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Antimicrobial evaluation of *Garcinia cambogia*-impregnated sodium montmorillonite

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ABSTRACT

Herein, *Garcinia cambogia* (GC) was introduced into the structure of sodium montmorillonite (Na^+-MMT), and then the antimicrobial properties of the new product (GC-MMT) were evaluated. The results of the GC-MMT evaluation by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), field emission scanning electron microscopy (FE-SEM), and thermogravimetric analysis (TGA) confirmed the presence of GC in the structure. The XRD results showed that after the exchange process, the peak appeared at lower values of 2θ and the *d*-spacing increased, which was due to the presence of GC. Also, the TGA results showed that approximately 17.5 *wt.%* of GC was present in the GC-MMT structure. The results of the antimicrobial evaluation showed that GC-MMT has an inhibitory and killing effect against Gram-positive and Gram-negative bacteria. In fact, GC contains bioactive compounds such as fukugetin, garcinol, guttiferone k, oxy-guttiferone k, arginine, glutamine, hydroxy citric acid, malic acid, citric acid, galic acid, procyanidine, which have the ability to exert antimicrobial properties.

1. Introduction

Several factors should be considered in the dye selection, including the compatibility between the polymer and the dye, the stability of the dye in the processing conditions of the polymer, and the dispersion [1]. Also, the presence of other additives is very effective on the dispersion of the dye in the polymer matrix [2]. Each type of dye has its advantages and disadvantages [3]. Unlike dyes, organic and inorganic pigments are insoluble in the polymer matrix and it is difficult to disperse them, but they have a good covering [4]. In addition, the migration of dyes out of the polymer matrix can occur [5]. Meanwhile, montmorillonite (MMT) clay is the most common phyllosilicate used to produce polymer nanocomposites [6,7]. Generally, clays are hydrophilic [8,9]. To be compatible with organic polymers, the surface of clay minerals must be modified before their use [10]. Organic cations such as ammonium or phosphonium ions are the most common organic modifiers used for clay minerals [11]. This modification involves cation exchange. Organic modification causes the expansion of the interlayer space and thus increases the distance between the plates to some extent [12]. Therefore, organic modification causes a polymer or a cationic molecule to penetrate into the interlayer space [13]. The presence of modified clay in the polymer matrix improves mechanical and thermal properties [14]. In fact, in pigments based on nanoclay, all or part of the cation exchange capacity of nanoclay is exchanged with an organic pigment and in some cases with organic surfactants such as tetravalent ammonium [15]. One of the big problems of organic dyes is environmental problems and their high price, which can be replaced by environmentally friendly dyes based on plants [16,17]. In this study, we used an easy way to introduce ethylene

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into the space between Na^+-MMT layers. The obtained results confirmed the presence of ethylene in the interlayer space. Also, the antimicrobial results showed that this nanoparticle is very effective against 4 types of Gram-positive and Gram-negative bacteria.

2. Experimental

2.1. Materials

The Na^+-MMT and GC were obtained from Rockwood Company (USA) and Peptina Company (Iran), respectively.

2.2. Preparation of GL-MMT

First, the Na^+-MMT was swollen [12-14], therefore, 10 g of it was stirred in 1000 mL of distilled water (at 25 °C, 30 h). Then, GC (4 g) was stirred in 500 mL of distilled water (at 25°C, 2 h) and next added to the Na^+-MMT mixture. Afterward, mixture was stirred for 30 h (at 25 °C) and then rested for 24 h. Eventually, it was centrifuged (6000 rpm) for 20 min and the GC-MMT was vacuum-dried (at 30 °C) for 24 h.

2.2. The measurements and characterization

FT-IR spectra of the samples were recorded on an Equinox 55 spectrometer (Bruker, Germany), within a range of 400 - 4000 cm^{-1} using a resolution of 4 cm^{-1}. XRD measurements were carried out using an Xpert Pro MPD diffractometer (Panalytical, Netherlands). The measurement was performed at room temperature and the system consists of a rotating anode generator which operated at 35 kV and 20 mA. A field emission SEM (FE-SEM-MIRAIII model-TESCAN Company) was used to investigate the samples. The TGA was a TGA/SDTA 851 (Mettler Toledo, Switzerland). The analysis was carried out in nitrogen atmosphere with a heating rate of 10 °C/min. To evaluate the antibacterial properties, the agar diffusion method was used as described in the literature [18-20], and the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) were also evaluated.

3. Results and discussion

Figure 1 and Table 1 show the FTIR results. As seen in the GC-MMT spectrum, in addition to MMT peaks, peaks related to the presence of GC are also observed. Figure 2 shows the XRD pattern of the samples. It can be seen that in GC-MMT, the peak appeared at lower 2θ values and the *d*-spacing increased. The increase in *d*-spacing is due to the absence of Na^+ cation and the presence of GC [8,19]. Figure 3 shows FE-SEM images of samples. The morphology did not change after the exchange process, which this behavior reported in the literature [8,12].

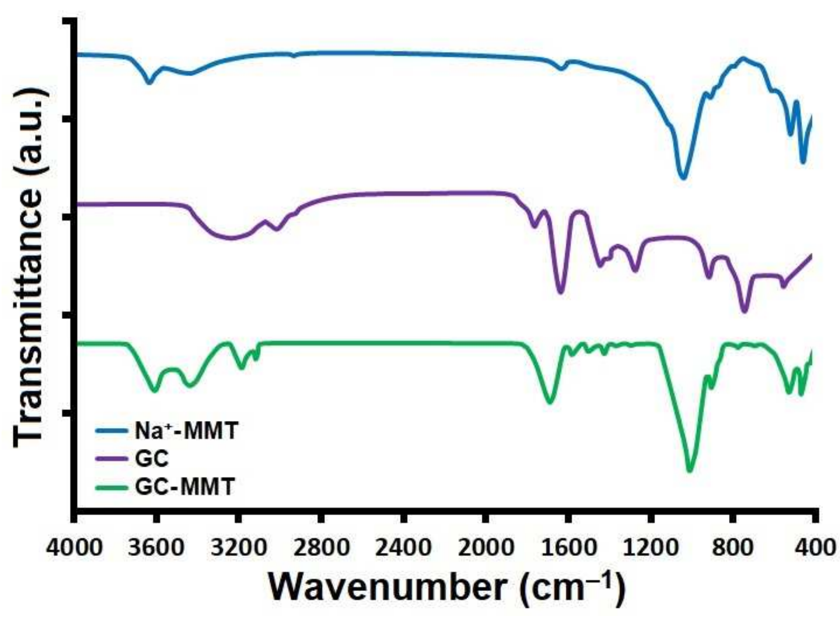

Figure 1. FT-IR spectra of samples.

Table 1. Absorption peak characteristic of FTIR spectrum.

Sample	Wavenumber (cm^{-1})	Characteristics	Ref.
Na^+-MMT	465 and 1043	Bending and stretching Si-O vibrations	[8]
	523	Si-O-Al vibration and MgO groups	[8,13]
	916	Al_2OH bending groups	[8,16]
	1635-3445	Scissoring vibrations and symmetric vibrations of OH units	[21-24]
	3633	Stretching of OH (SiOH groups)	[25-28]
GC	1207, 1407, and 2932	C-H stretching of alcohols, polyphenols, and alkenes	[29-32]
	3295	OH of alcohols, polyphenols, and alkenes	[29,33-36]
	1730	C=O stretching vibrations due to acid of anhydrides	[29]
	1600	C=C stretching of alkenes	[29,36]
	765	The aromatic C-H functional group	[29,37,38]
	610	Symmetric stretching mode and bending mode of C-H-H bands	[29,39]

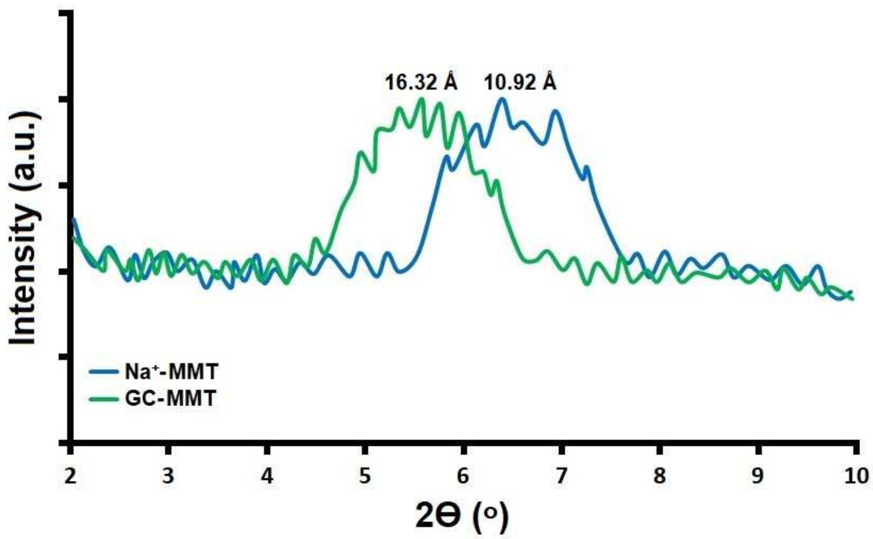

Figure 2. XRD patterns of samples.

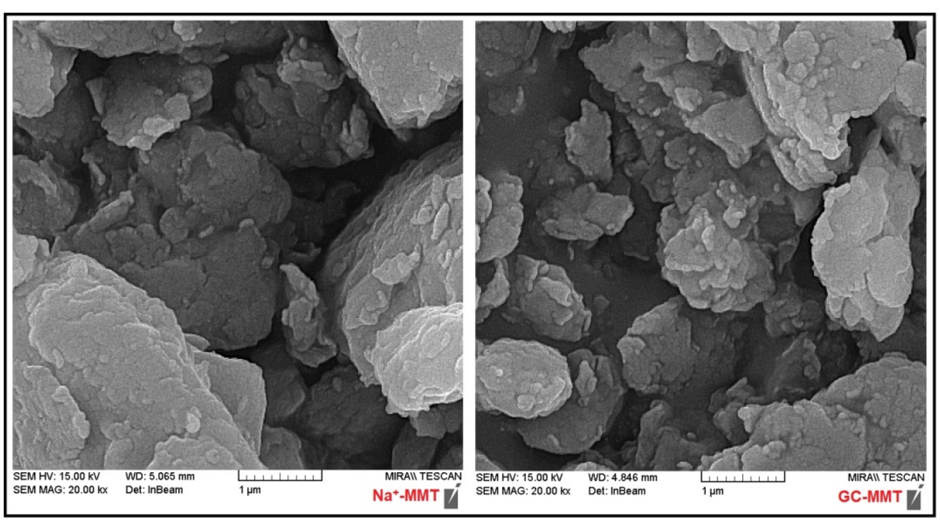

Figure 3. FE-SEM images of samples.

Figure 4 shows the TGA curves of samples. As can be seen, Na^+-MMT has a weight loss of about 12.5%. This weight loss up to the range of 200 °C is related to dehydration inside the interlayer space, and in the rest of the ranges it is related to the dehydroxylation of inorganic clay [16,19]. For GC, the weight loss up to the temperature range of 200 °C is caused by the evaporation of water and volatile compounds. In the rest of the ranges, it is caused by the destruction of cellulose groups as well as the decomposition of the carbon skeleton. However, the weight loss of GC-MMT is about 30%, and according to the weight loss of Na^+-MMT, it can be said that approximately 17.5 *wt.%* of GC is present in the structure of GC-MMT. Herein, the antimicrobial properties of GC-MMT against four types of bacteria, (*Bacillus subtilis* (gram-positive), *Staphylococcus epidermidis* (gram-positive), *Escherichia coli* (gram-negative), and *Shigella dysenteriae* (gram-negative)), were investigated (see Table 2). The formation of inhibition zones by GC-MMT is due to the presence of GC in the structure. GC contains many bioactive compounds [40]. GC contains fukugetin, garcinol, guttiferone k, oxy-guttiferone k, arginine, glutamine, hydroxy citric acid, malic acid, citric acid, galic acid, procyanidine [40,41]. That is why it has immune-enhancing, analgesic, anti-inflammatory, antioxidant, schistosomicidal, leishmanicidal, photoprotective, and antibacterial effects [40-42].

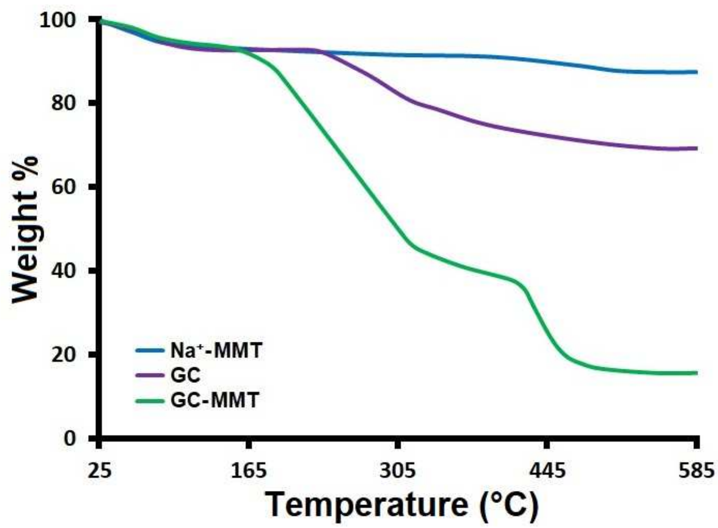

Figure 4. TGA curves of the samples.

Table 2. Antimicrobial activity of GC-MMT.

Microorganism	DD	MIC	MBC
Bacillus subtilis	9	500	1000
Staphylococcus epidermidis	7	500	1000
Escherichia coli	3	1000	2000
Shigella dysenteriae	2	1000	2000

Note:
* DD: Disk diffusion method, inhibition zones in diameter (mm) around the impregnated disk.
** DD: 600 µg per well
*** Concentrations of MIC and MBC as µg/mL

These compounds have the ability to suppress by membrane perturbation, reduction of host ligands adhesion, and neutralizing bacterial toxins [16,42-45]. The results show that GC has a greater effect on Gram-positive bacteria, which is due to the difference in the structure of the bacterial cell wall [16]. The cell wall of gram-positive bacteria is simple and porous compared to gram-negative bacteria, so it is easier to penetrate [19].

4. Conclusion

To sum up, we have been able to successfully incorporate GC into the structure of Na^+-MMT. The results of FTIR, XRD, TGA, and SEM showed that GC entered the Na^+-MMT layers. The GC-MMT has very good thermal stability. Also, antibacterial results showed that GC-MMT can be very effective.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] A. Katariya-Jain, R. R. Deshmukh, Effects of dye doping on electro-optical, thermo-electro-optical and dielectric properties of polymer dispersed liquid crystal films. *J. Phys. Chem. Solids*, 160 (2022) 110363.

[2] A. Marcinčin, Modification of fiber-forming polymers by additives. *Prog. Polym. Sci*., 27 (2002) 853-913.

[3] A. Mahmoodi, M. Ebrahimi, A. Khosravi, Epoxy/nanopigment coatings: preparation and evaluation of physical-mechanical properties. *Prog. Org. Coat*., 119 (2018) 164-70.

[4] A. Gürses, M. Açıkyıldız, K. Güneş, M. S. Gürses, Dyes and pigment Springer; 2016.

[5] R. Christie, A. Abel, Organic pigments: general principles. *Phys. Sci. Rev*., 6 (2021) 807-834.

[6] H. Sadeghi Nasrabadi, M.R. Kalaee, M. Abdouss, M. Sheydaei, S Mazinani, New role of layered silicates as phase transfer catalyst for in situ polymerization of poly (ethylenetetrasulfide) nanocomposite, *J. Inorg. Organomet. Polym. Mater*., 23 (2013) 950-957.

[7] M. Sheydaei, Synthesis, Characterization, Curing, Thermal and Mechanical Properties of Methylene-Xylene-Based Polysulfide Block Copolymer/Cloisite 30B Nanocomposites. *Polym. Sci. Ser. B*, 65 (2023) 201-208.

[8] M. Edraki, M. Sheydaei, D. Zaareia, A. Salmasifara, B. Azizi, Protective nanocomposite coating based on ginger modified clay and polyurethane: preparation, characterization and evaluation anti-corrosion and mechanical properties. *Polym. Sci. Ser. B*, 5 (2022) 756-764.

[9] M. Sheydaei, M. Edraki, Vinyl ester/C-MMT nanocomposites: investigation of mechanical and antimicrobial properties. *J. Chem. Lett*., 3 (2022) 95-98.

[10] A. A. Azeez, K. Y. Rhee, S. J. Park, D. Hui, Epoxy clay nanocomposites–processing, properties and applications: A review. *Composites, Part B*, 45 (2013) 308-320.

[11] M. H. Haghighat, A. Mohammad-Khah, Removal of trihalomethanes from water using modified montmorillonite. *Acta Chim. Slov*., 67 (2020) 1072.

[12] M. Edraki, M. Sheydaei, Investigation of the Dual Active/Barrier Corrosion Protection, Mechanical and Thermal Properties of a Vinyl Ester Coating Doped with Ginger Modified Clay Nanoparticles. *Russ. J. Appl. Chem*., 95 (2022) 1481-1488.

[13] M. Edraki, I. Mousazadeh Moghaddampour, E. Alinia-Ahandani, M. Banimahd Keivani, M. Sheydaei, Ginger intercalated sodium montmorillonite nano clay: assembly, characterization, and investigation antimicrobial properties. *Chem. Rev. Lett*., 4 (2021) 120-129.

[14] M. Edraki, M. Sheydaei, E. Vessally, A. Salmasifar, Enhanced mechanical, anticorrosion and antimicrobial properties of epoxy coating via pine pollen modified clay incorporation. *Iran. J. Chem. Chem. Eng*., 42 (2023) 2775-2786.

[15] M. Kaya, Y. Onganer, A. Tabak, Preparation and characterization of “green” hybrid clay-dye nanopigments. *J. Phys. Chem. Solids*, 78 (2015) 95-100.

[16] M. Sheydaei, M. Edraki, S. M. Radeghi Mehrjou, Anticorrosion and Antimicrobial Evaluation of Sol-Gel Hybrid Coatings Containing *Clitoria ternatea* Modified Clay. *Gels*, 9 (2023) 490.

[17] M. Edraki, M. Sheydaei, D. Zaarei, A brief review of the performance of azole-type organic corrosion inhibitors. *Chem. Rev. Lett*., 6 (2023) 79-85.

[18] M. Sheydaei, V. Pouraman, E. Alinia-Ahandani, E. Shahbazi-Ganjgah, PVCS/GO nanocomposites: investigation of thermophysical, mechanical and antimicrobial properties. *J. Sulfur Chem*., 43 (2022) 376-390.

[19] M. Sheydaei, M. Edraki, F.S.J. Abad, Matcha-modified clay polyurethane coating: improving thermal, mechanical, antimicrobial, and anticorrosion performance. *Iran Polym. J*., 32 (2023) 1643-1654.

[20] M. Sheydaei, V. Pouraman, M. Edraki, E. Alinia-Ahandani, S. M. Asadi-Sadeh, Targeted application of GO to improve mechanical and thermal properties of PVCS/RS composites. *Phosphorus Sulfur Silicon Relat. Elem*., 198 (2023) 345-353.

[21] M. Sheydaei, Sodium sulfide-based polysulfide polymers: synthesis, cure, thermal and mechanical properties. *J. Sulfur. Chem*., 43 (2022) 643-654.

[22] M. Sheydaei, M. R. Kalaee, M. Dadgar, M. H. Navid-Famili, A. Shockravi, M. Samar, Synthesis and characterization of a novel aromatic polysulfide in the presence of phase transfer catalyst. *In 27th World*

Congress of the Polymer Processing Society, May (2011) P-13-1088.
[23] M. Sheydaei, M. Edraki, I. Mousazadeh Moghaddampour, Poly(*p*-xylene trisulfide): Synthesis, Curing and Investigation of Mechanical and Thermal Properties. *Polym. Sci. Ser. B*, 64 (2022) 464-469.
[24] M. Sheydaei, M. Edraki, Poly (butylene trisulfide)/CNT nanocomposites: synthesis and effect of CNT content on thermal properties. *J. Chem. Lett*., 3 (2022) 159-163.
[25] M. Sheydaei, S. Talebi, M. Salami-Kalajahi, Synthesis of ethylene dichloride-based polysulfide polymers: investigation of polymerization yield and effect of sulfur content on solubility and flexibility. *J. Sulfur Chem*., 42 (2021) 67-82.
[26] M. Sheydaei, S. Talebi, M. Salami-Kalajahi, Synthesis, characterization, curing, thermophysical and mechanical properties of ethylene dichloride-based polysulfide polymers. *J. Macromol. Sci. Part A Pure Appl. Chem*., 58 (2021) 344-352.
[27] M. Edraki, I. M. Moghaddampour, M. Banimahd Keivani, M. Sheydaei, Characterization and antimicrobial properties of Matcha green tea. *Chem. Rev. Lett*., 5 (2022) 76-82.
[28] M. Sheydaei, H. Jabari, H. Ali-Asgari Dehaghi, Synthesis and characterization of ethylene-xylene-based polysulfide block-copolymers using the interfacial polymerization method. *J. Sulfur Chem*., 37 (2016) 646-655.
[29] V. Jayakar, V. Lokapur, B. R. Nityasree, R. K. Chalannavar, L. D. Lasrado, M. Shantaram, Optimization and green synthesis of zinc oxide nanoparticle using Garcinia cambogia leaf and evaluation of their antioxidant and anticancer property in kidney cancer (A498) cell lines. *Biomedicine*, 41 (2021) 206-222.
[30] M. Sheydaei, M. Edraki, I. Mousazadeh Moghaddampour, E. Alinia-Ahandani, Poly(butylene trisulfide)/SiO_2 nanocomposites: cure and effect of SiO_2 content on mechanical and thermophysical properties. *J. Sulfur Chem*., 43 (2022) 413-425.
[31] M. Sheydaei, M. Edraki, E. Alinia-Ahandani, E. Nezhadghaffar-Borhani, Poly (ethylene disulfide)/carbon fiber composites: cure and effect of fiber content on mechanical and thermal properties. *J. Sulfur Chem*., 42 (2022) 614-627.
[32] M. Sheydaei, M. Edraki, S. Javanbakht, E. Alinia-Ahandani, M. Soleimani, A. Zerafatkhah, Poly(butylene disulfide) and poly(butylene tetrasulfide): Synthesis, cure and investigation of polymerization yield and effect of sulfur content on mechanical and thermophysical properties. *Phosphorus Sulfur Silicon Relat. Elem*., 196 (2021) 578-584.
[33] A. H. Haghighi, M. Sheydaei, A. Allahbakhsh, M. Ghatarband, F. Sadat Hosseini, Thermal performance of poly (ethylene disulfide)/expanded graphite nanocomposites. J. Therm. Anal. Calorim., 117 (2014) 525-535.
[34] A. Allahbakhsh, A. H. Haghighi, M. Sheydaei, Poly (ethylene trisulfide)/graphene oxide nanocomposites: A study on interfacial interactions and thermal performance. *J. Therm. Anal. Calorim*., 128 (2017) 427-442.
[35] A. Allahbakhsh, M. Sheydaei, S. Mazinani, M. R. Kalaee, Enhanced thermal properties of poly (ethylene tetrasulfide) via expanded graphite incorporation by in situ polymerization method. *High Perform. Polym*., 25 (2013) 576-583.
[36] M. A. Bagherinia, M. Sheydaei, M. Giahi, Graphene oxide as a compatibilizer for polyvinyl chloride/rice straw composites. *J. Polym. Eng*., 37 (2017) 661-670.
[37] M. Sheydaei, M.R. Kalaee, A. Allahbakhsh, M. Samar, A. Aghili, M. Dadgar, G.S. Moosavi, Characterization of synthesized poly (aryldisulfide) through interfacial polymerization using phase-transfer catalyst. *J. Sulfur Chem*., 33 (2012) 303-311.
[38] M. Sheydaei, M. R. Kalaee, A. Allahbakhsh, E. O. Moradi-e-rufchahi, M. Samar, G. Moosavi, N. Sedaghat, Synthesis and characterization of poly(p-xylylene tetrasulfide) via interfacial polycondensation in the presence of phase transfer catalysts. *Des. Monomers Polym*., 16 (2013) 191-196.
[39] M. Sheydaei, A. Allahbakhsh, A. H. Haghighi, A. Ghadi, Synthesis and characterization of poly (methylene disulfide) and poly (ethylene disulfide) polymers in the presence of a phase transfer catalyst. *J. Sulfur Chem*., 35 (2014) 67-73.
[40] B. L. Espirito Santo, L. F. Santana, W. H. Kato Junior, F. D. de Araújo, D. Bogo, K. D. Freitas, R. D. Guimarães, P. A. Hiane, A. Pott, W. F. Filiú, M. Arakaki Asato. Medicinal potential of *Garcinia* species and their compounds. *Molecules*, 25 (2020) 4513.
[41] M. H. Baky, H. Fahmy, M. A. Farag. Recent Advances in Garcinia cambogia Nutraceuticals in Relation to Its Hydroxy Citric Acid Level. A Comprehensive Review of Its Bioactive Production, Formulation, and Analysis with Future Perspectives. *ACS omega*, 7 (2022) 25948-25957.
[42] M. Sheydaei, S. Shahbazi-Ganjgah, E. Alinia-Ahandani, M. Sheidaie, M. Edraki. An overview of the use of plants, polymers and nanoparticles as antibacterial materials. *Chem. Rev. Lett*., 5 (2022) 207-216.
[43] M. Sheydaei, E. Alinia-Ahandani, Cancer and the role of polymeric-carriers in diagnosis and treatment. *J. Fasa Univ. Med. Sci*., 10 (2020) 2408-2421.
[44] M. Sheydaei, E. Alinia-Ahandani, Breast cancer and the role of polymer-carriers in treatment. *Biomed. J. Sci. & Tech. Res*., 34 (2021) 27057-27061.
[45] M. Sheydaei, E. Alinia-Ahandani, P. Ghiasvandnia, Cancer and the role of polymer-carriers in drug delivery. *J. Genet. Cell. Biol*., 4 (2020) 217-220.