A Comprehensive Study of *Terminalia arjuna* Bark Extract Mediated Green-Synthesized Pure, Fe-Doped, and Ag-Decorated ZnO/CuO Nanocomposites

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Green synthesis of Nanoparticles

- Green synthesis involves synthesis of nanoparticles using plant extract and microorganisms such as bacteria and fungi.

- Green synthesis is a Bottom-Up approach.

- All the parts of a plant contains Phyto-chemicals which act as both reducing and stabilization agent.

Green synthesis of Nanoparticles (Contd.)

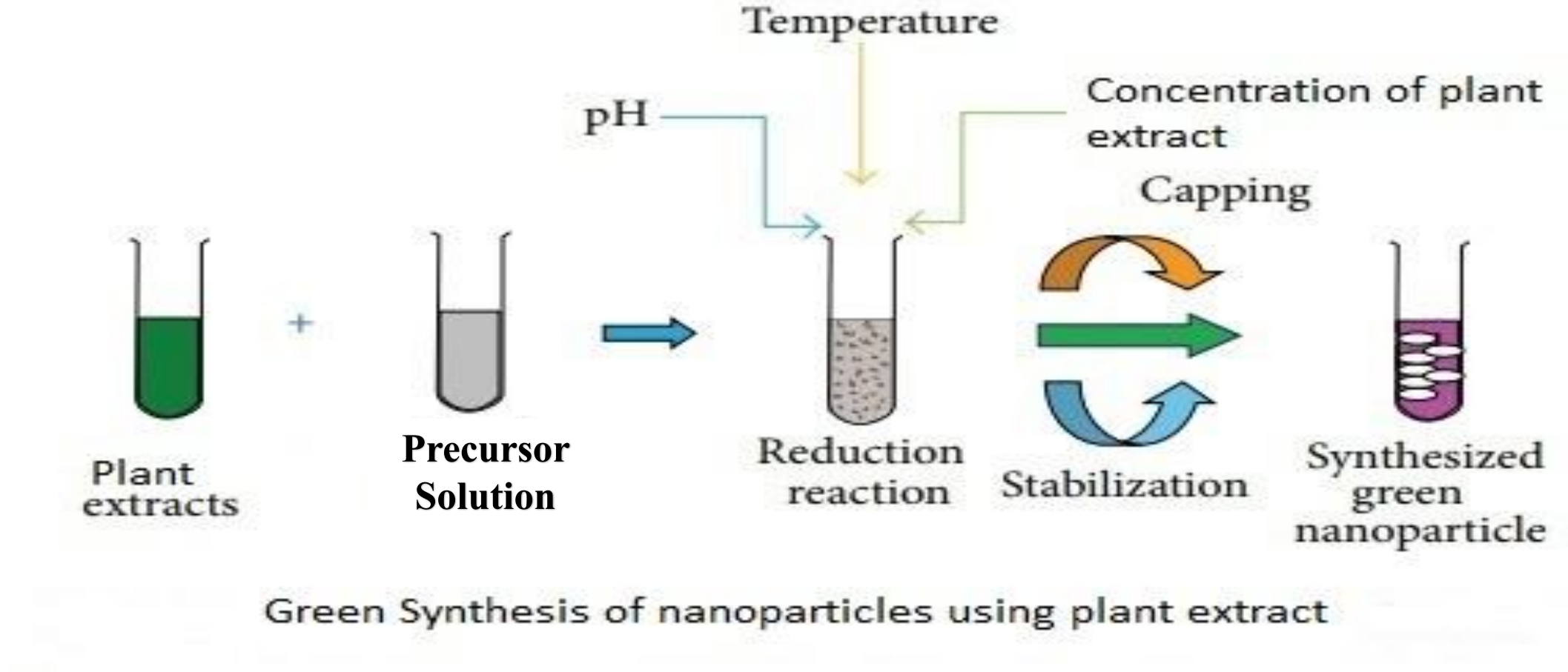


Fig.1: Green synthesis process

Image Credit: https://mnsl-journal.springeropen.com/articles/10.1186/s40486-021-00131-6

Green synthesis of Nanoparticles

Advantages:

- Green synthesis is simple and usually involves a one-pot reaction
- The toxicity-associated hazardous chemicals are eliminated
- Green biological entities can be used as reducing agents and capping agents
- The process is cost-effective

Disadvantages:

- Difficult to control size, shape & crystal growth of the nanoparticles in green synthesis
- Heating conditions such as temperature is required which increases production cost of nanoparticles

Flow Chart of Experimental Techniques

Preparation of Precursor Solutions

Precursor salts:
Zinc Nitrate [$Zn(NO_3)_2$]
Copper Nitrate [$Cu(NO_3)_2$]
Iron Nitrate [$Fe(NO_3)_3$]
Silver Nitrate [$Ag(NO_3)$]

Preparation of Plant Extract

Plant part:
Terminalia arjuna Bark

Reduction reaction initiates between precursors solutions and plant extract

Calcined the synthesized precipitated

Green synthesized nanomaterials

Characterizations of the prepared sample

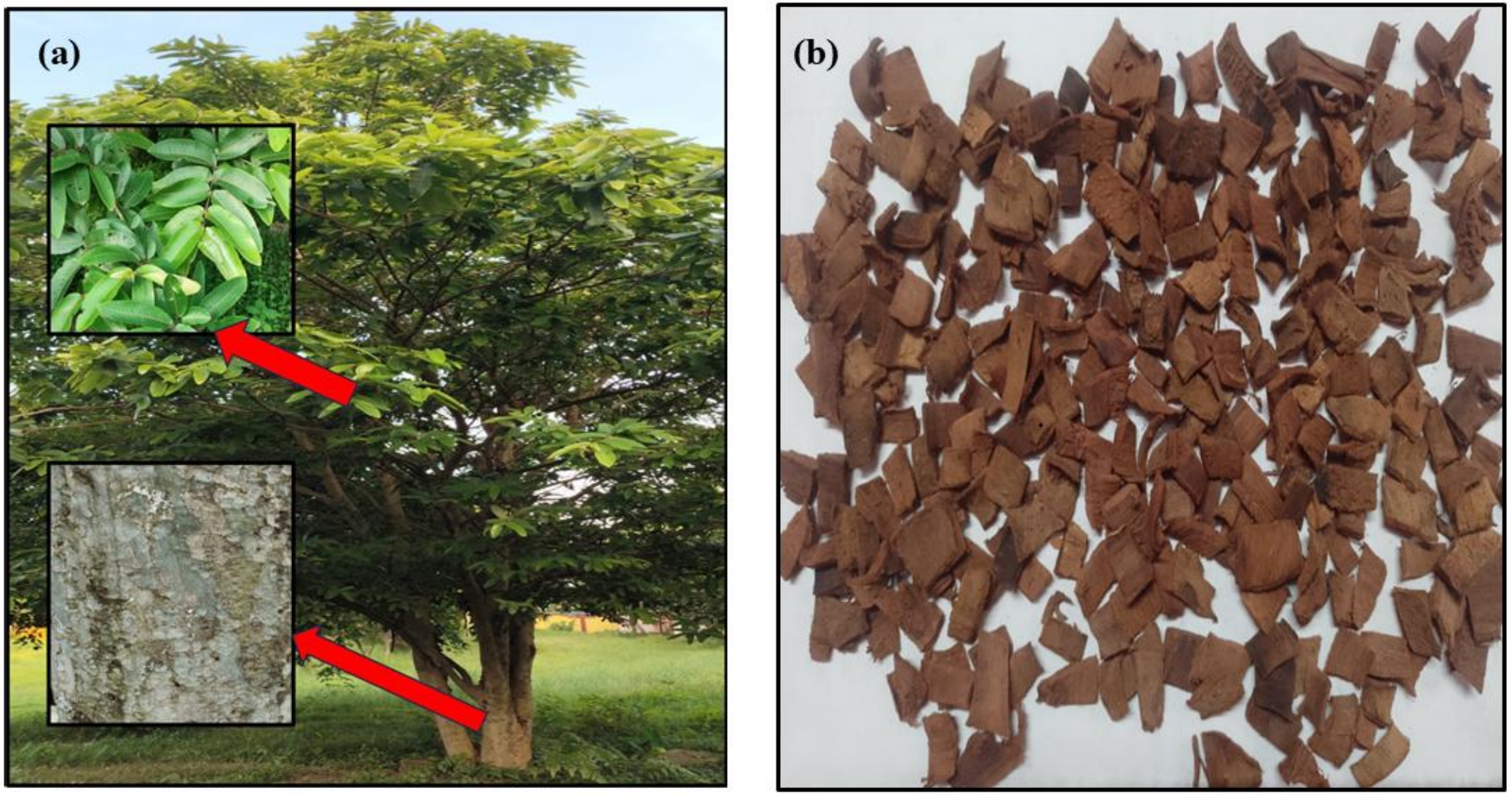
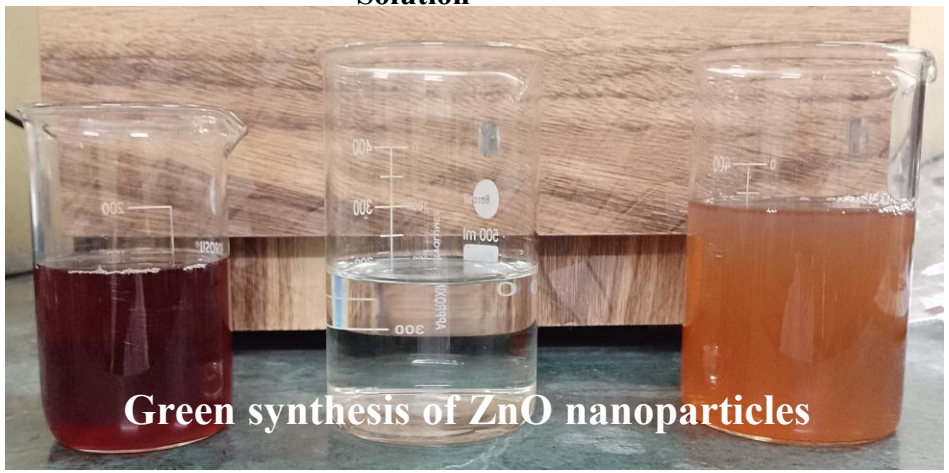


Fig. 2: (a) Photograph of *Terminalia arjuna* plant, (b) bark of *Terminalia arjuna*

Experimental Technique

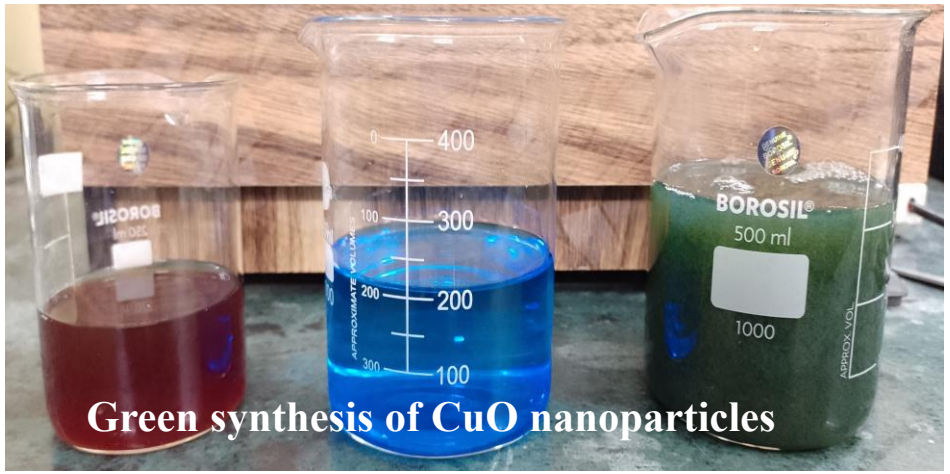
Green synthesis of ZnO, CuO, ZnO/CuO NCs using *Terminalia arjuna* bark extract

Arjuna Bark extract | $[Zn(NO_3)_2]$ Solution | Precursor + Extract Solution



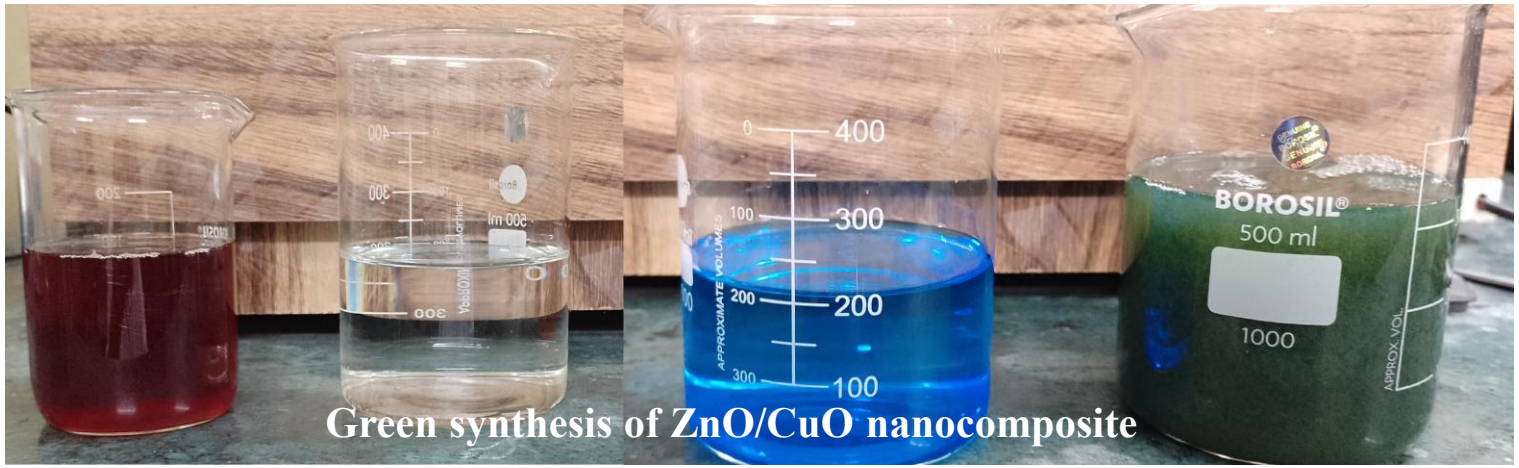
Green synthesis of ZnO nanoparticles

Arjuna Bark extract | $[Cu(NO_3)_2]$ Solution | Precursor + Extract Solution



Green synthesis of CuO nanoparticles

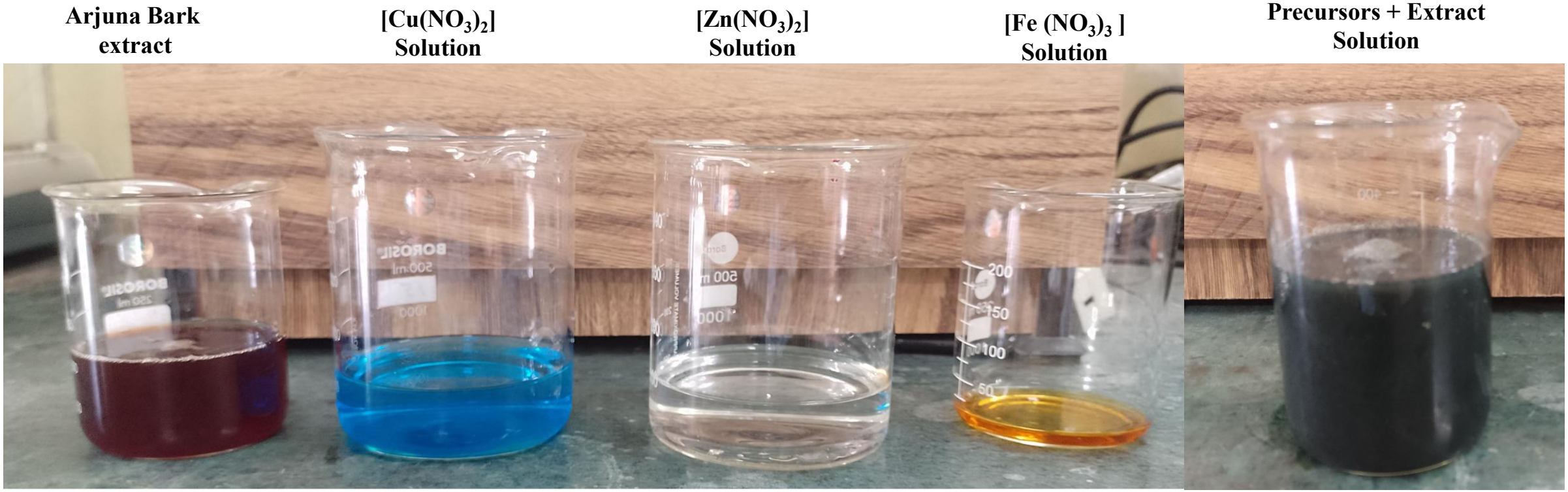
Arjuna Bark extract | $[Zn(NO_3)_2]$ Solution | $[Cu(NO_3)_2]$ Solution | Precursor + Extract Solution



Green synthesis of ZnO/CuO nanocomposite

Experimental Technique

Green synthesis of Fe_x-ZnO/CuO nanocomposites using *Terminalia arjuna* bark extract

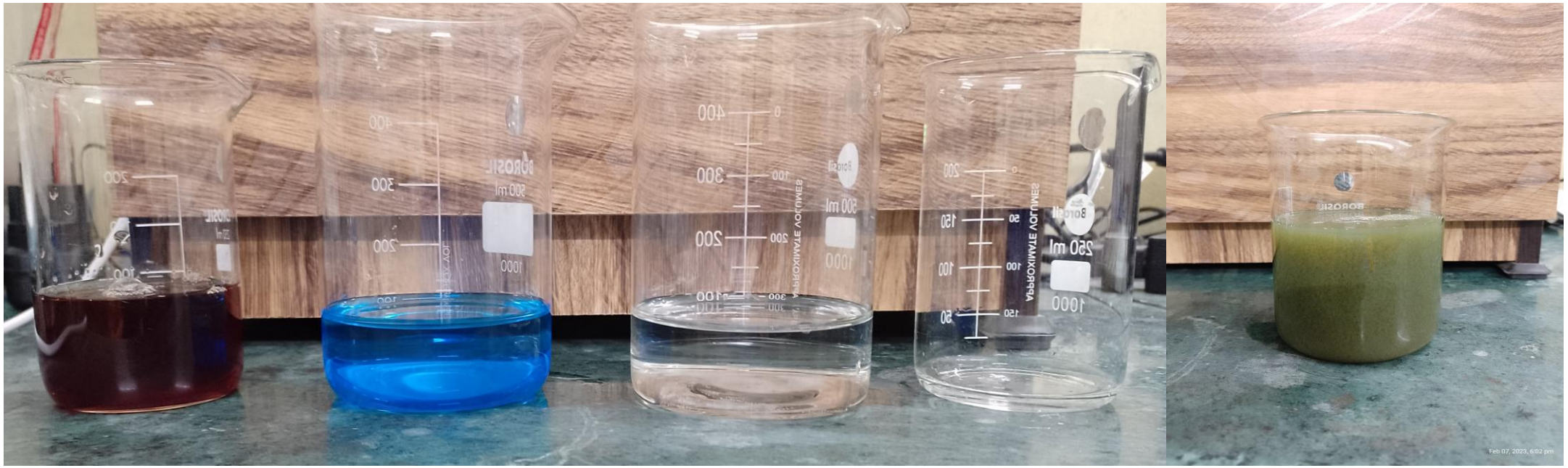


- The change in colour of the solution indicates the reduction reaction of precursors salts by *T. arjuna bark* extract.

Experimental Technique

Green synthesis of *x*Ag/ZnO/CuO nanocomposites using *Terminalia arjuna* bark extract

Arjuna Bark extract	$[Cu(NO_3)_2]$ Solution	$[Zn(NO_3)_2]$ Solution	$[Ag(NO_3)]$ Solution	Precursors + Extract Solution



- The change in colour of the solution indicates the reduction reaction of precursors salts by *T. arjuna bark* extract.

Green synthesis of Fe_x-ZnO/CuO nanocomposites at varying concentration of Iron salt

- The concentration of Iron (Fe) salt are *x*= 5 %, 10% and 15 %

- The synthesized nanocomposite are named as:

  F5 : $Fe_{0.05}$-ZnO/CuO

  F10 : $Fe_{0.10}$-ZnO/CuO

  F15 : $Fe_{0.15}$-ZnO/CuO

Green synthesis of *x*Ag/ZnO/CuO nanocomposites at varying concentration of Silver salt

- The concentration of silver (Ag) salts are *x*= 5 %, 10% and 15 %

- The synthesized nanocomposite are named as

  A5 : $_{0.05}$Ag/ZnO/CuO

  A10 : $_{0.10}$Ag/ZnO/CuO

  A15 : $_{0.15}$Ag/ZnO/CuO

XRD analysis of ZnO, CuO, ZnO/CuO nanocomposite

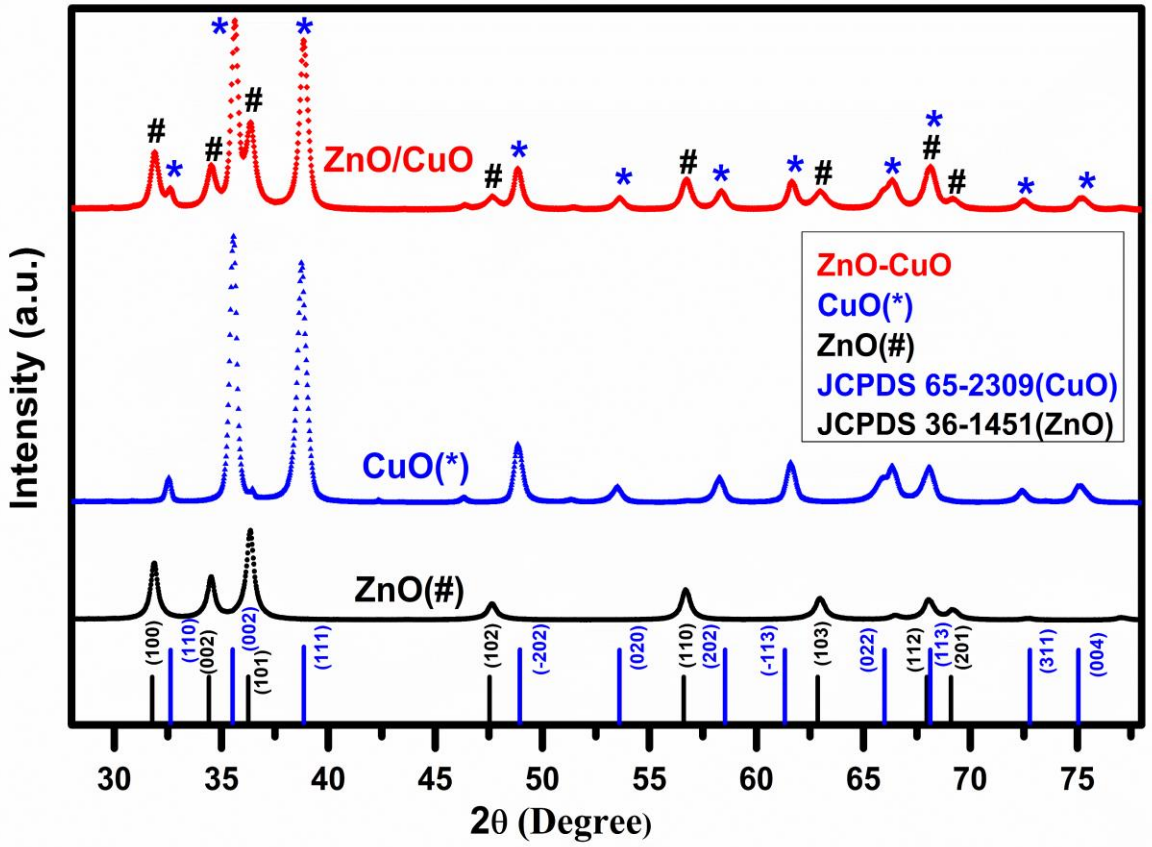


Fig. 3: XRD patterns of ZnO, CuO, ZnO/CuO nanocomposite

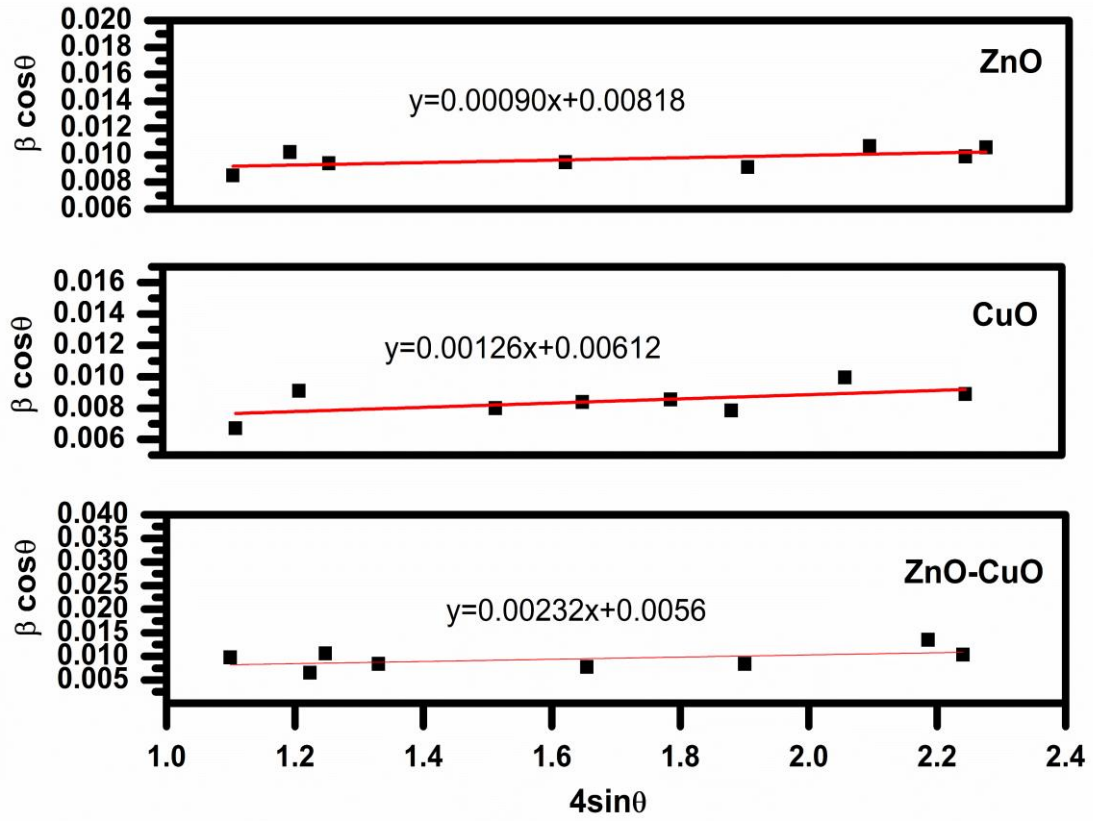


Fig. 4: W–H Plots of ZnO, CuO, ZnO/CuO nanocomposite

XRD analysis of Fe_x-ZnO/CuO nanocomposites

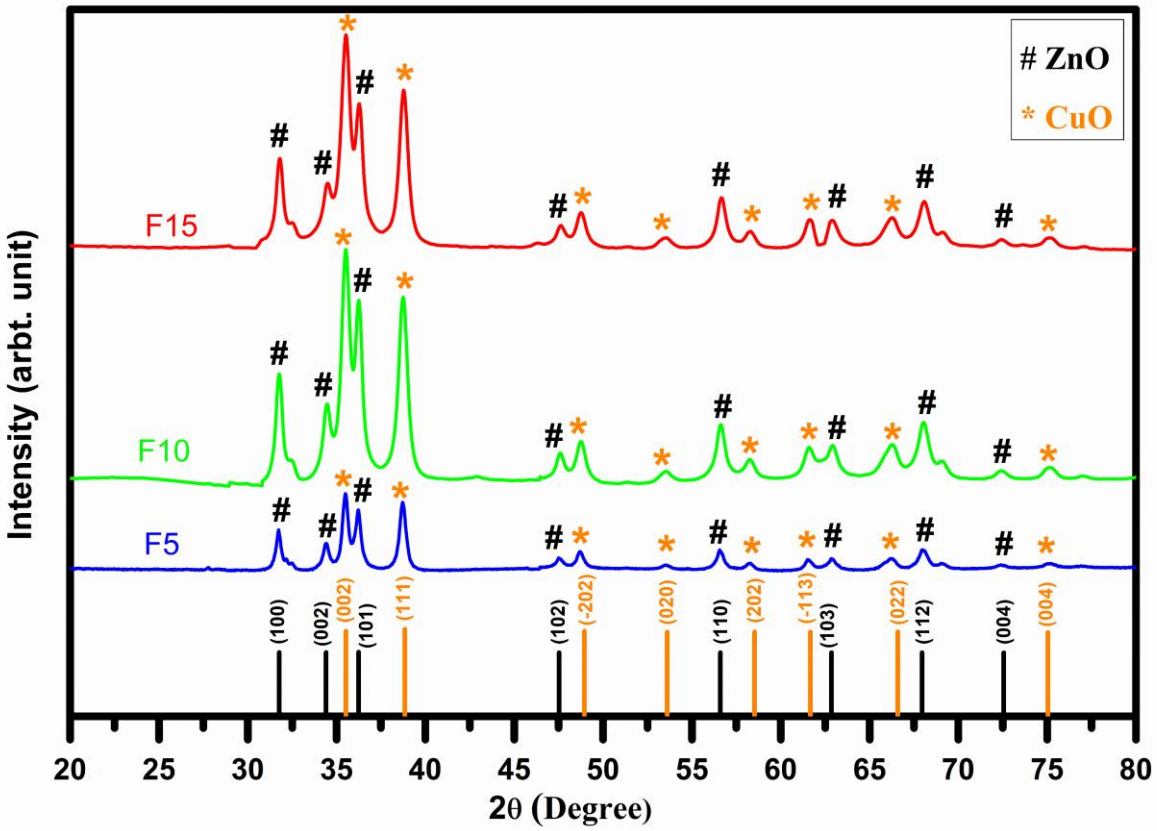


Fig. 5: XRD patterns of F5, F10, and F15 nanocomposites

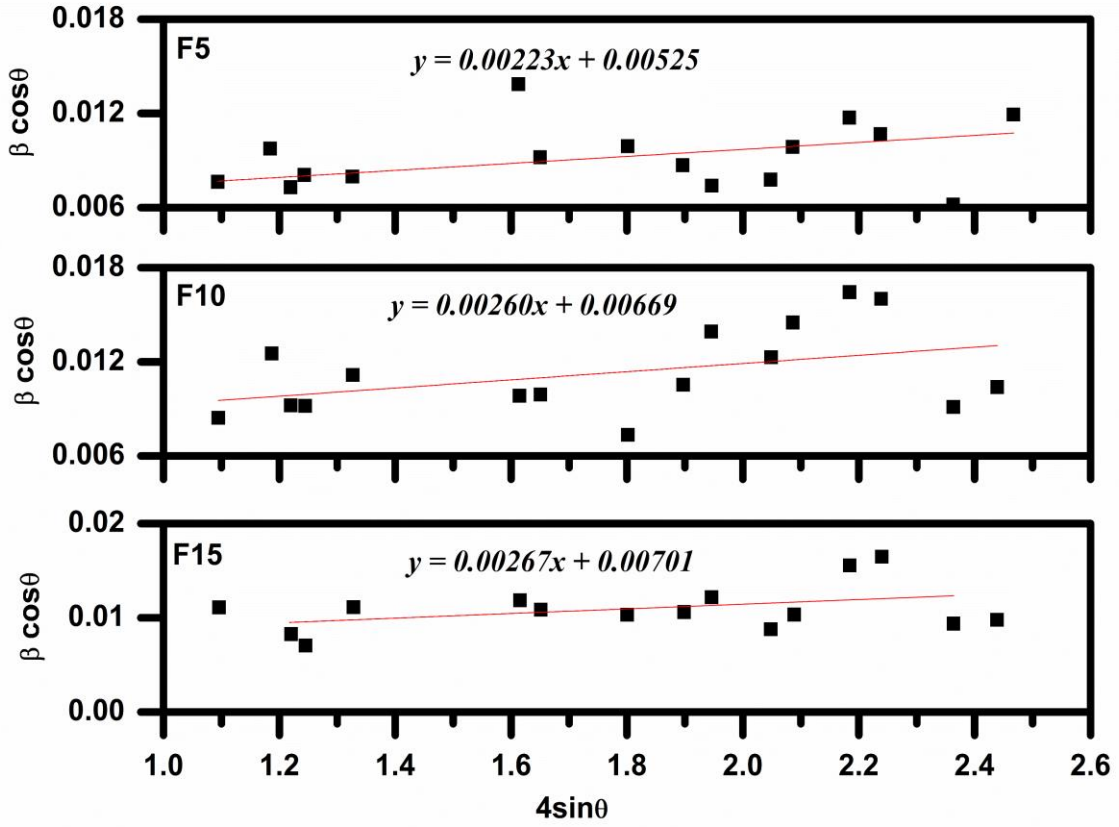


Fig. 6: W–H Plots of F5, F10, and F15 nanocomposites

- **ZnO (JCPDS No. 36-1451 and CuO (JCPDS No. 65-2309)**

XRD analysis of *x*Ag/ZnO/CuO nanocomposites

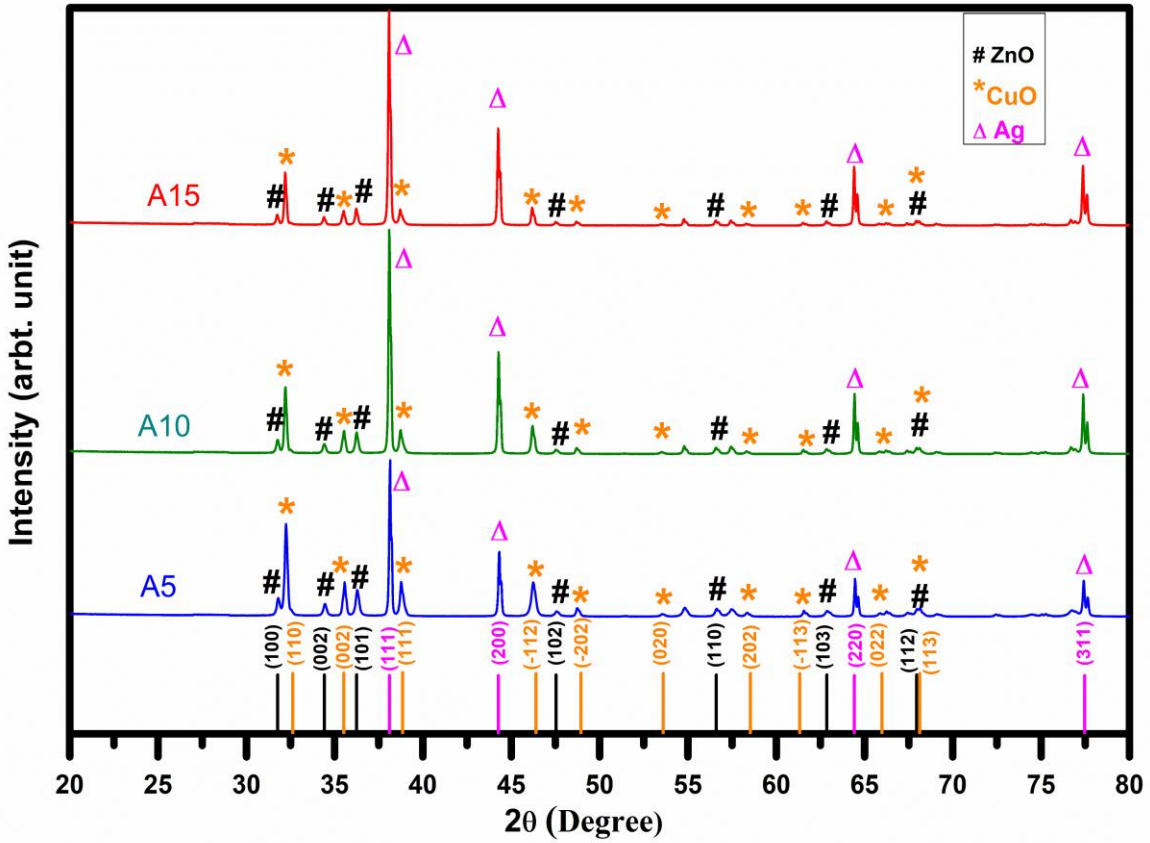


Fig. 7: XRD patterns of A5, A10, and A15 nanocomposites

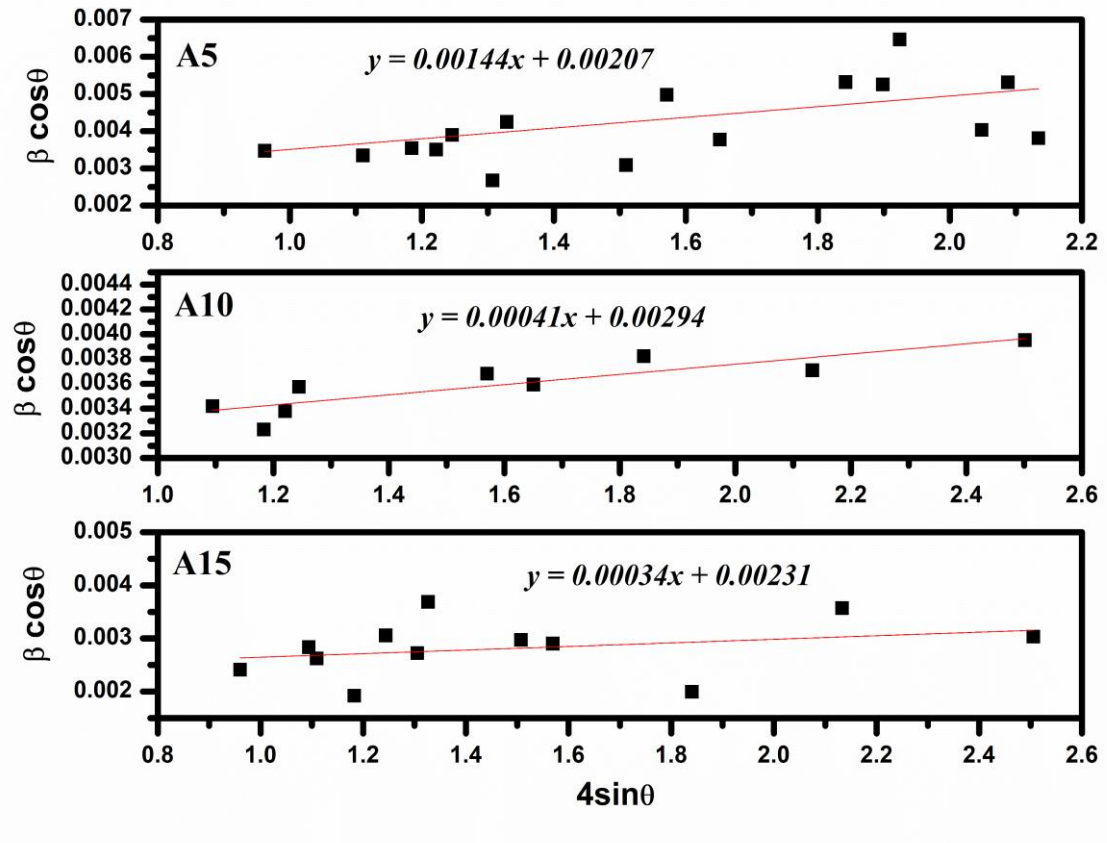


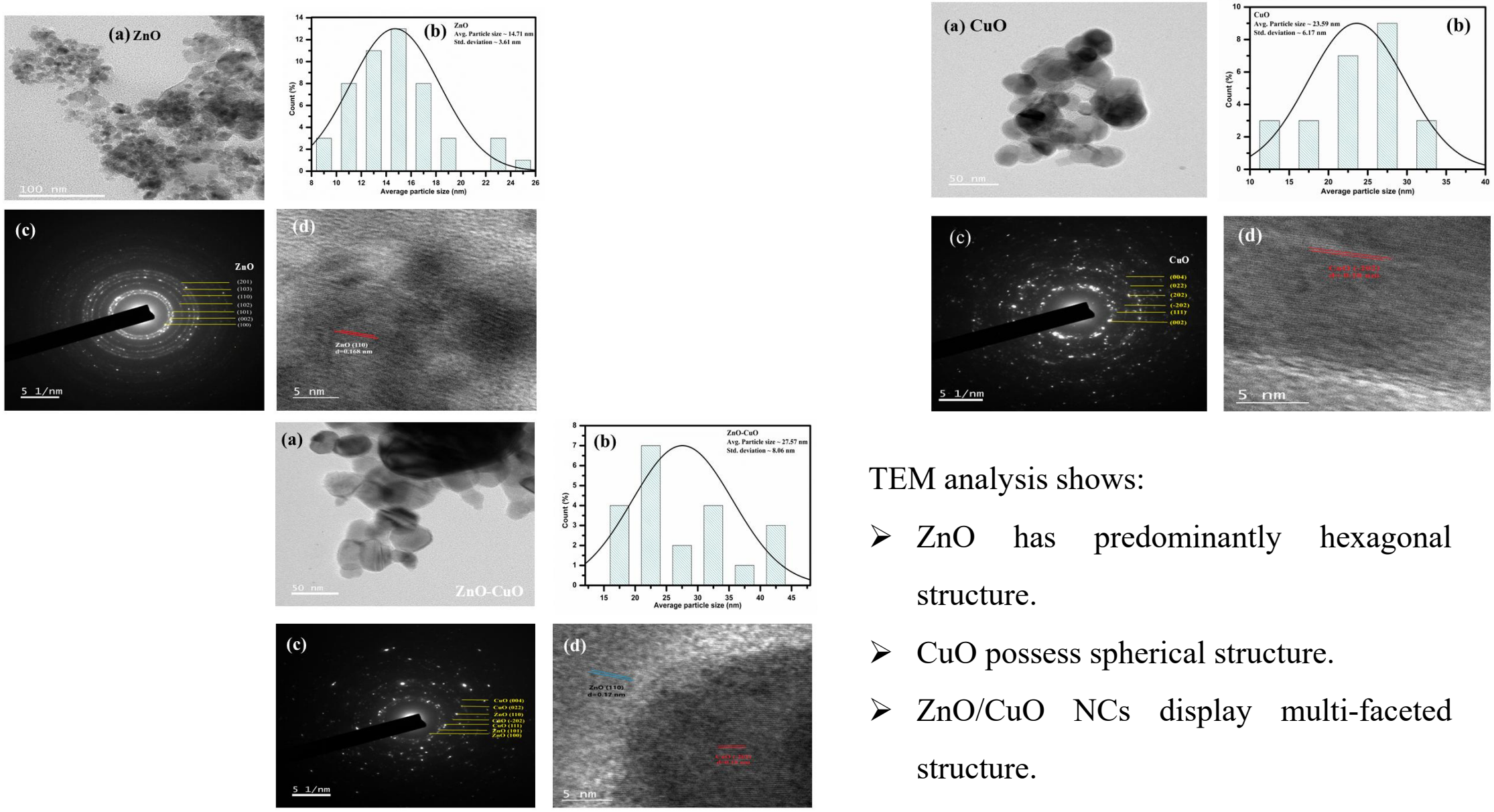
Fig. 8: W–H Plots of A5, A10, and A15 nanocomposites

- **ZnO (JCPDS No.: 36-1451, CuO (JCPDS No.: 65-2309), and Ag (JCPDS NO.: 04-0783**

Table 1: Crystallite Sizes of the synthesized nanomaterials obtained from the XRD analysis

Samples	Crystallite Size (nm)	
	Scherrer's formula	W-H plot
ZnO	11.60	16.95
CuO	13.53	22.65
ZnO/CuO NCs	12.54	24.37
F5 NCs	13.01	15.85
F10 NCs	10.79	12.44
F15 NCs	10.46	11.87
A5 NCs	28.91	40.19
A10 NCs	38.82	49.26
A15 NCs	43.74	62.69

TEM analysis of ZnO, CuO, ZnO/CuO nanocomposite

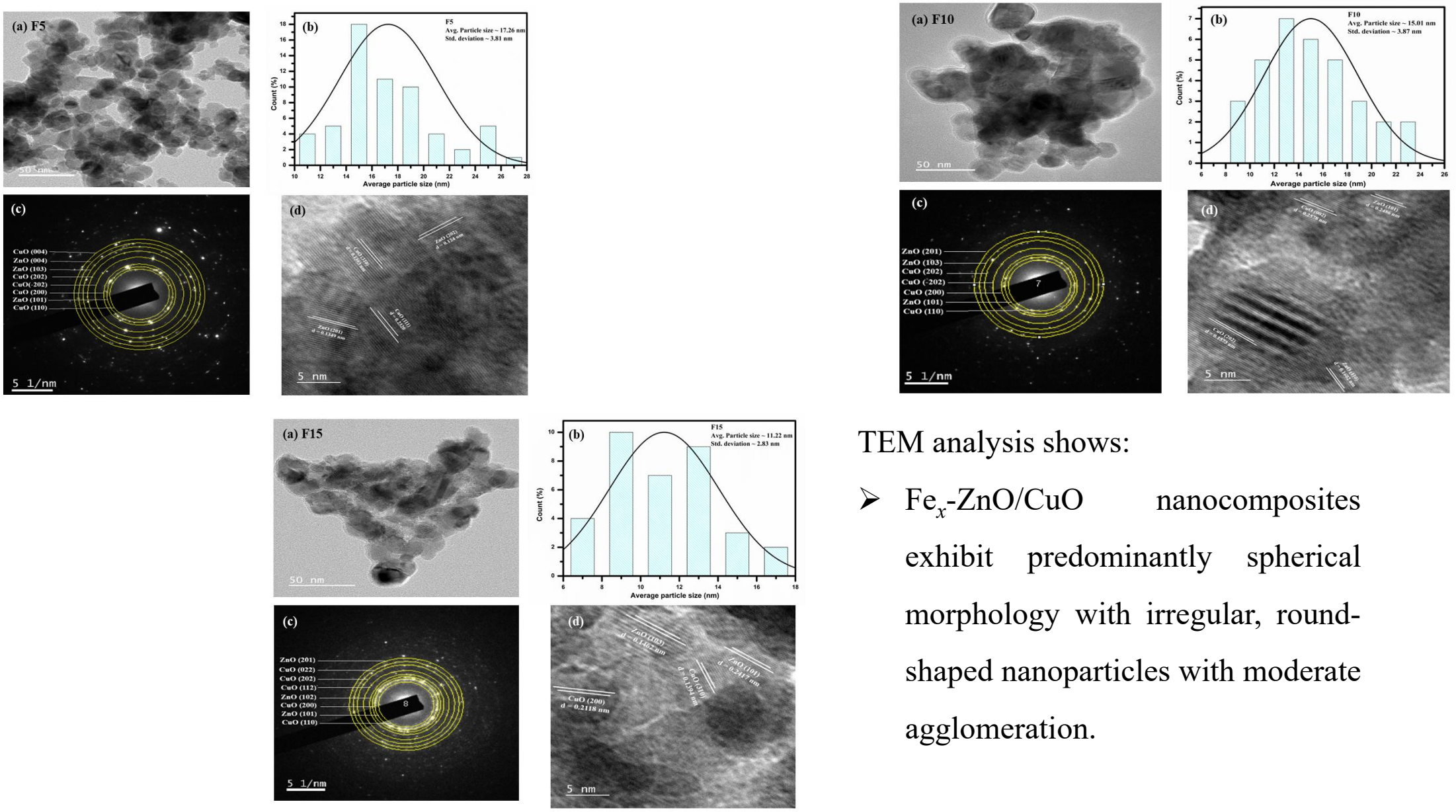


TEM analysis shows:

- ZnO has predominantly hexagonal structure.
- CuO possess spherical structure.
- ZnO/CuO NCs display multi-faceted structure.

Fig. 9: TEM, SAED, HRTEM images of ZnO, CuO, ZnO/CuO nanocomposite

TEM analysis of Fe_x-ZnO/CuO nanocomposites

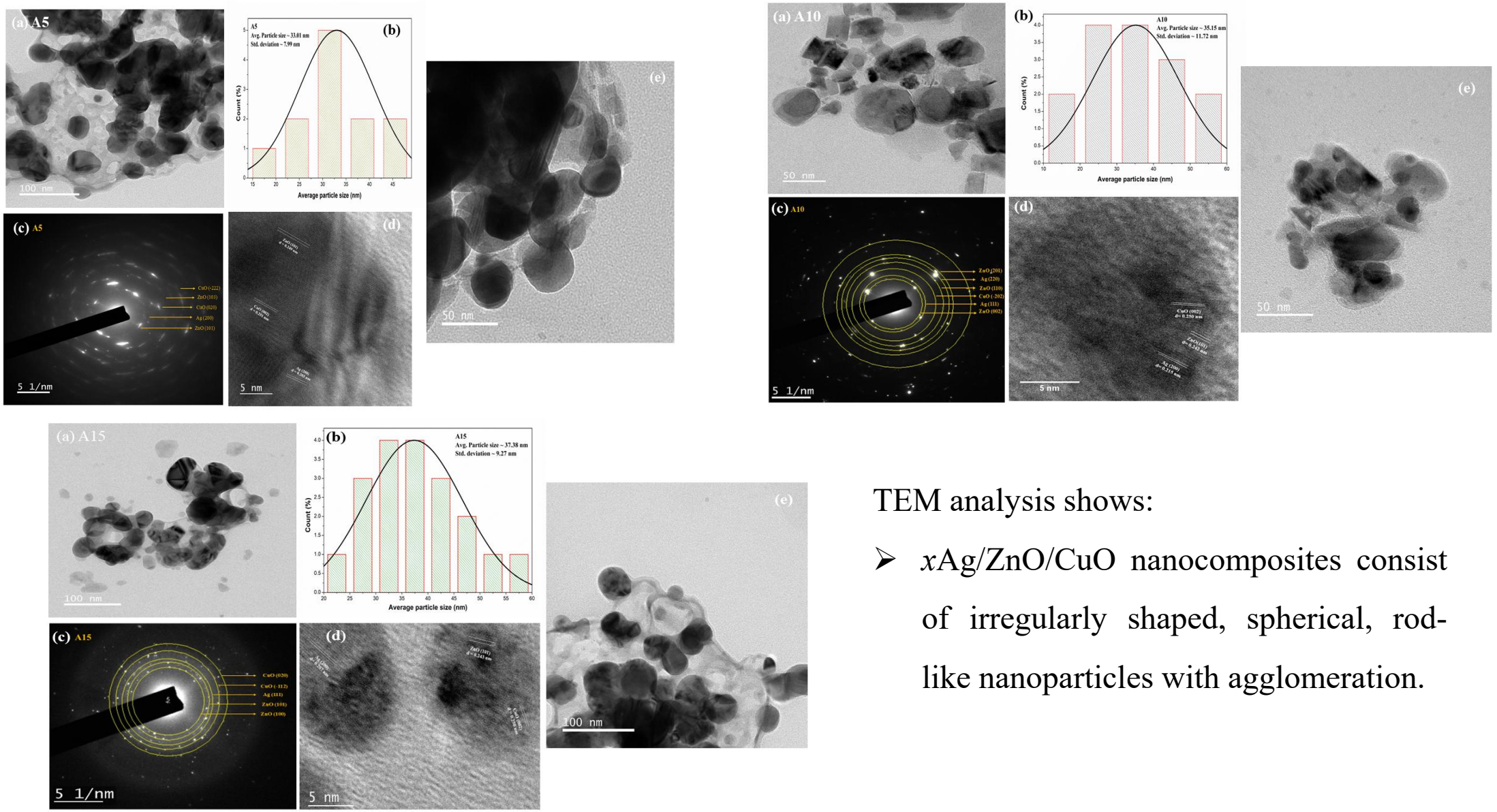


TEM analysis shows:

- Fe_x-ZnO/CuO nanocomposites exhibit predominantly spherical morphology with irregular, round-shaped nanoparticles with moderate agglomeration.

Fig. 10: TEM, SAED, HRTEM images of F5, F10, and F15 nanocomposite

TEM analysis of *x*Ag/ZnO/CuO nanocomposites



TEM analysis shows:

- *x*Ag/ZnO/CuO nanocomposites consist of irregularly shaped, spherical, rod-like nanoparticles with agglomeration.

Fig. 11: TEM, SAED, HRTEM images of A5, A10, and A15 nanocomposite

VSM analysis of ZnO, CuO, ZnO/CuO nanocomposite

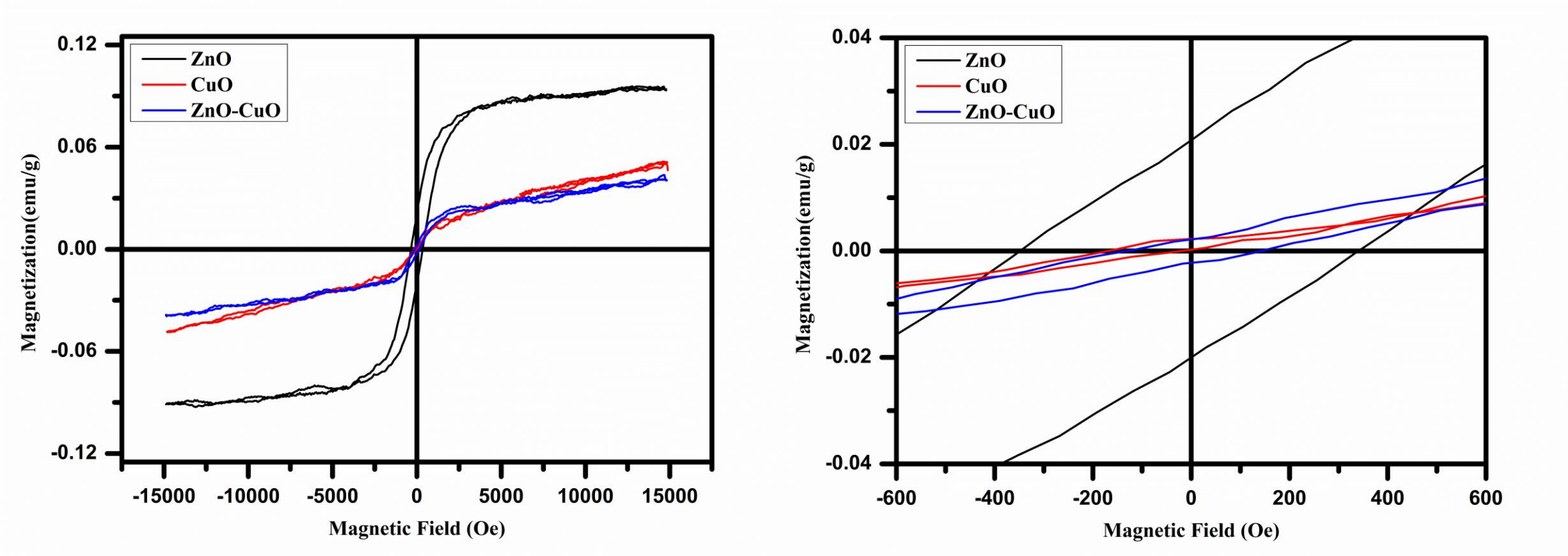


Fig. 12: M-H plots of ZnO, CuO, ZnO/CuO nanocomposite

VSM analysis of Fe_x-ZnO/CuO nanocomposites

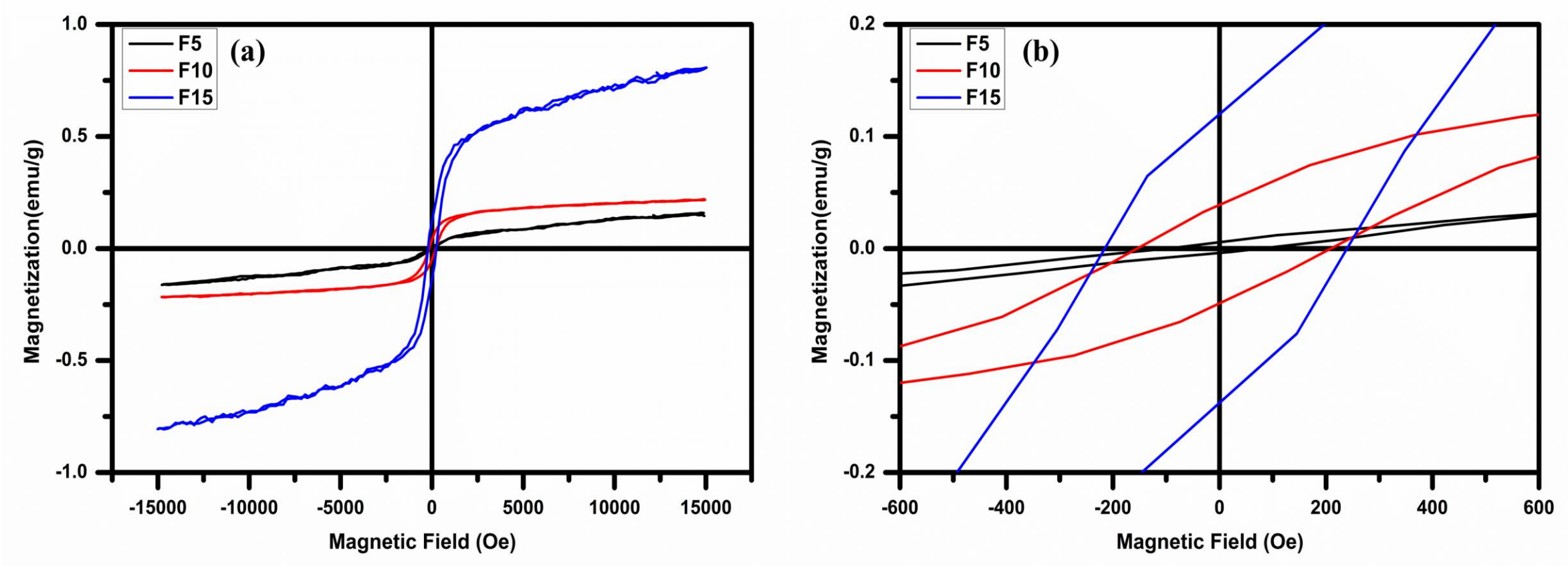


Fig. 13: M-H plots of F5, F10, and F15 nanocomposite

VSM analysis of *x*Ag/ZnO/CuO nanocomposites

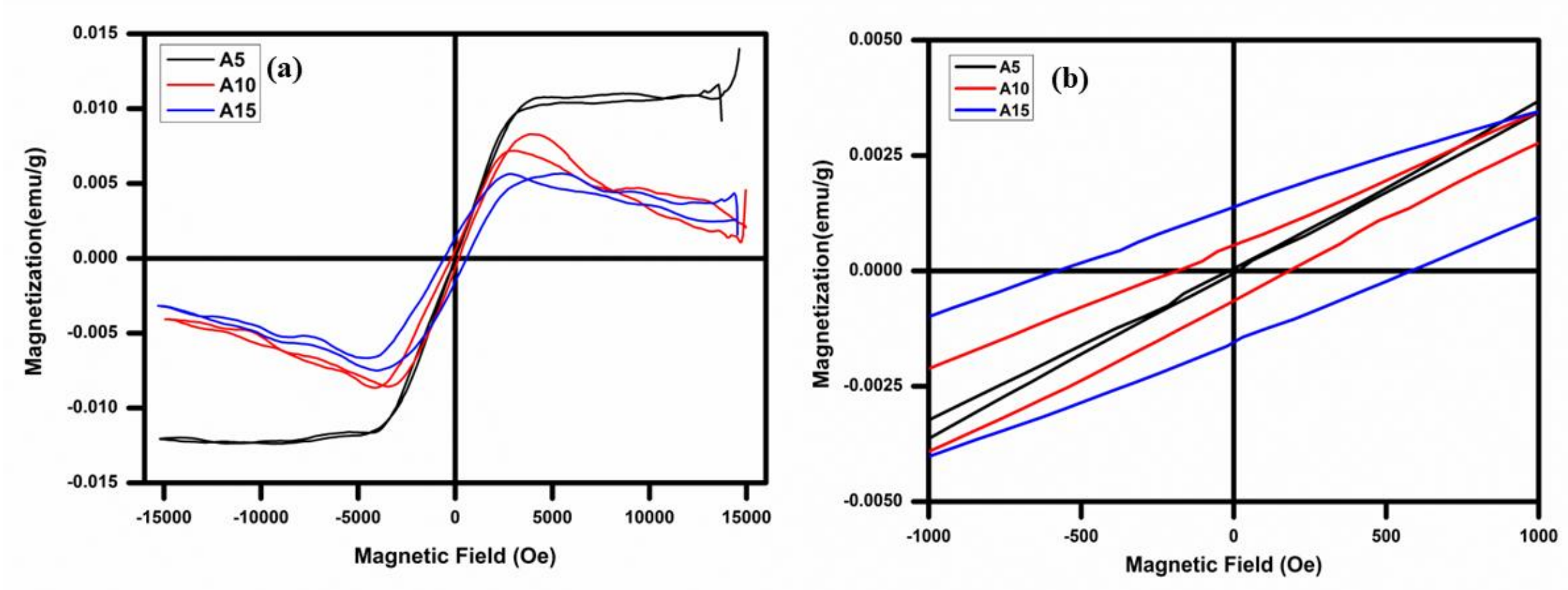
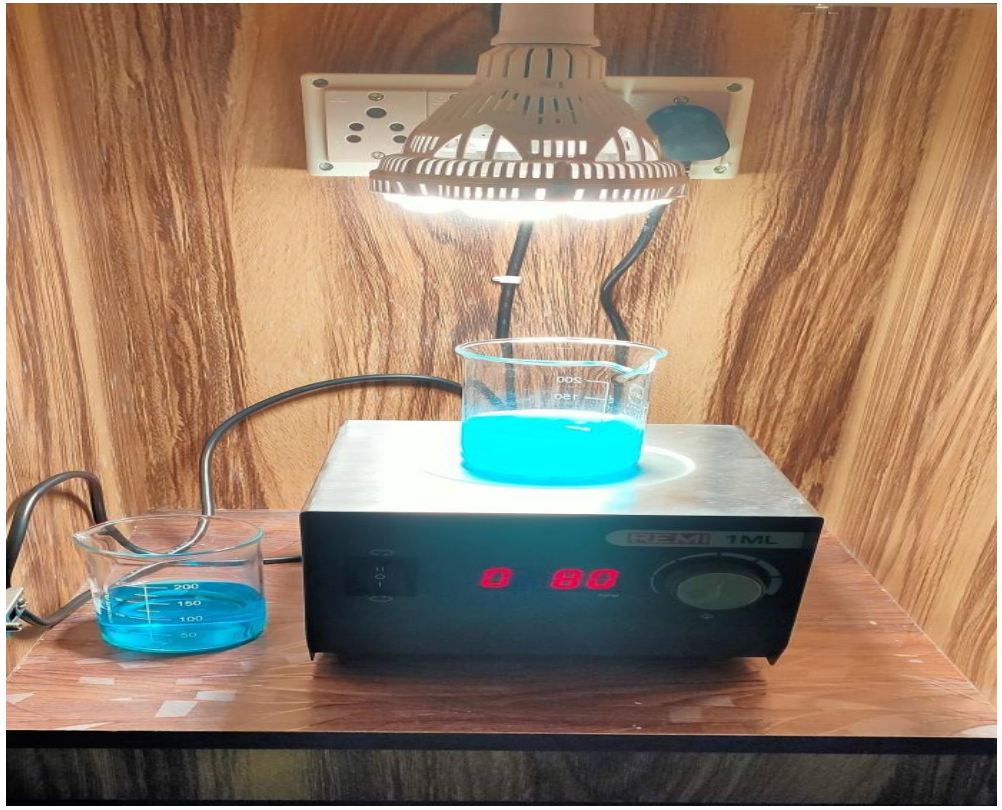


Fig. 14: M-H plots of A5, A10, and A15 nanocomposite

Table 2: Magnetic measurement of the synthesized nanomaterials obtained from the VSM study

Samples	Magnetic parameters		
	Coercivity (Oe)	Remanence (emu/g)	Saturation Magnetization (emu/g)
ZnO	345	0.0204	0.0932
CuO	75	0.0012	0.0470
ZnO/CuO NCs	136	0.0022	0.0393
F5 NCs	86.85	4.75×10^{-3}	1.59×10^{-1}
F10 NCs	180.31	4.39×10^{-2}	2.17×10^{-1}
F15 NCs	226.50	1.29×10^{-1}	8.05×10^{-1}
A5 NCs	14.63	5.45×10^{-5}	1.15×10^{-2}
A10 NCs	182.69	6.05×10^{-4}	7.95×10^{-3}
A15 NCs	577.82	1.48×10^{-3}	5.98×10^{-3}

Experimental Set up of photocatalytic degradation of MB dye using synthesized nanomaterials



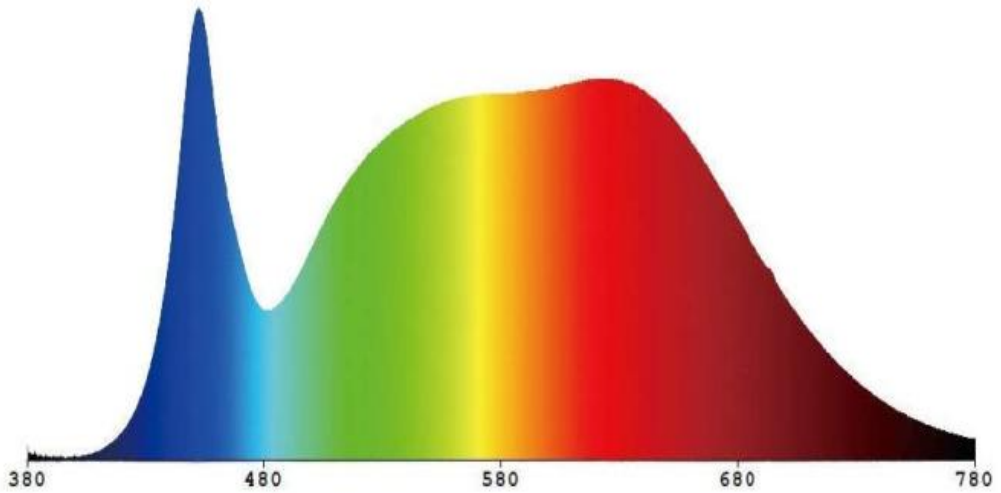
Concentration of Methylene Blue (MB) : 0.01 mM

Photocatalyst Loading : 15mg/15 mL MB solution

Light source: SANSI LED bulb (Visible light)

Intensity: 46.1 W/m^2

UV(380-399nm)	Blue (400-499nm)	Green (500-599nm)	Red (600-699nm)	FR (700-780nm)
0.05%	19.41%	37.7%	36.23%	6.61%



Spectrum of SANSI LED Bulb

Photocatalytic degradation of MB dye using ZnO nanoparticles

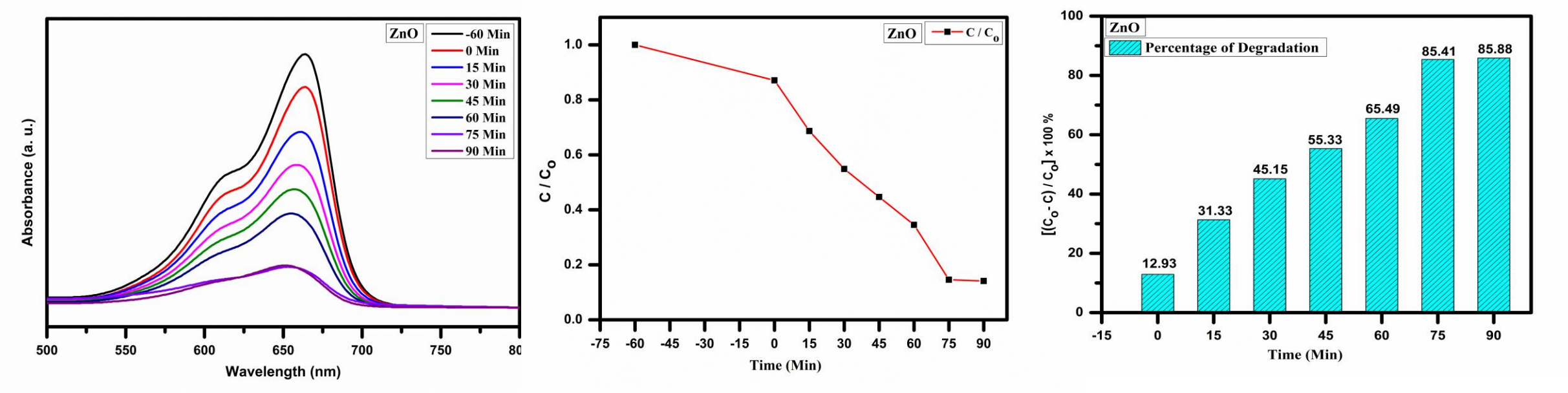


Fig.15: (a) Absorption spectrum of ZnO treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with ZnO nanoparticles

Photocatalytic degradation of MB dye using CuO nanoparticles

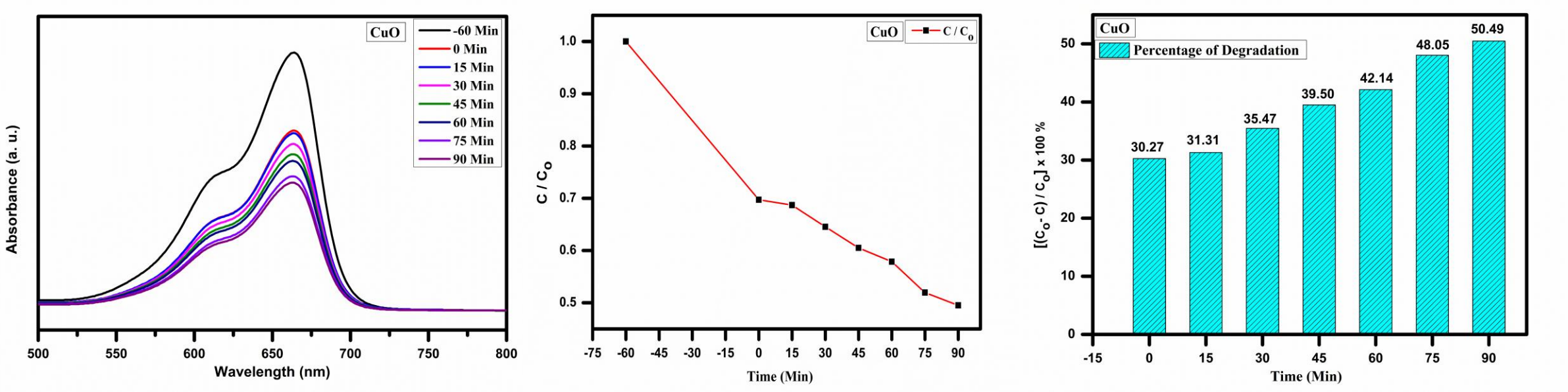


Fig.16: (a) Absorption spectrum of CuO treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with CuO nanoparticles

Photocatalytic degradation of MB dye using ZnO/CuO nanocomposite

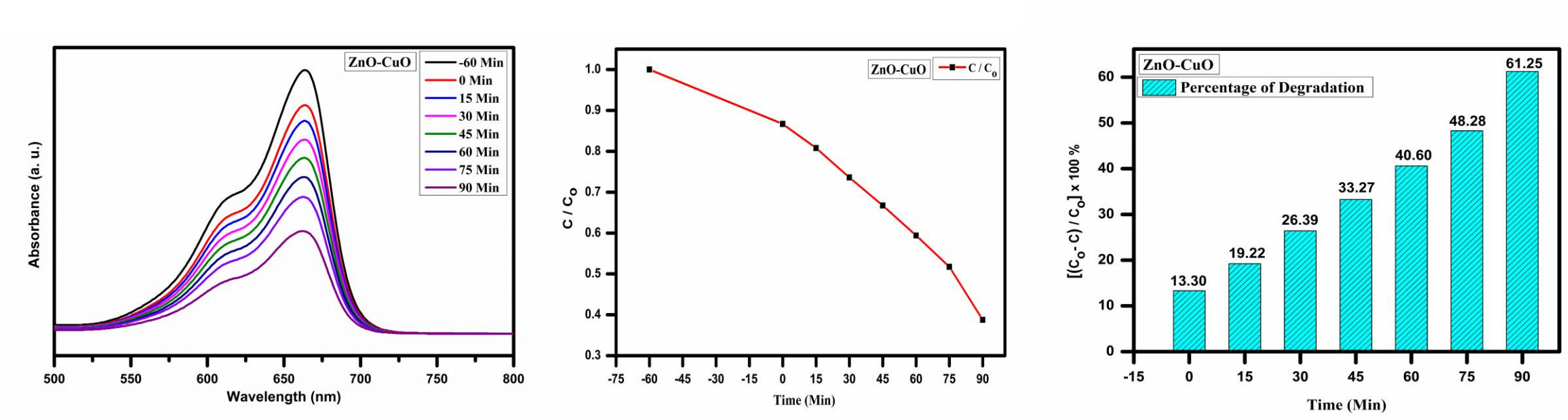


Fig.17: (a) Absorption spectrum of ZnO/CuO NCs treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with ZnO/CuO NCs

Photocatalytic degradation of MB dye using F5 nanocomposites

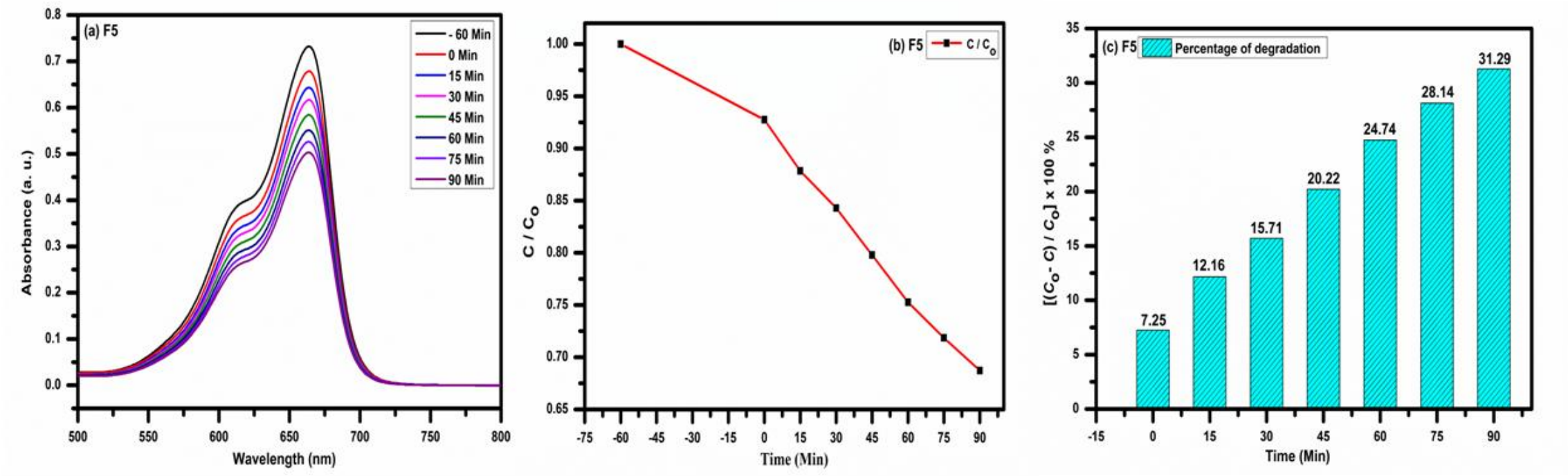


Fig.18: (a) Absorption spectrum of F5 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with F5 sample

Photocatalytic degradation of MB dye using F10 nanocomposites

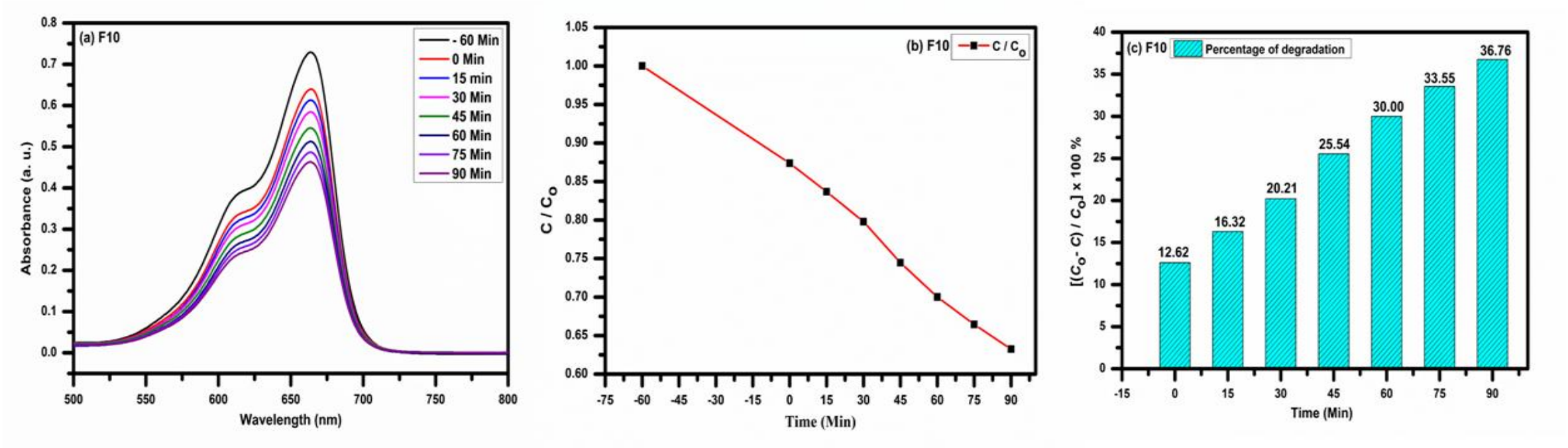


Fig.19: (a) Absorption spectrum of F10 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with F10 sample

Photocatalytic degradation of MB dye using F15 nanocomposites

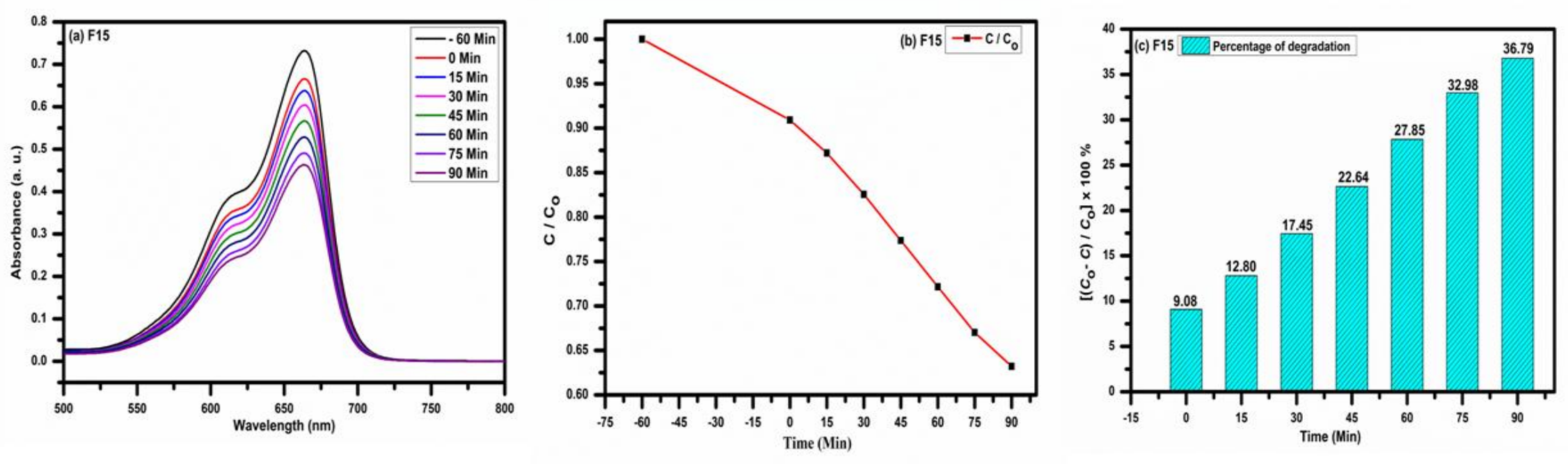


Fig.20: (a) Absorption spectrum of F15 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with F15 sample

Photocatalytic degradation of MB dye using A5 nanocomposites

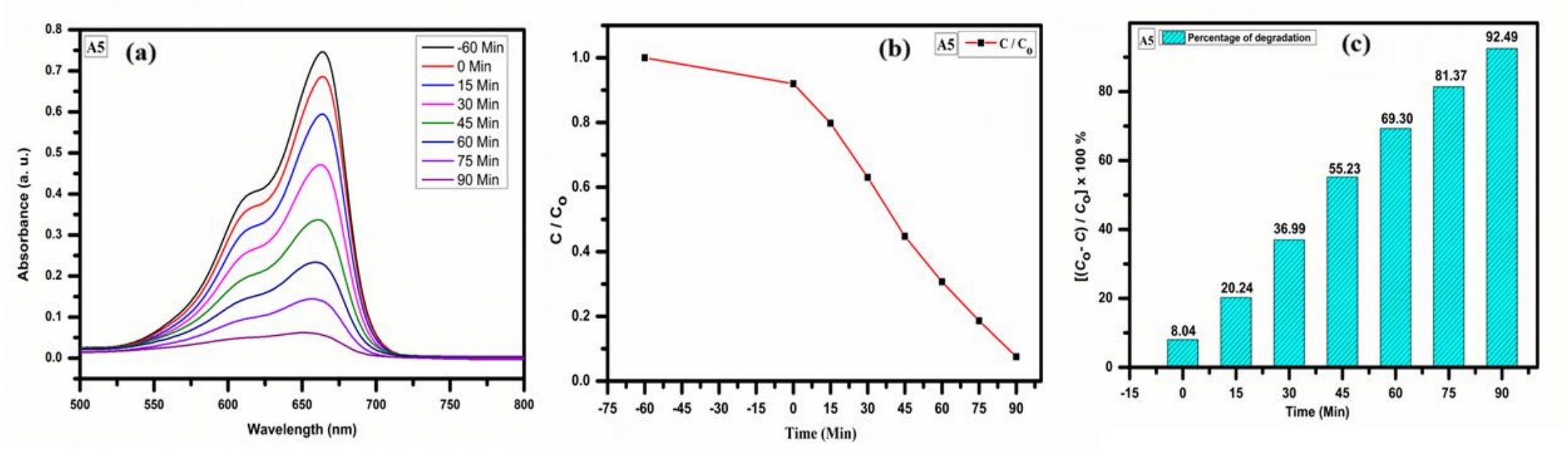


Fig.21: (a) Absorption spectrum of A5 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with A5 sample

Photocatalytic degradation of MB dye using A10 nanocomposites

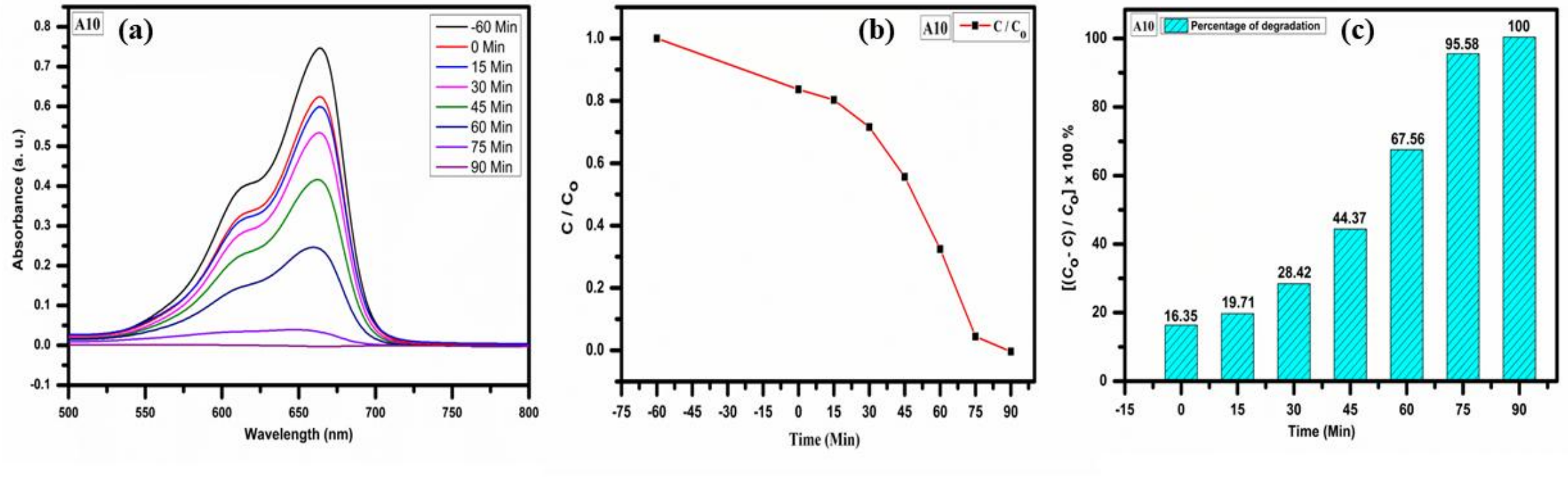


Fig.22: (a) Absorption spectrum of A0 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with A0 sample

Photocatalytic degradation of MB dye using A15 nanocomposites

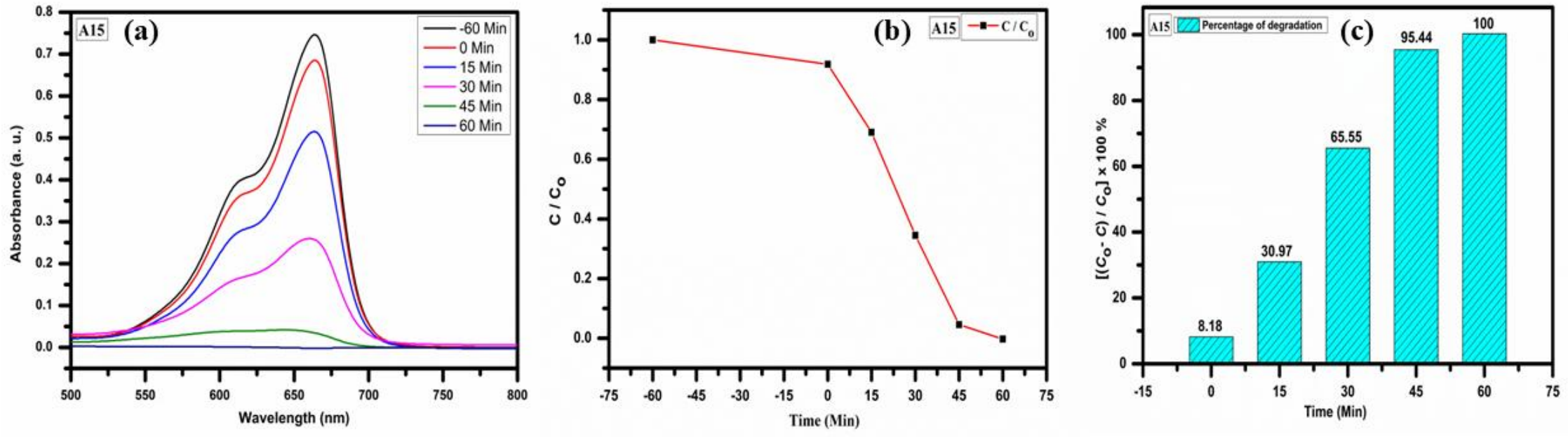


Fig.23: (a) Absorption spectrum of A15 treated MB Solution, (b) C/C_0 versus time curve, (c) percentage of degradation of MB solution treated with A15 sample

Conclusion

- The present study have successfully developed a green, cost-effective method to synthesize nanomaterials using *Terminalia arjuna* bark extract.
- XRD analysis revealed the crystalline nature of the prepared nanomaterials with the absence of any secondary or impurity phases, confirming the high purity of the synthesized samples.
- The morphological characterization of the synthesized nanomaterials were performed through TEM analysis.
- The VSM analysis demonstrated that the synthesized samples exhibited room temperature ferromagnetism, without adding any magnetic impurities to the samples.
- The prepared nanomaterials showed excellent photocatalytic degradation of Methylene Blue (MB) dye under visible light illumination.

Acknowledgement

- I am extremely grateful to the organizer of the 16th Regular Conference of the Physics Academy of the North East (PANE 2026).

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THANK YOU