Hydrothermal biosynthesis of chromium sulphide nanoparticles using egg yolk and its catalytic activity in degradation of dyes

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Abstract
Wastewater generated from industries consists of non-fixed dyes contributing to environmental pollution. Use of nanotechnology is being exploited for efficient degradation of dyes. Chromium sulphide nanoparticles have potential biological applications such as ion-selective membrane electrodes and probes for colocalization of membrane proteins. The biosynthesis of chromium sulphide nanoparticles by a high temperature hydrothermal approach has been reported herewith using chromium trioxide as the source of chromium and egg yolk (yellow) as the natural source of sulphur. Catalytic efficiency of chromium sulphide nanoparticles calcinated at 400 °C and 1000 °C has been tested for degradation of congo red, eosin Y, methylene blue as well as bromo cresol green of as prepared solutions and at acidic pH (pH 2.0).

Introduction
Environmental pollution is caused by wastewater generated by industries. Wastewater from the textile industries consists of significant quantities of non-fixed dyes. These non-fixed dyes as well as their intermediate products are known to be carcinogenic [1]. Out of the total production of dyes in the world; about 15% contributes to the effluents released from textile industries [2]. The release of dyes into the environment has caused water pollution as well as eutrophication ultimately damaging the aquatic life. To avoid this, processing of effluents is necessary before releasing them into the environment. Various physical, chemical as well as biological methods have been employed to remove these dyes from the effluents [3]. However, most of these methods have proven to be inefficient in treating dyes. Therefore, there is need for newer technologies ensuring effective treatment of dyes. Use of nanotechnology in waste water treatment has been emerging in recent times. Effectivity of nanoparticles in catalytic dye degradation has been observed by virtue of the characteristic properties shown by nanoparticles [4].

Chromium compounds are of great interest from the point of view of several industrial applications. They are used in metal surface treatment to prevent metallic corrosion, and also used as catalysts for a large variety of chemical reactions including alkylation, oxidation, hydrogenation, isomerization, polymerization, and dehydrogenation. They are extensively used in textile industry as oxidants to improve wash fastness of cotton fabric. They are also used in re-circulating water systems in cooling towers and automobiles to inhibit corrosion. They are being used increasingly as antiknock agents in unleaded gasolines.

Chromium sulphide belongs to a class of inorganic non-stoichiometric chromium compounds with formulas in the range of CrS to Cr0.67S (corresponds to Cr2S3). This compound is not extensively studied as found from literature survey. However, chromium sulphide nanoparticles have potential biological applications such as ion-selective membrane electrodes [5] and probes for co-localization of membrane proteins as cited in the literature [6]. This kind of study will translate them as model systems for new novel potential applications in the field of catalysis, sensing and diagnostics. There are very few reports on the synthesis of chromium sulphide

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nanomaterials. Among these, Hussain et al synthesized Cr$_2$S$_3$ nanorods from single and multi-source precursors and applied as photocatalysts [7]. Loukanov and Emin synthesized biotinylated chromium sulphide nanoparticles employing a microemulsion based method [6]. However, all these methods are not environmental friendly due to involvement of toxic chemicals like surfactant. Therefore, alternative eco-friendly green method of synthesis of chromium sulphide nanoparticles is essential.

Egg yolk is an affluent resource of cholesterol and other essential proteins, amino acids, minerals, vitamins, biotins, anti-oxidants, vital nutrients and other bio-active components which assists in healing of different chronic and other contagious diseases [8]. Egg yolk can be potentially used to synthesize metal nanoparticles, which is unexplored till date. There are few reports on egg-white and egg-yellow mediated green synthesis of metal nanoparticles in recent years. Quail egg yolk has been used for synthesizing gold as well as platinum nanoparticles [9, 10]. Egg-white mediated green synthesis of copper sulphide nanoparticles has also been reported [11].

Cost-effective and eco-friendly biogenic green synthetic protocols are used to synthesize metal nanoparticles which have become popular among researchers in recent years [12, 13]. It is possible to synthesize nanomaterials by use of micro-organisms (bacteria, fungi, viruses), plant and animal-based products [14–24].

We have reported the green synthesis of chromium sulphide nanoparticles by a high temperature hydrothermal approach using liquid egg yolk (yellow) as the natural bio-source of sulphur in this paper. Characterization of the synthesized chromium sulphide nanoparticles has been carried out by UV–vis spectroscopy, Fluorescence spectroscopy, Scanning electron microscopy, X-ray diffraction (XRD), Energy dispersive X-rays spectroscopy as well as Fourier transform infra-red (FT-IR) spectroscopy. We have also reported the study of catalytic degradation of dyes (Congo Red, Eosin Y, Bromo Cresol Green, Methylene Blue) using synthesized chromium sulphide nanoparticles.

Materials and methods

All high quality chemicals of analytical grade have been used in this study without further purification. Chromium Trioxide (CrO$_3$) (99%) has been purchased from Merck. All aqueous solutions have been prepared by using de-ionized water. Chromium Trioxide (CrO$_3$) and liquid chicken egg yolk (yellow) as the natural bio-source of sulphur are used as reactants. 1.0 gm of CrO$_3$ and 25 ml of liquid egg yolk (yellow) were mixed together in a 1000 ml of beaker under constant stirring. Subsequently, the resultant solution was heated for 2 hr at 80 °C in water bath shaker with continuous shaking. After constant stirring for 2 hr, brown-black solution was formed. Subsequently, this precipitate was transferred into silicone crucible and subjected to calcination at two temperatures, 400 °C and 1000 °C in furnace for 6 hr. Black and green crystals were obtained at 400 °C as well as 1000 °C respectively after cooling down the furnace. All the experimental procedures were performed open to the atmosphere.

The so-synthesized chromium sulphide nanoparticles calcinated at 400 °C and 1000 °C were initially analysed by UV–vis spectroscopy carried out on Shimadzu dual-beam spectrophotometer (model UV-1800, 240 V). Fluorescence spectroscopy was used to test the potential of these particles as semiconductor material performed on the instrument Jasco Spectrofluorometer FP-8300. X-ray diffraction (XRD) is one of the most versatile and non-destructive techniques used to reveal information in details regarding the chemical composition in addition to the crystallographic structure of natural as well as manufactured materials. Analysis of the diffraction patterns was done so as to determine the interplanar distances in a particular crystal. Measurements of X-ray diffraction (XRD) were performed using Bruker axs (model D8 Advance) instrument which operates at a radiation voltage of 40 kV as well as current of 40 mA along with CuK$_\alpha$, radiation ($\lambda = 1.5406$ Å). Multiple layered films prepared by drop coating on glass slab, dried and subjected to Bruker axs (Model D8 Advance). Measurements of SEM were performed using a JEOL model JSM–6360 A instrument operating at an accelerating voltage of 20 kV. Shimadzu (model FTIR 8400) instrument was used in the diffused mode of reflectance operating at 4 cm$^{-1}$ resolution to perform Fourier Transform Infra-red (FT-IR) spectroscopic analysis.

Experimental details of the dye degradation studies employing the as synthesized chromium sulphide nanoparticles have been described. Four different dyes such as Congo Red (CR), Eosin Y (EY), Bromo Cresol Green (BCG) as well as Methylene Blue (MB) have been used to test the catalytic activity of chromium sulphide nanoparticles. All the four dyes are used at a concentration of 5 ppm. 0.1 M HCl is used to adjust pH. 20 mg of chromium sulphide nanoparticles calcinated at 400 °C as well as 1000 °C were used to check the efficiency of dye degradation.
Results and discussion

Egg comprises of egg white as well as egg yolk. Egg yolk contains various vitamins, minerals, lipids like lecithin and proteins such as phosvitin, lipovitellin, etc [25, 26]. Egg yolk usually contains about ~9% (w/w) lecithin. Various yolk proteins have discrete roles. Phosvitin is a type of phosphoprotein present in egg yolk, which is important in various metal ions such as calcium, iron for the developing embryo. Lipovitellin is a kind of lipoprotein present in egg yolk, which plays a significant role in storage of lipids as well as metals. It consists of a heterogeneous mixture of lipids which are non-covalently bound, most of them being phospholipids.

Egg white proteins act as the main source of solutes occurring in egg white which contribute to almost 10% of its weight [27]. Some of the major constituents of egg white include ovalbumin, ovomucoid, ovotransferrin, ovomucin, G2 globulin, lysozyme, G3 globulin, avidin, etc Protein (albumen) is the one of the major constituents present in egg white, contributing 9.7%–10.6% (w/w). 0.5%–0.6% of egg white consisting of carbohydrates has been observed to be present in free form or conjugated with proteins. Glucose, present up to 0.5%, comprises of 98% of the total free carbohydrates. Egg white consisting of lipids (0.01%) is negligible as compared to those present in egg yolk. Ovalbumin forms more than half of the egg white protein by weight. It is the only protein present in egg white which contains free sulphhydryl groups. Heat stable ovalbumin (S-ovalbumin) is formed during the storage of shell eggs. The phenomenon of boiling egg is described as a plethora of protein denaturation and renaturation. The denaturation of protein involved in this process includes breaking hydrogen bonds, thus resulting in uncoiling of polypeptide chains which ultimately results in exposure of reactive groups. Here, the native monomer is denatured thereby forming denatured monomer upon induction of heat, followed by formation of soluble aggregates which further results into synthesis of gel or coagulum.

The process of gel formation can be divided majorly into three steps following the initial process of denaturation as well as unfolding of the native proteins: Firstly, formation of aggregates take place with the aid of hydrophobic interactions. Secondly, the interaction between sulphhydryl groups and disulphide linkages result in hardening of the already formed aggregates. Lastly, this drastic increase is suddenly seen in the elastic nature of these aggregates because of increased hydrogen bonding when subjected to cooling [28].
Figure 1 shows the schematic diagram along with the photograph for the preparation of chromium sulphide nanoparticles. When egg is heated, egg proteins are seen to undergo series of chemical reactions. At alkaline pH and high temperature, reactions involving sulphydryl groups have been observed to take place. The simplest reaction occurring is the replacement of sulphydryl group by a hydroxyl group resulting into transformation into serine from cysteine molecules. This mechanism has been exploited to synthesize chromium sulphide nanoparticles by reacting the evolving S\(^2\)\(^-\) with CrO\(_3\) present in the system (figure 1). At around 80°C temperature, denaturation of protein takes place and the linkages start breaking and sulphide evolves with the formation of H\(_2\)S. It is important to mention here that we have employed two temperatures 400°C and 1000°C for calcination of synthesized chromium sulphide.

Figure 2 shows the UV–vis as well as fluorescence spectra of CrS nanoparticles calcinated at 400°C and 1000°C. CrS nanoparticles calcinated at 400°C (CrS 400) shows absorption peak at 342 nm (Line 1) and those calcinated at 1000°C (CrS 1000) show absorption peak at 383 nm (Line 2) as depicted in figure 2(a). Using these wavelength values, band gap energy can be calculated by the following equation:

\[ E_g = \frac{1240}{\lambda} \]

where \( E_g \) is the band gap energy and \( \lambda \) is the lower cut-off wavelength. The band gap energies of CrS 400 and CrS 1000 were 3.6257 eV and 3.237 eV respectively thus highlighting that increase in calcination temperature decreases the corresponding band gap energy [29]. This correlates with the data available from the literature. The band gap energy (\( E_g \) in eV) calculated from the Tauc plot using the absorption data was found to be 3.6 eV. This was calculated from the extrapolation of the linear portion of Tauc plot to the abscissa to obtain the indirect optical energy band gap of chromium sulphide nanoparticles [30, 31]. From the absorption peak, the band gap energy of the chromium sulphide nanoparticles has been estimated. The band gap energy (\( E_g \)) was also calculated.
from the absorption spectrum and optical absorption coefficient ($\alpha$) near the absorption edge, which is given by the following formula, $\alpha h\nu = A(h\nu - E_g)^{1/2}$, where $E_g$ corresponds to the optical band gap of the crystal and $A$ is a constant. The plot of $(\alpha h\nu)^2$ as a function of the photon energy ($h\nu$) at room temperature exhibits almost a linear behaviour, ($\alpha$ is absorption coefficient and $h$ is Planck’s constant, value $6.627 \times 10^{-34}$ Js) which can be considered as a proof of the indirect transition between valence and conduction band. The band gap energy ($E_g$) can also be estimated by the linear extrapolation of the curve to the point $(\alpha h\nu)$ where $E_g$ corresponds to the optical band gap of the crystal and $\alpha$ is a constant. The band gap energy ($E_g$) can also be estimated by the linear extrapolation of the curve to the point $(\alpha h\nu)^2 = 0$. Using this method, the band gap of the chromium sulphide nanoparticles was found to be 3.6 eV. Figure 2(b) represents fluorescence spectrum recorded in the range 400–700 nm with excitation wavelength 467 nm for CrS 400 and 472 nm for CrS 1000. Fluorescence intensity of CrS 400 (Line 1) was higher as compared to CrS 1000 (Line 2).

The surface morphology in addition to the structural composition of the as synthesized chromium sulphide nanoparticles was studied by SEM and EDAX techniques. Figure 3 illustrates the SEM image of as synthesized and calcinated chromium sulphide nanoparticles. The average edge length of calcinated CrS at 1000 °C is ~150 nm and thickness ~40 nm.

It was clearly observed from the SEM images that the morphology of the chromium sulphide nanoparticles is strongly dependent on the calcination temperatures. As observed from the SEM study, flower petal like structure can be obtained when calcination temperature is 400 °C, while rice grain structures were obtained at 1000 °C. The different growth patterns observed at different calcination temperatures are both seen to be present in the micron scale. Mass transport is one of the key factors associated as a cause of dendritic growth as well as in the control of relative nucleation rates as opposed to their growth [32]. At moderate calcination temperature, chromium sulphide nanoparticles show morphology which is under controlled process of diffusion. Therefore, temperature is amongst the crucial factors involved in control of nucleation and rate of growth. The nucleation rate has been observed to be much faster along with diffusional control becoming insignificant, according to the FE-SEM images taken after calcinations at high temperatures.

Figure 4 illustrates the EDAX spectrum of as synthesized chromium sulphide nanoparticles. The EDAX spectrum demonstrated in figure 3 designates that there are obvious peaks for chromium and sulphur with the composition of the sample is mostly chromium (98.56 at %) and sulphur (1.44 at %) only in stoichiometric ratio. The composition of as synthesized chromium sulphide nanoparticles remains almost same with the change of calcination temperature.
The crystal structure of as-prepared chromium sulphide nanoparticles were determined by powder XRD study. Figures 5(a) and (b) illustrate the XRD patterns observed for the as synthesized chromium sulphide nanoparticles obtained by calcination at 400 °C as well as 1000 °C for 6 h. Seven diffraction peaks were observed for chromium sulphide nanoparticles calcinated at 400 °C with 2θ values 24.56°, 33.66°, 36.3°, 50.22°, 54.84°, 63.5° and 65.4° which corresponds to (003), (004), (022), (025), (130), (221) and (042) planes respectively. Seven diffraction peaks were observed for CrS nanoparticles calcinated at 1000 °C with 2θ values 24.7°, 33.76°, 36.36°, 50.44°, 54.96°, 63.56°, and 65.34° which corresponds to (003), (004), (022), (025), (130), (221), and (042) planes respectively. This result signifies formation of monoclinic structures of chromium sulphide (JCPDS File No. 85–1845).

Chromium sulphide nanoparticles synthesized using egg yolk were analyzed using FTIR spectroscopy in order to check for the functional groups present thus contributing to the stabilization of the so formed nanoparticles. Figures 6(a) and (b) illustrate the FTIR spectra of these nanoparticles at two different calcination temperatures. Confirmation of bonding between chromium and sulphide has been carried out using FTIR measurements. FTIR graph shows absorbance peak appearing at wave numbers 490 and 525 cm⁻¹ with 400 °C calcination temperature which indicates Cr-S stretching or bending vibrations which disappear when calcinated at 1000 °C [33, 34]. The peaks at 1165 cm⁻¹ in samples calcinated at 400 °C and 1138 cm⁻¹ in those heated at 1000 °C signify C=O stretching vibrations which may be attributed due to the high amount of biomolecules contributed by the egg yolk. The peaks at 1659 cm⁻¹ in 400 °C calcination samples and 1638 cm⁻¹ in 1000 °C calcination samples represent C=O stretching vibrations which represent the amide-I signals of the proteins present in the egg yolk which get coated upon the nanoparticles during synthesis [35]. The peak at 2353 cm⁻¹ from the samples at 400 °C corresponds to O–H and N–H stretching vibration which then disappear in samples calcinated at 1000 °C. The peak at 2926 cm⁻¹ from the samples at 1000 °C which is not present at 400 °C.
corresponds to O–H stretching vibration as well as intramolecular hydrogen bonding resulting in stabilization of the so formed nanoparticles. The peaks at 3279 cm⁻¹ in 400 °C calcination samples and 3242 cm⁻¹ in 1000 °C calcination samples represent N–H stretching in resonance with amide-II overtone contributed by the proteins from the egg yolk [35].

Chromium sulphide nanoparticles calcinated at 400 °C (CrS-400) as well as 1000 °C (CrS-1000) have been used to determine the catalytic efficiency in degradation of congo red, eosin Y, bromo cresol green as well as methylene blue. The (C/C₀ × 100) value as represented in table 1 shows the amount of respective dye remaining after the action of CrS nanoparticles expressed in percentage (%). Dye degradation of congo red, eosin Y as well as bromo cresol green was observed to show a significant effect of optimum pH. Ankamwar [36] had reported that complete adsorption of congo red, eosin Y as well as bromo cresol green takes place at pH 2 whereas methylene blue requires pH in the range 6–12 for complete adsorption. Because of this reason, acidic pH was not tested for methylene blue and dye degradation studies were not performed in basic pH range for rest of the dyes as stated above. The as prepared solutions of congo red showed pH 5.3, eosin Y showed pH 5.2, bromo cresol green showed pH 5.4 as well as methylene blue showed pH 6.3. All four dyes showed significant degradation in both particles at acidic pH. Methylene blue shows maximum efficiency in neutral pH range because of which it was not tested at pH 2.0.

**Figure 5.** XRD pattern of chromium sulphide nanoparticles calcinated at 400 °C for 6 h (a) and 1000 °C for 6 h (b). The Bragg reflections have been identified in the XRD pattern.
Figure 6. FTIR spectra recorded from chromium sulphide nanoparticles calcinated at 400 °C for 6 h (a) and 1000 °C for 6 h (b).

Table 1. \((\text{C/CO} \times 100)\) value of chromium sulphide nanoparticles calcinated at 400 °C (CrS-400) as well as 1000 °C (CrS-1000) for degradation of as prepared solutions of congo red, eosin Y and bromo cresol green as well as at optimum pH and methylene blue only in as prepared condition along with % difference in catalytic activity.

| Dye and pH  | CrS-400 | CrS-1000 | % Difference |
|-------------|---------|----------|--------------|
| CR at pH 5.3| 41.24   | 63.81    | +22.57       |
| CR at pH 2.0| 38.92   | 47.99    | +9.07        |
| EY at pH 5.2| 92.19   | 80.92    | -11.27       |
| EY at pH 2.0| 8.16    | 25.92    | +17.76       |
| BCG at pH 5.4| 91.96  | 80.27    | -11.69       |
| BCG at pH 2.0| 20.75  | 39.32    | +18.57       |
| MB at pH 6.3| 29.05   | 47.71    | +18.66       |
Figure 7. Catalytic activity of chromium sulphide nanoparticles calcinated at 400 °C for dye degradation of congo red (a), eosin Y (c), bromo cresol green (e) and methylene blue (g) of as prepared solutions as compared to dye degradation at optimum pH for congo red (b), eosin Y (d), bromo cresol green (f).
Figure 8. Catalytic activity of chromium sulphide nanoparticles calcinated at 1000 °C for dye degradation of Congo red (a), eosin Y (c), bromo cresol green (e) and methylene blue (g) of as prepared solutions as compared to dye degradation at optimum pH for Congo red (b), eosin Y (d), bromo cresol green (f).
Congo red is an anionic azo dye which is highly toxic as well as non-biodegradable in nature, because of which it is one of the non-fixed dyes from the textile industry contributing to environmental pollution. Because of these reasons, degradation of CR dye is crucial. We have reported use of CrS nanoparticles for its degradation.

Figure 9. Plausible mechanism for the action of chromium sulphide nanoparticles on degradation of congo red (a) (a partially) Reprinted from Environmental Technology & Innovation, 8, Bashir O, Khan M N, Khan T A, Khan Z and Al-Thabaiti S A, Influence of stabilizing agents on the microstructure of Co-nanoparticles for removal of Congo red, 327–342, 2017, with permission from Elsevier, (b) eosin Y (b), bromo cresol green (c) and methylene blue (d) Reprinted from Chemical Engineering Journal, 168(3), Li Z, Chang P H, Jiang W T, Jeam J S and Hong H, Mechanism of methylene blue removal from water by swelling clays, 1193–1200, 2011, with permission from Elsevier at different pH.
When congo red is present in aqueous medium, it shows SPR band at wavelengths 486 nm which corresponds to $\pi-\pi^*$ transition as well as 335 nm which corresponds to $n-\pi^*$ transition associated with the azo group [37]. Catalytic activity of these nanoparticles was also tested at optimal pH. CrS nanoparticles calcinated at 400 °C as well as 1000 °C serve as potential catalysts for degradation of as prepared CR (Figures 7(a), 8(a)) as well as at acidic pH (Figures 7(b), 8(b)) during a time period of 24 h. The efficiency ($C/C_0 \times 100$) values have been demonstrated in Table 1. The % difference in catalytic efficiency of CrS-1000 is $+22.57$ and $+9.07$ at pH 5.3 and pH 2.0 as compared to corresponding catalytic activity of CrS-400.

Eosin Y is an anionic dye which is heterocyclic in nature. EY is actively used in paper as well as textile industries. EY is also widely exploited for histochemical analysis. Release of EY into the environment is a serious issue because of its dark colour and high toxicity [38]. EY shows absorption maxima at wavelength 510 nm. Activity of CrS nanoparticles has been monitored of as prepared solutions as well as at acidic pH (pH 2.0) [39]. CrS nanoparticles calcinated at 400 °C as well as 1000 °C serve as potential catalysts for degradation of as prepared EY (Figures 7(c), 8(c)) as well as at acidic pH (Figures 7(d), 8(d)) during a time period of 24 h. The ($C/C_0 \times 100$) values have been demonstrated in Table 1. The % difference in catalytic efficiency of CrS-1000 is $-11.27$ and $+17.76$ at pH 5.2 and pH 2.0 as compared to corresponding catalytic activity of CrS-400.

Bromo cresol green (BCG) is categorized amongst the anionic dyes. It belongs to the triphenyl methane family. BCG has large applications in paper, textile as well as pharmaceutical industries. Its hazardous nature.
makes its removal indispensable. EY shows absorption maxima at wavelength 608 nm. Activity of CrS nanoparticles has been monitored for degradation of as prepared BCG as well as at acidic pH [40]. CrS nanoparticles calcinated at 400 °C as well as 1000 °C serve as potential catalysts for degradation of as prepared BCG (figures 7(e), 8(e)) as well as at acidic pH (figures 7(f), 8(f)) during a time period of 24 h. The \((C/C_0 \times 100)\) values have been demonstrated in table 1. The % difference in catalytic efficiency of CrS-1000 is -11.69 and +18.57 at pH 5.4 and pH 2.0 as compared to corresponding catalytic activity of CrS-400.

Methylene blue is classified as a heterocyclic aromatic dye. Its use in textile industry has alarmingly increased over the centuries. When MB is present in aqueous medium, it shows absorption maxima at 660 nm which can be related to \(n-\pi^*\) transition. The optimal pH for MB is neutral pH [4, 36]. Therefore, catalytic activity of CrS nanoparticles calcinated at 400 °C as well as 1000 °C was monitored for as prepared MB only (figures 7(g), 8(g)) for a time period of 24 h. The \((C/C_0 \times 100)\) values have been demonstrated in table 1. The % difference in catalytic efficiency of CrS-1000 is +18.66 as compared to CrS-400 at pH 6.3. The plausible mechanism involved in degradation of all these dyes by using CrS nanoparticles has been well depicted in figure 9 as subjoin below [38, 41–43].

Klaus Roth et al [44] had shown that different proteins present in the egg albumin as well in egg yolk have different denaturation temperatures. Denaturation occurs by the process of aggregation following which various proteins gather together. These resulting aggregates are maintained via disulphide linkages, hydrogen bonds, as well as an array of ionic bonds in addition to hydrophobic interactions. Aggregation of nanoparticles is due to the coagulation of proteins, which is not homogeneous in the system. Moreover, sulphur containing residues are not uniformly distributed within the protein structure. Uniform structure is achieved by reacting single sulﬁde anion obtained from cysteine and methionine linkages.

Moreover, the use of egg yolk should be extended in order to understand the role surface functionalization with potential applications in catalysis, pharmaceutics, biosensing and drug delivery. This will help in the overall understanding of the mechanism involving nanoparticles–protein interaction, which has a major role in drug delivery and diagnostics. At present, we are involved in the green biosynthesis of silver sulphide (Ag_{2}S) nanoparticles using egg white as sulphide source, which will be communicated later.

**Conclusions**

Herein, we have reported a facile egg yolk-assisted protocol for the green biosynthesis of chromium sulphide nanoparticles by a high temperature hydrothermal approach using chromium trioxide as the source of chromium and egg yolk (yellow) as the natural biosource of sulphur. Two distinct temperatures 400 °C as well as 1000 °C have been employed for the calcination of synthesized chromium sulphide nanoparticles. The synthesized chromium sulphide nanoparticles exhibit multiple structures like flower petal like structure, rice grain structures etc. Catalytic efficiency of these nanoparticles have been tested for degradation of congo red.
eosin Y, bromo cresol green dyes of as prepared solutions as well as at acidic pH (pH 2.0) and for methylene blue in as prepared condition only. It has been observed that eosin Y at pH 2.0 shows maximum degradation with CrS–400 as the amount of dye remaining after the action of CrS nanoparticles is 8.16%. The electron rich sulphide ion present in CrS contributes to the electron transfer between the dye and the nanoparticles which results in formation of stable intermediates which are colourless. The method reported can be exploited for large scale applications because of its non-hazardous nature. By further tuning the calcination temperature, chromium sulphide nanoparticles with various structures may find applications in the field of catalysis, sensing and diagnostics.

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Conflict of interest

The author declares no conflicts to declare.

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