Contents lists available at ScienceDirect

ELSEVIED



journal homepage: www.elsevier.com/locate/jorganchem

Journal of Organometallic Chemistry

Palladium supported terpyridine modified magnetic nanoparticles as an efficient catalyst for carbon-carbon bond formation



Bahram Ahmadi Baloutaki^a, Mohammad Hosein Sayahi^{a,b,*}, Mohammad Nikpassand^{a,*}, Hassan Kefayati^a

^a Department of Chemistry, Rasht Branch, Islamic Azad University, Rasht, Iran

^b Department of Chemistry, Payame Noor University (PNU), 19395–3697, Tehran, Iran

ARTICLE INFO

Article history: Received 3 November 2020 Revised 30 December 2020 Accepted 3 January 2021 Available online 6 January 2021

Keywords: Palladium catalyst SPION Mizoroki-Heck reaction Suzuki reaction Immobilized catalyst

1. Introduction

Carbon-carbon bond formation is a key reaction in organic chemistry. Several efforts have focused on extending methods for these reaction with higher efficiency in milder reaction conditions. Palladium catalyzed cross coupling reaction of aryl halides with alkenes (known as Mizoroki-Heck reaction), or with phenyl boronic acids (known as Suzuki reaction) are of high interest among carbon-carbon bond formation reactions [1–4]. Palladium is the most popular catalyst for the mentioned reactions using various ligands, such as bis pyrimidines [5,6], thiourea [7], β -diimines [8] and etc. For increasing the activity and reusability of palladium catalyst in Mizoroki-Heck and Suzuki reaction, an approach is to immobilize this metallic catalyst onto the modified solid supports [9–14]. Among several materials, which have been used as support for the immobilization of palladium, magnetic iron oxide nanoparticles are common candidates, due to their unique properties, including chemical and thermal stability, ease of separation from the reaction mixture and recovery, ease of functionalization and facility of the synthesis and fabrication [15-19]. Apart from applications in catalysis, superparamagnetic nanoparticles are of magnetic materials, which have wide applications in several areas, including

ABSTRACT

In this paper, a novel catalyst is designed, synthesized and characterized based on the functionalization of magnetic iron oxide nanoparticles by terpyridine as a ligand for the immobilization of palladium. The catalyst is fully characterized by several characterization methods, including SEM, FTIR, DLS, VSM, EDS and XRD analysis. The results of the characterization techniques proved the successful synthesis of the desired catalyst. The applicability of the catalyst was evaluated in Heck and Suzuki reaction. The catalyst showed very good activity through the mentioned carbon-carbon bond formation reactions. The catalyst is magnetically recoverable and could be separated simply from the reaction media by an external magnet. The use of the catalyst in 10 sequential reactions did not show any significant loss in the activity of the catalyst.

© 2021 Published by Elsevier B.V.

semiconductors [20,21], medical imaging and therapy [22,23], drug delivery [24,25] and the synthesis of polymer composites with improved properties [26–28].

Regarding the significance of Mizoroki-Heck and Suzuki reaction in carbon-carbon bond formation reactions and the versatility of superparamagnetic iron oxide nanoparticles in catalysis, in this paper modified iron oxide nanoparticles are used as a support for immobilization of palladium catalyst. Superparamagnetic iron oxide nanoparticles are modified by terpyridine as a ligand for the immobilization of palladium catalyst (denoted Pd@terPy@SPION). The catalyst is applied in Mizoroki-Heck and Suzuki carbon-carbon bond formation reactions.

2. Results and discussion

In continuation of our work concerning the synthesis of heterocyclic and pharmaceutical compounds under mild and green protocols [29–37] we herein report a green procedures for Mizoroki-Heck and Suzuki reaction using of Pd@terPy@SPION nanoparticle as a novel nano-catalyst. In this paper, Pd@terPy@SPION is designed and synthesized by the immobilization of palladium onto terpyridine functionalized Superparamagnetic iron oxide nanoparticles. For the fabrication of Pd@terPy@SPION catalyst, 1-(pyridin-2-yl)ethan-1-one (1), 4-nitrobenzaldehyde (2) and ammonium acetate (3) were reacted together to form 4'-(4-nitrophenyl)-2,2':6',2''-terpyridine (4). The reduction of nitro group in compound (4) leads to the formation of 4-([2,2':6',2''-

^{*} Corresponding authors.

E-mail addresses: sayahymh@pnu.ac.ir (M.H. Sayahi), Nikpassand@iaurasht.ac.ir (M. Nikpassand).



Fig. 1. (a) SEM, (b) DLS, (c) FTIR, and (d) VSM results of Pd@terPy@SPION catalyst.

terpyridin]-4'-yl)aniline (**5**), which then reacts to triethoxy(3isocyanatopropyl)silane (**6**) and gives 1-(4-([2,2':6',2''-terpyridin]-4'-yl)phenyl)-3-(4,4,4-triethoxybutyl)urea (**7**). SPION capsulated SiO₂ nanoparticles were separately synthesized in two steps. The first step involved the reaction of Fe²⁺ and Fe³⁺ in basic medium to give SPION nanoparticles. Tetraethyl orthosilicate (TEOS) was used for the encapsulation of SPION by SiO₂ moieties to form (**9**). 1-(4-([2,2':6',2''-Terpyridin]-4'-yl)phenyl)-3-(4,4,4-triethoxybutyl)urea (**7**) reacted with SPION capsulated SiO₂ nanoparticles (**9**) to form terpyridinmodified magnetic nanoparticles (**10**), which was used as a ligand for palladium catalyst. Pd@terPy@SPION (**11**) was synthesized by the reaction of (**10**) with palladium acetate. The preparation steps of Pd@terPy@SPION catalyst is presented in Scheme 1.

The synthesis of Pd@terPy@SPION catalyst was studied by several characterization methods, including SEM, IR spectroscopy, DLS, ICP and VSM method. The microstructure and the morphology of Pd@terPy@SPION catalyst was studied by SEM microscopy. The SEM image of Pd@terPy@SPION catalyst is presented in Fig. **1a**. It could be observed that the catalyst particles are spherical with the average size of 30 nm. The size of Pd@terPy@SPION catalyst particles were confirmed by DLS analysis. DLS result is presented in Fig. **2b**. According to the DLS result, the particles of Pd@terPy@SPION catalyst is about 30 nm. The successful synthesis of Pd@terPy@SPION catalyst was studied by FTIR spectroscopy. The FTIR spectrum of Pd@terPy@SPION catalyst and SiO₂@SPION are presented in Fig. **1c**. The characteristic peaks related to the desired bonds in the structure of the catalysts could be observed in FTIR spectrum. Surface hydroxyl groups of silica encapsulated magnetic iron oxide nanoparticles are observed at 3230 cm⁻¹. Vibrations of CH₂ bonds are observed at 2891 cm⁻¹. Vibration bands at 577 and 1100 cm⁻¹could be correlated to Fe-O-Fe and Si-O-Si vibrations, respectively. The bands belonging to terpyridine vibrations are observed at 766 and 1424 cm⁻¹. The carbonyl group of the urethane is observed at 1724 cm⁻¹. Comparing the FT-IR spectra of Pd@terPy@SPION catalyst and SiO₂@SPION clearly proves the functionalization of SiO₂@SPION and successful synthesis of the catalyst. In addition, the presence of palladium in the structure of the catalyst was confirmed by ICP analysis. ICP results showed the palladium content of the catalyst to be 0.19 wt% of Pd@terPy@SPION catalyst. Finally, the magnetic properties of Pd@terPy@SPION catalyst was compared to SPIO nanoparticles. The VSM results of SPION and Pd@terPy@SPION catalyst are presented in Fig.1d. According to the VSM results both SPION and Pd@terPy@SPION catalyst showed superparamagnetic behavior. It was observed that after the encapsulation of SPION by SiO₂, followed by functionalization by terpyridine moieties and the synthesis of Pd@terPy@SPION catalyst, the magnetization of the catalyst is decreased. However, it is still superparamagnetic and the magnetization in the presence of external magnetic field is sharp enough to be separated by a magnet from the reaction mixture.

Further structural analysis of Pd@terPy@SPION catalyst was performed by XRD analysis. The XRD pattern of Pd@terPy@SPION catalyst is presented in Fig. **2a**. It could be observed that, the diffraction pattern is in agreement with the desired structure of the catalyst. The presence of palladium in the structure of the catalyst



Fig. 2. (a) XRD, (b) EDS, (c) TGA results, and (d) TEM image of Pd@terPy@SPION catalyst.

could be confirmed in the XRD pattern. In addition, the presence of palladium in the structure of Pd@terPy@SPION catalyst was studied by EDS method. The EDS result is presented in Fig. **2b**. The presence of palladium can clearly be observed in the elemental analysis of the catalyst. In addition, the thermal behavior of the catalyst was studied by TGA analysis. The results are presented in Fig. **2c**. It could be observed that, the catalyst is thermally stable up to 300°C. A weight loss in 100°C could be correlated to the water, which is adsorbed by the catalyst nanoparticles. TEM image in Fig. **2d** confirm the particle size and structures of Pd@terPy@SPION catalyst.

The activity of Pd@terPy@SPION catalyst was evaluated in Mizoroki-Heck and Suzuki reaction. For finding the optimal reaction conditions, the reaction of bromobenzene and styrene were selected as a model reaction. The reaction was performed in different reaction conditions, including different bases, solvents and various amounts of the catalyst. The results are presented in Table 1. It could be observed that, the best results are observed in water as solvent by using sodium acetate as base. It should be noted that the best results were obtained when 1.5 equivalent of the base were used. The amount of the base was optimized in the reaction of bromobenzene and styrene. The best result was observed when 5 mg of the catalyst was used for each mole of the reactants. A blank rub was performed in the absence of Pd@terPy@SPION catalyst and the results proved that the presence of the catalyst is critical for the reaction performance. In the absence of the catalyst, no product was observed. In addition, hot filtration test was performed. This observation confirmed the necessity of the presence of the catalyst for the reaction performance. It should be noted that no product was observed without Pd@terPy@SPION catalyst for the reaction performance.

The generality of the catalyst for the mentioned carboncarbon bond formation reactions was evaluated by the reaction of various aryl halides and olefins including electron-withdrawing or electron-donating substituents. The results are presented in Table 2. It could be observed that all the substrate has given the product in good isolated yields. The catalyst has been active through both Mizoroki-Heck and Suzuki reaction with different substrates. All electron donating and electron withdrawing reactants have participated in the reaction and have given the products in high isolated yields. It should be noted that this catalyst is prominent due to the efficient recoverability, high turnover number (TON), and turnover frequency (TOF). The catalyst showed a cumulative TONs of about 12000 over 10 successive runs. In addition, the TOF for every run is approximately 1225. Moreover, the cumulative TON is obtained by the sum of the values for the TONs for all examined runs. Additionally, TOFs are calculated using TON.h⁻¹.

The reusability of Pd@terPy@SPION catalyst was evaluated in five sequential runs. For this purpose, after the reaction of styrene and bromobenzene was completed, the catalyst was separated from the reaction by an external magnet and Pd@terPy@SPION catalyst was used in the next reaction. The progress was repeated for five sequential runs. The results are presented in Fig. 3. It could be observed in Fig. 2 that the activity of the catalyst has not been decreased during the reactions. In addition, the stability of the catalyst was evaluated by hot filtration studies [38–41]. The hot filtration results clearly confirmed the stability of the catalyst. Also, this test confirmed the critical role of the catalyst in the reaction performance.

For studying the stability of Pd@terPy@SPION catalyst, the catalyst was isolated after 5th cycle and characterized by SEM microscopy. The SEM result of the recovered catalyst is presented in Fig. 4. It could be observed that the catalyst is highly stable under the reaction conditions.

In order to show the efficiency of Pd@terPy@SPION catalyst, its activity in Heck coupling reaction of styrene and bromobenzene was compared with various palladium catalysts based on the reaction time and yield. The results are presented in Table 3. According to the Table 3, Pd@terPy@SPION catalyst is the most effective catalyst for this purpose in comparison to previously reported cata

Table 1

Optimization of the reaction condition	for Pd@terPy@SPION catalyzed reaction.
--	--

Entry	Solvent	Base	Amount of base (mmol)	Amount of catalyst (mg)	Time (h)	Yield (%)
1	EtOH	NaOAc	1.5	5	4	77
2	MeOH	NaOAc	1.5	5	4	72
3	DMF	NaOAc	1.5	5	4	69
4	DMSO	NaOAc	1.5	5	4	70
5	CH₃CN	NaOAc	1.5	5	4	56
6	DCM	NaOAc	1.5	5	4	62
7	H_2O	NaOAc	1.5	5	4	66
8	H_2O	TEA	1.5	5	4	58
9	H_2O	NaOAc	1	5	4	70
10	H_2O	NaOAc	1.2	5	4	81
11	H_2O	NaOAc	1.5	5	2	96
12	H_2O	NaOAc	1.5	3	4	51
13	H_2O	NaOAc	1.5	7	4	96
14	H_2O	NaOAc	1.5	10	4	96
15	H_2O	NaOAc	2	5	4	96
16	H_2O	NaOAc	1.5	-	6	trace
17	H_2O	K ₂ CO ₃	1.5	5	4	40
18	H ₂ O	No base	-	5	6	trace

Table 2

Pd@terPy@SPION catalyzed carbon-carbon bond formation reaction with various substrates.



lysts. Also, this catalyst shows the highest catalytic activity in very small amounts compared to other catalysts mentioned as indicated in Table 3.

3. Experimental section

3.1. General remarks

All the chemicals, reagents and solvents were purchased from Merck, Across, and Scharlau. SEM image of the catalyst was recorded by a VEGATESCAN-LMU instrument. The particle size of the samples was analyzed by Nanotrac Wave from Microtrac DLS instrument. FT-IR spectra were recorded on a Bruker Tensor 27 FTIR spectrophotometer. Nuclear magnetic resonance spectra were recorded on a Bruker FT- 250 spectrometers using tetramethyl silane (TMS) as internal standard in pure deuterated solvents. Chemical shifts are given in the δ scale in parts per million (ppm) and singlet (s), doublet (d), triplet (t), multiplet (m) and doublets of doublet (dd) are recorded.

Table 3

A catalytic activity comparison of Pd@terPy@SPION with the previously reported catalysts for the Heck coupling reaction of styrene and bromobenzene.

Entry	Catalyst (mol%)	Conditions	Time (h)	Yields (%) ^{ref.}
1 2 3	TiO ₂ @Pd NPs (1) HMMS-NH ₂ -Pd (4) Fe ₃ O ₄ -NH ₂ -Pd (5)	DMF, Et ₃ N, 140°C NMP, K ₂ CO ₃ , 130°C NMP, K ₂ CO ₃ , 130°C	10 20 24	93 ^[42] 96 ^[43] 96 ^[44]
9	Pd@terPy@SPION	Current work		97

3.2. Synthesis of the catalyst

1-(Pyridin-2-yl)ethan-1-one (5 mmol, 605 mg) and 4nitrobenzaldehyde (2.5 mmol, 378 mg) were added to a flask containing acetic acid (10 mL) and stirred under reflux conditions. The reaction completion was monitored by TLC. After the reaction was completed, water (50 mL) and ethyl acetate (50 mL) were

 NO_2

added and the product was extracted from the reaction mixture. The product was added to a flask containing water and methanol mixture (1:1, 20 mL) and zinc powder (20 equivalent) was added portion wise during 1h. The reaction mixture was stirred at room temperature, monitored by TLC. After the reaction completion, the mixture was filtered and the filtrated was collected. The solvent was evaporated and the product was purified by recrystallization from ethanol.

The product (2 mmol, 648 mg), triethoxy(3-isocyanatopropyl)silane (2 mmol, 494 mg) and triethylamine (3 mmol, 303 mg) were added to a flask containing dry toluene (25 mL) and stirred at room temperature for 24 h. After 24 h, the solvent was evaporated and the product was washed three times with *n*-hexane, and then recrystallized from EtOH at 0° C to obtain 1-(4-([2,2':6',2''-terpyridin]-4'-yl)phenyl)-3-(4,4,4-triethoxybutyl)urea.



Scheme 1. Synthesis steps of Pd@terPy@SPION catalyst.



Fig. 3. Reusability of Pd@terPy@SPION catalyst.



Fig. 4. SEM image of the recovered Pd@terPy@SPION catalyst

Silica coated SPION (SiO₂@SPION) was synthesized according to previously reported method [40]. SiO₂@SPION (1 g) wasadded to a flask containing ethanol (500 mL) and sonicated for 60 min at room temperature. A solution was prepared by dissolving 1-(4-([2,2':6',2''-terpyridin]-4'-yl)phenyl)-3-(4,4,4-triethoxybutyl)urea (2 mmol) and ammonia (28%, 2 mL) in ethanol (25 mL) and then added to the SiO₂@SPION mixture. The reaction mixture was stirred for 48 h under argon atmosphere at room temperature. The product was isolated by external magnetic field and washed three time with ethanol and dried under reduced pressure.

The product was added to dried dichloromethane (20 mL) and palladium acetate (10 mmol) was added. The reaction mixture was stirred at room temperature for 48 h. Pd@terPy@SPION catalyst was separated by a magnet and washed by dichloromethane and dried in a vacuum oven overnight.

4. General procedure for the Heck/Sonogashira reactions

A mixture containing aryl halide (1.0 mmol), alkene (1.1 mmol)/ phenylboronic acid (1.0 mmol), sodium acetate (1.5 mmol) and Pd@terPy@SPION (5 mg, 0.11 mol%) was stirred in H₂O (3.0 mL) at room temperature. The reaction performance was monitored by TLC. After the reaction was completed, a magnet was applied for isolation of the catalyst. The solution collected and the product was extracted with ethyl acetate. The organic phase was dried over Na₂SO₄. The solvent was evaporated and the product was purified using column chromatography by *n*-Hexane: Ethyl acetate (6: 1) as eluent.

5. Conclusion

In this paper, a novel catalyst is designed and synthesized based on the immobilization of palladium on magnetic iron oxide nanoparticles. For this purpose, superparamagnetic iron oxide nanoparticles were prepared by the co-precipitation of Fe^{2+} and Fe^{3+} in basic medial the synthesized SPION were then encapsulated by SiO₂. The nanoparticles were functionalized by terpyridine moieties, which were used a ligand for palladium. The catalyst is characterized by several methods, including SEM, DLS, FTIR, ICP and VSM. The activity of the catalyst was evaluated toward Mizoroki-Heck and Suzuki reaction. The results were advantageous and showed that various substrates with different functionalities were successfully participated in the reaction and have gave the desired products in high isolated yields. The catalyst showed very good reusability and its activity did not decrease after five sequential reactions.

Declaration of Competing Interest

We declare that none of the authors of this manuscript are official representatives or on behalf of the government. So, we confirm that the research presented in the submitted paper is not funded by, or on behalf of, the State or Government of Iran.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors are not any Conflict of Interest.

References

- [1] N.T. Phan, M. Van Der Sluys, C.W. Jones, Adv. Synth. Cat. 348 (2006) 609-679.
- [2] R. Narayanan, Molecules 15 (2006) 2124–2138.
- [3] F. Christoffel, T.R. Ward, Cat. Lett. 148 (2018) 489-511.
- [4] B. Karimi, H. Behzadnia, E. Farhangi, E. Jafari, A. Zamani, Curr. Org. Synth. 7 (2010) 543–567.
- [5] C. Nájera, J. Gil-Moltó, S. Karlström, L.R. Falvello, Org. Lett. 5 (2003) 1451–1454.
 [6] M.R. Buchmeiser, T. Schareina, R. Kempe, K. Wurst, J. Organomet. Chem. 634 (2001) 39–46.
- [7] D. Mingji, B. Liang, C. Wang, Z. You, J. Xiang, G. Dong, J. Chen, Z. Yang, Adv. Synth. Cat. 346 (2004) 1669–1673.
- [8] D. Domin, D. Benito-Garagorri, K. Mereiter, J. Fröhlich, K. Kirchner, Organomet 24 (2005) 3957–3965.
- [9] P.R. Sruthi, V. Sarika, A. Suku, A. Krishnan, S. Anas, Inorg. Chimi. Acta 502 (2020) 119305.
- [10] S. Wu, et al., J. Organomet. Chem. 925 (2020) 121496.
- [11] T. Baran, N. Yılmaz Baran, A. Menteş, Appl. Organomet. Chem. 32 (2018) e4076.
- [12] T. Baran, M. Nasrollahzadeh, Carbohyd. Polym. 222 (2019) 115029.
 [13] Z. Tashrifi, S. Bahadorikhalili, H. Lijan, S. Ansari, H. Hamedifard, M. Mahdavi, New J. Chem. 43 (2019) 8930–8938.
- [14] S. Bahadorikhalili, L. Mamani, H. Mahdavi, A. Shafiee, RSC Adv. 5 (2015) 71297.
- [15] A. Schätz, Immobilization of homogeneous catalysts on nanoparticles and their application in semi-heterogeneous catalysis, (2009).
- [16] A.L. Isfahani, I. Mohammadpoor-Baltork, V. Mirkhani, A.R. Khosropour, M. Moghadam, S. Tangestaninejad, R. Kia, Adv. Synth. Cat. 355 (2013) 957–972.
- [17] M. Ghotbinejad, A.R. Khosropour, I. Mohammadpoor-Baltork, M. Moghadam, V. Mirkhani, S. Tangestaninejad, Nanochem. Res. 2 (2017) 230–236.
- [18] M.O. Sydnes, Catalysts 7 (2017) 35-41.
- [19] S. Bahadorikhalili, M. Mahdavi, L. Mamani, A. Shafiee, H. Mahdavi, T. Akbarzadeh, New J. Chem. 42 (2018) 5499.
- [20] W. Wu, C. Jiang, V.A. Roy, Nanoscale 7 (2015) 38-58.
- [21] F.X. Redl, K.S. Cho, C.B. Murray, S. O'Brien, Nature 423 (2003) 968–971.
- [22] C. Corot, P. Robert, J.-M. Idée, M.A. Port, Drug Deliv. Rev. 58 (2006) 1471-1504.
- [23] X.H. Peng, X. Qian, H. Mao, A.Y. Wang, Inter. J. Nanomed. 3 (2008) 311-321.
- [24] A. Marcu, S. Pop, F. Dumitrache, M. Mocanu, C.M. Niculite, M. Gherghiceanu, C.P. Lungu, C. Fleaca, R. Ianchis, A. Barbut, C. Grigoriu, I. Morjan, Appl. Surf. Sci. 281 (2013) 60–65.
- [25] R. Tarasi, M. Khoobi, H. Niknejad, A. Ramazani, L. Mamani, S. Bahadori khalili, A. Shafiee, J. Magn. Magn. Mater. 417 (2016) 451–460.
- [26] F. Cesano, G. Fenoglio, L. Carlos, R. Nisticò, Appl. Surf. Sci. 345 (2015) 175–181.
- [27] C. Baker, C.S.I. Shah, S. Hasanain, J. Magn. Magn. Mater. 280 (2004) 412-418.
- [28] J. Thévenot, H. Oliveira, O. Sandre, S. Lecommandoux, Chem. Soc. Rev. 42 (2013) 7099–7116.
- [29] M. Nikpassand, L.L. Zare Fekri, S. Sanagou, Dyes Pigm. 136 (2017) 140-144.
- [30] M. Nikpassand, Dyes Pigm. 173 (2020) 107936.
- [31] L. Zare Fekri, M. Nikpassand, S. Pourmirzajani, B. Aghazadeh, RSC Adv. 8 (2018) 22313–22320.

- [32] L. Zare Fekri, M. Nikpassand, S. Shariati, B. Aghazadeh, R. Zarkeshvari, N. Norouz pour, J. Organomet. Chem. 871 (2018) 60–73.
 [33] M. Nikpassand, D. Pirdelzendeh, Dyes Pigm 130 (2016) 314–318.
 [34] M. Nikpassand, LL. Zare Fekri, L. Karimian, M. Rassa, Curr. Org. Synth. 12
- (2015) 358-362.
- [35] M. Nikpassand, L.L. Zare Fekri, P. Farokhian, P. Synth, Commun. 45 (2015) 2303-2310.
- [36] M. Nikpassand, L.Z. Fekri, H. Taherkhorsand, Hetero. Commun. 23 (2017) 429-432.
- [37] M. Nikpassand, L.L. Zare Fekri, A. Pourahmad, J. CO₂ Util. 27 (2018) 320-325.

- Journal of Organometallic Chemistry 935 (2021) 121682
- [38] T. Baran, E. Açıksöz, A. Menteş, J. Molecul. Cat. A: Chem. 407 (2015) 47-52.
- [39] T. Baran, A. Menteş, J. Organomet. Chem. 803 (2016) 30–38.
 [40] T. Baran, E. Açıksöz, A. Menteş, Carbohyd. Polym. 142 (2016) 189–198.
- [41] T. Baran, N.Y. Baran, A. Menteş, Inter. J. Biologic. Macromol. 132 (2019) 1147-1154.
- [42] T. Azadbakht, M.A. Zolfigol, R. Azadbakht, V. Khakyzadeh, D.M. Perrin, New J. Chem. 39 (2015) 439-444.
 [43] X. Ma, et al., New J. Chem. 41 (2017) 9631–9638.
 [44] M. Adib, R. Karimi-Nami, H. Veisi, New J. Chem. 40 (2016) 4945–4951.