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Wheat straw extract as a green reducing agent for the synthesis of Copper, Iron, and Zinc nanoparticles

Sura Y. Mahmood
Department of Biology, College of Science, University of Mosul, Iraq. E-mail: sura.24scp62@student.uomosul.edu.iq

Hadeel A. Al-Ameri
* Corresponding author. Department of Biology, College of Science, University of Mosul, Iraq. E-mail: hadsbio43@uomosul.edu.iq

Abstract

Objective

The current study aims to utilize wheat straw for the green synthesis of copper oxide (CuONPs), iron oxide (FeONPs), and zinc oxide (ZnONPs) nanoparticles, as well as to characterize the synthesized nanoparticles using Energy-Dispersive X-ray Spectroscopy (EDS), UV-Visible (UV-Vis) spectroscopy, and X-ray Diffraction (XRD) techniques.

Materials and methods

The eco-friendly and green synthesis of copper, iron and zinc oxide nanoparticles was done using wheat straw. X-ray diffraction (XRD) was used to reveal the structural properties of the synthesized particles, under the condition of Cu Kα radiation (wavelength $\lambda = 1.5406$ Å). The diffraction patterns were compared to standard data (JCPDS) to identify the crystalline structure of the resulting diffraction patterns. The crystallinity of materials was successfully identified using scanning electron microscopy associated with energy dispersive x-ray spectroscopy (SEM-EDS) and the optical properties of the prepared nanoparticles were obtained using UV-Vis spectroscopy in the wavelength range 200-800 nm.

Results

The X-ray diffraction (XRD) spectrum of the copper oxide nanoparticles (CuONPs) confirmed the successful preparation of partially crystalline copper oxide, suggesting a mixed crystalline structure where the maximum peak is the one at about 43.3 degrees. The diffraction pattern of the iron oxide nanoparticles (FeONPs), however, revealed no sharp diffraction peaks and had a broad scattering, suggesting a low degree of crystallinity. Likewise, the diffraction pattern of the zinc oxide nanoparticles (ZnONPs) did not show peaks with high crystallinity to zinc oxide but rather a broad hump-like diffraction pattern. The energy-dispersive X-ray spectroscopy (EDS) analysis confirmed the presence of the constituent elements of all the synthesized nanoparticles and the key elements that were being analysed were found. The synthesized nanoparticles should, however, be confirmed for their oxide nature with other complementary techniques like X-ray photoelectron spectroscopy (XPS), detailed X-ray diffraction (XRD) analysis, or Fourier-transform infrared spectroscopy (FTIR).

Conclusions

It is concluded that these results give an idea for the sustainable production of nanoparticles using agricultural wastes. In particular, the results presented here illustrate how wheat straw extract can be used as an environmentally friendly reducing agent in the green synthesis of Cu, Fe and Zn nanoparticles. X-ray diffraction (XRD) analysis has shown that the oxide nanoparticles are crystalline in nature, and the energy-dispersive X-ray spectroscopy (EDS) analysis has confirmed that the elements of which the oxide nanoparticles are composed are present.

Keywords: green synthesis, copper oxide nanoparticles, wheat straw, zinc oxide nanoparticles, iron oxide nanoparticles.,

Paper Type: Research Paper.

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Introduction

We are living in a time of climate change, limited land resources and food insecurity, and it is more important than ever that we have sustainable alternatives to agriculture. Rapid urbanization, coupled with the increasing challenges posed by traditional farming methods, necessitates a radical shift in how food is grown, and urban agriculture emerges as a promising solution that enables communities to produce food locally and mitigate the negative impacts of these global challenges (Langemeyer et al., 2021). On the other hand, nanotechnology is a multidisciplinary scientific field that uses a set of tools and techniques derived from engineering, physics, chemistry and biology (Mohammadabadi and Mozafari, 2018). Advances in nanoscience and nanotechnology have routinely enabled the fabrication and identification of submicron bioactive carriers. The delivery of bioactive substances to target sites in the body and their release behavior are directly affected by particle size. Compared to micrometer-sized carriers, nanocarriers provide more surface area and have the potential to increase solubility, increase bioavailability, improve controlled release, and enable precise targeting of entrapped substances (Mohammadabadi et al., 2009). Green synthesis of nanoparticles using agricultural waste is one of the most important applications of sustainable development, as it combines recycling waste - such as crop residues, sawdust, etc., instead of burning or disposing of it in ways that cause environmental pollution - and reducing the use of harmful chemicals on the one hand, and producing materials of economic and scientific value on the other, in addition to protecting the environment and reducing energy consumption through the global trend towards more efficient and sustainable agriculture (Zhang et al., 2019). An eco-friendly and sustainable alternative in green synthesis is the use of plant extracts. Plants possess natural biomolecules with the ability to reduce metal ions and convert them into nanoparticles (Abady et al., 2025), which are environmentally friendly, has low cost, fast processing, and can be scaled up for production (Barzinjy & Azeez, 2020; Mustafa et al., 2023). The green synthesis of nanoparticles has become an important research field due to its ability to revolutionize many fields, including materials engineering, environmental science, medicine, and others (Pal et al., 2019; Karunakaran et al., 2023). Unlike traditional chemical synthesis techniques, which are often costly, dangerous, and potentially harmful to the environment, the biosynthesis of nanoparticles offers a more sustainable option (Saxena et al., 2025). The study of developments in the green synthesis of nanoparticles may be carried out using plant extracts as reducing agents. These extracts not only possess reducing properties but also antioxidant properties, which act as reducing agents for the preparation of nanoparticles and also act as stabilizers to protect them from oxidation (Bao et al., 2021). Using plant-based synthesis instead of hazardous chemicals is known as "green chemistry." It significantly reduces the energy required to produce nanoparticles. Plant-based synthesis uses extracts that may be environmentally safe, unlike conventional synthesis which may use toxic and hazardous chemicals (Yap et al., 2021). This ensures the safety of individuals and ecosystems. Furthermore, the use of renewable plant resources promotes a sustainable synthesis cycle (Mawthoh et al., 2023). Plants also act as organic stabilizers and reducing agents (Singh et al., 2023), Most importantly, this approach avoids the formation of toxic byproducts, which are commonly found in chemical synthesis. Biosynthesized nanoparticles are typically prepared from plant extracts, usually derived from biological parts of plants such as leaves, roots, pith, peel, flowers, and essential oils, and are widely used in the synthesis of metallic nanoparticles (Barzinjy & Azeez, 2020). Furthermore, the various plant parts are readily accessible and can be extracted using simple aqueous or mild aqueous-alcoholic techniques. This makes the entire process scalable and cost-effective, facilitating its clinical application.

Materials and methods

Source of nanoparticles synthesized with the green method: Wheat straw extract was used as the reducing and stabilizing agent for the synthesis of CuONPs, FeONPs, and ZnONPs.

Preparation of an aqueous extract from wheat straw: Wheat straw was washed with running tap water, then with distilled water to remove any remaining impurities. The straw was then dried in the sun to remove moisture and subsequently ground into a fine powder. One hundred grams of wheat straw powder was added to one liter of distilled water. The mixture was heated on a hotplate stirrer (Lab Tech LMS 1003, Korea) for 45 minutes with continuous stirring. The plant extract was filtered using filter paper (15 cm) to be used as a reducing agent in the preparation of copper, iron, and zinc nanoparticles. The filtrate was collected and stored in dark bottles in the refrigerator at 4°C until later use (Nazir et al., 2024; Amer and Awwad, 2021).

Green synthesis of copper oxide nanoparticles (CuONPs): Copper oxide nanoparticles (CuoNPs) were prepared by adding 50 mL of distilled water to 1.5 g of copper sulfate and 500 mL of wheat straw extract. The mixture was heated on a hotplate stirrer (Lab Tech LMS 1003, Korea) for 30 minutes with continuous stirring and observation of the color change. The mixture was then cooled to room temperature and centrifuged at 3000 rpm for 20 minutes. After centrifugation and separation of the precipitate, it was washed several times with distilled water, followed by several washes with ethanol. Finally, it was dried at room temperature for 24 hours to obtain a dark green dry powder, which was stored in dark containers for the characterization of biosynthesized nanoparticles (Lithi et al., 2025).

Green synthesis of iron oxide nanoparticles (FeONPs): Iron oxide nanoparticles (IONPs) were prepared by adding 50 mL of distilled water to 1.5 g of ferrous sulfate and 500 mL of wheat straw extract. The mixture was heated on a hotplate stirrer (Lab Tech LMS 1003, Korea) for 30 minutes with continuous stirring and observation of the color change. The mixture was then cooled to room temperature and centrifuged at 3000 rpm for 20 minutes. After centrifugation and separation of the precipitate, it was washed several times with distilled water, followed by several washes with ethanol. Finally, it was dried at room temperature for 24 hours to obtain a dry, black powder. This powder was stored in dark containers for the characterization of biosynthesized nanoparticles (Nazir et al., 2024).

Green synthesis of zinc oxide nanoparticles (ZnONPs): Zinc oxide nanoparticles (ZnONPs) were prepared by adding 50 mL of distilled water to 1.5 g of zinc sulfate and 500 mL of wheat straw extract. The mixture was heated on a hotplate stirrer (Lab Tech LMS 1003, Korea) for 30 minutes with continuous stirring and observation of the color change. The mixture was then cooled to room temperature and centrifuged at 3000 rpm for 20 minutes. After centrifugation and separation of the precipitate, it was washed several times with distilled water, followed by several washes with ethanol. Finally, it was dried at room temperature for 24 hours to obtain a dark gray dry powder, which was stored in dark containers for the characterization of biosynthesized nanoparticles (Amer and Awwad, 2021; Nazir et al., 2024; Lithi et al., 2025).

Characterization of green synthesized Copper, Iron, and Zinc nanoparticles: The green synthesis of copper, iron, and zinc nanoparticles was characterized using the following techniques:

1- X-ray diffraction (XRD) spectrometer: The crystal structure of copper, iron, and zinc nanoparticles was determined using XRD with Cu Kα radiation ($\lambda = 1.5406$ Å), and the resulting (2θ) peak positions were compared with the Joint Committee on Powder Diffraction Standards (JCPDS) database cards to determine the crystalline phase of the formed material. The average crystalline size of the nanoparticles was also calculated using the Debye-Scherrer equation.

$$D = \frac{K\lambda}{\beta\, cos\theta}$$

Where, D = Crystal size (nanometers), K = Scherrer constant (0.9), λ = X-ray wavelength, β = Peak width at half maximum intensity (FWHM), and θ = Diffraction angle.

2- Energy dispersive X-ray spectroscopy (EDS): A scanning electron microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy (EDX) system was used to determine the elemental composition and nanoparticle size of copper, iron, and zinc. Samples were placed in the EDX chamber of the SEM, and the high electron voltage was set to 15 kV to provide sufficient energy for X-ray emission from the sample elements. The electron beam was directed at the sample, and the EDX instrument recorded the X-ray spectrum emitted by each element. The elements were identified by the position of peaks in the spectrum, and the weight percentage (wt%) and atomic percentage (at%) of each element were determined. Nanoparticle sizes and their distribution were measured using SEM images. The EDX data were combined with the images to confirm the elemental composition of the nanoparticles for each extract and the distribution of elements within it.

3- UV-Vis spectroscopy (UV-Vis): A stock suspension of 0.1 g nanoparticles in 100 mL distilled water was prepared and further diluted prior to analysis. The solution was placed in a quartz cell, and the absorbance was measured at wavelengths of 200-800 nm using a UV-Vis spectrometer located at the College of Science, University of Mosul.

Results and discussion

X-ray diffraction (XRD) spectrometer: Figure 1-A shows the X-ray diffraction (XRD) plot of copper oxide nanoparticles (CuO NPs) exhibiting a hybrid structure. This is clearly evident in the semi-crystalline structure, indicated by the appearance of very sharp and prominent diffraction peaks. These peaks suggest the presence of specific and fully developed crystalline levels of the nanomaterial (Ali et al., 2021), with the main peak and highest intensity appearing at a diffraction angle of approximately 43.3, exceeding an intensity of 1000 units (Counts), This is followed by a second distinct peak at an angle of 50.5, and a third, less intense peak at an angle of 74.2, which are characteristic peaks that usually relate to the standard crystalline planes of copper oxide nanoparticles (Yadav et al., 2023). Meanwhile, this scheme rests on a high, broad, plateau-like background that extends in the bounded range between angles of 20 ~ 20% and 35°, accompanied by some noise. This is common when nanoparticles are prepared by biochemical or thermochemical methods, where nanocrystals grow within a completely matrix or base (Khan et al., 2020; Rodríguez et al., 2021; Yadav et al., 2023). Figure 1-B shows the X-ray diffraction (XRD) pattern of iron oxide nanoparticles (FeO NPs). It exhibits a distinctive pattern that reflects the crystallin nature or very weak crystallinity of the prepared nanomaterial. This structural behavior is evident through the wide dispersion and the appearance of a broad, bulging, plateau-like peak extending approximately in the range between diffraction angles 18 and 38, accompanied by a high noise ratio and oscillations, With a complete absence of any sharp, narrow, prominent peaks (Sharp crystalline peaks) that usually characterize the pure and complete crystalline phases of iron oxide; this random appearance in the long-range atomic arrangement is attributed to preparation conditions and factors (such as the use of plant extracts in green or low temperatures that did not give the atoms sufficient kinetic energy for structural order (Ali et al., 2021)), meaning that the particles are still in their initial phase and need a heat treatment or annealing process at high temperatures to stimulate the growth and formation of crystals (Suzuki et al., 2020; Ali et al., 2022). Figure 1-C shows the X-ray diffraction (XRD) pattern of the prepared zinc oxide nanoparticles (ZnO NPs). It exhibits as a non-crystalline or very weakly crystalline materials, as evidenced by the presence of a broad, dispersed, plateau-like peak that begins to rise from an angle of 15 ~ 20 to reach its peak at an angle of approximately 22 before gradually and randomly descending accompanied by high noise levels (Suzuki et al., 2020), With the complete absence of the sharp, prominent peaks that characterize the pure crystalline phase of zinc oxide (such as the Wurtzite crystal structure, whose peaks usually appear at angles of 31 and 34), this structural behavior is often due to preparation conditions (such as green chemical methods or low temperatures) that did not give the atoms enough energy to arrange themselves into a regular long-range crystal lattice, meaning that the sample may need a heat treatment or annealing process at high temperatures to induce crystallization (Suzuki et al., 2020; Ali et al., 2022).

Energy dispersive X-ray spectroscopy (EDS): This technique was used to determine the purity and elemental composition of the studied samples. Figure 2-A presents the EDS spectrum of copper (Cu), which exhibits characteristic peaks at approximately 0.93, 8.04, and 8.90 keV, corresponding to the Cu-Lα, Cu-Kα, and Cu-Kβ emission lines, respectively. The presence of these prominent peaks confirms the existence of copper as the dominant element within the analyzed region. The quantitative EDS results indicate a weight percentage of 100 wt.% Cu, demonstrating the high purity of the examined area. Furthermore, the high intensity and sharpness of the peaks, together with the absence of additional elemental signals, suggest a homogeneous elemental distribution and negligible contamination within the detection limits of the instrument. Copper nanoparticle sample in Figure 2-A show the chemical purity of the tested material (Park et al., 2022) and suggests the effectiveness of the preparation method in obtaining nanocopper (Koyama et al., 2022). This gives it high reliability and may be suitable for further investigation in various applications in advanced electronic, medical and industrial applications that require high chemical quality and purity (Collins et al., 2020; Mele et al., 2023). Figure 2-B illustrates the EDS spectrum of iron (Fe). Distinct peaks were observed at approximately 0.70, 6.40, and 7.06 keV, which are attributed to the characteristic Fe-L, Fe-Kα, and Fe-Kβ transitions, respectively. These peaks are consistent with the standard X-ray emission energies of iron and confirm the successful identification of Fe in the analyzed region. Quantitative analysis indicates that iron is the dominant constituent in the examined region; furthermore, the low background noise and the high intensity of the peaks associated with the high iron concentration attest to the reliability of the spectrum acquired from the sample.

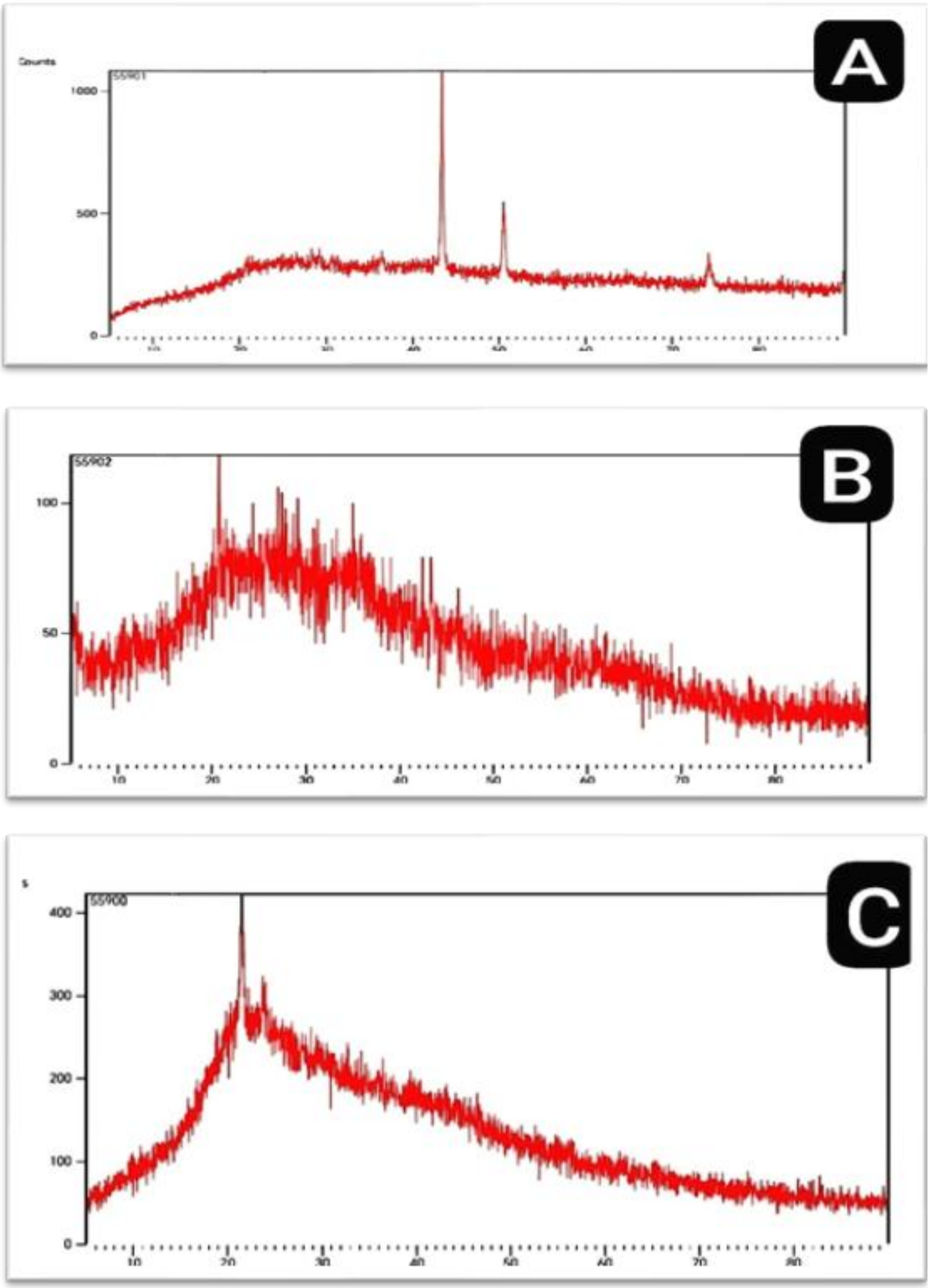

Figure 1. X-ray diffraction (XRD) spectroscopy of copper, iron, and zinc nanoparticles synthesized using green synthesis from wheat straw. A: Copper nanoparticles (CuO NPs), B: Iron nanoparticles (FeO NPs), C: Zinc nanoparticles (ZnO NPs)

However, no peak corresponding to other metallic elements are detected, showing very good elemental homogeneity and purity and a high efficiency of the process for the production of iron nanoparticles with high chemical purity for medical and advanced engineering applications (Collins et al., 2020; Mele et al., 2023). The Zinc (Zn) EDS spectrum had very strong peaks at energies of about 1.01keV associated with the Zn-Lα emission line, 8.63keV associated with the Zn-Kα emission line and 9.57keV associated with the Zn-Kβ emission line (Figure (2-C)). The peaks indicate the presence of zinc. The quantitative analysis showed that the detected element (Zinc) was present in the analysed area. The high quality of the EDS measurements and the high concentration of zinc is observed. The sharp and well-defined peaks in the EDS spectra in (A), (B), and (C) confirm the successful identification of copper (Cu), iron (Fe), and zinc (Zn), respectively. Moreover, the lack of other elemental peaks suggests the homogeneity and high purity of the analyzed areas, which shows the success and efficiency of the method used to achieve a high-quality nanocomposite with structural purity, confirming the effectiveness of the preparation and characterization procedures used in this study (Wang et al., 2026). The information from UV-Vis spectroscopy was not the only evidence used to demonstrate the formation of the nanostructure; other evidence in the manuscript, including EDS, corroborated this finding. To shed light on this, the observed absorption in the UV-range could be attributed not only to biomolecules from plants, but also to the synthesized nanoparticles; also the successful formation of the zinc oxide (ZnO) nanostructure was confirmed by the integrated characterization results.

UV-Vis spectroscopy (UV-Vis): Figure 3 shows the results of the UV-Vis spectroscopy: The absorption spectra show large absorption peaks in the ultraviolet range (200-300 nm). Sample S1 (zinc oxide nanoparticles—ZnONPs) exhibited the highest absorption intensity, peaking at a wavelength of 210 nm with a value of approximately 3.1. Sample S2 (FeONPs) followed, showing similar behavior with a relatively lower absorption. In contrast, sample S3 (CuONPs) showed the lowest absorption intensity in the UV region, while it exhibits slightly higher absorption values in the visible light range (above 400 nm) compared to the S1 eye, this may indicate that the optical properties and energy gap are influenced by the type of nanoparticles used. The figure shows that all samples share the characteristic of gradually decreasing absorbance with increasing wavelength towards the visible region, demonstrating the high clarity and reliability of these materials in the visible range and their strong response to high energy in the ultraviolet range.

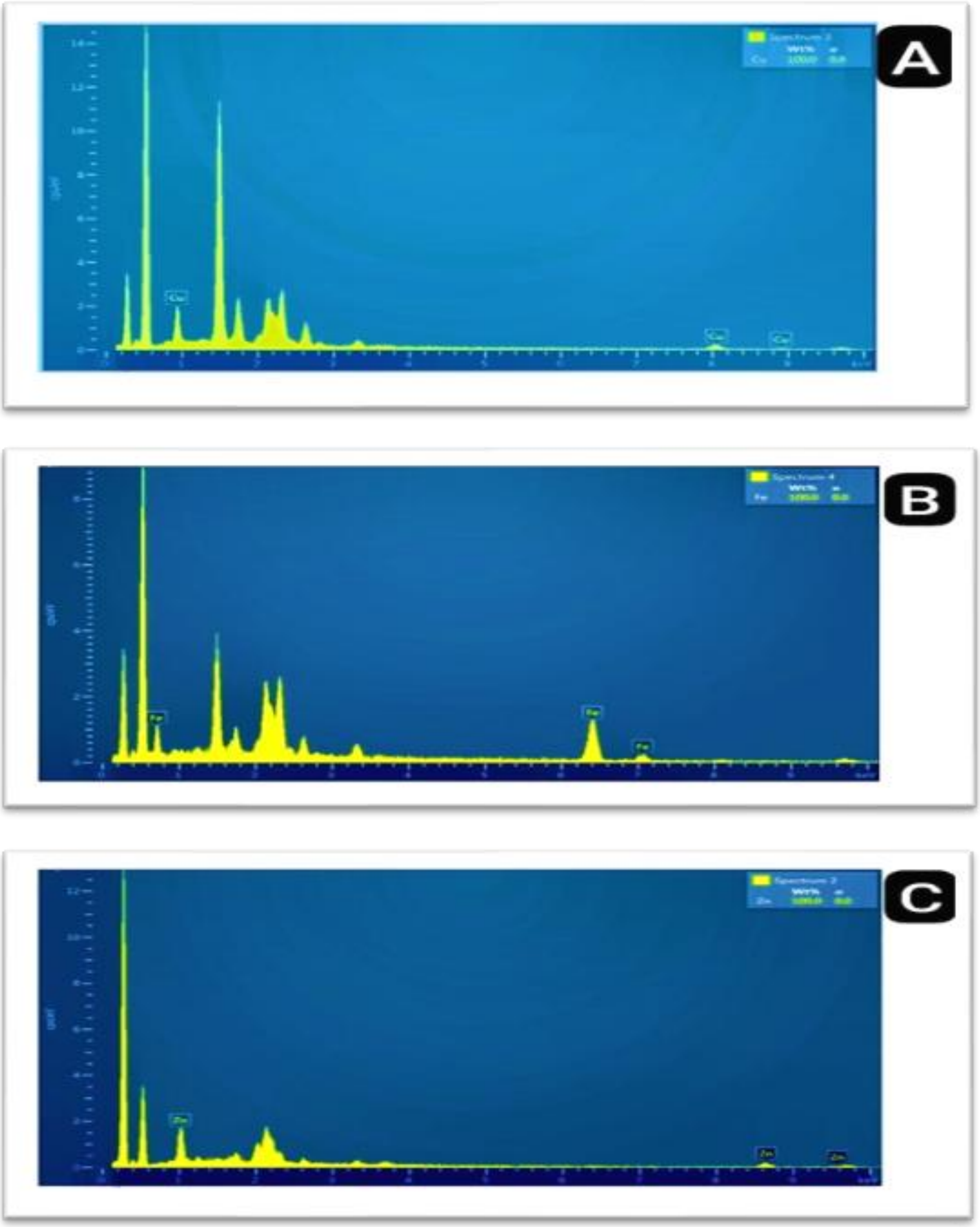

Figure 2. Energy Dispersive X-ray Spectroscopy (EDS) of copper, iron and zinc nanoparticles synthesized by green synthesis from wheat straw, A: Copper nanoparticles (CuO NPs), B: Iron nanoparticles (FeO NPs), C: Zinc nanoparticles (ZnO NPs)

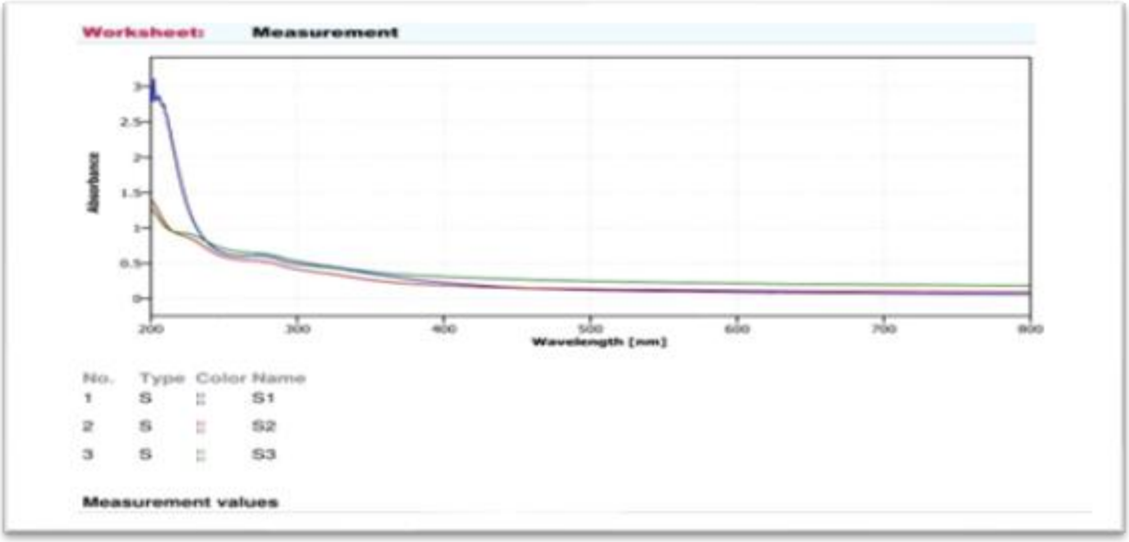

Figure 3. UV-Vis spectroscopy (UV-Vis), where S1 represents the ZnONPs sample, S2 represents the FeONPs sample, and S3 represents the CuONPs sample.

Plant metabolites, such as phenols, terpenoids, alkaloids, flavonoids, proteins, and carbohydrates, among others, play a significant role in the stabilization and reduction of copper metal to copper nanoparticles (El-Seedi, 2019). The reduction rate and nanoparticle formation can be greatly increased by increasing the incubation time, such that the color intensity increases with increasing reaction time (Badawy et al., 2021). Due to their optical properties, the nanoparticles exhibit different colors in solutions (Wu et al., 2020), and the color change is a result of surface plasmon resonance excitation in the nanoparticles. Copper nanoparticles possess interesting optical properties that are directly related to the localization of surface plasmon resonance and are highly dependent on the nanoparticle morphology (Badawy et al., 2021). The reduction of ions to nanoparticles during exposure to plant extracts can be followed by a color change. This color change in the extract is a clear indicator of copper nanoparticle formation and positive biosynthesis. The color changes observed are a result of the reduction process due to surface plasmon resonance, a property sometimes seen in certain metals for example, copper, due to the transformation of metal particle diameters to the nanoscale (Alwaan et al., 2021; Schletz et al., 2021). Color change is a primary indicator of nanoparticle biosynthesis, and the different colors that appear in the colloidal solution are irregular spherical, pentagonal, and circular shapes of copper nanoparticles (Siddiqi et al., 2018). The reduction of copper nano-ions to copper nanoparticles after treatment with plant extracts can be followed by a color change. The reason for the color change has been explained as the fact that plants may possess different metabolic compounds such as terpenoids, phenols, alkaloids, flavonoids, and others. These compounds play a major role in stabilizing metallic copper and reducing it to copper nanoparticles (CuNPs). The metallic nanoparticles exhibit different colors in solution due to the optical properties they possess. (Saliem et al., 2016; Rasaee et al., 2018) have shown that the rate of reduction and nanoparticle formation can be greatly increased by increasing the incubation time, and thus the color intensity increases with increasing the reaction time. Plant extracts not only possess reducing properties but also antioxidant properties, acting as reducing agents for the preparation of nanoparticles and also as stabilizers to protect them from oxidation (Bao et al., 2021; Alinaghi et al., 2024). Flavonoids, phytic acid, anthocyanins, ascorbic acid, sugars, antioxidant vitamins, polyphenols, terpene derivatives, sulfur compounds, phytoestrogens, alkaloids, minerals, coumarins, sterols, xanthones, unsaturated fatty acids, and dietary fiber are among the classified phytochemicals that may be present in plants (Piro et al., 2022; Hanna et al., 2023). The functional groups (-OH, -COOH, $-NH_2$) present in these same phytochemicals reduce the concentration of metal ions, stabilize nanoparticles by preventing agglomeration, regulate their size and shape, and improve their biocompatibility. Controlling the size and structure of nanoparticles requires this dual property (Susanti et al., 2022). These phytochemicals are essential for reducing metals to nanoparticles, facilitating the production of reproducible nanoparticles (Riaz et al., 2023), which reduces the use of hazardous compounds and benefits both human health and the environment (Edo et al., 2025; Madkour, 2023). The size and shape of the final nanoparticles may vary depending on the concentration of the extract used. An optimal concentration is necessary to produce nanoparticles with ideal physical properties. Before reaching the optimal concentration, the size of the generated nanoparticles decreases as the extract concentration increases. This is because higher concentrations of extracts are associated with higher concentrations of phytochemicals that act as stabilizers and reducing agents in the biosynthesis of gold and silver nanoparticles, thus increasing the rate of nanoparticle formation while reducing the size compensation (Ahmad Kuthi et al., 2022). Surfactants significantly increase productivity by stabilizing nanoparticles in solution and enhancing the solubility of reducing agents. SDS boosted the productivity of gold nanoparticles by more than 40% when mixed with aloe vera extract, and PVP improved the productivity and strength of zinc oxide nanoparticles synthesized using green tea extract (Wei et al., 2019). Surfactants also aid in the extraction of phytochemicals by disrupting plant cell membranes, thereby increasing the amount of reducing agents (Nady et al., 2023).

Conclusion: In this study, the feasibility of the use of wheat straw extract to a green and eco-friendly method of synthesis of copper, iron and zinc nanoparticles using the reducing agent was investigated. The results show that bioactive compounds in wheat straw can be involved in the reduction and stabilization process during the process of the formation of nanoparticles. The structures obtained by X-ray diffraction (XRD) analysis indicated the formation of copper containing nanoparticles with semi-crystalline nature, while the structures of iron and zinc were from crystalline to poorly crystalline under the synthesis conditions used. The major detectable elements in the samples were identified by energy-dispersive X-ray spectroscopy (EDS) as being copper, iron and zinc and no signal was detected within the limits of the analysis that indicated that the samples contained impurities. The characteristic absorption bands in the UV-Vis shown by the analysis confirmed the formation of nanomaterials. In summary, the results point towards the possibility of wheat straw being used as a green and eco-friendly reducing agent for the synthesis of nanoparticles at low cost. However, other characterization methods like TEM, FTIR, XPS, and SEM are recommended to fully confirm the morphological, chemical, and structural features of the synthesized materials. It is recommended that future studies optimize synthesis parameters to further improve stability, crystallinity, and the potential for large-scale production of these nanomaterials and explore the environmental, biological and industrial applications of these nanomaterials.

Author contributions

All authors have equal contribution. All authors have read and agreed to the published version of the manuscript.

Data availability statement

Not applicable.

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Ethical considerations

The authors avoided data fabrication, falsification, plagiarism, and misconduct.

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Conflict of interests

The authors declare no conflict of interest.

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استفاده از عصاره کاه گندم به عنوان عامل کاهنده سبز برای سنتز نانوذرات مس، آهن و روی

سرا ی. محمود

گروه زیست‌شناسی، دانشکده علوم، دانشگاه موصل، عراق. ایمیل: sura.24scp62@student.uomosul.edu.iq

هدیل ا. العامری

* نویسنده مسئول. گروه زیست‌شناسی، دانشکده علوم، دانشگاه موصل، عراق. ایمیل: hadsbio43@uomosul.edu.iq

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چکیده

هدف: این مطالعه با هدف سنتز نانوذرات اکسید مس (CuONPs)، نانوذرات اکسید آهن (FeONPs) و نانوذرات اکسید روی (ZnONPs) از کاه گندم با استفاده از رویکرد سنتز سبز و همچنین مشخصه‌یابی نانوذرات سنتزشده به وسیله پراش پرتو ایکس (XRD)، طیف‌سنجی پراکندگی انرژی پرتو ایکس (EDS) و طیف‌سنجی فرابنفش-مرئی (UV-Vis) انجام شد.

مواد و روش‌ها: نانوذرات اکسید مس، اکسید آهن و اکسید روی از کاه گندم به روش سنتز سبز و سازگار با محیط زیست تولید شدند. ویژگی‌های ساختاری نانوذرات سنتزشده با استفاده از پراش پرتو ایکس (XRD) و تابش Cu Kα ($\lambda = 1.5406$ Å) مورد بررسی قرار گرفت. الگوهای پراش به‌دست‌آمده با داده‌های مرجع استاندارد JCPDS مقایسه شدند تا فازهای بلوری مواد شناسایی شوند و اندازه بلورک‌ها با استفاده از معادله دبای-شرر (Debye-Scherrer) برآورد گردید. ترکیب عنصری و خلوص نانوذرات با استفاده از میکروسکوپ الکترونی روبشی مجهز به طیف‌سنجی پراکندگی انرژی پرتو ایکس (SEM-EDS) ارزیابی شد. علاوه بر این، طیف‌سنجی UV-Vis برای بررسی ویژگی‌های نوری نانوذرات سنتزشده در محدوده طول موج ۲۰۰ تا ۸۰۰ نانومتر به کار گرفته شد.

نتایج: آنالیز XRD نانوذرات اکسید مس (CuONPs) وجود یک ساختار بلوری مختلط را نشان داد که شدیدترین پیک آن در حدود زاویه ۳/۴۳ درجه مشاهده شد. این نتیجه بیانگر تشکیل موفق نانوساختار اکسید مس با بلورینگی نسبی است. در مقابل، الگوی پراش نانوذرات اکسید آهن (FeONPs) دارای ویژگی‌های پراکندگی گسترده و فاقد پیک‌های تیز پراش بود که نشان‌دهنده ساختاری با بلورینگی بسیار پایین یا تقریباً آمورف است. به‌طور مشابه، نانوذرات اکسید روی (ZnONPs) نیز الگوی پراش پهن و

برآمده‌ای را بدون پیک‌های مشخص و تیز مربوط به اکسید روی با بلورینگی بالا نشان دادند. نتایج آنالیز EDS حضور عناصر اصلی تشکیل‌دهنده تمامی نانوذرات سنتزشده را در نواحی مورد بررسی تأیید کرد. با این حال، ماهیت اکسیدی نانوذرات سنتزشده باید با استفاده از روش‌های مکملی مانند طیف‌سنجی مادون قرمز تبدیل فوریه(FTIR) ، طیف‌سنجی فوتوالکترون پرتو ایکس (XPS) یا آنالیز دقیق‌تر XRD بیشتر تأیید شود.

نتیجه‌گیری: یافته‌های این پژوهش نشان می‌دهد که عصاره کاه گندم می‌تواند به عنوان یک عامل کاهنده سازگار با محیط زیست برای سنتز سبز نانومواد مبتنی بر مس، آهن و روی مورد استفاده قرار گیرد. نتایج XRD وجود نانوذرات اکسید مس، اکسید آهن و اکسید روی با بلورینگی نسبی را نشان داد و آنالیز EDS حضور عناصر متناظر را تأیید کرد. این نتایج از قابلیت استفاده از پسماندهای کشاورزی برای تولید پایدار و سازگار با محیط زیست نانوذرات حمایت می‌کند.

کلمات کلیدی: سنتز سبز، کاه گندم، نانوذرات اکسید آهن، نانوذرات اکسید روی، نانوذرات اکسید مس

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