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Fabrication of metal incorporated polymer composite: An excellent antibacterial agent

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ABSTRACT

US Food and Drug Administration (FDA) allowed for direct addition of castor oil

for human consumption as food and most recently FDA approved castor oil as over-the-counter

(OTC) for laxative drug. The present article highlights the green route phosphorylation of castor oil (COL) via condensation polymerization. Further, the incorporation of metal ions Cu (II)) and Zn (II) into the polymer matrix have been carried out at elevated temperature using catalyst p-toluene sulphonic acid (PTSA). The modification of the said material has been confirmed by FT-IR, UV–VIS, and ^{1}H and ^{31}P-NMR spectroscopy. Further, the *in vitro* antibacterial activities of the metal incorporated-COL has been performed by standard methods against *B. cereus* (MCC2243) (gram-positive) and *E. coli* (MCC2412) (gram-negative) bacteria. The results revealed that the incorporation of metal ions into the polymer matrix increases the antibacterial activity largely. This may be governed by the electrostatic interaction between metal ions and microbes, also the generation of free active oxygen hinders the normal activity of bacteria. These results suggest that the synthesized material may act a potential candidate for low cost, environment friendly antibacterial agents and may find their application in clinical fields. Herein we are also proposing mechanism of antibacterial activity.

1. Introduction

Polymers have made revolutionary changes in the daily lives need and accessories, polymers are successfully converted into clothes, electronic gadgets and even sophisticated medical/ surgical instruments such as personal protective equipment (PPE) which made urgent headlines in the present Covid-19 pandemic. U.S. department of labor under occupational safety and health administration guidelines (OSHA 3151–12R) recommended chemical-resistant gloves are made with different kinds of rubber: natural, butyl, neoprene, nitrile and fluorocarbon (viton); or various kinds of plastic: polyvinyl chloride (PVC), polyvinyl alcohol and polyethylene. Most polymers are based on petrochemicals, which is largely environmental concern considering the rate of global warming. The utter need for polymers to meet the requirements of sustainable development is necessary to the scientific society for better human friendly development. Biomedical applications of polymers especially synthetic polymers in clinical medicine have drawn a new era of polymeric medicine [1,2]. Vegetables oil based polymers meets many of the 12 Principles of Green Engineering of sustainable development [3]**.** The rise of antibacterial resistance (AMR) has destabilized the mechanism and functions of present bactericidal & bacteriostatic drugs. Overuse of traditional antibacterial drugs have made bacteria highly drug resistant with grave consequences. A recent report by WHO in 2019, on AMR estimated about 10 million deaths every year by 2050 (greater than cancer), which could return to dark age of medicine [4]. In order to counter AMR, adequate researches have been made to obtain antibacterial property without bacterial resistant. The trend of antibacterial drug resistance has made traditional and over exposed antibacterial futile. The sustainable and distinctive source for antibacterial could make potential antibacterial productive. The grown interest in extracted materials from natural products for

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antimicrobial discovery is due to their high degree of stereochemistry with low toxicity and upright sustainability. A wide range of procedures have been applied to meet the green route synthesis [5]. Castor oil (COL) has drawn extraordinary research interest due to their idiosyncratic physicochemical properties and ability to get modified into polymers by acyclic triene metathesis (ATMET) polymerizations [6], ring-opening metathesis polymerization (ROMP) [7], polyamides [8], polyurethane [9], high solids polyurethane [10], acyclic diene metathesis (ADMET) polymerization [11], polyamides [8], polyurethane [9], high solids polyurethane [10], alkyd-Castor Oil-Epoxy Resin [12], metal incorporated polymers [13–15], and to act as a medium for synthesizing nonmaterial [16].

COL has also been modified into polyurethane, epoxy, polyester, and metal incorporation via double bond modification, condensation and polymerization [6,15]. COL was also transformed into rigid polyurethane, waterborne polyurethane, thermoplastic polyurethane and linear & branched acetal polymers via acetal metathesis polymerization are few [17–20]. Literature survey widely revealed that the incorporation of metals in the fabricated compounds and polymer can enhance the antibacterial properties.

Literature survey further revealed that metals especially transition metals ions like Silver [Ag(I)], Platinum [Pt (II)], Copper [Cu (II)], and Zinc [Zn (II)] etc. are some bioactive metals proclivity to influence the biological activity in the ligands, macromolecule, monomer and their environment [21]. Among them, Cu (II) and Zn (II) are two prominent metal ions with antibacterial, antifungal, and catalytic influences [22,23]. Researchers have made plant extract based metal composite with enhanced biological activity [24–26]. The degree of variation in the structures due to modifications and their ability to release metal ions in the pathogen active sites, apart from electrons movement have given a big go for metal composite as a potential antibacterial with little bacterial defiance. It is then expected that the incorporation of Cu (II) & Zn (II) with modified-COL could have the desirable antibacterial functions compared to virgin COL. COL is a very potential sustainable material for drug discovery and development due to its traditional practice as medicine. The transfers of electrons between the synthesized materials with the bacterial surface have suggested their potentiality as an antimicrobial agent [27–34]. The transfer of electrons plays most critical step of bacterial respiration; the supply of energy for growth, proliferation and maintenance of cell of bacteria is carried out on cell membrane via election transfer [35–37]. Irregularities of electron transfer in bacteria results the production of reactive oxygen species (ROS), which subsequently inhibit the growth of bacteria [37]. Charging the surface of bacteria can also inhibit the growth both in positive, negative surfaces and can facilitate the antibacterial efficiency. For instance, the efficiency of chitosan as an antibacterial for gram negative bacteria on polymers has been reported in many advance literature [38–41]. Although COL based polyesters with antibacterial activity is reported but without established mechanism [42], but the scope of metal ion incorporated modified COL for potential antibacterial is yet to be investigated and propagated.

Herein, we highlight the phosphorylation of castor oil (COL) and the incorporation metal ions, Cu (II) and Zn (II) into the polymer matrix with enhanced antibacterial resistance and mechanism of antibacterial nature for the same. The formulation, structure and modification of the synthesized polymer has been confirmed by FT-IR, UV–VIS, and ^{1}H and ^{31}P-NMR spectroscopy. Moreover, the synthesized metal incorporated polymeric materials have been explored for in vitro antibacterial activities against *B.cereus* (MCC2243) (gram-positive) and *E. coli* (MCC2412) (gram-negative) bacteria. The results obtained from these in vitro antibacterial studies have suggested that the synthesized metal incorporated polymeric materials may act as a potential antibacterial. The modified materials based on the line of sustainability that made them convenient for exploring antibacterial application. The mechanism of antibacterial action of metal incorporated polymeric material is also proposed.

2. Materials and method

Castor oil (14030006) (refractive index: 1.470–1.490, hydroxyl value: 155–167, iodine value: 80–90, saponification value: 175–185) and phosphoric acid (1004) were purchased from S.D Fine Chem Ltd, Mumbai. P-toluenesulfonic acid (PTSA) (6101), sodium chloride (5234), copper (II) acetate monohydrate (165397), diethyl ether (100926), ethanol (702), zinc (II) acetate dihydrate (2724192), were purchased from Fisher Scientific, New Delhi. *Bacillus cereus* (MCC2243) and *E. coli* (MCC2412) were purchased for antibacterial activities. All reagents and other chemicals were used without any modification and further purifications.

2.1. Synthesis of polyol (COP)

Castor oil and phosphoric acid in a 1: 2 Molar ratios were poured into a three necked round bottom flask with a nitrogen inlet tube, a mercury thermometer, a condenser and a 5 MLH magnetic stirrer. (0.00016 g) PTSA was added for catalysis. Phosphoric acid was added in fractions and temperature maintained between 130 and 140 °C at 500 rpm. The reaction was monitored by measuring acid value and taking FT-IR spectra at regular intervals. When positive acid value and desired FT-IR spectrum was recorded, reaction was stopped. The reaction was cooled and washed with 50 mL diethyl ether followed by 15% brine solution. The washed solution was kept for overnight and separated. The lower layer was decanted, and upper oily layer named as COP was kept for further modifications. Before metal ions incorporation the COP was passed through sodium sulfate and dried again.

2.2. Synthesis of copper and zinc incorporated polymer (CPC) and (CPZ)

2 g dried COP was taken in two clean reaction chambers in the inert environment and 0.045 M Copper (II) Acetate monohydrate in fractions namely 0.03, 0.005, 0.008 and 0.0020 M were added into the reaction mixture (A) at $\frac{1}{2}$ h interval at 150–155 °C at 550 rpm for 5 h. While 0.0265 M Zinc (II) Acetate dihydrate in fractions 0.018, 0.0020, 0.0025, 0.004 M were added in reaction mixture (B) at the same time interval at 140–145 °C at 550 rpm for 4 h. Weight in milligram of metal ions incorporated in polymers matrix is given in Table 1.

The progresses of the reactions were monitored similarly as mentioned for COP synthesis. Acid value is given in Table S1. On completion of the reactions, two clear visible layers were obtained on both chamber A & B. Blue oily layer in chamber A (CPC) and orange layer in chamber B (CPZ) were obtained; subsequently they were separated and purified by the same above COP process. The final product of reactions is accomplished via condensation polymerization with the release of small molecule i.e. acetic acid. The major advantage of condensation polymerization is the lack of broad molecular weight distribution during the polymerization, which helps to get controlled molecular weight polymer [43]. Fur-

Table 1
Weight in milligram of metal ions incorporated in polymers matrix.

	Cu in CPC	Zn in CPZ
Weight (milligram) of Metal	810.675	477.3975
Moles	0.045 M	0.0265 M

ther, the building blocks of animals, polypeptides DNA, RNA is also formed via condensation polymerization.

3. Characterizations

The Fourier transform infrared (FT-IR) spectra of the Castor Oil (COL), COP, CPC and CPZ were determined using a Perkin-Elmer Spectrum GX FT-IR spectrophotometer (Perkin-Elmer, Beaconsfield, UK, in the range of 4000–400 cm^{-1} wavenumber. All data were taken at room temperature. UV–visible spectral analyses were performed by a Multiskan GO spectrophotometer (Thermo Fisher Scientific, Vantaa, Finland) and all spectra were recorded from wavelength 200 to 800 nm. The nuclear magnetic resonance (NMR) spectral analyses were done in the solvent Chloroform d-6 (1 mL). All the NMR spectra were recorded at 30 °C on a 400 MHz Bruker AVANCE 400 spectrophotometer (Bruker BioSpin, Rheinstetten, Germany) for both ^{1}H and ^{31}P NMR.

4. Antibacterial methodology

Antibacterial activity was analyzed using agar well plate diffusion methods [44]. Bacterial cultures were procured from microbial culture collection at national center for cell science, Pune, India. Bacterial inoculates *B. cereus* (MCC2243) Gram +ve and *E. coli* (MCC2412) Gram –ve bacteria were prepared by growing a single colony in nutrient broth medium and adjusting the turbidity to 0.5 McFarland standards. A 200 μL portion of bacterial culture was spread onto 25 mL Mueller−Hinton agar medium plates, and different concentrations (10, 20, 30, 40 $\mu g/mL^{-1}$) of synthesized compound was taken from the stock solution of 1000 $\mu g\ mL^{-1}$ were put on added on the sterilized disk of 5 mm size. Samples in solution were used to investigate the antibacterial activity. Standard antibiotic (streptomycin) 10 $\mu g\ mL^{-1}$ used as a control. These plates were incubated at 37 °C for 24 h. The results were expressed as the mean diameter of inhibition zone in mm ± standard deviation. All experiments were performed in three times.

5. Results and discussion

5.1. FT-IR spectra

The FT-IR spectra of COL, CPC and CPZ are shown in Fig. 1. For COL, the major peaks i.e.; the peak at 3380 cm^{-1} corresponding to

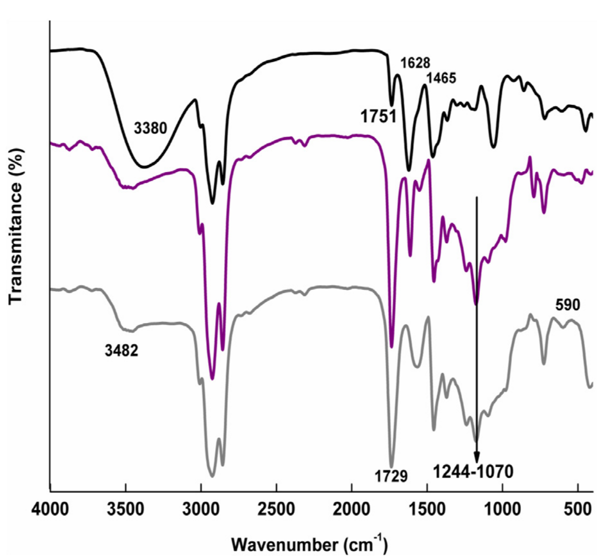

Fig. 1. FT-IR Spectra of COL, CPC and CPZ.

hydroxyl group, at 1736 cm^{-1}, $C = O$ of ester of triglycerides and 1628 cm^{-1} is due to $C = C$· at 2925 & 2849 cm^{-1} appeared due to the asymmetric and symmetric vibrations of C–H bond, while bending vibration of C–H gives peak is at 1465 cm^{-1}. The intense peak at 722 cm^{-1} is due CH_2 rock [45], and for CPC and CPZ, an intense additional peaks at 1171 cm^{-1} with a shoulder 1070–1090 is due to the vibrations of $P = O$ and P-O-C respectively [46]. While the Metal oxygen bonds appeared for CPC and CPZ at 590, 484 cm^{-1} respectively that clearly indicates the coordination of COP with Cu and Zn [47]. The decrease in the intensity of hydroxyl peak along with the shifting of peaks positions of $C = O$ ester and $C = C$ of triglyceride chain by 35–45 cm^{-1} clearly suggest the incorporation of Cu and Zn in COL Framework.

5.2. Identification metal containing-COL; CPC and CPZ by UV–Vis spectral analysis

UV spectrum of COL is shown in supplementary Fig. S1, the peaks at 295 and 315 nm is due to $n \rightarrow \pi^*$, $\pi \rightarrow \pi^*$ transitions respectively, while Fig. 2 shows interaction of COL with metal ion Cu (II) and Zn (II). For CPC, the intraligand charge transfer peaks appeared due to $n \rightarrow \pi^*$ (324 nm), and $\pi \rightarrow \pi^*$ (390 nm) and the broad peak in between 680 and 720 nm associated with a shoulder at 490 nm is due to Jahn Teller distortion. The distortion lowered the symmetry, the Jahn Teller effect is more pronounced in six-coordinate complexes [47,48], moreover the distorted geometry of Cu (II) was strongly supported by magnetic susceptibility measurement Table S2. While in case of CPZ, Fig. 3 shows peaks at 322 nm is due to $\pi \rightarrow \pi^*$ transition and the peak between 380 and 410 nm is due ligand to metal charge transfer (LMCT) of Zn (II) [47]. The n $\rightarrow \pi^*$ is vanished in CPC and CPZ. It is needless to prove; this is due to the interaction of Cu (II) and Zn (II) with COP. Nonetheless the existence of intense $\pi \rightarrow \pi^*$ intra-ligand transitions band in CPC and CPZ is strongly supported by FT-IR spectra.

5.3. Physico-chemical study of COL, CPC and CPZ

Primarily the progress of the reactions for oil-based polymer is monitored my TLC and by determining physico-chemical characteristics. The critical characterization was acid and saponification value determination. The physico-chemical properties are given in Table S 1. The data for specific gravity, refractive index and inherent viscosity were increasing in the order COL < CPC< CPZ, while hydroxyl, saponification and iodine value were found in opposite trend, this could be attributed to increases of chain length and hence unsaturated concentration also increases due to polymerization and metal incorporation in COP chain [15,49,50]. The maximum acid value is for CPC (3.98 mg/KOH) followed by CPZ (3.84 mg/KOH). These data endorsed the interaction of Cu & Zn metal acetates in the backbone of the COP main chain as shown in Fig 2. Moreover these results strongly makes an agreement with the literature [47]. The greater risk due to insolubility of new material in aqueous medium is unquestionably a real threat in developing new pharmaceuticals and industrial products. COL has long been used medically as a laxative and as an excipient. The insolubility of COL in aqueous medium remains a major concern to make it a drug even after having a positive drug linkage value Fig S2.

The critical criterion of any potential drug is that it must get absorbed and interact with the antigen or radical species. Since insolubility will influence both pharmacokinetic and pharmacodynamic properties of any potential drug in repressive way and it can dramatically reduce productivity in drug discovery, development and its delivery. Although COL is miscible with absolute ethanol, methanol, ether, chloroform, acetic acid but the percentage of miscibility has increased due to metal ion coordination with modified

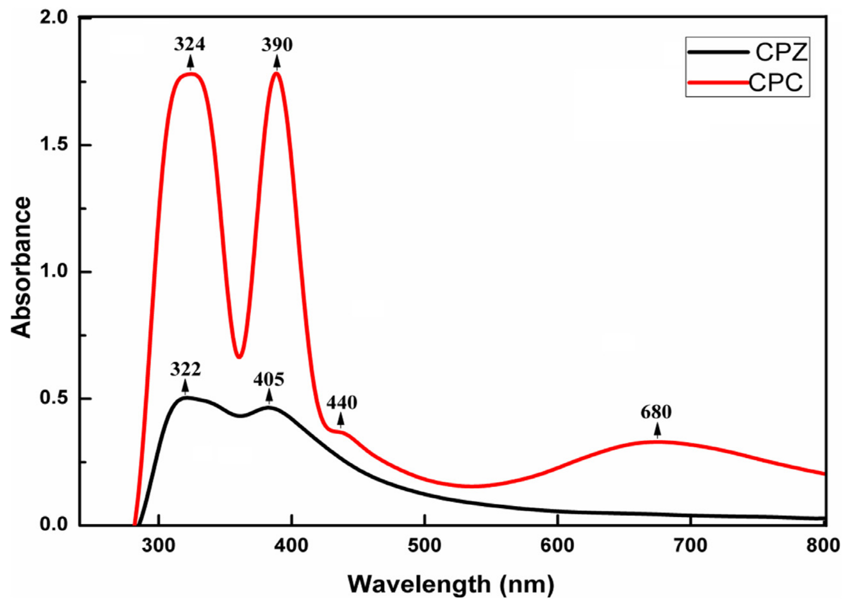

Fig. 2. UV-Visible spectra of CPC & CPZ.

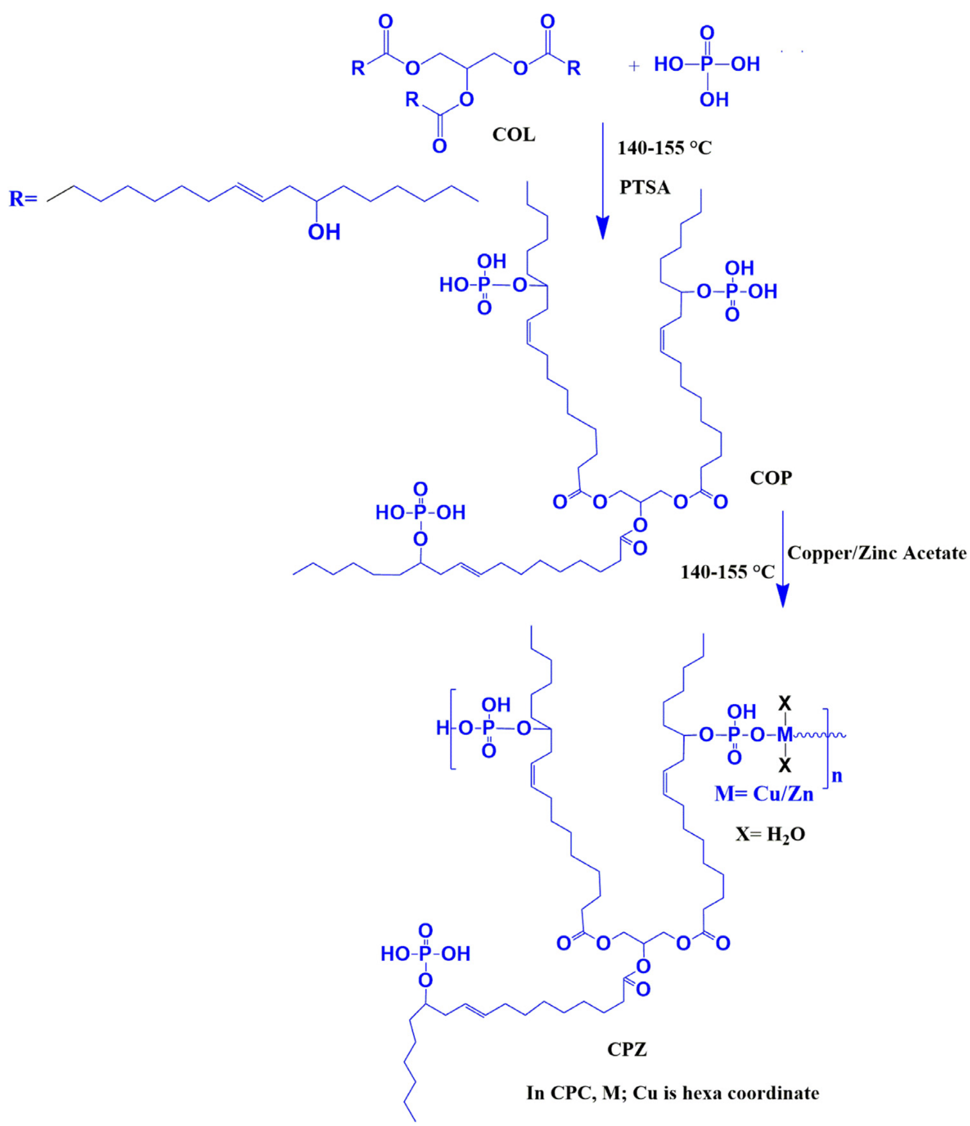

Fig. 3. Reaction scheme for synthesis of CPC/ CPZ.

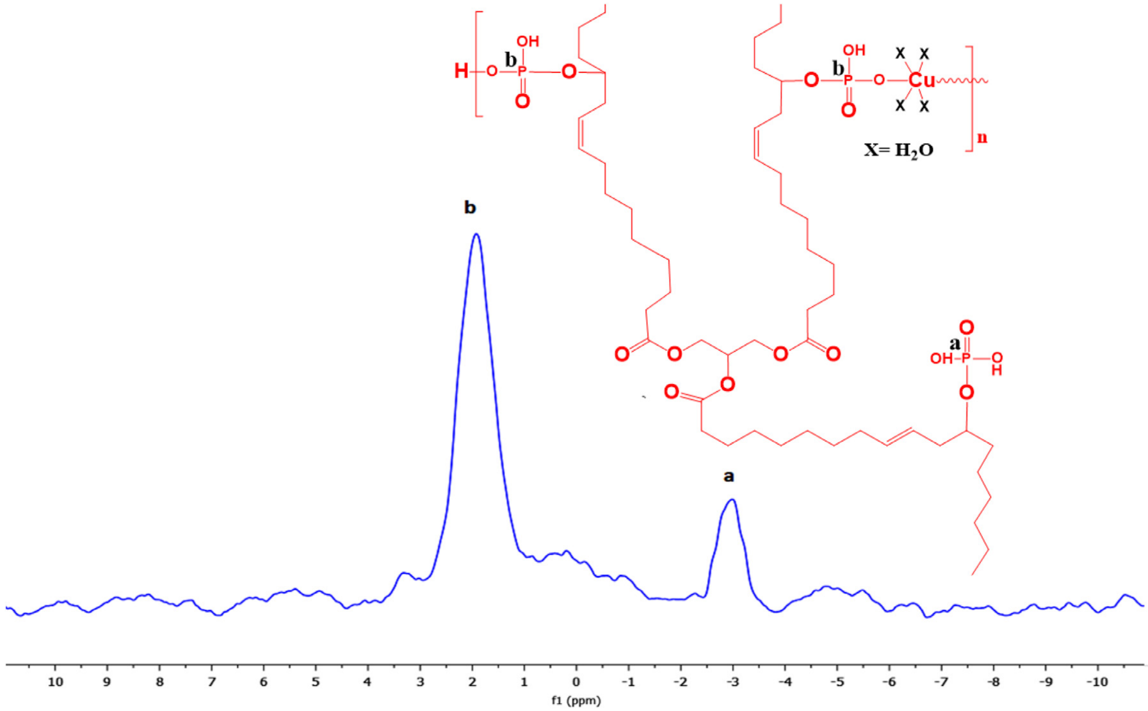

Fig. 4. ^{31}P NMR (δ) of CPC.

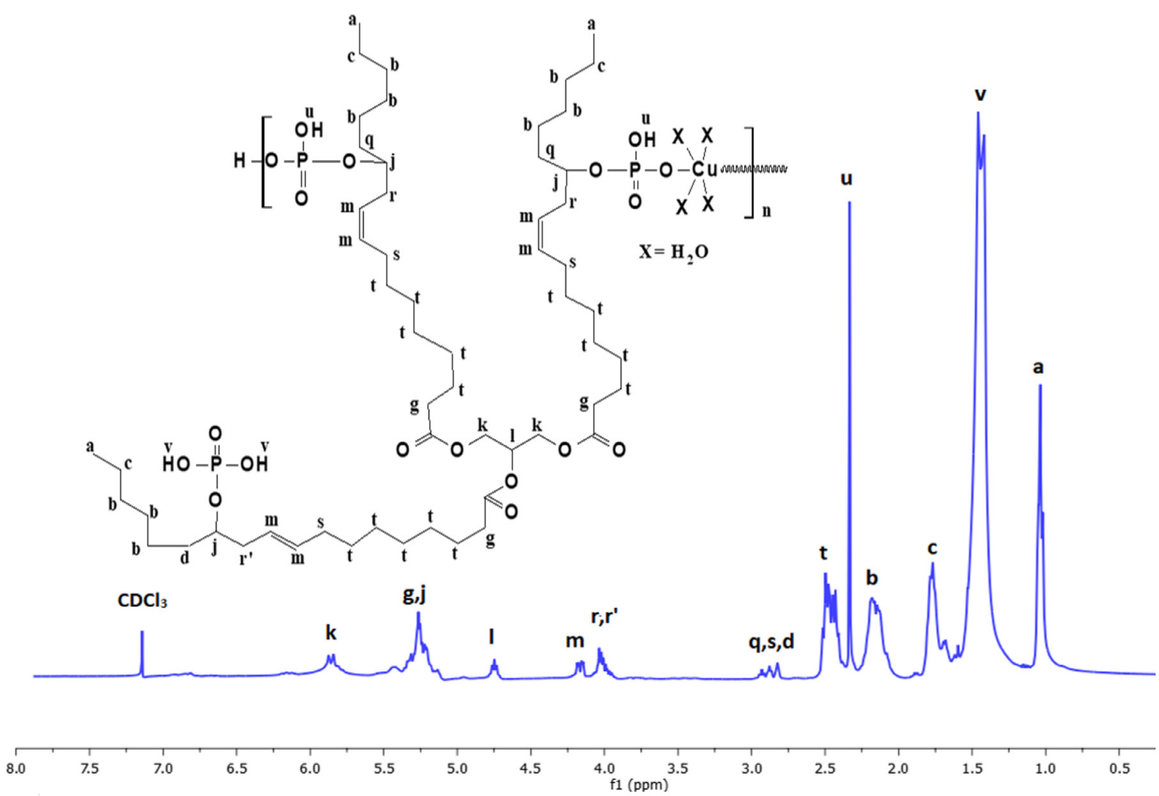

Fig. 5. ^{1}H NMR (δ) of CPC.

COL; COP. Both CPC and CPZ have shown partial solubility in aqueous medium.

5.4. Determination of the magnetic susceptibility of CPC and CPZ

The magnetic susceptibility is given Table S2 for Cu (II) and Zn (II) in CPC and CPZ respectively. The magnetic moment of Cu (II) in CPC complex is 1.99 BM, this subnormal value is due to the distorted octahedral geometry of CPC which is as a result of lowering its symmetry [51]. Zn (II) is in d^{10} configuration CPZ polymer; diamagnetic. The coordinating environment in CPC & CPZ polymer are hexa coordinate and tetra coordinate respectively. The proposed geometry of CPZ is tetrahedral. Moreover in crowded environment; macromolecules or large monomer, Zn (II) is more likely to from

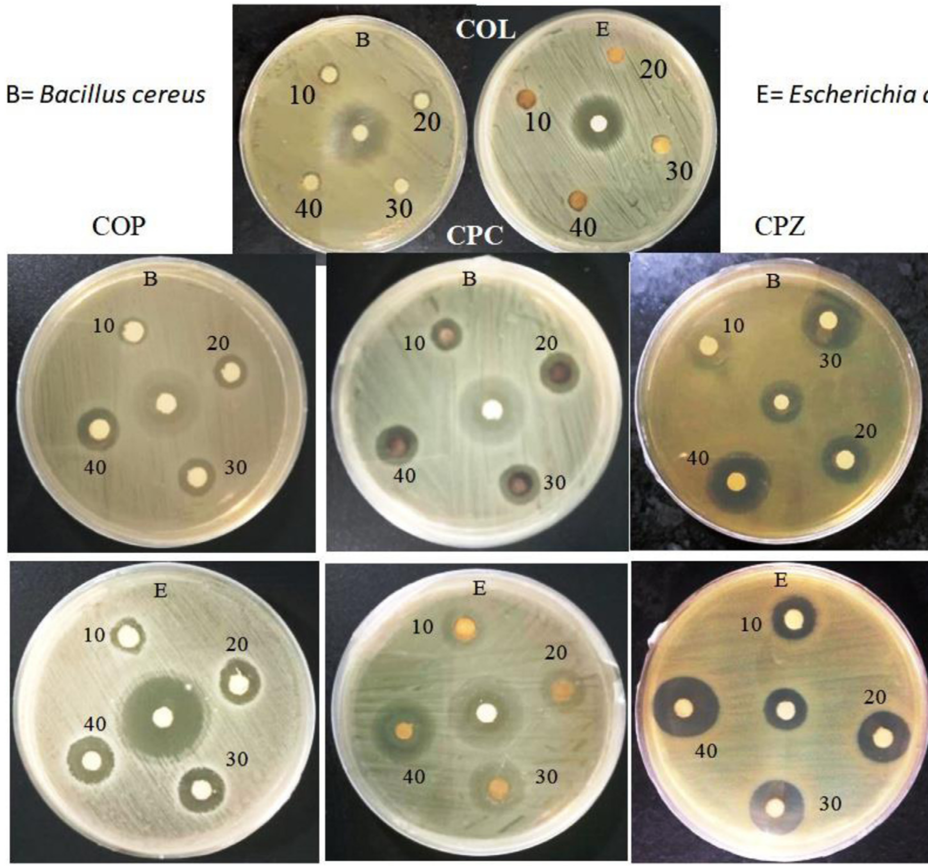

Fig. 6. Antibacterial nature of COP, CPC and CPZ against *Bacillus cereus* (MCC2243) and *Escherichia coli* (MCC2412).

tetrahedral than octahedral [52]. The proposed generic structure of CPC and CPZ is shown in Fig. 3 along with its reaction scheme.

5.5. Stability of CPC and CPZ

Stability of metal ion coordinated complexes depends on both the nature of metal ion and nature of ligands. Theoretical interpretation for the stability of CPC over CPZ complex is due to the smaller size of Cu (II) ion compared to the size of Zn (II) ion [53]. The distortion of CPC due d^9 configuration of Cu (II) makes it more likely to have better stability compared to the CPZ. Since the ligands are same in both polymeric complexes so the trend of stability is expected to be same. Moreover, distorted octahedral nature of CPC stabilizes the complex compared to CPZ which is tetrahedral nature.

5.6. Establishment of CPC and CPZ structure by spectral analysis (^{31}P & ^1H NMR)

Fig. 4 and 5 represent the ^{31}P & ^1H NMR spectra of CPC. In the ^{31}P spectra of CPC, Fig. 4, the peaks appeared at $\delta = -3$ ppm and $\delta = 1.99$ ppm is attributed to the presence of two distinctive phosporous nuclei. Phosphorous atom attached with the electron withdrawing group; copper ion attached site is noted at $\delta = -3$ ppm while the second phopshrous atom is noted at $\delta = 1.99$ ppm. While the same peaks were appeared for ^{31}P spectra of CPZ, Fig. S4, at $\delta = -3$ ppm and $\delta = 2.55$ ppm respectively in the similar trend. The ^1H spectra of CPC, Fig. 5 and CPZ, Fig. S5, the peaks appeared at $\delta = 1$ and 1.1 ppmis due to the sp^3 proton attached to the fatty acid chain. The signals at $\delta = 4.1$ appeared for both CPC and CPZ may be ascribed to the sp^2 proton of fatty acid chain. While the peak at $\delta = 5.3$ ascribed to proton directly attached to oxygen atom and the protons attached to the carbonyl group [54].

The obtained chemicial shift (δ) for CPC & CPZ are different and broaden compare to virgin COL, Fig. S3. The assigned and broadening of peaks of CPC & CPZ compare to COL is strongly in agremment with the coordination of Cu (II) and Zn (II) in modified-COL; COP [55]. The chemical shift (δ) of the protons of CPC & CPZ at different asigned peaks are precisely shown in Fig. 5, and S5 respectively, these data strongly supports the coordination of metal ions i.e. Cu (II) & Zn (II) to the main phosphorous polyol chain, Fig. 3. Neverthless these data are well in agrement with the FT-IR and UV spectra.

6. Antibacterial study of COL, COP, CPC and CPZ

The antibacterial properties of synthesized COP, CPC and CPZ were evaluated against both *B. cereus* (MCC2243) (Gram +ve) and *E. coli* (MCC2412) (Gram –ve) bacteria in solution form. The different concentration taken for analysis are given in Table 2. The virgin castor oil compound (COL) showed no zone of inhibition or any strain of bacteria, which revealed that COL alone is inef-

Table 2
Different amount taken for antibacterial analysis.

Sample	Amount (μg/mL)				Results
COL	10	20	30	40	No result
COP	10	20	30	40	Increases with concentration
CPC	10	20	30	40	Increase with increase in concentration
CPZ	10	20	30	40	Increase with increase in concentration

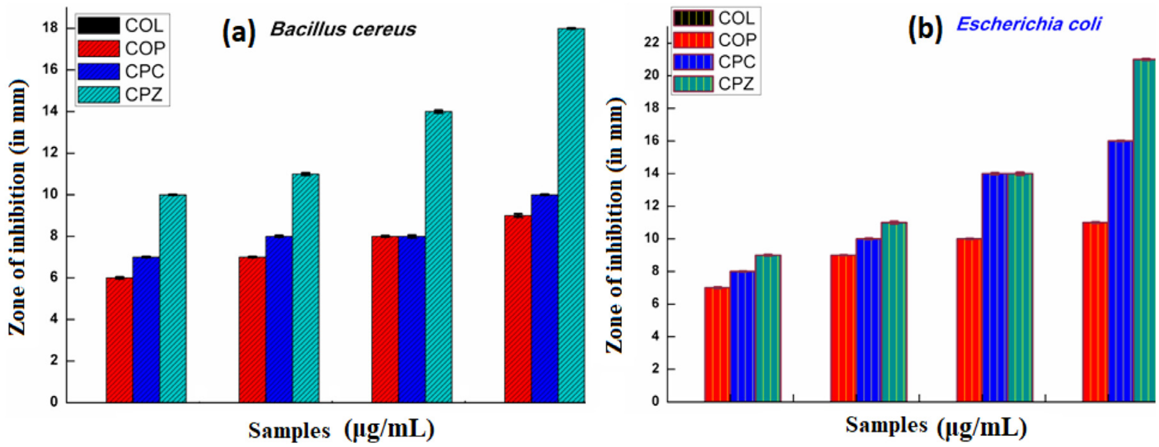

Fig. 7. Zone of inhibition (in mm) induced by COP, CPC & CPZ in (a) *Bacillus cereus* and (b) *Escherichia coli*. ($P < 0.05$).

Table 3
Comparative performance of the present system with the similar reported work.

S.No.	Composite system	Bacteria	Zone of inhibition (mm)	Ref.
1.	CPZ	*E. coli*	22	Present study
2.	Polyurethane/TEOS	*E. coli*	20	[59]
3.	LMPOL/0.06CuO	*E. coli*	21	[60]
4.	Carboxymethylcelulose/CuO	*E. coli*	14	[61]
5.	Poly(ethylene glycoldiacrylate)/Cu	*E. coli*	20	[62]

fective for antimicrobial activity. Further, the antimicrobial activity tested for COP, CPC, and CPZ have shown bactericidal nature. All of them exhibited the high degree of susceptibility against both the gram positive and gram-negative bacteria *(B.Cerus* and *E.Coli)*. It has been observed that with the increased concentration of CPC material (10–40 μg/mL) an increase in the antibacterial activity is observed and the best performance was observed against *E.Coli* than the *B.Cerus*. The better performance of the CPC over COP material against both *B.cerus* and *E.Coli* may be due to the greater interaction between metal ion and microbial agents. While in case of CPZ shown in Fig. 6, with the increased concentration of CPZ material (10–40 μg/mL), similar results were observed, on comparison with CPC, CPZ has shown outstanding performance against both gram-positive and gram-negative bacteria Fig. 7(a) & (b).

The potential influence of zinc for antibacterial tendencies is well known, while copper has become a potential material due to its ion forming tendencies and its active interaction with its neighbor. Both CPZ and CPC have shown greater zone of inhibition compared to COP due to the metal ion coordination with COP [56]. The proposed mechanism of antibacterial activity of CPZ and CPC is depicted in Fig. 8. The enhancement in the antibacterial activity of CPZ and CPC may be attributed to (i) polymer coating provide the stability to the metal ion and controls the release of metal ions that led to the increase in antibacterial activity (ii) electrostatic interaction between the metal ion and microorganisms that induces electron transport and oxidative phosphorylation at the cell membrane. (iii) Further, this electron transport led to the release of antimicrobial ions i.e. reactive oxygen species (ROS) such as OH^-, O_2^-etc., which interacted with the cell wall of bacteria that help in the rupturing of bacterial cell and inducing antibacterial property. The release ions may occur because the metal ions are loosely held in the polymer matrix through phosphorylated coordination sites so as to pursue thermodynamically more favorable interactions with the cells, leading to the increase in antibacterial activity [57,58].

These results have been compared with the other reported similar work (Table 3) and found that the composite showed comparatively better antibacterial performance than those of reported and cited studies.

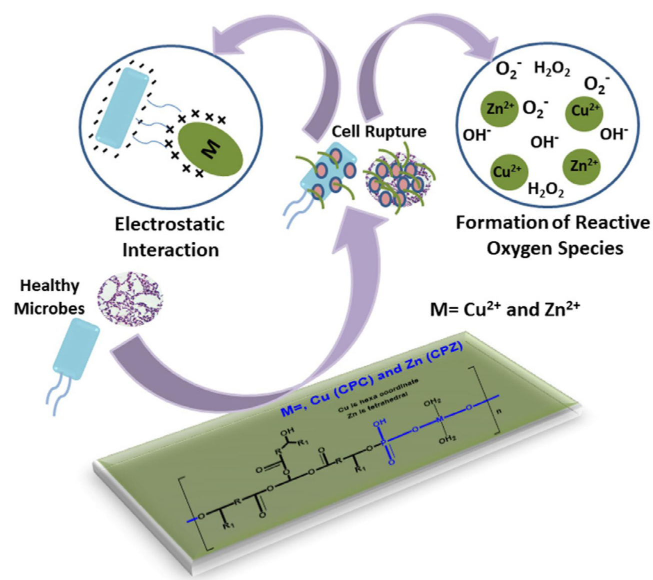

Fig. 8. Probable mechanism of antibacterial activity of CPC and CPZ polymer.

7. Conclusion

Catalytic phosphorylation of castor oil was successfully done and subsequently metal ions; Cu (II) & Zn (II) were incorporated in modified-COL (COP) at elevated temperature. The structures were established with FT-IR, UV-Visible, ^{1}H NMR and ^{31}P-NMR spectra. The castor oil polyol (COP), copper and zinc ions incorporated polymer i.e. CPC and CPZ showed potency of antibacterial activity against both *B. cereus* (MCC2243, Gram +ve) and *E. coli* (MCC2412, Gram –ve). Among CPC and CPZ polymer, the CPZ has displayed excellent antibacterial activity, explicitly against *E. coli* (MCC2412, Gram –ve) bacteria. This excellent antibacterial activity of CPZ may be attributed to the ability to produce antibacterial ions, which interacted electrostatically with the pathogens wall and causes cell rupture. These results strongly suggest that the metal ions incorporated polymer i.e. CPC and CPZ may find their application as environment friendly antibacterial agent. Moreover, on comparison with other similar system, CPZ is found efficient in killing bacteria.

Credit author statement

Professor Athar Adil Hashmi is corresponding author of the manuscript and will manage all future queries. He has supervised, reviewed and edited the manuscript. Md Ikbal Ahmed Talukdar has fabricated and characterized polymers (CPC & CPZ). He has also interpreted the data and written the manuscript. Irshad Ahamad and Tasneem Fatma have contributed equally to investigate antibacterial activities. Manzoor Ahmad Malik, Ovas Ahmad Dar, Md. Khursheed Akram have contributed equally in formal analysis. Sajid Iqbal has contibuted in designing antibacterial mechanism.

Notes

The authors declare no conflict of interest with any person or any organization.

Declaration of Competing Interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.molstruc.2020.129091.

Appendix

COL-Castor oil, COP-Castor oil polyol, CPC-Copper (II) incorporated polymer, CPZ-Zinc (II) incorporated polymer, *E.coli-Escherichia. coli* and *B.cereus-Bacillus cereus*.

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