these nanoparticles characteristics is illustrated in Table 2. The results show the nanoparticles formed was varied in the color, size and shape. The PSA, AFM, TEM and SEM studies provide nanometer measurement of the size of nanoparticles and closer image of the shape of the nanoparticles. The presence of ketones, aldehydes, carboxylic acid, alcohol, phenolic compound, amide, amine and other compoment was revealed in FTIR studies. The peak observed in XRD graph also confirm the type of nanoparticles as the peak value coincide with the references value. The biosynthesis of nanoparticles from aloe vera plant occured from the interaction by hidrogen bond and electrostatic between bio-organic capping molecules (Mano *et al.*, 2011).

MECHANISME OF REACTION AND BIOMOLECULE INVOLVEMENT

Basically, redox reaction was involved in the process of NPs biosynthesis. The fundamental of redox (reduction-oxidation) reaction was well explained as a chemical reaction that involves a transfer of electrons between two species. The ion or molecule that accepts electrons is called oxidizing agent, which cause oxidation to another molecule. on the other hand, the ion or molecule that donates electron is called reducing agent, which cause reduction to another molecule (Hall 1929). This could be explained in Haber process, nitrogen was reduced by accepting electron from hydrogen and the hydrogen was oxidized by donating its electron.

$$2\ NO_2\ (g) + 7\ H_2\ (g) \rightarrow 2\ NH_3\ (g) + 4\ H_2O\ (g) \quad (1)$$

In term of biosynthesis prosess, the color change in colloidal mixture of aloe vera extract and precursor was occur due to reduction of Ag^+ into Ag (Yuvasree *et al*., 2013). Similar result also reported by Muralikrishna et al., (2014) where the appearance of violet color was the evident of formation of gold NPs and the hydroxyl group release the ion proton in which reduce the Au^{3+} to Au^0. The hydroxyl group from the aloe vera extract was believed containing y-terpineol, citronellol, borneol, trans-nerolidod, cis/trans-linalol oxides, a-sitosterol, phytol, geraniol, stigma sterol or any other secondary metabolites and various acid.

Another possible mechanism occur during biosynthesis of NPs was gycolysis process in which conversion of the carbohydrate to energy. Large amount of H^+ ions are produced along Adenosine Triphosphate (ATP) production. ATP is an energy carrier and nicotinamide adenine dinucleotide (NAD^+) is a coenzyme found in all living cells. NAD^+ is strong oxidizing agent which accept electron from other molecules and result in reduction process. The reaction forms NADH, which can donate electrons. Thus, this redox reaction was kept repeating and might have led to the transformation of Ag ions to Ag^0 (Ibrahim et al. 2014).

$$\begin{aligned} &AgNO_3 \rightarrow Ag^+ + NO_3^-, \\ &NAD^+ + e \rightarrow NAD, \\ &NAD + H^+ \rightarrow NADH + e^- \\ &e^- + Ag^+ \rightarrow Ag^0 \end{aligned} \quad (2)$$

The water soluble substances such as aloemodin, chrysophonal and helminthospor presence in fresh aloe vera extract might react with oxygen and form the electron. This free electron reduces the Ag^+ ion to Ag^0.

Chandran *et al.*, (2006) separated the aloe vera extract with 3 kDA nylon dialysis bag in order to study the biomolecules responsible for formation of gold nanoparticles. Fraction 1 with molecular weight less than 3 kDa that affect the NPs formation from the very broad surface plasma resonance. From the FTIR, the biomolecule detected from the fraction of aloe vera extract was carbonyl and alcohol group. The absence of peak 1200 cm^{-1} in the reaction mixture indicates the reduction of the gold ions is coupled to the oxidation of the alcoholic component in aloe vera extract. Based on the FTIR results, the peak observed at 3396 cm^{-1} and 1608 cm^{-1} correspond to alcohol, phenol and amines in aloe vera extract involved in NPs synthesis (Nithya *et al.*, 2013). The EDX results revealed a strong gold element which indicate that there are biomolecule compound bound around the gold NPs.

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Table 1 Summary of parameter and condition for biosynthesized nanoparticles from aloe vera plant.

NPs	Precursor	Aloe vera conc (ml)	Reaction time (h)	Precursor conc (M)	Temperature (^oC)	Total solution (ml)	Anti microbial test	References
Gold	Choloroauric acid	0.5 – 4	30	0.001 (6 ml)	80	10	N/A	(Chandran et al. 2006)
Silver	Silver nitrate	5	24	0.01 (5 ml) Added 2.5 ml of 30% NH_3	N/A	50	N/A	
Gold	Tetrachloroauric acid	10	1	0.001	N/A	100	N/A	(Muralikrishna et al. 2014)
Indium oxide	Indium (III) acetylacetonate	30	Few hours	3 g	60	30	N/A	(Maensiri et al. 2008)
Zinc oxide	Zinc nitrate	5 – 50 %	5 – 6	N/A	150	N/A	N/A	(Gunalan et al. 2011)
Zinc oxide	Zinc nitrate	N/A	5 – 6	N/A	150	250	√	(Gunalan et al. 2012b)
Cupric oxide	Copper sulphate	10 – 50 %	7	N/A	130	N/A	N/A	(Gunalan et al. 2012a)
Zinc oxide	Zinc nitrate	30	N/A	3g	60	N/A	√	(Jeeva et al., 2012)
Zinc oxide	Zinc sulphate	40	3	0.25	60	200	√	(Ali et al., 2016)
Silver	Silver nitrate	20	24	0.001 (20 ml)	Room temp	40	√	(Yuvasree et al. 2013)
Silver	Silver nitrate	5	24	0.001 (42.5 ml) 2.5 ml of NH_3	N/A	50	√	(Ibrahim et al. 2014)
Silver	Silver nitrate	10	48	0.0015 (90 ml)	Room temp	100	√	(Medda et al. 2015)
Silver	Silver nitrate	20	6 & 12	0.3 (20 ml)	100 – 200	40	√	(Tippayawat et al. 2016)
Silver	Silver nitrate	2	20 min	0.001 (20 ml)	Room temp	22	√	(Yadav et al. 2016)
Iron	Ferric chloride	2	N/A	(2 ml)	N/A	4	N/A	
Silver	Silver nitrate	5	N/A	0.01 (5 ml)	N/A	10	√	(Logaranjan et al. 2016)
Titanium dioxide	$TiO(OH)_2$	20	24	0.005 (100 ml)	Room temp	120	N/A	(Nithya et al. 2013)
Cerium oxide	Cerium (III) nitrate hexahydrate	10	30 min	0.1 (40 ml of distilled water added)	80	50	N/A	(Sai Priya et al. 2014)
SUMMARY		**2 – 50 ml**	**20 min – 48 h**	**0.001 – 0.3 M**	**Room temp – 200 C**	**4 – 250 ml**		

Table 2 Characteristic of biosynthesized nanoparticle produced from aloe vera plant.

NPs	Color	Size (nm)	Shape	Functional groups	Referances
Gold	Brownish red	50 – 350	Triangular, hexagonal and spherical	1731 cm-1 (carbonyl group in ketones, aldehydes and carboxylic acids) 1588 cm-1 (aromatic C-C skeletal vibration) 3320 cm-1 (hydroxyl group in alcohol and phenolic compound)	(Chandran et al. 2006)
Silver	Pale yellow	15.2 ± 4.2	Spherical		
Gold	Light yellow to dark brown	N/A	Spherical	N/A	(Muralikrishna et al. 2014)
Indium oxide	N/A	5 – 50	Cubic	N/A	(Maensiri et al. 2008)
Zinc oxide	Pale white	25 – 40	Spherical	528 cm^{-1} (metal oxide ZnO) 3451 cm^{-1} (-OH) 1552 cm^{-1} (C=O) 1393 & 922 cm^{-1} (alkanes C – C) 2900-3700 cm^{-1} (amide linkage) 3450 cm^{-1} (1^o, 2^o amines) 3266 cm^{-1} (O – H alcohol) 2932 cm^{-1} (C – H alkanes) 1640 cm^{-1} (amide I) 1540 cm^{-1} (amide II)	(Gunalan et al. 2011)
Zinc oxide	Pale white	N/A	N/A	N/A	(Gunalan et al. 2012b)
Cupric oxide	Greyish black	15 – 30	Shperical	3495 cm^{-1} (primary amine) 3154 cm^{-1} (alcohol) 2910 cm^{-1} (alkanes) 1640 cm^{-1} (amide I) 710 cm^{-1} (alcohol) 1053 cm^{-1} (phenolic) 1125 cm^{-1} (aliphatic C – N) 1399 cm^{-1} (aromatic amines)	(Gunalan et al. 2012a)
Zinc oxide	Yellow	100 x 500	Rod-shaped	N/A	(Jeeva et al., 2012)
Zinc oxide	White	15	Spherical, oval and hexagonal	3432 cm^{-1} (phenol –OH) 3452 & 2934 cm^{-1} (amines, alcohol O-H and alkanes C-H)	(Ali et al., 2016)
Silver	Pale brown to yellowish brown	N/A	N/A	N/A	(Yuvasree et al. 2013)
Silver	Pale yellow	500	Spherical	N/A	(Ibrahim et al. 2014)
Silver	Reddish brown	70	Rectangular, triangular and spherical	1631 cm^{-1} (amide group) 3433 cm^{-1} (alcoholic hydroxide groups)	(Medda et al. 2015)
Silver	Grey	70.70 ± 22 – 192.02 ± 53	Spherical	N/A	(Tippayawat et al. 2016)
Silver	Reddish brown	36.61 ± 4.88	Spherical	3446, 3417 cm^{-1} (alcohol or phenol O-H) 2918 & 2362 cm^{-1}, 2961 & 2924 cm^{-1} (carboxylic acid O-H) 2849 & 2734 cm^{-1}, 2816, 2728 cm^{-1} (alkanes C-H) 1593, 1591 cm^{-1} (aromatics C-C ring) 1466, 1483 cm^{-1} (aromatics C-C ring) 1383 cm^{-1}(alkanes C-H) 1350 cm^{-1} (nitro compound N-O) 1169, 1018 cm^{-1} (esters, ethers C-O) 1080 cm^{-1} (aliphatic amines C-N) 765, 762 cm^{-1}(1^o, 2^o amines N-H) 720 cm^{-1} (aromatic C-H) 554 & 453, 451 & 434 cm^{-1} (C-Br alkyl halides)	(Yadav et al. 2016)
Iron	Reddish brown	34.93 ± 0.84	Spherical		
Silver	Orange yellow	5 - 50	Spherical	1587.6 cm^{-1} (aromatic C=C) 1386.4 cm^{-1} (gemical methyls) 1076 cm^{-1} (ether linkages)	(Logaranjan et al. 2016)
Titanium dioxide	Light green	80 – 90	N/A	3396 cm^{-1} (hydroxyl) 1608 cm^{-1} (amino) 1000 cm^{-1} (metal oxide)	(Nithya et al. 2013)
Cerium oxide	N/A	63.6	Spherical	1417.73 & 1384 cm^{-1} (alkane –C-H-) 1653.03 cm^{-1} (carbonyl C=O) 1151.54 cm^{-1} (alkyl halide C-F) 879.57 cm^{-1} (alkene =C-H) 624.96 cm^{-1} (alkylhalide C-Cl)	(Sai Priya et al. 2014)

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CONCLUSION

This review compiles the advantages of aloe vera plant that contain active compounds which then allow it to act as reducing agent and produce biosynthesized nanoparticles. All sixteen methods were compiled and it can be concluded that various types of nanoparticles can be biosynthesized from aloe vera plant. In fact, biosynthesized ZnO and AgNPs revealed enhanced antimicrobial properties compared to chemically synthesized NPs. Even not all articles discuss on resulting size of NPs, in overall, the size of nanoparticles were varied by manipulating the concentration of aloe vera extract and temperature used in the biosynthesis process.

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