Journal of King Saud University – Science 33 (2021) 101368

Contents lists available at ScienceDirect

Journal of King Saud University – Science

journal homepage: www.sciencedirect.com

Original article

Green synthesis of Cerium oxide / *Moringa oleifera* seed extract nano-composite and its molluscicidsal activities against *biomophalaria alexanderina*

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ARTICLE INFO

Article history:
Received 27 November 2020
Revised 21 January 2021
Accepted 6 February 2021
Available online 18 February 2021

Keywords:
Cerium oxide/ *Moringa oleifera* nano-composite
Nanoceria
Schistosomiasis
Molluscicide

ABSTRACT

The green synthesis method is one of the most economic and ecofriendly approach for preparation of metal oxide nanoparticles. In the current study, *Moringa oleifera* seed was used for synthesis of Ce_2O_3/*M. oleifera* (Ce_2O_3/MNCs) nano-composite. The bio-composite was characterized using FT-IR, XRD, SEM and HR-TEM. The FTIR analysis confirmed the phytochemical involvement in bio-composite. Its crystalline and size was well demonstrated through X-ray Diffraction and HR-TEM. The TEM images revealed these particles in circle shape with average size of 30 nm. The present investigation showed that Ce_2O_3/MNCs was toxic to *B. alexandrina* snails with LC_{50} of 314.5 mg/L. The survival and the reproductive rates of the snails were significantly reduced after exposing to ¼ and ½ of LC_{50} of Ce_2O_3/MNCs. The present study showed that Ce_2O_3/MNCs has significant ovicidal and larvicidal activities. Also, the exposure to ½ of LC_{50} of Ce_2O_3/MNCs showed alterations in the tegmental architectures of the head-foot region, in addition it caused significant damages in both of the hermaphrodite and digestive glands of *B. alexandrina*. Conclusively, Ce_2O_3/MNCs nano-composite could be utilized as a new molluscicidal agent for the snails of schistosomiasis.

1. Introduction

Phytosynthesis of metal and their oxide nanoparticles (NPs) has gained a great interest as it is safe, cost-effective, and eco-friendly method (Singh et al., 2018). Cerium oxide nanoparticles, nanoceria, (Ce_2O_3 NPs) has received much consideration as a reliable photo-catalysts, oxygen sensors, ultraviolet absorbent, and as a possible therapeutic alternative in biology and medical sciences (Charbgoo et al., 2017). Several studies confirmed the synthesis of cerium oxide nanoparticles using green methods from the leaf extract of *Acalypha indica*, *Gloriosa superba* and *Aloe vera* (Rajeshkumar & Naik, 2018).

Schistosomiasis is a parasitic disease caused by blood flukes (trematode worms) of the genus *Schistosoma* and it is recognized as leading cause of significant mortality and morbidity worldwide (Augusto and de Mello-Silva, 2018). Snails of the genus of *Biomphalaria* are the intermediate host for *Schistosoma mansoni* (Ibrahim and Sayed, 2019). Thus, the elimination or control of snails may be an alternative approach to control and to interrupt the transmission of schistosomiasis (Omobhude et al., 2017). Chemical molluscicides are the most common approach to control snails for prevention of *Schistosoma* transmission (King and Bertsch, 2015). Currently, the application these molluscicides is hampered by their high cost, toxicity to non-target organisms and environmental hazards (Mandefro et al., 2017). Recently, nanomaterials have been proven to have molluscicidal activities either due to their toxic effect or/and due to its ability to reduce the snail fertility (Ali et al., 2012; Yang et al., 2019). Nowadays, several studies highlighting the potential of biogenic nanoparticles

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksus.2021.101368
1018-3647/

compared to their chemically made analogs (Guilger et al., 2017; Xiong et al., 2018; Capeness et al., 2019).

It has been previously established that *Moringa oleifera* seed extract has potent molluscicidal and ovicidal activities against the snails of genus *Biomphalaria* (Ibrahim and Abdalla, 2017). As the Phytosynthesized Ce_2O_3 NPs have no side effects in biomedical applications (Charbgoo et al., 2017), our present investigation was therefore inspired additional investigation into the use of plant extracts for the synthesis of nanoceria from the *M. oleifera* seed extract. The present study was also, aimed to: (i) characterize *M. oleifera* phytosynthesized Ce_2O_3 NPs with using FTIR, XRD, SEM and TEM (ii) testify its molluscicidal activity and its effect on the biological systems of *B. alexandrina* snails (iii) evaluate its toxicity on the larval stages of *S. mansoni*.

2. Materials and methods

2.1. Preparation of Cerium oxide / M. Oleifera nano-composite (Ce_2O_3/MNCs)

The collected *M. oleifera* seeds were dried at 50 °C in digital electrical drier for 48 h, and then grinded to size range from 1 mm to 0.2 mm. To obtain seed extract, 6 g of the grinded seeds were dispersed in 30 ml distilled water under stirring for 30 min at 70 °C. The obtained extract was mixed with 50 ml of $CeSO_4$ (0.1 M) and warmed at 65 °C for 3 h. Then, it was left at room temperature overnight for precipitation Cerium oxide particles which was separated and washed several times by ethanol and distilled water. Finally, the fabricated Ce_2O_3/MNCs was dried at 60 °C for 12 h and then calcinated at 350 °C for 3 h.

2.2. Characterization of the Cerium oxide / M. Oleifera nano-composite (Ce_2O_3/MNCs)

Ce_2O_3/MNCs were characterized using X-ray diffraction pattern (a PANalytical (Empyrean) X-ray diffractometer), JEOL-JEM 2100 transmission electron microscopy (TEM), and Gemini, Zeiss-Ultra 55 scanning electron microscope (SEM). Meanwhile, FT-IR spectra were investigated with a Bruker (Vertex 70 FTIR-FT Raman) spectrometer.

2.3. Snails and larvae of schistosomiasis mansoni

Adult *B. alexandrina* snails, *Schistosoma mansoni* ova and cercariae were obtained from Theodor Bilharz Research Institute (TBRI). The snails were maintained in plastic aquaria and fed on oven dried lettuce leaves and TetraMin®. Water of the aquaria was changed once a week. For collecting the egg masses, pieces of polyethylene sheets were used.

2.4. Determination of the LC_{50} and LC_{90}

Snails of *B. alexandrina* were exposed to different concentrations of Ce_2O_3/MNCs (200, 250,300,350 and 400 mg/L) for 48 h at room temperature (22–25 °C) to calculate the LC_{50} and LC_{90}. Snails of the same size were exposed to dechlorinated water only and considered as the control group. Then, the snails were removed from the exposure solution, and maintained in dechlorinated tap water for 24 hr for recovery. The snails' percent mortality was recorded (WHO, 1965). The lethal concentration and the slope values were estimated by Probit analysis. Three replicates of 10 snails were used for each concentration.

2.5. Effect of ¼ and ½ of the LC_{50} of Ce_2O_3/MNCs on the survival and reproductive rates of B. Alexandrina

B. alexandrina snails were exposed to ¼ and ½ of the LC_{50} of Ce_2O_3/MNCs for two weeks (24 h/d) while snails of the control group were maintained in dechlorinated water. The effects of these concentrations on the net reproductive rate (R_0) of *B. alexandrina* snails were represented by the summation of survival rate (Lx) multiplied by the mean number of eggs/snail/week (Mx) during the experimental period as suggested by El-Gindy et al. (1965).

2.6. Scanning electron microscopic studies of the head foot region of B. Alexandrina

The head foot regions of snails were separated under a stereomicroscope. Then, the specimens were fixed, dehydrated, critically dried and coated as recommended by Ibrahim and Abdel-Tawab (2020). Finally, they were photographed by JSM-6510 LA.

2.7. Ovicidal activity

100 eggs of *B. Alexandrina* on polyethylene sheets were used and subjected to ¼ and ½ of the LC_{50} of Ce_2O_3/MNCs for 24 h. Then, the eggs were transferred to petri dishes containing dechlorinated water and were examined daily for seven days under a stereomicroscope. Another 100 eggs in dechlorinated water were used as a control group.

2.8. Miracidicidal and cercaricidal activities

100 freshly hatched *S. mansoni* miracidia, and cercariae in 5 ml of water were mixed in a separated petri dish with 5 ml of LC_{50} of Ce_2O_3/MNCs. Another petri dish containing 10 ml dechlorinated tap water with either 100 freshly hatched miracidia or 100 freshly shed cercariae were kept as control (Abdel-Ghaffar et al., 2016). The motility of cercariae and miracidia were noticed by a dissecting microscope for any alterations. Immobile ones were supposed to be dead (Obare, 2016).

2.9. Histological evaluation of B. Alexandrina snail's digestive and hermaphrodite glands

After two weeks of exposure and recovery, some *B. alexandrina* adult snails were selected randomly and dissected. The digestive and hermaphrodite glands were removed, and fixed in Bouin's solution. Glands were dehydrated and then embedded in paraffin wax. Finally, both gland were sectioned and stained with hematoxylin and eosin (Mohamed and Saad, 1990).

2.10. Statistics

The lethal concentration (LC_{10}, LC_{25}, LC_{50}, and LC_{90}) values, slop and the 95% Confidence limit (CL) of LC_{50} were calculated by Probit analysis (Finney, 1971) using SPSS v. 22.

3. Results

3.1. Characterization of the Cerium oxide / M. Oleifera nano-composite (Ce_2O_3/MNCs)

The polycrystalline nature of the biogenic Ce_2O_3/MNCs was confirmed by XRD pattern (Fig. 1A). The diffraction pattern is fitted well with the characteristic peaks of the pure Cerium oxide (Ce_2O_3, 00-044-1086). The phase structure of Ce_2O_3 was hexagonal with P-321 as a space group and its number 158. The lattice parameters

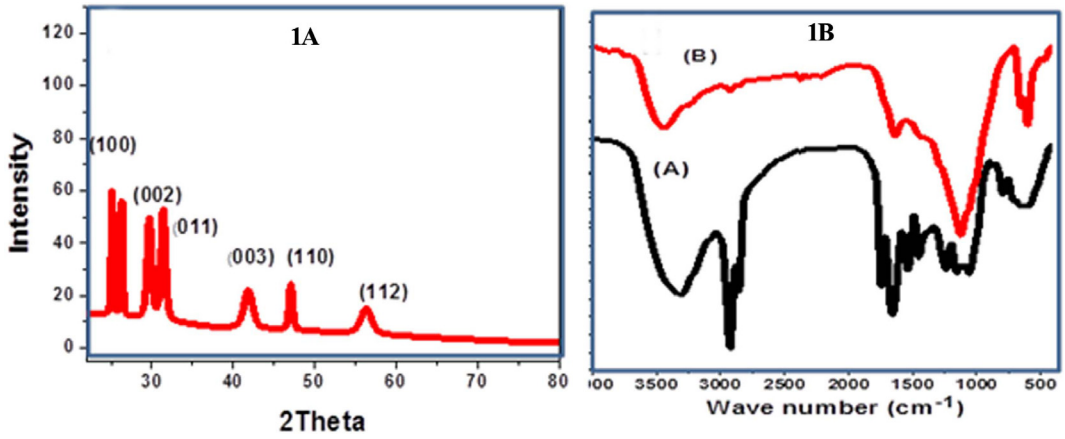

Fig. 1. Characterization of Ce_2O_3/MNCs. (1A) XRD patterns of Ce_2O_3/MNCs, (1B) FT-IR spectra of *Moringa* extract (A) and Ce_2O_3/MNCs nanostructure (B).

were a = b = 3.891 Å and C = 6.0630 Å and cell volume unit was 79.5×10^6 pm^3. The noticed diffraction pattern at 2θ = 26.5, 29.6, 30.5. The peaks of 44.8, 46.91, and 56.2 are regarding to the crystallographic planes (100), (002), (011), (003), (110), and (112) which can be matched to Ce_2O_3 pattern. The peak intensity in XRD diffraction elucidated the high crystallinity of the biogenic Ce_2O_3/MNCs. The crystallite size (D) were estimated using Scherrer equation (D = 0.9λ/W Cosθ), where W is the full width at half maximum in radians, θ is the Bragg's angle, and λ is the X-ray wavelength (CuKα = 0.15405 nm). The estimated value of D was ~ 30. 5 nm. The lattice defects number of biogenic cerium oxide was investigated. The dislocation density was calculated according to Williamson and Smallman's relation, δ = N/D^2; where N equals unity in case of the minimum dislocation density. The estimated value of δ is10 $\times$ 10^{-4} dislocation/nm^2. This small value of δ showed a good lattice structure for cerium oxide sample. FT-IR spectra of *M. oleifera* seeds and Ce_2O_3/MNCs were showed in Fig. 1B and Table 1. Both of them illustrated the characteristic functional groups of the studied structures.

The morphological criteria of *Moringa* seeds and biogenic Ce_2O_3/MNCs were obsereved through the FE-SEM images (Fig. 2A, B). *Moringa* seed exrtact was appeared as layers that were wrapped to be like cabbage papers (Fig. 2A). The synthesized Ce_2O_3/MNCs were strongly agglomerated to form nanoparticles with a size ranged from 25 to 35 nm (Fig. 2 B) and with uniform nanoporous features which was shown in the magnified image (Fig. 2B). TEM revealed the Ce_2O_3/MNCs as crystalline stacked nanograins with circle like shapes and with average particles size ranged from 28.5 to 30 nm (Fig. 2C).

Table 1
The characteristic functional groups of *M. oleifera* seeds and Ce_2O_3/MNCs via FT-IR spectra.

Absorption bands cm^{-1}	*M. oleifera* seeds	Ce_2O_3/MNCs
3311	O-H stretching **of** fatty acids, carbohydrates and the lignin units and to N–H stretching	
2923 and 2852	C–H symmetric and asymmetric stretching vibration in CH2	
1750 and 1630	C=O connection stretching	
1587	C–N stretching vibration and the deformation of the N–H starching vibration	
3673 cm^{-1} and 1611		hydrogen bonded OH groups present in the aqueous phase
2350		CH stretching vibration
1362 and 1113 cm		Ce_2O_3 nanoparticles and C–O–C stretching
750,604 and 460		chemical interaction between Ce and oxygen

3.2. Biological activities

In the present study, Ce_2O_3/MNCs was tested for its molluscicidal activity against snails of *B. alexandrina*. Probit analysis showed that the LC_{50} was 314.5 mg/L while the LC_{90} was 386.5 mg/L (Table 2, Fig. 3).

3.3. Effect of ¼ and ½ of the LC_{50} of Ce_2O_3/MNCs on the survival and reproductive rates of B. Alexandrina

It was found that the survival rate of *B. alexandrina* snails was significantly reduced ($p < 0.05$) when compared with the control group after the treatment with doses of ¼ and ½ of the LC_{50} of Ce2O3/MNCs in dose dependent manner (Fig. 4A). Also, the fecundity (M_X) of snails was significantly reduced and this was associated with significant reduction ($p < 0.01$) in the reproductive rate (R_o) (Fig. 4B).

3.4. Effect of Ce_2O_3/MNCs on the head foot region of B. Alexandrina

The scanning electron micrographs of the soft part of *Biomphalaria alexandrina* snails showing the normal tentacles with a smooth surface (Fig. 5A), the smooth tegmental surface of mantle with microvilli and fine spines (Fig. 5B), and foot plantaris with notable surface fold (Fig. 5C). Following the exposure to ¼ of the LC_{50}, the tentacles appeared rough with erosion and damaged cilia (Fig. 5D). Also, the tegmental surface of mantle became rough with mostly complete destroyed microvilli while foot appeared with dense cilia (Fig. 5E, F). Meanwhile after the exposure to ½ of LC_{50}, tentacles appeared rough with erosion (Fig. 5G) and the mantle tegmental architectures was alternated and showed rough surface sometimes with nipples and erosion (Fig. 5H). The foot plantaris folds became flat and the cilia were significantly disappeared (Fig. 5I).

3.5. Ovicidal activity

The exposure of *B. alexandrina* snail's eggs to the doses of ¼ and ½ of the LC50 of Ce2O3/MNCs led to variation in the embryonic

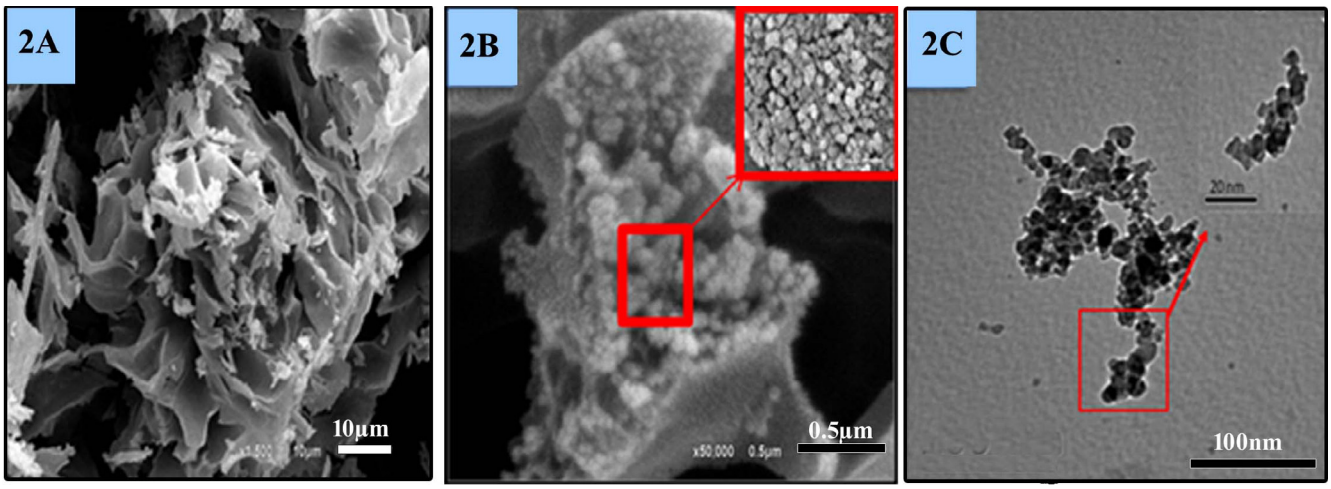

Fig. 2. Electron microscopic characterization. (2A) SEM of the *Moringa* extract, (2B) SEM of the Ce_2O_3/MNCs, (2C) TEM of Ce_2O_3/MNCs.

Table 2
Shows molluscicidal activity of Ce_2O_3/MNCs for adult *B. alexandrina*, snails after 48 h of exposure followed by 24 h for recovery.

Snails	LC_{10} (mg/L)	LC_{25} (mg/L	LC_{50} (mg/L)	Confidence limits of LC_{50} (mg/L)	LC_{90} (mg/L)	Slope
Biomphalaria alexandrina	242.6	276.7	314.5	271.1- 364.9	386.5	1.3

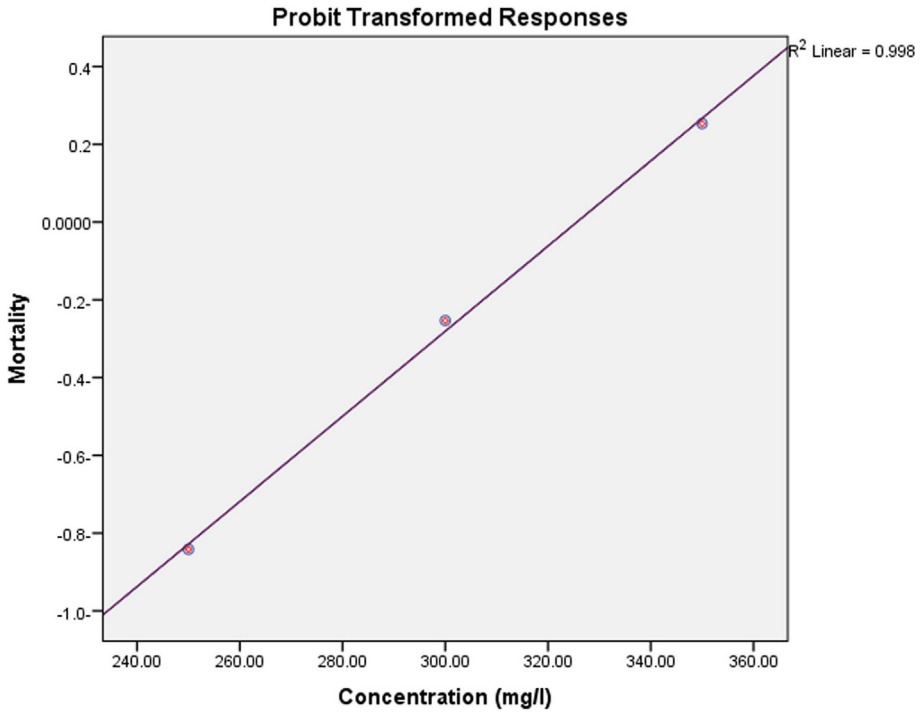

Fig. 3. Molluscicidal activity of the tested Ce_2O_3/MNCs against adult *B. alexandrina* snail.

development, where some embryos were degenerated and others were died (Fig. 6).

3.6. Miracidicidal and cercaricidal activities:

Exposing of *S. mansoni* miracidae to the dose LC_{50} of Ce_2O_3/MNCs caused 100% death rate after 210 min compared to 55% in the control group (Table 3). While, 100% death rate of cercariae was achieved after 240 min compared to 60% in the control group.

3.7. Histological evaluation

The sections of the control group revealed the hermaphrodite gland containing female oogenic cells with normal oocytes and mature ova and the male reproductive cells with normal spermatocytes and sperms (Fig. 7A). The treatment of snails with a dose of ¼ of the LC_{50} caused slight disintegration of some oocytes, mature ova, spermatocytes and sperms (Fig. 7B). While, the treatment with a dose of ½ of the LC_{50}, showed significant as the connective tissue

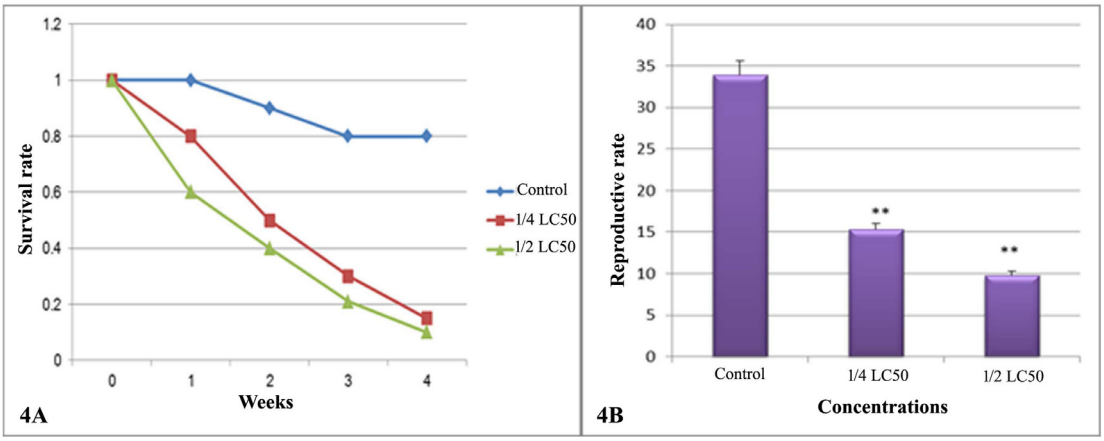

Fig. 4. Survival and reproductive rates of *B. alexandrina* snails. (4A) The survival rate, (4A) The reproductive rate.

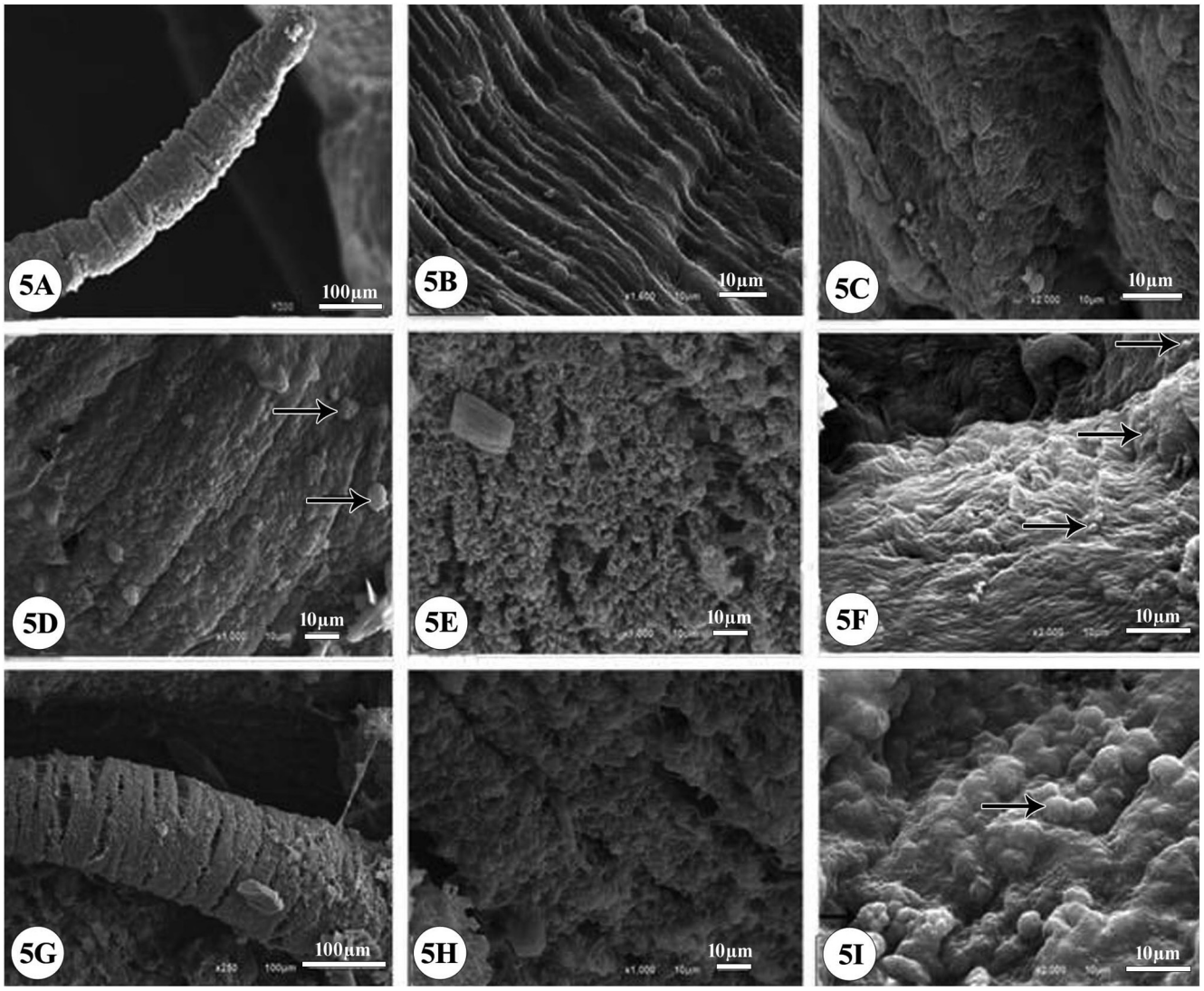

Fig. 5. Scanning electron micrographs (SEM) of *B. alexandrina* snails (soft part). (5A) Normal ultrastructure of tentacles with a smooth surface, (5B) the smooth tegmental surface of mantle with conspicuous microvilli and fine spines, (5C) foot plantaris with notable surface fold. After exposure to ¼ of LC_{50} of Ce_2O_3/MNCs for 24 h: the micrographs showing limited changes in ultrastructure morphology; (5D) tentacles became rough with erosion (arrows); (5E) the tegmental surface of mantle became rough, most microvilli completely destroyed, (5F) foot with dense cilia (arrows). After exposure to ½ of LC_{50} of Ce_2O_3/MNCs for 24 h; (5G) tentacles became rough with erosion (5H) showing alteration of mantle tegmental architectures, rough surface, nipples and erosion, (5I) foot folds became flat, nipples appeared (arrows), the cilia disappeared significantly.

Fig. 6. Embryos of *B. alexandrina* snails (7 days old). (6A) Normal control embryos of seven-days-aged where the snails completely formed (E: eye; HF: head foot; S: shell). (6B) After exposure of the egg mass to ¼ of LC_{50} of Ce_2O_3/MNCs while (6C) after exposure to ½ of LC_{50} of Ce_2O_3/MNCs for 24 h followed by 24 h of recovery; showing the embryos died (thin arrow) and some degenerated (thick arrow).

Table 3
Effect of LC_{50} of Ce_2O_3/MNCs on *Schistosoma mansoni* miracidia and cercariae.

Conc (mg/L)	mortality % (cumulative) of miracidia and cercariae after the following intervals (min)								
	30	60	90	120	150	180	210	240	
Miracidia	Control	0	0	5	20	40	50	55	65
	treated	10	30	60	70	80	90	100	
Cercariae	Control	0	0	0	10	20	35	40	60
	treated	5	30	35	40	50	80	95	100

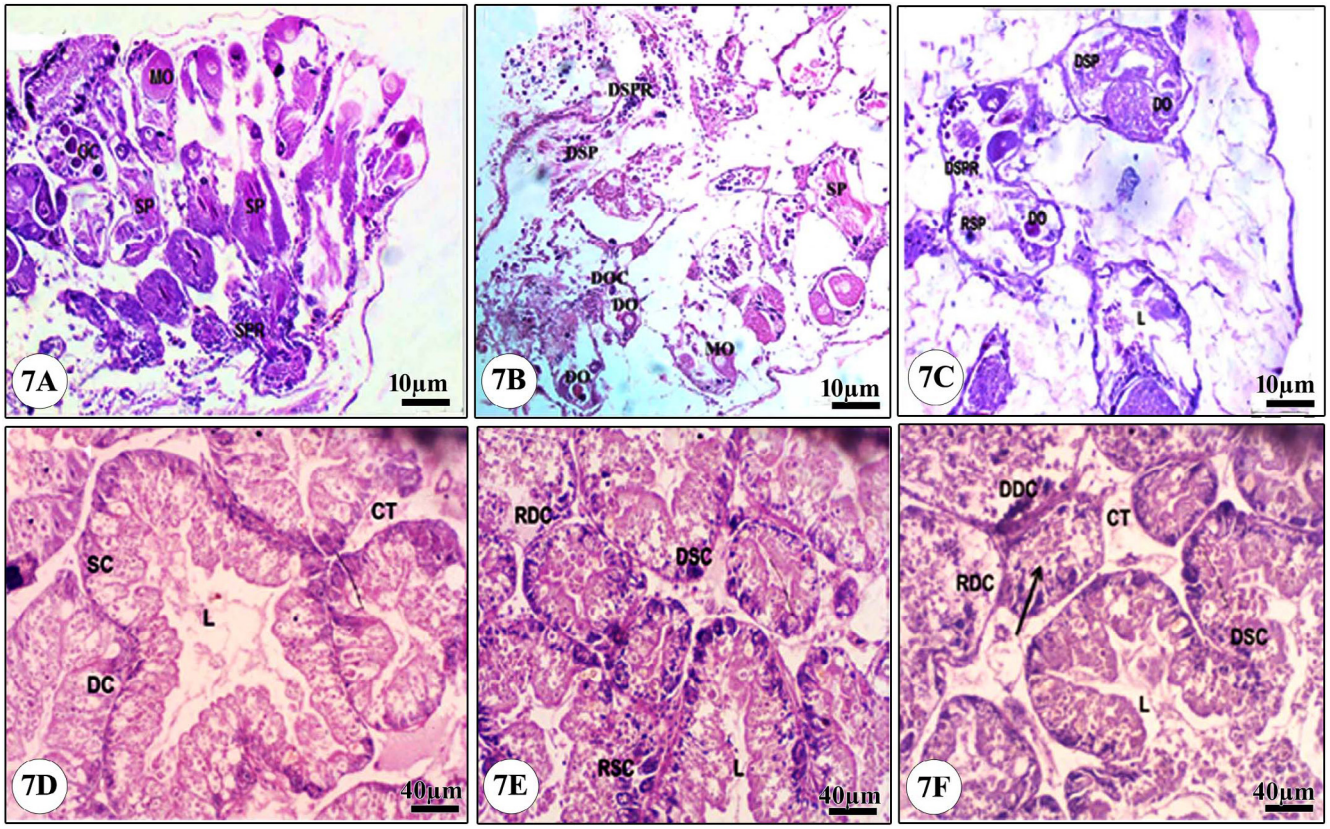

Fig. 7. Light micrograph of the hermaphrodite and the digestive glands of *B. alexandrina* snails. (7A) Normal hermaphrodite gland, (7B) Snails exposed to ¼ of LC_{50} of Ce_2O_3/MNCs, (7C) Snails exposed to ½ of LC_{50} of Ce_2O_3/MNCs, (7D) Normal digestive gland, (7E) Snails exposed to ¼ of LC_{50} of Ce_2O_3/MNCs, (7F) Snails exposed to ½ of LC_{50} of Ce_2O_3/MNCs. MO: Mature ovum, OC: Oocytes, SP: Sperms, SPR: Spermatocytes, DO: Degenerated ovum, DSP: Degenerated sperms, DOC: Degenerated oocytes, DSPR: Degenerated spermatocytes. DC: Digestive cells, SC: Secretory cells, L: Lumen, CT: Connective tissue, RDC: Ruptured digestive cells, DDC: Degenerated digestive cells, DSC: Degenerated secretory cells, RSC: Ruptured digestive cells. The arrow indicated that the tubule is totally ruptured.

was disappeared and replaced by vacuoles with great damage in the gonadal cells in addition to degeneration and destruction in sperms, eggs, spermatocytes, and oocytes (Fig. 7C).

The digestive gland of the control group showed many tubular glands with one layer of two cells types; secretory cells (SC) and digestive cells (DC) (Fig. 7D). Treatment with ¼ of the LC_{50} caused some digestive cells rupture and vacuolization in addition to a significant increase in the number of SC (Fig. 7E). While the treatment with ½ of the LC_{50} led to lumen (L) increase, degeneration and rupture of most of the DC and SC while the tubular glands lost their confirmed shape (Fig. 7F).

4. Discussion

Cerium oxide is one of the important nanomaterials recorded by the Organization for Economic Cooperation and Development (OECD) (Djanaguiraman et al., 2018). The synthesis of Ce_2O_3/MNCs bio-composite was carried out through activation, growth and termination stages (Thilagavathi et al., 2015). This newly formed nanoceria possessing large surface area, where, their average particles size ranged from 28.5 to 30 nm as estimated form SEM micrographs and these values were fit to these obtained from XRD data by Debye-Scherrer equation. This novel Ce_2O_3/MNCs could serve as a new molluscicide.

Therefore, the present study investigated the molluscicidal activities of Ce_2O_3/MNCs against *B. alexandrina*. The results showed that Ce_2O_3/MNCs was toxic to *B. alexandrina* with LC_{50} of 314.5 mg/L. Few studies explored the effect of NPs against *B. alexandrina* as ZnONPs which exhibited molluscicidal effects against *B. alexandrina* (Fahmy et al., 2014). Also, iron nanoparticles caused significant mortality in *B. alexandrina* (Khalil et al., 2018). These variations in the molluscicidal effects of the nanoparticles were due to the nature of structure materials and the size differences of the used nanoparticle (Attia et al., 2017). Our results revealed that exposing of *B. alexandrina* snails to the doses of ¼ and ½ of the LC_{50} of Ce_2O_3/MNPs for 24 hrs/ week significantly reduced its survival rate. Similarly, Oliveira-Filho et al. (2019) found that the silver nanoparticles caused adverse effects on the survival and the reproduction rates of *Biomphalaria glabrata*.

Also, in the present study the concentrations of ¼ and ½ of LC_{50} of Ce_2O_3/MNPs were negatively affected the fecundity of the exposed snails and this was associated with significant reduction ($p < 0.01$) in the reproductive rate (R_o). These adverse effects might be due to the ability of Ce_2O_3/MNCs to cause oxidative stress (Khorrami et al., 2019) which led to decreasing fertility, delaying in the snail development, and subsequently the death of this snail (Fahmy et al., 2014). Also, these results could be attributed to the harmful effects of Ce_2O_3/MNCs on the reproductive system of treated snails, hence considerably reduced their oviposition and this was supported by the histological evaluation of the hermaphrodite gland (Seitz et al., 2013; Gallo et al., 2016).

In the present investigation, the exposure of *B. alexandrina* snails' eggs to the doses of ¼ and ½ of the LC_{50} of Ce_2O_3/MNCs caused embryonic degeneration and embryonic death. The alterations in the embryonic development and the mortalities in embryonated eggs were related to accumulation of particles in egg mass which led to the changes in the nature of hyaline material (ootheca) as suggested by Fahmy et al. (2014). Similarly, Besnaci et al. (2016) found that the application of Fe_2O_3 nanoparticles on the eggs of *Helix aspersa* exhibited egg membrane deformation with significant reduction in the hatching rate.

The electron micrographs of *B. alexandrina* soft parts treated with Ce_2O_3/MNCs showed alterations in the tentacles and the tegmental architectures. In general, nanomaterials possessed highly adhesive properties to a cell membrane therefore, it affects the membrane structures and its macromolecules (Attia et al., 2017; Rasel et al., 2019). Similarly, the damage in the tegument structure of *B. alexandrina* due to the exposure to Ce_2O_3/MNCs could the main cause for its death (Ibrahim and Abdel-Tawab, 2020).

The present results evidenced that Ce_2O_3/MNCs had cercaricidal and miracidicidal activities. These results agreed with that of Moustafa et al. (2018) who found that silver and gold nanoparticles caused significant increase in the mortality of *S. mansoni* cercariae and therefore, it could prevent or modulate the infectivity of cercariae in vivo. Also, Shaldoum et al. (2016) found that the infection rate of snails exposed to Cu_2O NPs was significantly decreased.

The histological sections of the hermaphrodite gland of *B. alexandrina* after the exposure to Ce_2O_3/MNCs showed great damage in the gonadal cells with degeneration of some mature ova, spermatocytes, oocytes and sperms. Also, the connective tissue

was vacuolated and dissolved. Saad et al. (2019) reported similar histological alterations in *B. alexandrina* treated with Cu_2O NPs. The observed reduction in snail egg production due to destruction of hermaphrodite glands which possibly attributed to apoptosis and oxidative damage induced by Ce_2O_3/MNCs (Omobhude et al., 2017).

Exposing of the digestive gland of *B. alexandrina* to Ce_2O_3/MNCs led to significant increase in the number of SC. Meanwhile, DC were ruptured and vacuolated and the tubular glands lost their confirmed shape. Correspondingly, Fahmy and Sayed (2017) reported similar histological alterations in the digestive gland of *Coelatura aegyptiaca* treatmented with ZnONPs.

4.1. Mechanism of action

The speculated mechanism for bioactivity of Ce_2O_3/MNCs against *B. alexandrina* snail was suspected to be as following: Firstly, the exposure of the snails to the testified concentrations of Ce_2O_3/MNCs caused a noticeable reduction in survival and hatchability rates. Ibrahim and Abdalla, 2017 attributed these effects to the significant increase in the levels of transaminases (ALT and AST) that led to hepatic damage.

Secondly, Ce_2O_3/MNCs may be uptake into the snail through ingestion and translocate across the gut wall, thus it affects the digestive gland and the hermaphrodite gland which leads to increase in the secretory cells number and loss of the connective tissues in addition to deformed sperms and degenerations of eggs (Cross et al., 2019).

Finally, the exposure to Ce2O3 nano-composite caused damage and alteration in the tegmental architectures of the snail soft parts which induced excessive cellular reactive oxygen species (ROS) production and subsequently leading to noticeable tissue damage due to the oxidative stress (Eom and Choi, 2009; Rogers et al., 2015).

Table 4 showed that the efficiency of our biocatalyst which are higher than the previously reported properties using different biocatalysts from different parts of *Moringa*.

5. Conclusion

Herein, we are successfully synthesized Ce_2O_3/MNCs bio-composite by low cost green synthesis method. The newly synthesized Ce_2O_3/MNCs bio-composite was characterized by several techniques including XRD, FTIR, HR-TEM, and FE-SEM. The morphological study revealed the formation of uniform agglomeration of spherical particles with average size of 30 nm. The present results showed that the newly synthesized Ce_2O_3/MNCs has significant lethal effect on *B. alexandrina* snails and this can affirm its suitability as biodegradable molluscicidal agent. Further field stud-

Table 4
Comparison of efficiency of the present work with previously reported catalysts for *moringa*-based catalysts.

Plant	Plant part	Snail	Dose	Activity	Reference
Moringa oleifera	Ground seed	*Biomphalaria glabrata, Physa marmorata* and *Melanoides tuberculatus*	*M. oleifera* is active against *B. glabrata* (LC_{50}: (419mg/l; LC_{90}: (1000mg/l and *P. marmorata* (LC_{50}: (339mg/l; LC_{90}: (789mg/l) but has no effect against *M. tuberculatus*.	The seed powder has molluscicidal activity as it caused mortality to the *B. glabrata* and *P. marmorata* snail	(Silva et al., 2013)
	Aqueous extract of flower	*Biomphalaria glabrata*	LC_{50} (2.37mg/ml)	The flower extract has molluscicidal activity as it delayed the development of embyos and caused mortality to *Biomphalaria glabrata* adult snails. Also, the embryos generated by snails exposed to the extract were affected	(Rocha-Filho et al., 2015)
	Ethanolic extracts of leaf powder	*Lymnaea acuminate*	96h LC_{50}: (197.59 mg/L)	The leaf powder has molluscicidal activity as it is inhibited secreation of acetylcholinesterase (AChE) and acid / alkaline phosphatase (ACP/ ALP) in the nervous tissue of *L. acuminate*.	(Upadhyay et al., 2013)

ies are needed to evaluate the effect of Ce_2O_3/MNCs on the surrounding no target organisms.

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.

Acknowledgements

This work was supported by Researcher Supporting Project (RSP-2020/3), King Saud University.

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