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Nano-Composite of Magnetite and Hot-Water-Soluble Starch: A Cooperation Resulting in an Amplified Catalytic Activity on Water

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Bis-coumarins and xanthenes are privilege compounds with diverse pharmaceutical activities. Hence, we introduce here an efficient synthesis of 3,3'-aryImethylene-bis-(4-hydroxycoumarin-3-yl) and 1,8-dioxooctahydroxanthenes under soft catalytic activity of magnetite encapsulated hot-water-soluble starch nanoparticles. The greater catalytic efficiency of the bio-derived nano-composite in these syntheses over magnetite and hot-water-soluble starch was ascribed to cooperation of its two components in proton exchange with the reactants. The enhanced proton exchange of the nano-composite was better interpreted as being conducted by its bioorganic shell through switching between the covalent and the coordination bonds it forms with the magnetite core. Application of a nontoxic and superparamagnetic bio-consistent catalyst, simple work-up procedure, and short reaction times are the prominent advantages of the synthetic methods presented here. The nano-catalyst is stable, as can be recycled in the model reactions at least four times without appreciable decrease in its catalytic activity.

glucans. Upon these structural characteristics, amylopectin

molecules gain more stabilization energy than amylose molecules

on crystallization.⁶ As a consequence, the hydroxyl groups arranged

along the backbone of amylose molecules are less involved in

crystalline regions by intermolecular hydrogen bonding and are

reactive groups. Owing to these reactive pendant hydroxyl groups

arranged along its polymeric chains, hot-water-soluble starch

(HWSS) provides a matrix for entrapment and morphological

modification of metal oxides^{7,8} and is endowed with a potential

catalytic activity.^{9,10} However, still due to these reactive hydroxyl

groups, HWSS exists as solid aggregates in most organic solvents.

Aggregation of HWSS chains into insoluble solids makes their

recovery feasible, though, with the expense that a majority of their

reactive hydroxyl groups get buried within the hierarchy of the

Introduction

In recent decades, application of natural polymers as catalysts has captivated much attention.¹ Interests in this topic lie particularly in rise of global consciousness about environmental protection and substitution of the limited resources with those of renewable natural products. Biopolymers are the best candidates to mimic the catalytic action of enzymes in designing new catalysts. Despite this potential advantage, however, a majority of biopolymers are not available inexpensively, require especial precautions to remain native in reaction media, or are decomposed easily by molds and ever-present microorganisms growing on them. Because of these criteria, much interest was drawn towards applications of cellulose and chitosan, the most abundant and reasonably robust bio-derived polymers, which have been applied as backbones or supports in fabrication of many catalysts.² However, these bio-polymers are not available in low molecular weights as easily as starch for production of nano-catalysts.³ Starch is the most abundant polysaccharide, after cellulose, being produced by plants for energy storage and carbon reserve.⁴ Native starch is a heterogeneous mixture of amylose and amylopectin, which differ in molecular size and degree of branching. Flour starch is routinely separated into two fractions by dispersion in hot water. The soluble fraction largely consists of amylose and minute amounts of lower amylopectin molecules, whereas the insoluble ingredient consists entirely of large amylopectin molecules.⁵ Indeed, there are structural reasons behind the solubility differences between these two fractions. Amylose molecules are small and essentially linear α -1,4-glucans with tiny amounts of α -1,6-branch linkages. On the other hand, amylopectin molecules are larger and branched α -1,4- and α -1,6-

hydrogen-bonded chains. The ratio of surface hydroxyl groups relative to those concealed between the H-bonded chains can be increased by scaling the size of HWSS to nano-dimensions. However, on the other hand, decreasing the size of solids to nanoscales will burden their separation from reaction mixtures with the difficulty of fine-filtering or ultracentrifugation. A practical strategy to obviate such laborious separation methods is to support HWSS on magnetic nanoparticles. Typically, nano-magnetic catalysts are resolved from reaction mixtures by using a simple magnet with much more efficiency and convenience than filtration or centrifugation. This makes the so-called magnetic separation costless and promising for green applications. To date, magnetite has been the most widely employed material for preparation of magnetic nanoparticles.^{11,12} This mixed metal oxide is an excellent support for preparation of magnetic nano-catalysts due to being an environmentally compatible compound and possessing a high superparamagnetic property in nano-sizes. Superparamagnetic nano-catalysts are strongly attracted to an applied magnetic field during their magnetic separation from reaction mixtures and gain a New J. Chem., 2017, 00, 1-3 | 1

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good dispersion by lose of their magnetism instantly after removal of the applied field. Magnetite nanoparticle provides a high surface area ornamented with reactive Fe-OH functionalities, which are responsible for its intrinsic catalytic activity¹³⁻¹⁶ and its ability to form stable composites by physical adsorption or chemical anchoring of reactive catalysts.¹⁷⁻¹⁹ Immobilization of catalysts on surface of magnetite nanoparticles is a delicate strategy to approach homogeneous catalysis by using easily isolable heterogeneous catalysts.^{20,21} It was proved that magnetite do not play just as a support in several of such catalytic composites,²² but is able to enhance some catalytic activities via polarization of the supported catalysts ²³ or cooperation in the catalysis by its Fe^{II}/Fe^{III} system.²⁴ Direct coordination and chelation with hydroxy ligands such as carboxylates, phosphates, and catechols again confirm that magnetite nanoparticle is reactive at its surface.¹² In this background, we introduce here HWSS as a reactive ligand for direct assembling a superparamagnetic composite with magnetite nanoparticles and show that the prepared nano-composite is an efficient catalyst in the synthesis of 3,3'-(arylmethylene)-bis-(4hydroxycoumarin) and 1,8-dioxooctahydroxanthenes on water. Xanthenes are interesting heterocycles due to their promising antibacterial, antitumor, anticancer, antiviral and antimicrobial activities.^{25,26} In addition, these compounds are used as lasing molecules and pH sensitive fluorescent materials for incarnation of biomolecules.^{27,28} However, several routes have so far been developed for synthesis of xanthenes, 29-32 these compounds are usually synthesized through the reaction of aldehydes with phenols or cyclic enols by using various catalysts such as p-toluenesulfonic acid,³³ molecular iodine,³⁴ K₅CoW₁₂O₄₀,³⁵ amberlyst-15,³⁶ cation-exchange resins,³⁷ silica sulfuric acid,³⁸ sulfamic acid,³⁹ AcOH-H₂SO₄,⁴⁰ CuS quantum dots,⁴¹ Sc(OTf)₃,⁴² cyanuric chloride,⁴³ $BF_3.SiO_2$, ⁴⁴ Yb(OTf)₃, ⁴⁵ In(OTf)₃, ⁴⁶ P₂O₅/Al₂O₃, ⁴⁷ and ionic liquids. ⁴⁸

Coumarin and its derivatives are widespread in natural products and in the structures of many synthetic bio-active molecules.⁴⁹⁻⁵¹ Some bis-coumarin derivatives strongly inhibit tubulin aggregation and can play essential roles against cancer cells *via* varied mechanisms involving anti-angiogenesis and promotion of apoptosis. These findings tend to classify bis-coumarin derivatives as privileged drug candidates.⁵²⁻⁵⁶ 3,3'-AryImethylene-bis(4hydroxycoumarin-3-yl)s are directly synthesized through the reaction of arylaldehydes and 4-hydroxycoumarin with the aid of various catalysts.⁵⁷⁻⁵⁹ Although, many of these methods have their own advantages, it is still worthwhile to develop alternative expedient and green methods for synthesis of 3,3'-(aryImethylene)bis-(4-hydroxycoumarin-3-yl)s and 1,8-dioxooctahydroxanthenes by using efficient and recyclable catalysts fabricated of bio-compatible materials.

Results and discussion

A one-pot procedure was set up for the preparation of the magnetite nanoparticles encapsulated in hot-water-soluble starch (HWSS). This method delivers the nanoparticles of magnetite through coprecipitation of Fe^{III} and Fe^{II} oxides and disperses them freshly in the matrix of HWSS. Owing to the finite size of the

magnetite nanoparticle, its surface iron atoms form less bridging bonds to other iron atoms of the lattice, so tend to complete their valence by coordination with the hydroxyl groups of HWSS. Similar interactions may lead to formation of covalent C-O-Fe bonds and allow the HWSS to be chemisorbed onto magnetite nanoparticles. Formation of the hybrid nano-composite HWSS@Fe₃O₄ is also rendered by physisorption, mainly through hydrogen bonding, and coordination of amylose hydroxyl groups with the iron atoms present on surface of the magnetite nanoparticles. As a result of these interactions and thinness of the HWSS film sorbed onto Fe₃O₄ nanoparticle, the extent of hydrogen bonding between HWSS molecules is considerably reduced by formation of the composite. Figure 1 is illustrating these facts by comparing the FT-IR spectra of HWSS and HWSS@Fe₃O₄. The IR spectrum of the freeze-dried HWSS displays a very broad O-H stretching band at 3383 cm⁻¹, evidencing that a wide range of hydrogen bonding exists within the bulk amylose. In contrast, similar vibrations for HWSS@Fe₃O₄ appear as two distinguishable and relatively thinner bands at 3408 cm⁻¹ and 3198 cm⁻¹, arising from the non-coordinated hydroxyl groups of the nano-composite and those coordinated with the iron atoms of magnetite, respectively. A similar explanation accounts for the appearance of two O-H bending bands in the IR spectrum of HWSS@Fe₃O₄. Of these, the band at 1520 cm⁻¹ results from a member of O-H bonds in the HWSS layer, which have partially lost their strength on coordination with iron atoms of magnetite, and the band at 1625 cm⁻¹ relates to bending of the non-coordinated OH groups. $^{\rm 60}$ Another notable difference between these spectra occurs in the region of C-O stretching and C-O-H bending at 1154-1022 cm⁻¹. In this region, the bulk HWSS displays multiple bands resulting from varied intermolecular interactions between its molecules and in sharp contrast with HWSS@Fe₃O₄, which rather gives only two simple relevant bands at 1121 cm⁻¹ and 1049 cm⁻¹. Moreover, unlike HWSS, the band characteristic to amorphous starch at nearly 1022 cm⁻¹ is not seen in the IR spectrum of $HWSS@Fe_3O_4$.⁶¹ These findings imply that the magnetite nanoparticles were coated with thin layers of mostly ordered amylose chains. Due to its thinness and ordered structure, the amylose shell of the nano-composite gives also more simple C-H stretching (2919 cm⁻¹ and 2850 cm⁻¹) and CH₂ bending (1422 cm⁻¹ and 1385 cm⁻¹) bands relative to HWSS. It is also worthy to note that unlike bare magnetite nanoparticles, with different surface and inner Fe-O bond-strengths and hence two Fe-O stretching bands,⁶² only one Fe-O band is seen for HWSS@Fe₃O₄.



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Figure 1. (a) The IR spectrum of HWSS@Fe₃O₄, (b) The IR spectrum of HWSS.

Apparently, the surface and inner Fe-O bonds of the magnetite nanoparticles achieve comparable strengths as the surface iron atoms complete their valence by formation of C-O-Fe bonds or coordination to amylose molecules.



Figure 2. The scanning electron microscopy image of HWSS@Fe₃O₄



Figure 3. The transmission electron microscopy image of HWSS@Fe $_3O_4$. The dark points of the magnetite nano-crystallites are shown by the arrows.

Scanning electron microscopy (SEM) was employed to explore the morphology of HWSS@Fe₃O₄. As Fig. 2 shows, the SEM image of this nano-composite displays the spherical morphology and almost mono-dispersion aspect of its nanoparticles. In this SEM image, the nanoparticles are seen as tightly packed bright balls. Next to the SEM image is seen the size distribution histogram of the particles

showing a monomodal Gaussian distribution with the median of 60-80 nm and slight drifts to both larger (144 nm) and smaller (32 nm) sizes. The SEM micrograph substantially differs from that of native starch, which normally consists of unpacked oval or spherical granules with smooth surfaces.⁶³

Further insight into the structure of the nano-composite was obtained from its transmission electron microscopy (TEM) image (Fig. 3). This image displays the very fine crystallites of magnetite as dark points dispersed in the grey matrix of nano-sized HWSS particles. The TEM image illustrates that the nanoparticles seen in the SEM image (Fig. 2) are indeed the conglomerates of Fe₃O₄ nanocrystallites and HWSS in which the magnetite crystallites are majorly separated by thin layers of HWSS surrounding them. It is obvious that HWSS have disassembled the agglomerates of magnetite nanoparticles into smaller sizes and even to their constituent nano-crystallites, presumably by formation of chemical bonds with magnetite. The interaction between the two components is strong enough to overcome the Van der Waals, Hbonding, and the magnetic attractions between the crystallites. By reducing the size of the magnetite nanoparticles, they acquire more and more surface energy which render them to behave as reactive sorbents. In this way, the magnetite nanoparticles serve as seeds for formation of the nano-composite HWSS@Fe₃O₄. The TEM image also displays that the nano-sized conglomerates partially change morphology and divide into smaller conglomerates of HWSS@Fe₃O₄ during dispersion in ethanol used for preparation of the image.



The X-ray powder diffraction pattern of HWSS@Fe₃O₄ (Fig. 4) shows strong and sharp peaks at around $2\theta = 30.5^{\circ}$, 35.8° , 43.5° , 54.2° , 57.3°, and 63.0°, corresponding to the Bragg reflections from (2.2 0), (3 1 1), (4 0 0), (4 2 2), (5 1 1) and (4 4 0) Miller planes in the cubic inverse spinel structure of magnetite, according to the ICDD card number 19-0629. There are no other resolvable peaks in this spectrum except the moderate unindexed peak at 2θ = 74.6°, which previously reported for magnetite⁶⁴ and very weak peaks at 2θ = 17.4°, 22.9°, and 23.8° attributing to reflections from (3 0 1), (1 2 1), and $(4 \ 1 \ 2)$ planes of starch.⁶⁵ The weakness and paucity of the diffraction peaks relevant to HWSS layer indicate that HWSS@Fe₃O₄ nano-particles were constructed from thin films of this polysaccharide. Evidently, the HWSS layer of the nano-composite is too thin to form nano-crystalline whiskers on surface of the magnetite nanoparticles. This means that a majority of the hydroxyl groups pending from the amylose backbone, especially those reside on surface of the composite, are not stabilized by interchain hydrogen bonding and remain as very reactive groups. These reactive hydroxyl groups are expected to enable the nanocomposite to take part efficiently in physical interactions as well as in chemical reactions with substrates. As a consequence of possessing these surface hydroxyl groups, the HWSS@Fe₃O₄ nanoparticles acquire energetic surfaces which force them to be tightly packed in dry solid state (Fig. 2).

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Magnetic susceptibility measurements for Fe₃O₄ and HWSS@Fe₃O₄ at room temperature by using a vibrating sample magnetometer (VSM) led to the hysteresis loops shown in Fig. 5. Accordingly, the saturation magnetization of HWSS@Fe₃O₄ was measured to be 20 emu.g⁻¹, which is significantly higher than that of the pristine Fe₃O₄ nanoparticles (ca. 3 emu.g⁻¹) it was made from. Disassembly of the pristine magnetite nanoparticles to smaller nano-crystallites through interaction with HWSS is the main reason accounting for the higher magnetic saturation of HWSS@Fe₃O₄ with respect to pristine Fe_3O_4 . Upon reduction in size, the multidomain Fe_3O_4 nanoparticles turn into single-domain magnetic nano-crystallites. When subjected to an external magnetic field, these particles develop strong internal magnetization from exchange coupling of electrons within their single-domain and thus become superparamagnetic. This observation is indicative of a chemical separation and dispersion of magnetite nano-crystallites by HWSS and is better conceived as being driven through formation of chemical bonds between these two components. Because of possessing high magnetization susceptibility, HWSS@Fe₃O₄ shows significant magnetic responses to separation from reaction mixtures by using an external permanent magnet. The thermogravimetric analysis (TGA) of HWSS@Fe₃O₄ displayed a two-step thermal degradation trace (Fig. 6). The first step of this thermogram occurs within the temperature range of 42-239 °C and results in a mass loss of about 6.4%. This step corresponds to the early exothermic trace in the differential scanning calorimetry (DSC) curve of the nano-composite. Evaporation of the water molecules, which are

liberated from the nano-composite on formation of additional covalent or coordination bonds between HWSS and magnetite, seems to be the main event of this degradation step. Removal of these water molecules from the nano-composite sets the scene for the amylose chains to adopt a much ordered structure on surface of the magnetite core by formation of more coordination and covalent bonds with the iron atoms. Overall, this step seems to be an inverse gelatinization of amylose, so appears as an exotherm and associates with early dehydration of HWSS@Fe₃O₄ at around 40 °C. The DSC trace is followed instantly by a second exotherm peaking at 329 °C, which coincides with the midpoint of the main mass-loss in the TGA curve. Apparently, the main mass-loss step, which initiates at the onset point of 263 °C, consists of endothermic condensation between hydroxyl groups of amylose chains and the dominant exothermic processes such as oxidative degradation of amylose by magnetite. By the end of this step, totally 13.5% of the mass is lost at around 400 °C and after that the TGA curve goes down smoothly with a small mass-loss attributing to disintegration of amylose layer and the residual char decomposition.⁶⁶ Based on these analyses, the average weight of HWSS shell in the nano-composite is estimated to be ~ 7%.

Owing to the hydrophilic nature of their outermost HWSS layer, the nanoparticles of HWSS@Fe₃O₄ are well dispersed in water. Moreover, the nano-composite is expected to bring the organic reactants in close vicinity together by adsorbing them on its surface, where they experience the catalytic effect of the reactive surface hydroxyl groups especially those having significant acidity due to coordination with the iron atoms of magnetite. In this viewpoint, we aimed at exploring the catalytic efficiency of the nanocomposite in the synthesis of 3,3'-arylmethylene-bis-(4hydroxycoumarin-3-yl) and 1,8-dioxooctahydroxanthenes. In order to find an optimum condition, synthesis of 3,3'-(4chlorophenyl)methylene-bis-(4-hydroxycoumarin-3-yl) 4d and 3,4,6,7-tetrahydro-3,3,6,6-tetramethyl-9-(4-chlorophenyl)-2H-

xanthene-1,8(5H,9H)-dione **5b** via the pseudo three-component reactions of 4-chlorobenzaldehyde **1** with, respectively, 4-hydroxycoumarin **2** and 5,5-dimethyl-1,3-cyclohexadione **3** (dimedone) were chosen as the models to be examined in the presence of various amounts of HWSS@Fe₃O₄ in different solvents and at varying temperatures.

According to the results tabulated in Table 1, only moderate vields of the desired products 4d and 5b are formed in the absence of any catalyst even after prolong refluxing in water (entry 1). The best results in terms of yields and reaction times are obtained by performing the trial reactions in refluxing water and using the bioderived nano-composite HWSS@Fe3O4 as catalyst (see also the electronic supplementary information, ESI). Notably, the same reaction mixtures give very low yields in volatile and non-hydroxy solvents (see ESI). Certainly, solvent plays crucial roles in these synthetic methods such as mass transfer, lowering the energy gap between reactants and transition states, dispersion of the nanocomposite, and removal of products from surface of the catalyst to disrobe its catalytic sites. The supremacy of water is particularly attributed to sorption of this solvent onto HWSS@Fe₃O₄, leading to fine dispersion of the nano-catalyst and assisted desorption of the products from its surface. Upon adsorption of water molecules, the nano-composite acquires a greater density of fixed surface hydroxyl groups to carry out its catalytic action. It is noteworthy that HWSS and Fe_3O_4 are able to realize the trial syntheses within reasonable times in refluxing water (entries 12, 13), however, with lower efficiencies than is met by using the same quantity of their nanocomposite HWSS@Fe₃O₄.

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After these preliminary evaluations of the nano-catalyst, we set out to explore the scope of the method by employing a variety of arylaldehydes **1** to synthesize 3,3'-arylmethylene-bis-(4hydroxycoumarin-3-yl)s **4** and 2*H*-xanthene-1,8(5*H*,9*H*)-diones **5** under the optimal conditions set forth above. As the results show (Table 2), this method can inherently tolerate the various functional groups present at different positions of the reacting arylaldehydes. Nevertheless, it is noticeable that electron-rich arylaldehydes and particularly those bearing sterically demanded groups at ortho position react slowly and give slightly lower yields than the electron-deficient arylaldehydes. A plausible mechanism for the catalytic role of HWSS@Fe₃O₄ was typically presented in Scheme 1. Presumably, the reactions are catalyzed *via* a cascade of proton exchange that the nano-composite makes with the reacting species adsorbed on its surface. The supremacy of HWSS@Fe₃O₄ over HWSS, magnetite, and the hydroxy solvents (H₂O and Et-OH) in catalysis of the above reactions may be referred to cooperation of its bioorganic and inorganic components.

 Table 1. Determining the optimized amounts of the catalyst, solvent, and temperature for the trial synthesis of 3,3'-(4-chlorophenyl)methylene-bis-(4-hydroxycoumarin-3-yl) 4d and 3,4,6,7-tetrahydro-3,3,6,6-tetramethyl-9-(4-chlorophenyl)-2H-xanthene-1,8(5H,9H)-dione 5b



Entry	Catalyst ^a	Charged	Solvent	Temp (°C)	Product 4d		Product 5b	
					Time	Yield (%) ^a	Time	Yield (%) ^a
1			H ₂ O	90	35 min	23	30 min	9
2	HWSS@Fe₃O₄	15 mg	H ₂ O	80	35 min	84	30 min	82
3	HWSS@Fe ₃ O ₄	15 mg	H ₂ O	90	35 min	90	30 min	87
4	HWSS@Fe₃O₄	15 mg	H ₂ O	90	45 min	90	40 min	87
5	HWSS@Fe ₃ O ₄	15 mg	H ₂ O	100	35 min	88	30 min	86
6	HWSS@Fe₃O₄	15 mg	H₂O/EtOH ^b	90	35 min	82	30 min	71
7	HWSS@Fe ₃ O ₄	15 mg	H ₂ O	r.t.	35 min	trace	30 min	
8	HWSS@Fe₃O₄	15 mg		90	35 min	trace	30 min	
9	HWSS@Fe ₃ O ₄	20 mg	H ₂ O	90	35 min	90	30 min	87
10	HWSS@Fe ₃ O ₄	10 mg	H ₂ O	90	35 min	81	30 min	63
11	HWSS@Fe ₃ O ₄	5 mg	H ₂ O	90	35 min	64	30 min	28
12	HWSS	15 mg	H ₂ O	90	35 min	53	30 min	56
13	Fe ₂ O ₄	15 mg	H ₂ O	90	35 min	41	30 min	36

Reaction conditions: 4-hydroxycoumarin (2 mmol) and 4-chlorobenzaldehyde (1 mmol) in distilled water (2 mL). Dimedone (2 mmol) and 4-chlorobenzaldehyde (1 mmol) in distilled water (2 mL). ^aYields of the isolated products (± 2%), averaged over three experiments. ^bAqueous ethanol 50%.

 Table 2. The viability of the method by using different substituted arylaldehydes^a

	O Ar O 5	0 3 HWSS@Fe ₃ O ₄ H ₂ O/90 °C	1 Ar-CHO HW55@Fe ₃ O ₄ H ₂ O/90 °C	OH Ar	OH 4	
Product	Ar	Time (min)	Yield ^b (%) —	M.P. (°C)		– Ref.
		(11111)		Observed	Reported	
4a	C ₆ H ₅	30	92	229-230	228 - 230	[58]
4b	4-NO ₂ C ₆ H ₄	25	94	231-235	232 - 234	[58]
4c	2-CIC ₆ H ₄	50	79	196-200	198-199	[70]
4d	4-CIC ₆ H ₄	35	90	256-258	258 - 259	[71]
4e	2-FC ₆ H ₄	40	83	213-218	215-217	[72]
4f	4-CH ₃ OC ₆ H ₄	43	80	248-249	249 - 250	[71]
4g	$4-CH_3C_6H_4$	40	86	264-269	269 - 270	[71]
4h	3-CH ₃ OC ₆ H ₄	35	85	235-240	238	[57]
5a	C ₆ H₅	35	88	205-209	201-203	[67]
5b	4-CI-C ₆ H ₄	30	87	223-226	231-233	[67]
5c	3,4-(MeO) ₂ -C ₆ H ₃	40	73	182-186	184-186	[68]
5d	4-F-C ₆ H ₄	35	84	258-261	259-260	[73]
5e	4-NO ₂ C ₆ H ₄	30	86	227-231	224-226	[67]
5f	3-MeO-C ₆ H ₄	35	78	181-185	177-180	[54]
5g	2-MeO-C ₆ H ₄	40	76	207-212	209-210	[73]
56		20	00	220 224	220	1601

^aReaction conditions: An arylaldehyde (1 mmol), 4-hydroxycoumarin (2 mmol) or dimedone (2 mmol), HWSS@Fe₃O₄ (15 mg) in distilled water (2 mL) at 90 °C. ^b Isolated yields (± 2%), averaged over three experiments.



Scheme 1. A proposed push-pull proton donating and accepting mechanism for HWSS@Fe₃O₄.

Certainly, the proton exchange is conducted through hydrogen bonding and its efficiency can be better interpreted as involving interchanges between the covalent and the coordination bonds which HWSS forms with the iron atoms of magnetite.⁷⁴ Upon Haccepting hydrogen bonding with the nano-composite, the reacting aldehydes 1 become activated toward nucleophilic addition and the Fe-coordinated hydroxyl bond I involved in this H-bonding turns into C-O-Fe covalent bond II. On the other hand, dimedone and 4hydroxycoumarin gain an enhanced nucleophilic character upon Hdonating Hydrogen bonding with the nano-composite, leading the C-O-Fe covalent bond II involved in this hydrogen bonding to switch into a coordination bond I. A cluster of water molecules are expected to rely the proton exchange between the proton-donating I and proton-accepting II sites of the nano-catalyst.⁷⁵ Similar concerted proton transfers are conceivable for the Michael additions of the condensates 6 and 7 with the second molecule of the enolic nucleophile (2 or 3) and likewise for a Thorpe-Ziegler type cyclization of the intermediate 8 (Scheme 1). The syntheses go through nucleophilic addition of 4-hydroxycoumarin 2 or dimedone 3 on the aldehyde 1 followed by dehydration to give the intermediate condensates 6 and 7, respectively. Nucleophilic addition of 6 with a second molecule of 4-hydroxycoumarin in a Michael manner gives the product 4. The intermediate 7 similarly undergoes a Michael addition with the second enolic molecule of dimedone to give the adduct 8 which cyclocondenses through a Thorpe-Ziegler type cyclization to deliver the product 5. All of these step reactions are typically nucleophilic additions in nature, so can be catalysed by the dual H-donating-accepting functions of HWSS@Fe₃O₄. Upon adsorption on surface of this nanocomposite, the nucleophiles and the electrophiles gain more activities by proton removing or proton accepting actions of the catalyst, respectively. In overall, HWSS@Fe₃O₄ completes the proton transfer cycle from the nucleophiles to the electrophiles without undergoing any total structural change. That is, in each H-transfer cycle, HWSS@Fe₃O₄ do not acquire any momentary protonated or

deprotonated functional group. Therefore, the net enthalpy of proton transfers by HWSS@Fe₃O₄ seems to be determined only by the reactants and presumably the supremacy of HWSS@Fe₃O₄ over HWSS seems to be due to running the concerted proton transfers between the reactants with less activation energy.



Figure 7. Reusability tests for the catalyst in the model syntheses: a) 1,8-dioxooctahydroxanthene 5b and b) 3,3'-bis-coumarin 4d

A beneficial characteristic of the nano-catalyst is the ease with which it can be separated from the reaction mixtures. Thus, the recyclability of the nano-catalyst in the model reaction between 4-hydroxycoumarin and 4-cholorobenzaldehyde was tested. After completion of the reaction, ethanol was added, while stirring, to the reaction mixture and the hot solution of the product was separated from the nano-catalyst by decantation on a permanent magnet. The separated catalyst was washed once again with hot ethanol and then dried before being reused in the next cycle of the same model reaction. As figure 7 shows, the catalytic activity of the nano-composite was almost not changed even after four times consecutive recycling in the same model reactions. This finding can be evidenced to the intact structure of the recycled nano-catalyst, as is further supported by FT-IR spectroscopy that displays no

Journal Name

appreciable changes in the pattern of vibrational bands with respect to that of the fresh one. Separate experiments showed that HWSS is not leached sensibly from the nano-composite by boiling water. Interestingly, addition of iodine to the water boiled with HWSS@Fe₃O₄ did not turn its colour into blue. Alternative tests showed that iodine is nearly completely sorbed from a watery solution by the suspended nanoparticles of HWSS@Fe₃O₄. As another evidence of stability, the nano-composite showed nearly the same diffuse reflectance spectra (DRS) before and after a prolong refluxing in water (Fig. 8). These facts are indicative of strong binding between magnetite nanoparticles and HWSS and lend support to the postulate of covalent bonds between these two components.



Figure 8. The DRS spectra of the iodine-complexed nano-composite before (a) and after 6 h refluxing (b) in water.

Table 3. A comparative catalytic efficiency of HWSS@Fe $_3O_4$ in the synthesis of the model products 4b and 5b.

Ent	Prd.	Catalyst	Conditions	Time	Yield %	Ref.
1		On-water (50 mL)	95 °C	4.5 h	98	[76]
2		Piperidine (a few drops)	r.t. /EtOH (10 mL)	4 h	96	[57]
3	4b	SDS (20 mol%),	60 °C / water	3 h	98	[77]
4		SiO ₂ Cl (3 g)	40 °C /CH2Cl2	3.5 h	85	[78]
5		HWSS@Fe ₃ O ₄ (15 mg)	90 °C /H ₂ O	25 min	94	This work
6		Amberlyst-15 (200 mg)	reflux/ CH ₃ CN	5 h	94	[79]
7		TMSCl (20 mmol)	reflux/ CH ₃ CN	8 h	81	[80]
8	5b	Cellulose sulfonic acid (0.05 g)	110 °C/ solvent- free	5 h	94	[81]
9		[Hmim]TFA (0.1 g)	80 °C/ solvent- free	5 h	84	[82]
10		HWSS@Fe ₃ O ₄ (15 mg)	90 °C/ H ₂ O	30 min	87	This work

An additional noteworthy observation is that, unlike HWSS, the bioderived nano-composite sensibly resists toward a short-term biodegradation by molds.

Comparison of HWSS@Fe₃O₄ with some previously reported catalysts in the synthesis of the model products **4b** and **5b** are presented in Table 3. This table is ranking HWSS@Fe₃O₄ as one of the most effective catalysts for the pseudo three-component syntheses discussed above. It is obvious that the "on water" synthesis of **4b** at 95 °C takes place one order of magnitude slower than the method of using HWSS@Fe₃O₄ as catalyst in the same conditions (compare entries 1 and 5). All the previous methods based on using the other catalysts of this table similarly give the products **4b** and **5b** within much longer times with respect to the protocol presented here. Although some of the catalysts have the

advantage of working at lower temperatures, they are either sensitive to moisture (entries 4 and 7) or cannot be separated from the reaction mixture and solvent (entries 2 and 3) as easily as HWSS@Fe₃O₄. Other methods employ either expensive or non-biocompatible materials (entries 6 and 9).

Conclusions

In summary, encapsulation of magnetite nanoparticles with hotwater-soluble starch provided the bio-derived nano-composite HWSS@Fe₃O₄. The IR spectrum of this bioorganic-inorganic hybrid can be better interpreted as exhibiting strong coordination and covalent bonds between its two components. Visual monitoring by iodine test and an alternative DRS study displayed no sensible leaching of starch from the magnetic support even after prolong refluxing of the nano-composite in water. This finding can be evidenced to formation of covalent and coordination bonds between HWSS and the iron metals of magnetite core and so delineates an altered chemical property for the nano-composite with respect to its components. Indeed, the nano-composite has shown better catalytic activities than pure HWSS and pristine Fe₃O₄ nanoparticles in the pseudo three-component syntheses of 3,3'arylmethylene-bis-(4-hydroxycoumarin-3-yl) and 1.8 dioxooctahydroxanthenes in water. The catalytic activity of $HWSS@Fe_{3}O_{4}\xspace$ was suggested to be arisen from its prominent proton-donating and proton-accepting capacity. Certainly, these proton exchange occur on surface of the HWSS coating and seem to be amplified by interchanges between the covalent and coordination bonds which it makes with the iron atoms at surface of the magnetite core. The nano-catalyst is simply recovered by a permanent magnet and can be reused several times without significant decrease in catalytic activity.

Experimental

General

Wheat starch and other materials were purchased from Merck and used without further purification. FT-IR spectra were received in KBr wafers on a Shimadzu FT-IR 8300 spectrophotometer. X-ray powder diffraction (XRD) analysis was obtained on a Panalytical X'Pert Pro X-ray diffractometer using Cu-Kα radiation of wavelength 1.54 Å. Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) data were obtained on a SETARAM thermal analyzer. The thermal behavior of the specimens was scanned from 40 °C to 600 °C at the rate of 20 °C/min under Helium gas flow. The surface morphologies and elemental analysis of HWSS@Fe₃O₄ were determined by a scanning electron microscope equipped with an energy dispersive X-ray analyzer (SEM-EDX, VEGA3 TESCAN). The magnetic properties were measured at room temperature using a BHV-55 vibrating sample magnetometer. The transmission electron microscopy (TEM) images were taken on a Zeiss - EM10C microscope at acceleration voltage of 100 kV. The sample was dispersed in deionized water by sonication for 10 min with Misonix-S3000 ultrasonicator (QSonica, Newtown, CT) before coating on formvar carbon coated grid Cu mesh 300.

Preparation of hot-water-soluble starch (HWSS) for coating of Fe $_3O_4$ nanoparticles.

HWSS was prepared using a modification of a previously reported method.⁸³ Thus, wheat starch (0.5 g) was wetted with ethanol (95%, 1 mL) in a 100 mL conical flask. Redistilled water (50 mL) was added to this flask and the slurry heated at 98 °C for 15 min with constant stirring. For separation of hot-water-insoluble starch (HWIS) from

the supernatant solution of the HWSS fraction, the resulting suspension was centrifuged at 3000 rpm for 5 min. The separated solution was concentrated under reduced pressure by using a rotary evaporator operating at 50 °C. Complete dryness of the extract was accomplished through freeze-drying of the resulting syrup at -30 °C for 24 hours.

For preparation of HWSS@Fe₃O₄ nanoparticles, a mixture of FeCl₂•4H₂O (0.5 g) and FeCl₂•6H₂O (1.3 g) was dissolved in a solution of HCl (0.33 M, 6.5 mL). To this solution, while stirring vigorously, was added dropwise a solution of NaOH (3.74 g) in H₂O (62.5 mL). The resulting suspension of Fe₃O₄ nanoparticles was sonicated at room temperature for 1 h. This suspension of pristine Fe₃O₄ nanoparticles was added to a solution obtained by dissolution of HWSS (0.03 g) in redistilled water (15 mL) via rapid mechanical stirring (10 min) at 50 °C. The combined fluid was then refluxed at 60 °C for 6 h. At this end, the resulting nanoparticles of $\mathsf{HWSS}@\mathsf{Fe_3O_4}$ were collected on an external magnet, rinsed thoroughly with distilled water and finally dried in an oven at 50 °C.

General procedure for synthesis of 3,3'-arylmethylene-bis-(4hydroxycoumarin-3-yl) and 1,8-dioxooctahydroxanthenes.

For the synthesis of 3,3'-(arylmethylene)-bis-(4-hydroxycoumarin-3yl)s and 1,8-dioxooctahydroxanthenes, a mixture of 4hydroxycoumarin/ or dimedone (2 mmol), an aldehyde (1 mmol), HWSS@Fe₃O₄ (0.015 g) and H₂O (2 mL) was stirred at 90 °C. After completion of the reaction (as monitored by TLC on silica gel using ethyl acetate/n-hexane 1/1 as eluent), ethanol (95%, 5 mL) was added with stirring to the reaction vessel and the supernatant hot solution of the product was decanted on a magnet (0.7 Tesla). Washing of the nano-composite, remained in the vessel, was repeated with another portion of hot ethanol (95%, 3 mL) and the combined ethanolic extract was cooled at 4 °C to make the product crystalize completely. The solid product was filtered and dried at 50 °C. All the known products gave the physical data consistent with those reported in the literature and the authentic samples prepared through previously reported methods. The separated nano-catalyst was dried at 60 °C before using in the next reaction.

Conflicts of interest

There are no conflicts of interest to declare.

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References

- 1 K. Rajender Reddy, K. Rajgopal, C. Uma Maheswari, M. L. Kantam, New J. Chem., 2006, **30**, 1549.
- 2 Z. Liu, H. Wang, B. Li, C. Liu, Y. Jiang, G. Yu, X. Mu, J Mater. Chem., 2012, 22, 15085.
- L. Qi, Z. Luo, X. Lu, Green Chem., 2018, 20, 1538. 3
- S. Pérez, P. M. Baldwin, D. J. Gallant, in Starch: Chemistry and Technology, J. BeMiller and R. Whistler, Eds, Third Edition, 2009. Elsevier Inc.
- 5 R. Chinnaswamy, K. R. Bhattacharya, Starch, 1986, 38, 51.
- R. P. Cuevas, R. G. Gilbert, M. A. Fitzgerald, Carbohydr. 6 Polym., 2010, **81**, 524.
- S. Chancharoenrith, C. Kamonsatikul, M. Namkajorn, S. 7 Kiatisevi, E. Somsook, Carbohydr. Polym., 2015, 117, 319.

- 8 B. Boury, S. Plumejeau, Green Chem., 2015, 17, 72.
- K. Rad-Moghadam, N. Dehghan, J. Mol. Catal. A: Chem., 2014, 392, 97.
- 10 F. Buazar, M. H. Baghlani-Nejazd, M. Badri, M. Kashisaz, A. Khaledi-Nasab, F. Kroushawi. Starch. 2015. DOI: 10.1002/star.201500347.
- 11 R. K. Sharma, S. Dutta, S. Sharma, R. Zboril, R. S. Varma, M. B. Gawande, Green Chem., 2016, 18, 3184.
- 12 L. M. Rossi, N. J. S. Costa, F. P. Silva, R. Wojcieszak, Green Chem., 2014, 16, 2906.
- 13 M. M. Mojtahedi, M. S. Abaee, A. Rajabi, P. Mahmoodi, S. Bagherpoor, J. Mol. Catal. A: Chem., 2012, 361-362, 68.
- 14 F. Shi, M. K. Tse, M. M. Pohl, A. Bruckner, S. Zhang, M. Beller, Angew. Chem., Int. Ed., 2007, 46, 8866.
- 15 Y. Li, F. Ma, X. Su, C. Sun, J. Liu, Z. Sun, Y. Hou, Catal. Commun., 2012, 26, 231.
- 16 A. Dhakshinamoorthy, S. Navalon, M. Alvaro, H. Garcia, Chemsuschem, 2012, 5, 46.
- 17 T. J. Yoon, W. Lee, Y. S. Oh, J. K. Lee, New J. Chem., 2003, 27, 227.
- 18 M. Ikenberry, L. Peña, D. Wei, H. Wang, S. H. Bossmann, T. Wilke, D. Wang, V. R. Komreddy, D. P. Rillema, K. L. Hohn, Green Chem. 2014, 16, 836.
- 19 Y. Long, K. Liang, J. Niu, X. Tong, B. Yuan' J. Ma, New J. Chem., 2015, 39, 2988.
- 20 X. Zheng, S. Luo, L. Zhang, J. P. Cheng, Green Chem., 2009, **11**. 455
- 21 Y. Lin, H. Chen, K. Lin, B. Chen, C. Chiou, J. Environ. Sci., 2011, 23. 44.
- 22 C. Kamonsatikul, T. Khamnaen, P. Phiriyawirut, S. Charoenchaidet, E.Somsook, Catal. Commun., 2012, 26, 1.
- 23 Y. Lee, M. A. Garcia, N. A. Frey Huls, S. Sun, Angew. Chem., Int. Ed., 2010, 49, 1271.
- 24 W. Sun, Q. Li, S. Gao, J. K. Shang, Appl. Catal., B, 2012, 125, 1.
- 25 J. J. Yu, L. M. Wang, J. Q. Liu, F. L. Guo, Y. Liu, N. Jiao, Green Chem., 2010, 12, 216.
- 26 (a) G. W. Rewcastle, G. J. Atwell, L. Zhuang, B. C. Baguley, W. A. Denny, J. Med. Chem., 1991, 34, 217. (b) N. Mulakayala, P. V. N. S. Murthy, D. Rambabu, M. Aeluri, R. Adepu, G. R. Krishna, C. Malla Reddy, K. R. S. Prasad, M. Chaitanya, C. S. Kumar, M. V. Basaveswara Rao, M. Pal, Bioorg. Med. Chem. Lett., 2012, 22, 2186. (c) J. M. Jamison, K. Krabill, A. Hatwalkar, E. Jamison, C. Tsai, Cell Bio. Int. Rep., 1990, 14, 1075.
- 27 C. G. Knight, T. Stephens, Biochem. J., 1989, 258, 683.
- 28 M. Ahmad, T. A. King, D. K. Ko, B. H. Cha, J. Lee, J. Phys. D: Appl. Phys., 2002, 35, 1473.
- 29 D. Quintás, A. García, D. Domínguez, Tetrahedron Lett., 2003, **44**, 9291.
- 30 D. W. Knight, P. B. Little, J. Chem. Soc. Perkin Trans. 1, 2001, 14, 1771.
- 31 A. Jha. J. Beal. Tetrahedron Lett., 2004, 45, 8999.
- 32 G. Casiraghi, G. Casnati, M. Cornia, Tetrahedron Lett., 1973, 14. 679.
- 33 A. R. Khosropour, M. M. Khodaei, H. Moghannian, Synlet 2005. **6**. 955.
- 34 B. Das, B. Ravikanth, R. Ramu, K. Laxminarayana, B. V. Rao, J. Mol. Catal. A: Chem., 2006, 255, 74.
- 35 L. Nagarapu, S. Kantevari, V. C. Mahankhali, Catal. Commun., 2007, 8, 1173.
- 36 S. Ko, C. F. Yao, Tetrahedron Lett., 2006, 47, 8827.
- 37 B. Patil, R. P. Bhat, S. D. Samant, Synth. Commun., 2006, 36 2163.
- 38 H. R. Shaterian, M. Ghashang, A. Hassankhani, Dyes Pigm., 2008. 76. 564.
- 39 B. Rajitha, B. Sunil Kumar, Y. Thirupathi Reddy, P. Narsimha Reddy, N. Sreeni-Vasulu, Tetrahedron Lett., 2005, 46, 8691.
- 40 R. J. Sarma, J. B. Baruah, Dyes Pigm., 2005, 64, 91.

- 41 P. Bansal, G. Ram Chaudhary, N. Kaur, S. K. Mehta, *RSC Adv.*, 2015, **5**, 8205.
- 42 R. Singh, G. Panda, Org. Biomol. Chem., 2010, 8, 1097.
- 43 M. A. Bigdeli, M. M. Heravi, G. H. Mahdavinia, Catal. Commun., 2007, 8, 1595.
- 44 B. F. Mirjalili, A. H. Bamoniri, A. Akbari, *Tetrahedron Lett.*, 2008, **49**, 6454.
- 45 W. Su, D. Yang, C. Jin, B. Zhang, *Tetrahedron Lett.*, 2008, 49, 3391.
- 46 S. Urinda, D. Kundu, A. Majee, A. Hajra, *Heteroat. Chem.*, 2009, **20**, 232.
- 47 A. Zarei, A. R. Hajipour, L. Khazdooz, *Dyes Pigm.*, 2010, **85** 133.
- 48 K. Rad-Moghadam, S. C. Azimi, J. Mol. Catal. A: Chem. 2012, 363-364, 465-469.
- 49 34 J. H. Lee, H. B. Bang, S. Y. Han, J-G. Jun, Tetrahedron Lett., 2007, 48, 2889.
- 50 35 R. D. R. S. Manian, J. Jayashankaran, R. Raghunathan, *Tetrahedron Lett.*, 2007, **48**, 1385.
- 51 36 H. Zhao, N. Neamati, H. Hong, H. Hong, A. Mazumder, S. Wang, S. Sunder, G. W. A. Milne, Y. Pommier, T. R. Burke Jr, J. Med. Chem., 1997, 40, 242.
- 52 N. Au, A. E. Rettie, Drug Metab. Rev., 2008, 40, 355.
- 53 M. K. Li, J. Li, B. H. Liu, Y. Zhou, X. Li, X. Y. Xue, Z. Hou, X. X. Luo, *Eur. J. Pharmacol.*, 2013, **721**, 151.
- 54 F. Pérez-Cruz, S. Serra, G. Delogu, M. Lapier, J. D. Maya, C. Olea-Azar, L. Santana, E. Uriarte, *Bioorg. Med. Chem. Lett.*, 2012, **22**, 5569.
- 55 S. N. Kim, N. H. Kim, Y. S. Park, H. Kim, S. Lee, Q. Wang, Y. K. Kim, *Biochem. Pharmacol.*, 2009, **77**, 1773.
- 56 H. Madari, D. Panda, L. Wilson, R. S. Jacobs, *Cancer Res.*, 2003, **63**, 1214.
- 57 K. M. Khan, S. Iqbal, M. A. Lodhi, G. M. Maharvi, Z. Ullah, M.
 I. Choudhary, A. Rahman, S. Perveen, *Bioorg. Med. Chem. Lett.*, 2004, **12**, 1963.
- 58 M. Kidwai, V. Bansal, P. Mothsra, S. Saxena, R. K. Somvanshi, S. Dey, T. P. Singh, J. Mol. Catal. A: Chem., 2007, 268, 76.
- 59 J. M. Khurana, S. Kumar, Tetrahedron Lett., 2009, 50, 4125.
- 60 M. Božič, S. Gorgieva, V. Kokol, Carbohydr. Polym. 2012, 89, 854.
- 61 O. Sevenou, S. E. Hill, I. A. Farhat, J. R. Mitchell, Int. J. Biol. Macromol., 2002, 31, 79.
- 62 M. Ma, Y. Zhang, W. Yu, H. Shen, H. Zhang, N. Gu, *Colloids Surf.*, A 2003, **212**, 219.

- 63 L. Hu, Y. Zheng, Y. Peng, C. Yao, H. Zhang, Int. J. Biol. Macromol., 2016, 86, 105.
- 64 F. Ning, T. Qiu, Q. Wang, H. Peng, Y. Li, X. Wu, Z. Zhang, L. Chen, H. Xiong, *Food Chem.*, 2017, **221**, 1797.
- 65 A. Lopez-Rubio, B. M. Flanagan, E. P. Gilbert, M. J. Gidley, *Biopolymers*, 2008, **89**, 761.
- 66 M. S. Ellid, Y. S. Murayed, M. S. Zoto, S. Musié, S. Popovié, J. Radioanal. Nucl. Chem., 2003, **258**, 299.
- 67 A. John, P. J. P. Yadav, S. Palaniappan, J. Mol. Catal. A: Chem., 2006, 248, 121.
- 68 M. T. Maghsoodlou, S. M. Habibi-Khorasani, Z. Shahkarami, N. Maleki, M. Rostamizadeh, *Chin. Chem. Lett.*, 2010, **21**, 686.
- 69 M. A. Bigdeli, F. Nemati, G. H. Mahdavinia, H. Doostmohammadi, *Chin. Chem. Lett.*, 2009, **20**, 1275.
- 70 S. Qadir, A. Ahmad Dar, K. Zaman Khan, Synth. Commun., 2008, 38, 3490.
- 71 G-X. Gong, J-F. Zhou, L-T. An, X-L. Duan, S-J. Ji, Synth. Commun., 2009, **39**, 497.
- 72 B. Karmakar, A. Nayak, J. Banerji, *Tetrahedron Lett.*, 2012, 53, 4343.
- 73 F. Shirini, M. Abedini, R. Pourhasan, *Dyes Pigm.*, 2013, **99**, 250.
- 74 S. Okumoto, S. Yamabe, J. Non-Cryst. Solids, 2001, 291, 167.
- 75 M. J. Lee, J. S. Kang, Y. S. Kang, D. Y. Chung, H. Shin, C. Ahn, S. Park, M. Kim, S. Kim, K. Lee, Y. Sung, ACS Catal., 2016, 6, 2398.
- 76 A. D. Gupta, S. Samanta, R. Mondal, A. K. Mallik, Bull. Korean Chem. Soc., 2012, 33, 4239.
- 77 H. Mehrabi, H. Abusaidi, J. Iran. Chem. Soc., 2010, 7, 890.
- 78 R. Karimian, F. Piri, A. A. Safari, S. J. Davarpanah, J. Nanostruct. Chem., 2013, 3, 52.
- 79 64 B. Das, P. Thirupathi, I. Mahender, V. S. Reddy, Y. K. Rao, J. Mol. Catal. A: Chem., 2006, 247, 233.
- 80 65 S. Kantevari, R. Bantu, L. Nagarapu, ARKIVOC, 2006, 16, 136.
- 81 66 H. A. Oskooie, L. Tahershamsi, M. M. Heravi, B. Baghernejad, E. J. Chem., 2010, 7, 717.
- 82 67 M. Dabiri, M. Baghbanzadeh, E. Arzroomchilar, Catal. Commun., 2008, 9, 939.
- 83 68 R. M. Ward, Q. Gao, H. de Bruyn, R. G. Gilbert, M. A. Fitzgerald, *Biomacromolecules*, 2006, **7**, 866.

Graphical Abstract

Nano-Composite of Magnetite and Hot-Water-Soluble Starch: A Cooperation Resulting in an Amplified Catalytic Activity on Water

Sanaz Razi-Kazemi, Kurosh Rad-Moghadam, and Saeedeh Tourchi-Roudsari

The composite of hot-water-soluble starch and magnetite nanoparticles appeared as an efficient catalyst for the pseudo threecomponent synthesis of bis-coumarins and xanthenes. The greater catalytic activity of the nano-composite over magnetite and soluble starch in these syntheses is attributed to a cooperation between the two components of the composite in conducting proton exchanges with the reactants.

