Facile Green Synthesis and Characterization of Moringa Oliefera Extract-Capped Silver Nanoparticles (MO-Agnps) And Its Biological Applications

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Abstract. In the current study, we developed a simple, eco-friendly, quick and economical process to synthesize stable silver nanoparticles (AgNPs) using medicinal herb Moringa oliefera leaves extract. Obtained AgNPs are characterized by spectrophotometrical and microscopic techniques such as UV-Visible spectroscopy, x-ray diffraction (XRD), scanning electron microscopy (SEM) and high resolution transmission electron microscopy (HR-TEM). The study on the in vitro antidiabetic activities displayed that the particles have greater α-amylase inhibition potentials. In addition, exceptional antioxidant activity on 1, 1-Diphenyl-2-picrylhydrazyl (DPPH) is observed. Cytotoxic study against Michigan Cancer Foundation-7 (MCF-7) cell lines displayed significant anticancer activity of AgNPs and hence they can be employed as a promising, cost-reliable and non-toxic strategy for treating these diseases in future.

Keywords: Anticancer, Antidiabetic, Antioxidant, Moringa Oliefera, Phytochemicals, Silver Nanoparticles,

1. Introduction
Nanotechnology is a multidisciplinary science field that intended to produce atomic, molecular and supramolecular materials with enriched functionalities. Electronic, magnetic, catalytic and optical behaviors of nanoparticles (NPs) rely on their size, shape, physical and chemical natures [1] for which they found
great importance in remarkable applications in numerous fields such as catalysis, cosmetics, photonic crystals analysis, food, agriculture, drug delivery, paints, coatings, health care and material science. Various metal and metal oxide particles in nanoscale such as Ag, Au, Pt, Cu, ZnO, NiO etc., have been synthesized and analyzed in specific domains for their interesting unusual physicochemical characteristics. The development of simple, cost-reliable and environment-friendly methods for production of NPs is most significant fields of research in nanoscience [2]. The NPs can be produced by different approaches such as chemical, physical and biological methods [3]. Electro-deposition, vapour deposition methods, laser ablation, pyrolysis, sol-gel, lithography are some examples for physical and chemical methods, many of these processes imposes toxic effects on environment and human health, which confines their enormous applications [4]. Physical and chemical approaches have advantageous in NPs uniform size distribution whereas the major drawbacks are huge energy requirement, duration, expensive and practice of toxic chemicals. In biological method, NPs are synthesized using yeast, fungi, bacteria, algae, and plants [5]. Use of plant extract or bioactive molecules as source for the NPs synthesis are most promising than bacterial and chemical approaches since there is no risk of contamination from bacteria, hazardous chemicals and optimum energy consumption provides greater applicability and simplicity. Bioactive secondary constituents like tannins, glycosides, saponins, flavonoids, alkaloids and terpenoids present in plants can act as reducing and capping agents. Moreover, plant extracts have inherent biological properties such as antihyperglycemic, antioxidant, antimutagenic, cytotoxic, antifungal, anti-inflammatory, antiviral and antibacterial potential which may apparent in the final AgNPs biological activities and may therefore be used in medical applications [6]. Silver nanoparticles (AgNPs) are specially interested among other different metal nanoparticles (MNPs) and drawing more consideration of scientists due to its various applications in bimolecular detection, diagnosis, therapeutics, catalysis and micro-electronics. Researchers have also revealed their medicinal use as antifungal, antimicrobial, anti-inflammatory, antidiabetic, antioxidant agents and several studies also described the AgNPs use in cancer treatments [7].

Oxidative stress is a phenomenon induced by disturbance between production and accumulation of reactive oxygen species (ROS) including singlet oxygen (\(^{1}\text{O}_2\)), hydrogen peroxide (\(\text{H}_2\text{O}_2\)), hydroxyl radicals (\(\cdot\text{OH}\)) and Superoxide radicals (\(\text{O}_2^{•−}\)) are commonly produced by several biochemical processes within the body. Excess free radicals overtake the natural body antioxidant defense system leading to oxidative stress. A large body of evidences displays that oxidative stress can lead to the development of age-related diseases like metabolic syndromes, dementia, osteoporosis, atherosclerosis, vascular diseases, obesity, arthritis, cancer and diabetes. The role of oxidative stress is an essential factor in understanding the complex mechanism and complications of diabetes. In this perspective, numerous researchers are focused on the characterization of the ROS sources, their activation path, scavenging and antioxidant constituents in diabetes [8].

Diabetes mellitus (DM) is an endocrine disease characterized by chronic hyperglycaemia, triggered by the combination of genetic and the environmental factors. Two major types of DM are type-1(insulin dependent) and type-2 (non-insulin dependent), type-2 DM is the most prevalent form of the disease, contributing for 90-95% of cases. Severity of diabetes is connected with permanent damage and failure of different organ systems and can cause cardiovascular disease, blindness, kidney failure and lower limb amputation [9]. Type 2 diabetes can increase the risk of bladder, breast, blood and colorectal cancers by 20% to 50%. Starches, hydrolyzed dietary carbohydrates are the major source of blood glucose. Pancreatic \(\alpha\)-amylose breaks down the complex carbohydrates by hydrolysis to simple carbohydrates like maltose and glucose. \(\alpha\)-glucosidase performs the end line process by which carbohydrates are absorbed by the small intestine. Identifying the inhibitors for these digestive enzymes is one of the prominent therapeutic methods to regulate the blood sugar by hindering the glucose uptake [10]. Cancer is disease characterized by unusual
cell growth with the potential to attack or spread through the body parts and hence considered as the world's most devastating diseases. There are several treatments are available such as surgery, radiation and chemotherapeutic drugs but these treatments have limitation of normal cell death and toxicity. Therefore, non-toxic, ecological and inexpensive drugs are essential to be discovered. Rapidly evolving field of different materials and devises in nanoscale incorporating has height ened the possibility for the timely identification and management of these diseases including cancer with minimum toxicity [11]. Many researches have been made to identify materials to inhibit the free radicals and carbohydrate-hydrolyzing enzymes that leads to various complications. Recently researchers demonstrated that AgNPs are very effective as antimicrobial, antioxidant, antifungal agents and antidiabetic activity. AgNPs have also proved to be the cytotoxic to different cancer cell lines. Particularly, AgNPs synthesized by green method have reported for inhibition of cancer proliferation [12].

*Moringa oleifera* (MO) is a member of moringaceae family, commonly known as the drumstick tree, is a wonderful plant that is used throughout the world traditionally. This serves as a stimulant to circulation and to the heart. The MO is a conventional medicinal tree that has displayed significant prospective in complementary and alternative medicine. It is historically being used in the therapy of hyperglycemia, inflammation, microbial and cancer infections. It contains high constituents of antioxidants and biologically active compounds, which performs a major role in their effectiveness. All parts of the plant were apparently used in traditional medicine. Especially, leaves are recognized for their natural remedial characteristics and are consumed universally in a variety of ways [13]. Thus, the objective of the present work was to assess the biosynthesis of AgNPs using MO leaf extract. The NPs obtained by green synthesis were characterized by analytical techniques like XRD, SEM and TEM. Further, study of its activity against *a*-amylase enzymes, antidiabetic properties and cytotoxic activity against human breast cancer cell line MCF-7.

2. Experimental

2.1 Materials used
Silver nitrate (AgNO₃) of analytical grade was purchased from Hi- Laboratories Pvt. 2,2-diphenyl-1-picrylhydrazyl (DPPH) and alcohol were procured from Sigma Aldrich. All glassware's were washed and dried in an oven, throughout the experiments double distilled water (DDW) was used.

2.2 Collection and preparation of leaves extract
MO leaves were collected from GMIT campus, healthy and free from disease leaves were picked and washed thoroughly with tap water to remove dirt and adhering substances followed by double distilled water. In 100 ml of distillate water, 20 gm of leaves were boiled at 60°C for 30 minutes, cooled to room temperature. The resulting mixture was filtered through Whatman grade-1 filter paper and refrigerated at 4°C until further use.

2.3 Phytochemical screening of *Moringa oleifera* extract
The MO extract has been subjected for qualitative analysis for various active chemical components which are accountable for their nutritional and biological application. Phytochemical analysis was carried by following standard protocol [14].

2.4 Green Synthesis of Silver Nanoparticles
The MO leaves extract of 10 milliliters was combined with 90 milliliters of 0.001 M silver nitrate solution, mixture was kept in dark for overnight to achieve complete reduction of Ag⁺ to Ag⁰ [36]. AgNPs synthesis was performed at 25°C ± 2°C temperature. Change in color of the solution to brown from pale yellow indicates
completion of the reaction. The AgNPs are obtained by centrifugation of the colloidal mixture for 15 min at 8000 rpm accompanied by repeated washing with mixture of distilled water and alcohol. For further studies AgNPs powder thus obtained were deposited in airtight viols.

2.5 Characterization

*Moringa oleifera* extract mediated synthesized AgNPs (MO-AgNPs) were characterized by Synthesized AgNPs were characterized using Agilent Technologies-Cary 60 UV-Vis spectrophotometer. The XRD spectrum of AgNPs coated on XRD measuring grid was furnished using (Rigaku Smart Lab, Cu – Kα, λ = 1.5406 Å with scanning angle 2θ = 20° to 90°) X-ray diffractometer. MO-AgNPs morphology was studied using scanning electron microscopy (Jeol-JSM-IT500LA: 5 to 3,00,000, Acc. Voltage 0.3–30 kV). High resolution transmission electron microscopic (HR-TEM) examination was performed on the sample of MO-AgNPs to investigate the scale, shape and distribution of synthesized nanoparticles. Small amount of colloidal dispersion of nanoparticles was loaded on carbon standard TEM grids and enabled to dry within a vacuum dryer, scanned by TEM analyzer (Jeol-JEM 2100, LaB6/200 kV).

3. Antioxidant activity

The in vitro antioxidant capability of MO-AgNPs were determined by DPPH assay, it is a well-known and more stable free radical for evaluating the antioxidant properties of compounds [15]. For the study, in a sequence of test tubes different concentrations of MO-AgNPs and standard (20, 40, 60, 80 and 100 µg/mL) were mixed with dimethyl sulfoxide (DMSO) and volume was adjusted to 500 μL using Methanol. 5 mL of 0.1 mM DPPH dissolved in methanol was added to each tubes and shaken vigorously. Control was prepared as above excluding sample, ascorbic acid was used as standard for the analysis. The mixture was vortexed and left to stand in the dark for 30 min at room temperature to allow radical scavenging of the DPPH. Absorbance was recorded at 517 nm [16], antioxidant level was determined using the below equation.

\[
\text{Free radical scavenging (\%)} = \frac{A_{\text{Control}} - A_{\text{Sample}}}{A_{\text{Control}}} \times 100
\]

Where, \(A_{\text{Control}}\) - absorbance of control, \(A_{\text{Sample}}\) - absorbance of MOE@AgNPs.

4. Antidiabetic activity

Diabetic mellitus is a non-transmissible disease that is mostly genetic in nature but can evolve due to lifestyle changes resulting in the hyperglycemia over a sustained period of time. \(\alpha\)-amylase inhibition is an important therapeutic target in controlling postprandial blood glucose production in diabetic patients. MO-AgNPs antidiabetic efficacy was measured in-vitro by starch hydrolysis in the presence of \(\alpha\)-amylase enzyme. Different concentration of MO-AgNPs (50,100, 150 & 200 µg/mL) in 1mL of sodium phosphate buffer (PBS) solution were taken in an Eppendorf tubes and mixed with \(\alpha\)-amylase (0.5 µg/mL). The mixture of solution was incubated for 10 min at 25±2°C followed by the addition of 5 µg/mL starch, again incubated for 10min. The reaction was terminated by adding 1mL of dinitrosalicylic acid (DNS). Tubes were placed on water bath at 100°C for 5min and cooled. Absorbance was measured at 540 nm for both sample and control (prepared as above without sample) [17]. Metformin was taken as standard, the percentage of inhibition of \(\alpha\)-amylase activity was calculated by given formula.

\[
\% \text{ of } \alpha - \text{amylase inhibition} = \frac{AC - AS}{AC} \times 100
\]

where, \(AC\) and \(AS\) are the absorbance of control and sample, respectively

5. Anticancer activity

MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-di-phenyltetrazolium bromide), a yellow tetrazolium assay on human breast adenocarcinoma cell line (MCF-7) was employed to establish the cytotoxic capacity of the
MO-AgNPs. The cells were cultured and maintained in Dulbecco's Modified Eagles Medium (DMEM). Then, trypsinized and aspirated to 96-well microtiter plates at density of $1 \times 10^4$ cells/well then incubated at 37 °C with 5% CO$_2$ atmosphere. Medium was then carefully drained from the wells and replaced by a suspension of 200 μL of selected concentrations of MO-AgNPs (20 to 100 μg/mL) and again incubated in the above atmosphere for 24Hrs. Plates were separated from the incubator and drugs comprising media was removed. Final concentration was made to 0.5 mg/mL by adding 10% MTT reagent medium (200 μL) and incubated at 37°C for 3Hrs. Then culture media was entirely extracted without upsetting crystals formed, then 100 μL DMSO was added and thoroughly mixed to solubilize formazan. Absorbance at 570 nm was recorded using a microplate scanner. 50% inhibition concentration (IC$_{50}$) value was determined graphically and the effect of the MO-AgNPs on the proliferation of MCF-7 cells was expressed. Cells viability (%) was estimated using below formula [18].

$$\text{Cell viability (\%)} = \left( \frac{OD_{\text{Sample}}}{OD_{\text{Control}}} \right) \times 100$$

Where, $OD_{\text{Sample}} = \text{Optical density of test sample}$

$OD_{\text{Control}} = \text{Optical density of control}$

6. Result and discussion

Solution obtained by the extraction of MO leaves was screened for its phytochemical constituents which are responsible for their biological importance. Qualitative analysis indicates the existence of tannins, flavonoids, glycosides and phenolic compounds. Results were presented in Table 1.

| SL No | Phytochemical       | Result |
|-------|---------------------|--------|
| 1     | Reducing sugars     | -      |
| 2     | Tannins             | +      |
| 3     | Saponins            | -      |
| 4     | Glycoside           | +      |
| 5     | Phenolic compounds  | +      |
| 6     | Flavonoids          | +      |
| 7     | Alkaloids           | -      |

+ refers present and – refers absent

Confirmation of these phytochemicals in the aqueous extract was thought to be participating in reduction and capping of AgNPs. Extract (10mL) is mixed in the stoichiometric ratio of 1:9 with the freshly prepared silver nitrate solution (0.001M) for the synthesis of AgNPs. Dark brown color formation from light yellow indicates the reduction of Ag$^+$ to Ag$. For a complete reduction of MO-AgNPs solution mixture was kept in dark for 24Hrs.

6.1 Characterization of silver nanoparticles synthesized with MO extract
The formation of MO-AgNPs was confirmed by UV-Visible spectroscopy. One of the most fascinating characteristics of MNPs are their optical properties which changes according to the morphology of NPs. They contain valence electrons, which produces surface plasmon resonance (SPR) absorption bands because of the collective electronic and light wave vibrations in resonance. For MO-AgNPs, sharp SPR band was observed at 442 nm as shown in Figure 1.

Further, AgNPs were characterized by XRD to study crystalline nature and geometric arrangements. The XRD plot (Figure 2) displayed four major characteristic diffraction peaks at 2θ = 32.4°, 38.0°, 64.20° and 77.40° corresponding to lattice planes (111), (200), (220) and (311) respectively confirming that the MO-AgNPs are having face-centered cubic (fcc) structure. Debye–Scherer equation was used to calculate the average crystalline size which is found to be 15.5 nm.

\[ d = \frac{k\lambda}{\beta \cdot \cos\theta} \]

Where, d- crystal size, k- Scherer constant, λ- wavelength of X-ray, β- line extension in radians; θ- Bragg angle.

Surface morphology, size and shape of MO-AgNPs were studied by electron microscopic techniques such as SEM (Jeol-JSM-IT500LA model) and HR-TEM. The SEM images as shown in Figure 3 specifies that the MO-AgNPs are almost spherical in shape with slight agglomeration. However, each agglomerate was composed of small crystallites. HR-TEM results obtained by capturing images at different ranges reveals that the MO-AgNPs are in nanoscale, uniform and spherical with an average size of ≈ 21.5-40nm (Figure 4).
6.2 Antioxidant activity
DPPH free radical scavenging assay was used to study the free radical scavenging potential of the MO-AgNPs. This method is reliant on the reduction of DPPH$^+$ to stable DPPH−H by hydrogen-contributing antioxidants. DPPH absorbance was decreased at 517 nm with rise in concentrations of NPs changing its color from violet to light yellow [19]. MO-AgNPs showed the oxidant activity of 14.77, 27.42, 36.46, 48.29 and 57.32% for the concentrations of 20, 40, 60, 80 and 100 μg/mL. Compelled with the standard ascorbic
acid which is having maximum scavenging potential of 93.88 % at 100 μg/mL. 50% inhibition concentration was found to be 62.6 μg/mL (Figure 5). Dose-dependent free radical scavenging behavior of MO-AgNPs is tabulated in Table 2.

Table 2. Antioxidant activity of MO-AgNPs

| SL.No | Concentration | % of free radical scavenging activity |
|-------|---------------|--------------------------------------|
| 1     | 20 μg/mL      | 14.77                                |
| 2     | 40 μg/mL      | 27.42                                |
| 3     | 60 μg/mL      | 36.46                                |
| 4     | 80 μg/mL      | 48.29                                |
| 5     | 100 μg/mL     | 57.32                                |

Figure 5. Free radical scavenging activity with IC\textsubscript{50} value

6.3 Antidiabetic activity
The inhibition of carbohydrate digesting enzymes such as α – Amylase is a significant target for preventing a sudden rise in blood glucose levels, thereby intercepting the conversion of carbohydrates into simple sugars which is a major source for elevation in the blood sugar [20]. In the present analysis, in comparison with the standard drug metformin, the α-amylase inhibition by MO-AgNPs was observed in an increasing order of concentration as shown in Figure 6. It is presumed that the biomolecules present in the extract enhanced the antidiabetic potential of MO-AgNPs, hence they can be utilized in the diabetic treatments.
6.4 Anticancer activity

The MO-AgNPs mediated apoptosis in MCF-7 cells were examined using cytotoxicity assay of MTT dye conversion. Apoptosis is a programmed biochemical event within the cell which leads to death of cells. The intracellular production of ROS by the NPs is believed to enhance the anticancer activity [21] and these are dose dependent. Different concentrations of MO-AgNPs (20 μg/mL to 100 μg/mL) were treated with MCF-7 cell line to assess their cytotoxic potential and cisplatin (15 μg/mL) was used as the reference drug for study. Minimum and maximum inhibitions were observed at 20 μg/mL and 100 μg/mL respectively in comparison with the standard which exhibited 77.54% inhibition of cell growth at 15 μg/mL. IC50 value calculated from dose-response curve is found to be 68.03 μg/mL. The findings are shown in Figure 7 and the viabilities of the cells at various concentrations are depicted in Figure 8. Comparison of anticancer activity of AgNPs synthesized by various plants extracts are tabulated in Table 3.

Figure 6. α – Amylase inhibition activity of MO-AgNPs

Figure 7. Anticancer activity of MO-AgNPs
Figure 8. MCF-7 cell viabilities treated with MO-AgNPs

Table 3. Comparison table of Anticancer activity of AgNPs synthesized using other plant extracts.

| SL. No | Plant name            | AgNPs sizes | IC₅₀ Value | References |
|--------|-----------------------|-------------|------------|------------|
| 1      | Syzygium aromaticum   | 5 – 50 nm   | 70 µg/mL   | [22]       |
| 2      | Adenium obesum        | 10 – 30 nm  | 217 µg/mL  | [23]       |
| 3      | Artocarpus integer    | 5.76 -19.1 nm | 90 µg/mL | [24]       |
| 4      | Multiple fruits       | 25 nm       | 500 µg/mL  | [25]       |
| 5      | Moringa oleifera      | 21.5- 41 nm | 68.03 µg/mL | Present work |

7. Conclusion
We successfully synthesized the AgNPs using aqueous extract of Moringa oleifera leaves which is well known for their therapeutic applications. Applied green synthesis method offered simple, rapid, and ecological advantages for MO-AgNPs synthesis. In order to assess their purity, size and shape, AgNPs were then characterized by standard analytical techniques such as XRD, SEM, and HR-TEM. The XRD analysis demonstrates that the AgNPs are in face-centered cubic (fcc) lattice. SEM and TEM examinations revealed that the AgNPs are spherical and size ranging from 21.5 nm to 41.0 nm. MO-AgNPs displayed strong α-amylase inhibition activity. DPPH radical scavenging ability with IC₅₀ value of 62.6 µg/mL and concentration-dependent cytotoxicity towards MCF-7 cell line exhibiting the half maximal inhibitory concentration of 68.03 µg/mL. MO-AgNPs are therefore considered to be a good candidate for biomedical and environmental bioremediation.

References
[1] Behravan M, Panahi AH, Naghizadeh A, Ziaee M, Mahdavi R and Mirzapour A 2019 Int. J. Biol. Macromol. 124 148-54
[2] Kumar C R, Betageri V S, Nagaraju G, Pujar G H, Onkarappa H S and Latha M S 2020 J. Inorg. Organomet. Polym. Mater. 1-8
[3] Singh A and Dutta P K 2020 Int. J. Biol. Macromol.
[4] Dakshayani SS, Marulasiddeshwara MB, Kumar S, Golla R, Devaraja SRHK and Hosamani R 2019 *Int. J. Biol. Macromol.* **131** 787-97

[5] Hemmati S, Rashtiani A, Zangeneh MM, Mohammadi P, Zangeneh A and Veisi H 2019 *Polyhedron.* **158** 8-14.

[6] Orlowski P, Zmigrodzka M, Tomaszewska E, Ranoszek-Soliwoda K, Czupryn M, Antos-Bielska M, Szemraj J, Celichowski G, Grobelny J and Krzyzowska M 2018 *Int. J. Nanomed.* **13** 991

[7] Raj S, Mali SC and Trivedi R 2018 *Biochem. Biophys. Res. Commun.* **503** 2814-19

[8] Liu Z, Zhou T, Ziegler A C, Dimitrion P and Zuo L 2017 *Oxid. Med. Cell. Longev.*

[9] Baldea LAN, Martineau LC, Benhaddou-Andaloussi A, Armasion J T, Lévy É and Haddad P S 2010 *J. Ethnopharmacol.* **132** 473-82

[10] American Diabetes Association 2016 *Diabetes Care Supplement* 1 S4-S5

[11] Saratale RG, Shin HS, Kumar G, Benelli G, Ghodake GS, Jiang YY, Kim DS and Saratale GD 2018 *Environ. Sci. Pollut. Res.* **25** 10250-263

[12] Saratale GD, Saratale RG, Benelli G, Kumar G, Pugazhendhi A, Kim D S and Shin H S 2017 *J. Clust. Sci.* **28**(3) 1709-27

[13] Aisida S O, Madubuonu N, Alnasir M H, Ahmad I, Botha S, Maaza M and Ezema F I 2020 *Appl. Nanosci.* **10**(1) 305-15

[14] Harborne JB 1973 *Phytochemical methods* Chapman Hall 49-188

[15] Jacob SJP, Mohammed H, Murali K and Kamarudeen M 2012 *Colloids Surf. B.* **98** 7-11

[16] Zangeneh MM, Bovandi S, Gharehyakheh S, Zangeneh A and Irani P 2019 *Appl. Organomet. Chem.* **33** 4961

[17] Popli D, Anil V, Subramanyam AB, Rao SN, Rai RV and Govindappa M 2018 *Artif. Cells. Nanomed. Biotechnol.* **46**(sup1) 676-83

[18] Kiran MS, Betageri VS, Kumar CR, Vinay SP and Latha MS 2020 *J. Inorg. Organomet. Polym. Mater.* 1-10

[19] Saratale RG, Shin HS, Kumar G, Benelli G, Kim DS and Saratale GD 2018 *Artif. Cells. Nanomed. Biotechnol.* **46** 211-22

[20] Du L, Suo S, Wang G, Jia H, Liu KJ, Zhao B and Liu Y 2013 *Chemistry–A European Journal* **19** 1281-87

[21] Mortazavi-Derazkola S, Ebrahimzadeh MA, Amiri O, Goli HR, Rafiei A, Kardan M and Salavati-Niasari M 2020 *J. Alloys Compd.* **820** 153186

[22] Venugopal K, Rather HA, Rajagopal K, Shanthi MP, Sheriff K, Illiyas M, Rather R A, Manikandan E, Uvarajan S, Bhaskar M and Maaza M 2017 *J. Photoch. Photobio. B.* **167** 282-89

[23] Farah MA, Ali MA, Chen SM, Li Y, Al-Hemaid FM, Abou-Tarboush FM, Al-Anazi KM and Lee J 2016 *Colloids Surf. B.* **141** 158-69

[24] Majeed S, Bakhtiar NFB, Danish M, Ibrahim MM and Hashim R 2019 *Sustain. Chem Pharm.* **12** 100138

[25] Naganathan K and Thirunavukkarasu S 2017 *In IOP Conf. Ser.: Mater. Sci. Eng.* **191** 012009