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Biosequestration potentials of *Tenuisentis niloticus*(Meyer, 1932) (Acanthocephala: Tenuisentidae) on organochlorine pesticide burden in *Heterotis niloticus* (Cuvier, 1829) (Actinopterygii: Arapaimidae) from Lekki lagoon, Lagos, Nigeria

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ABSTRACT

This study aimed to investigate the presence of organochlorine pesticide (OCP) residues in *Heterotis niloticus* and its acanthocephalan parasite, *Tenuisentis niloticus* .Total protein, glucose, triglycerides, and lipoproteins in the fish were analysed using standard methods, and OCP congeners in the tissues of the fish and parasite were tested using Gas Chromatography-Mass Spectrometry (GC–MS). Superoxide dismutase (SOD), catalase (CAT), reduced glutathione (GSH), glutathione peroxidase (GPx), and malondialdehyde (MDA) and other mentioned parameters were tested in the infected and uninfected fish groups. Results showed that of the 18 OCP congeners tested in *H. niloticus,* 6 were undetected and 10 were of higher concentrations in the intestine than the liver. Only gamma-lindane (γ-HCH) and methoxychlor were higher in the liver than the intestine of the fish. The concentrations of Alpha-Lindane (α-HCH), Beta-Lindane (β-HCH), and Delta-Lindane (d-HCH) in the intestine of the uninfected fish were significantly higher than the concentrations in the intestine of the infected fish, the liver of the infected and the liver of the uninfected ($p<0.05$).The concentration of Endosulfan sulfate and Dieldrin in the liver and intestine of the uninfected fish was higher than the infected fish ($p<0.05$). The parasite, *Tenuisentis niloticus* showed the tendency to depurate α-HCH, β-HCH, D-HCH, Heptachlor epoxide, and Endosulfan I in the infected fish. There were significantly higher ($p<0.05$) concentrations of SOD and MDA in the uninfected fish than the infected. Endrin exhibited a strong positive correlation (0.763) with Deildrin, which in turn negatively correlated (-0.537) with CAT and GSH (-0.748). The microbial analysis conducted on the fish showed the bacteria genera *Staphylococcus, Enterococcus, Bacillus, Pseudomonas, Salmonella, Klebsiella, Escherichia*, and *Proteus,* particularly in the infected fish, were susceptible to plasmid elimination (curing). In line with the expectations that stemmed from the stated hypothesis, the study has demonstrated the novelty of *Tenuisentis niloticus* in attenuating mainly endosulfan sulfate and dieldrin burden in *H. niloticus* in Lekki lagoon. The protective role of the parasites on its host found expression in ameliorating the oxidatives stress which may have been inflicted on the fish by the OCP toxicity, although at high parasitic prevalence.

1. Introduction

The utilization of organochlorine pesticides (OCPs) in agricultural production techniques to prevent vector-borne diseases, particularly in developing countries, is seemingly indispensable (John et al., 2001) The widespread accumulation of organochlorines in the food chain is due to their lipophilicity, hydrophobicity, and non-biodegradability (Bedi et al., 2005; Aulakh et al., 2006). These factors underlie the biomagnification effect, enhancing the chemical's toxicity to humans (Surendernath et al., 2008).

In developing countries such as Nigeria, the indiscriminate and unregulated use of OCPs has led to the contamination of water bodies and reported OCP residues in aquatic life (B. Akinsanya et al., 2019; B. Akinsanya et al., 2020) . Humans who consume OCP-contaminated fish may elicit various health hazards such as endocrine dysfunction, congenital disabilities, breast cancer, reduced sperm count, and testicular cancer (B. Akinsanya et al., 2019; B. Akinsanya et al., 2020; Brody and Rudel, 2003; Garry, 2004).

Fishes are at the top of the aquatic food chain; hence, they are excellent bioindicators because they exhibit responses to environmental

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changes. Fishes are readily available, have high toxicant accumulation potential, and an optimum size for analysis (Batvari et al., 2007). Quantitative analysis of contaminants in the water does not clearly explain bioavailability and ecotoxicity in the aquatic ecosystem (Javed et al., 2015). However, the use of fish as a specimen in biomonitoring studies has shown reliable and promising results (Taweel and Ahmad, 2011).

Parasites and pollutants may affect the endocrine system of the host fish. Parasites usually exist in equilibrium with their hosts as a survival strategy (Sures, 2004; Saliu et al., 2014). Conversely, they may be beneficial to the host in sequestration of the toxicant burden by sharing toxicant concentration load in the fish host (B. Akinsanya et al., 2020; P.O. Isibor et al., 2020). Hence, endoparasitic infections may be useful sentinel species in the study of an exposed fish host as they readily respond to and reflect the conditions of the host (Avenant- Oldewage, 2001).

There have been reported indiscriminate use of organochlorine chemical products such as pesticicides and agrochemicals around Lekki lagoon (B. Akinsanya et al., 2020; B. Akinsanya et al., 2019). These may result in pollution that may inevitably lead to deleterious impacts on the public health, environment, which occur at organismal and sub-organismal levels (Velkova-Jordanoska and Kostoski, 2005).

The protection of human health and the environment from persistent organic pollutants (POPs) was one of the Stockholm Convention's major objectives. Ratification of the convention verdict in Nigeria requires frequent biomonitoring studies, particularly in Lekki lagoon where POP residues in environmental matrices have heightened lately (B. Akinsanya et al., 2020), particularly in the bottom sediment of the lake, which has been reported as a significant repository to OCPs and source of future re-pollution due to the high octanol-water partition coefficients of the lipophilic compounds (B. Akinsanya et al., 2019). This necessitates the assessment of OCPs in the biota, especially the benthopelagic fish such as *Heterotis niloticus,* which has a substantial commercial value and high exposure chances to OCPs (Adite et al., 2005).

Several studies have demonstrated the potentials of parasites to sequeatrate toxicants from hosts. The sequestration phenomenon has been tested in wide range of toxicants, including heavy metals (B. Akinsanya et al., 2019; Adite et al., 2005; P.O. Isibor et al., 2020), BTEX, and OCPs (B. Akinsanya et al., 2019). Many studies have also tested this phenomenon in hosts and parasites at different trophic levels, ranging from various species of fish (P.O. Isibor et al., 2020) to toads (B. Akinsanya et al., 2020). Available data show that in some cases, the parasites showed significant sequestratsion of the investigated toxicants in the host and in some other instances, the reverse was the case. Complex interacting factors may be responsible for the fate of toxicants in the host-parasite relationship, it is however possible to determine some leading factors based on the trends in available scientific reports. A noticeable trend so far is that the larger the organism, the less the depurative impact of its endoparasites. This may be based on the high bioaccumulative capacity of the larger host being unmatched by the sequestration capacity of the parasite (B. Akinsanya et al., 2020).

Heterotis niloticus of Lekki lagoon serves as affordable source of animal protein to large number of Nigerian population and exotic export to nearby West African countries. Several studies have previously established the detection of orgnochlorines in the lagoon (B. Akinsanya et al., 2019; B. Akinsanya et al., 2020; Akinsanya et al., 2015). Presence of OCPs in the lagoon may therefore impact *H. niloticus* and its consumers, being an exotic bottom dwelling fish species. In the event of pollution of the aquatic environment, remediation efforts may be essential but restoration cost may be conserved if opportunistic parasites could be utilized in the remediation process at levels too low for significant parasitic consequencies.

If the pollution in Lekki lagoon has not inflicted parasitological implications in the *H. niloticus*, it is possible to harness the endoparasites in the attempt to sequestrate the OCP already bioaccumulated by the fish. Furthermore, based on research conducted by Sures (Sures and Reimann, 2003), parasite accumulation of organic pollutants could lead to a reduction in parasitism. *Tenuisentis niloticus* is a member of the phylum, Acanthocephala, and an endoparasite of *H. niloticus*. This phylum of parasites has been reported to be very useful in environmental impact studies because they can detect low concentrations of contaminants due to their great accumulative capacity (Sures and Reimann, 2003), hence may be useful in sequestering the OCP burden in *H. niloticus,* while reducing the parasite abundance in the host simultaneously..

The study aimed to determine the concentrations of OCP residues in *H. niloticus*, and its enteric parasite using tools such as bioaccumulation factors and parasitological biomarker response indices to determine the stress conditions in Lekki lagoon.

The phenomenon adopted in this study is based on the hypothesis that a correlation is expected between the sum of a given congener in the infected host and its parasite when compared with the uninfected host. This rationale is based on the simplistic expectation that the uninfected fish bears the burden concentration alone, while the infected counterpart shares the burden with its parasite.

It is expected that the combinations of the OCP load in the infected *H. nilotocus* and its enteric parasite will correlate with the concentrations found in the uninfected counterpart. This comparison will shed some light on the parasite's depurative capacity. This study therefore seeks to explore the depurative potential of *H. niloticus* parasite on the OCP burden.

2. Materials and methods

2.1. The study area

The study area is Lekki lagoon (Fig. 1), with a surface area of about 247km^2 (Adesalu and Nwankwo, 2009) which lies within 6°25′- 6°35′N and 4°00′- 4°13′E is predominated by notably alternating dry and wet seasons (Adesalu and Nwankwo, 2009).

The Oshun and Oni Rivers discharge into the north-western and north-eastern parts of Lekki lagoon, respectively (Akinsanya, 2007). Land in the study area is predominantly used for agriculture, one of the significant sources of pesticide pollution (Akinsanya et al., 2015; Adesalu and Nwankwo, 2009).

The lagoon is characterized by fringing macrophyte vegetations, which are dominated by mangrove species identified as *Rhizophora racemosa* (Red mangrove), *Avicennia nitida* (White mangrove), *Acrosticum aureum, Paspalum orbiculare* and Dryopteris. The coastal vegetation is also dominated by *Cocos nucifera* and *Terminalia cattapa* trees. A variety of floating macrophytes such as *Eichhornia crassipes* Solm, *Pistia stratiotes, Lemna pausicaudata,* and *Vosia cuspidata* infiltrate the lagoon through the various surrounding rivers and creeks.

2.2. Collection and examination of samples

A total of 65 fish; an average of 4 fish samples (more or less in some cases, depending on catch) per location were collected from 14 sampling locations scattered around the lagoon for a good representation of the aquatic habitat. The coordinate of the locations were taken and recorded for map presentation (Fig. 1).

2.3. Identification and analysis of fish

The fish specimens were identified as *Heterotis niloticus* using identification manual such as Olaosebikan and Raji (Olaosebikan and Raji, 1998) and Idodo-Umeh (Idodo-Umeh, 2003). A total of sixty-five (65) specimens of *Heterotis niloticus* were sampled from Lekki lagoon from July- November 2019 using fishing traps, hooks, and gill nets. Morphometric assessment such as standard length and total length were assessed using a meter rule and recorded to the nearest centimeter, and weight was measured using Denward weight balance (Model - TX3202L-V) and recorded to the nearest gram. The sex of the fish was determined by visual examination of the gonads.

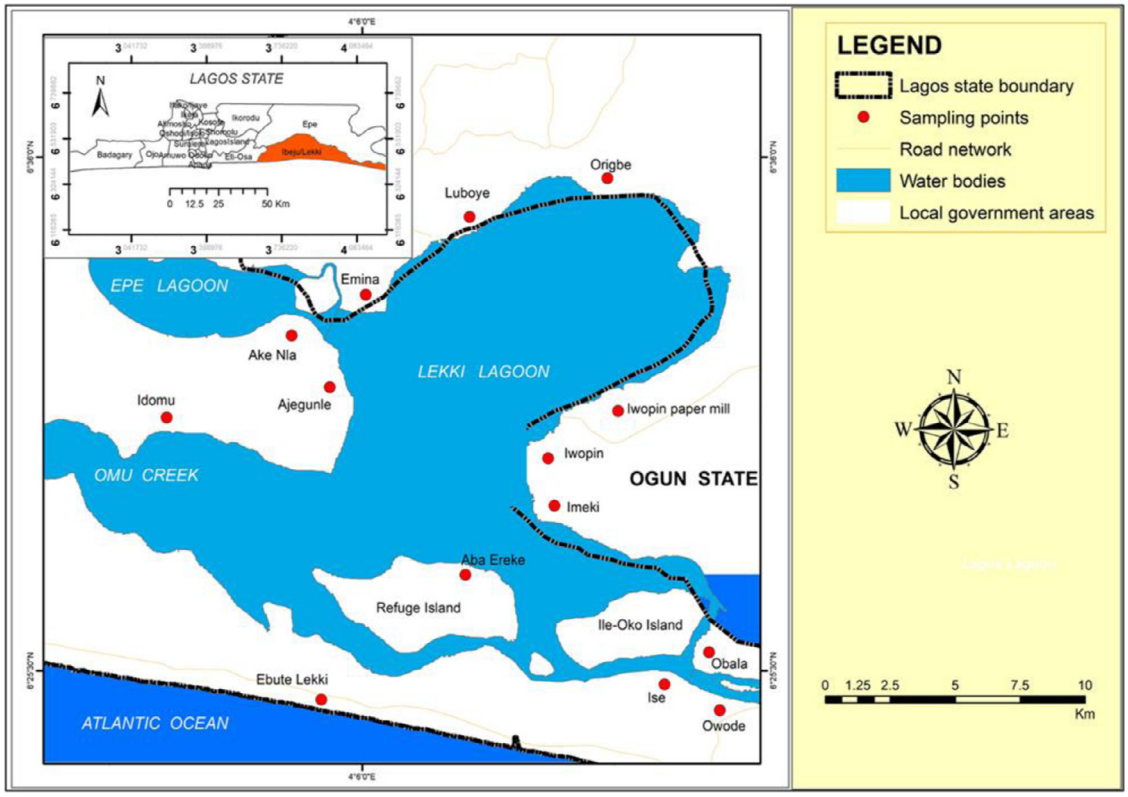

Fig. 1. Map of Lekki lagoon (B. Akinsanya et al., 2019).

The parasites, liver and intestine of fish were eviscerated and stored in labeled universal bottles with 0. 09% saline for further analysis. The technique of Akinsanya (Akinsanya, 2007) was adopted for examining the gastrointestinal parasites of the fish. The intestine excised with the aid of a sterile blade, and the emerging parasites were counted, identified, and recorded accordingly.

2.4. Identification and analysis of parasites

Identification of intestinal parasites was undertaken at the pathology laboratory of the Department of Veterinary Pathology, University of Ibadan, Nigeria.

Live parasite specimens collected from the dissected host guts were kept in a deionized water until parasite proboscis were everted. Afterwards, they were fixed in 70% ethanol. The specimens were stained in Mayer's acid carmine, destained in 4% hydrochloric acid in 70% ethanol, then dehydrated in ascending concentrations of ethanol (70%, 80%, 90%, 90%, 100%), and cleared in 100% xylene, then in 50% Canada balsam and 50% xylene. Each step was at the interval of 24 h. Whole worms were then mounted on slide and analyzed. All measurements were recorded in micrometer. The width was measured as the maximum width, while the trunk length was measured without including the proboscis, neck, or bursa.

Specimens previously fixed in 70% ethanol were placed in critical-point drying baskets and dehydrated using ethanol series of 95% and 100% for at least 10 min per soak followed by critical point drying (Lee, 1992). Samples were gold coated and observed under a scanning electron microscope XL30 ESEMFEG (FEI, Hillsboro, Oregon, USA). Digital images of the structures were obtained with the aid of Olympus BH2 compound light microscope (Olympus Optical Co., Tokyo, Japan), equipped with an AmScope camera MU900 (United Scope, Irvine, California), in conjuncton with digital imaging software. Detailed studies were then carried out on the para-receptacle structure by sectioning the specimens using plastic and diamond knives under the scanning electron microscope.

Using Omar *et a.* (Oma et al., 2016) as the parasite identification manual, some of the taxonomic identification keys used include possession of proboscis which is spineless at the anterior and apical ends. The posterior end of the proboscis and conical neck exhibited depressions similar to sensory structures. Furthermore, the apical end of the proboscis possess an apical epidermis cone, while the posterior of the proboscis had thin latero-dorsal and massive ventral hooks as described by Omar *et al.* (Oma et al., 2016).

The number of parasites recovered from each fish was recorded and preserved in saline solution for analysis. Parasite prevalence (Eq. (1)), abundance (Equation 2), and mean intensity (Eq. (3)) were calculated thus: (Ewald, 1983; Ewald, 1983; Ezewanji et al., 2005)

$$\text{Parasite prevalence} = \frac{\text{Number of infected fish} \times 100}{\text{Number of examined fish}} \quad (1)$$

$$\text{Parasite abundance} = \frac{\text{Number of parasites}}{\text{Number of fish examined}} \quad (2)$$

$$\text{Meanintensity} = \frac{\text{Number of parasites}}{\text{Numberofinfectedfish}} \quad (3)$$

2.5. Determination of OCP concentrations in fish and parasites

The liver and intestines excised from the fish samples were weighted and parasite samples were pooled and weighed separately. OCP was tested in separately in the media using the method described by Anastassiades et al. (Anastassiades et al., 2003). Sixty five (65) samples each of liver, intestine, and parasites were estimated to measure up to 15±0.01 g in a 50 mL centrifuge tube. Acetonitrile (15 mL, with 1% acetic acid) and internal standard (IS) were added to each sample. The tube containing 6 g of anhydrous $MgSO_4$ and 1.5 g of anhydrous CH_3COONa, QuEChERS salt packet (Agilent bond elute-5982) was added into it the mixture in the tube and vortexed vigorously for 1 min till phase separation between

water and acetonitrile was achieved. Afterwards, the samples were centrifuged for 1 min at 1500 rpm. Then, dispersive solid phase extraction (dSPE) with the resin was used to remove fatty acids. Using a pippete, 6 mL each sample of fish and parasites was taken in a tube containing 150 mg of primary and secondary amine exchange material (PSA) and 1 g of $MgSO_4$ (Agilent dispersive kit-5982), were vortex for 2 min and centrifuged for 1 min at 1500 rpm using an electric centrifuge (Hermle Labortechnik GmbH, Siemensstr D-78,564 Wehingen, Germany). to separate the solid materials. With the aid of a 0.22 μm syringe filter, 1 mL of the extract was transferred to a gas chromatography (GC) vial and injected to the GC–MS, a gas chromatography mass spectrometer coupled with electron capture detector). The OCP concentrations in the fish and parasites were then determined using Gas Chromatograph (Model 5890/5970, Walnut, Greek, CA, USA) with a mass selective detector (quadrupole mass analyzer, 70 eV) equipped with a Hewlett-Packard 7673 A autosampler and a film thickness column of 30 $m \times 0.25$ mm ID $\times$ 0.10 μm HP-5MS. A 1 μL sample was injected using a splitless injection mode at 250 °C and GC-MSD interface temperature of 280 °C. The OCPs were identified and quantified by comparison of retention duration and spectra of internal standards.

2.6. Determination of biochemical biomarkers

2.7. Determination of cholesterol

Total cholesterol was determined using enzymatic end point method described by Roeschlau et al. (Roeschlau et al., 1974).

2.8. Determination of high-density lipoprotein-associated cholesterol (HDL-C)

The high-density lipoprotein-associated cholesterol was spectrophotometrically measured using a series of coupled reactions as described by Burstein et al. (Burstein et al., 1980).

2.9. Low-density lipoprotein-associated cholesterol (LDL-C)

All reagents used in the analysis were provided as ready to use. The method of Assman et al. (Assman et al., 1984) was adopted in analysis of low-density lipoprotein-associated cholesterol, which is a combination of polyvinyl sulfate precipitation and enzymatic method.

2.10. Determination of protein (PRO)

The perotein content of the liver and intestine of 16 uninfected and 49 infected fish was estimated using Biuret method as dscribed by Umemoto (Umemoto, 1966).

2.11. Triglycerides

Triglycerides were analyzed in the 65 fish samples using the enzymatic method described by Tietz (Tietz, 1990).

2.12. Glucose

The glucose concentrations in the liver and intestine of the 16 uninfected and 49 infected fish were determined within 30 min of collection using the method of Wedermeyer and Yasutake (Wedermeyer and Yasutake, 1977).

2.13. Catalase (CAT)

Catalase (CAT) was assayed calorimetrically at 620 nm and expressed as moles of hydrogen peroxide (H2O2) consumed /min/ mg protein as described by Quinlan et al. (Quinlan et al., 1994). The reaction mixture (1.5 ml) contained 1.0 ml of 0.01 M pH7.0 phosphate buffer, 0.1 ml of Plasma and 0.4 ml of 2 M H_2O_2. The reaction was stopped by the addition of 2.0 ml of dichromate-acetic acid reagent (5%potassium dichromate and glacial acetic acid were mixed in 1:3 ratio). The specific activity of catalase was expressed as moles of reduced per minute per mg protein.

2.14. Superoxide dismutase (SOD)

Superoxide Dismutase activity in liver homogenates was determined using the procedure described by Marklund and Marklund (Marklund and Marklund, 1974). The method is based on the ability of SOD to inhibit the autoxidation of pyrogallol. In 970µL of buffer (100 mMTris - HCl, 1 mM EDTA, pH 8.2), 10µL of homogenates and 20µL pyrogallol 13 mM were mixed. Assay was performed in thermostated cuvettes at 25 °C and changes in absorption were recorded by a spectrophotometer (Spectronic 20D) at 480 nm. One unit of SOD activity was defined as the amount of enzyme that can inhibit the auto-oxidation of 50% the total pyrogallol in the reaction.

2.15. Glutathione (GSH)

Reduced glutathione (GSH) was determined by the method of Ellman (Ellman, 1959). To the liver homogenate 10% TCA was added and centrifuged. 1.0 ml of supernatant was treated with 0.5 ml of Ellmans reagent (19.8 mg of 5,5′-dithiobis nitro benzoic acid (DTNB) in 100 ml of 0.1%sodium nitrate) and 3.0 ml of phosphate buffer (0.2 M, pH8.0). The absorbance was read at 412 nm.

2.16. Glutathione peroxidase (GPx)

Glutathione peroxidase catalyses the reduction of hydrogen peroxide and lipid peroxide into water and lipid alcohol through the oxidation of reduced glutathione (GSH) into glutathione disulphide (GSSG) (Arthur, 2000). Samples were incubated using hydrogen peroxide in the presence of glutathione for a particular time period. The amount of utilized hydrogen peroxide is then determined by directly 5, 5′- estimating GSH content using Ellman's reagent, dithio bisnitrobenzoic acid (DTNB).

2.17. Malondialdehyde (MDA)

Malondialdehyde (MDA) an index of lipid peroxidation was determined by adding 1.0 ml of the supernatant was added to 2 ml of (1:1:1) TCA-TBA HCL reagent (thioarbituric acid 0.37%, 0.24n HCL and 15% TCA) tricarboxylic acid-thioarbituric acid-hydrochloric acid reagent boiled at 100 °C for 15mins, and allowed to cool. Flocculent materials were removed by centrifuging at 3000 rpm for 10mins. The supernatant was removed and the absorbance read at 532 against a blank. MDA was calculated using the molar extinction coefficient for MDATBA-complex of 1.5 $\times$ 105 M/cm.

2.18. Quality assurance/ quality control

For quality assurance purposes, the blanks, duplicates, standard reference materials, and standard mixtures were used. The concentrations of OCPs were determined from 5 points, within the range 0.01–10 µg/L on the calibration curve of each tested OCP congener by plotting the integrated peak areas against the concentrations.

2.19. Linearity and sensitivity

The linearity of the calibration graphs were checked by running the concentrations of each compound 15 times and then calculating the correlation coefcient (R^2) which were all >0.99997 (ranged from 1.5- 2.5).

The limit of detetection (LOD) and limit of quantification (LOQ) were determined according to the recommendations of EPA (EPA, Environmental Protection Agency 1991) and PAM (PAM, Pesticide Analytical

Manual 1994). The LOD was calculated as the lowest concentration of OCP which provided a chromatographic peak height 3 times greater than the average baseline reading at the same retention time. The LOQ was determined as the corresponding value of 10 times the baseline reading of the blank sample.

The range of the LOD of the instrument was 0.02- 0.06 ng $g-1$. A 30 m, 0.32 mm id., 0.25 mm film thickness, cross-linked 5% Phenylmethylsiloxane, HP-5MS capillary column (AgilentTech.) was used for the separation of the OCPs. The instrument was calibrated using analytical quality certified standards (AccuStandards Inc, USA) in comprising 18 congeners.

2.20. Precision and repeatability

For the assessment of precision of the proposed method, repeatability (intra-day assay precision) and intermediate precision (inter-day assay precision) were determined. The intra-day and inter-day precision were determined by repeating the analysis of fve fortifed fsh samples on the same day and 5 consecutive days, respectively. The average percentage of recovery for each compound and the relative standard deviation (RSD) were calculated.

The accuracy of the analytical method was determined using the calculation of average percentages recoveries for OCPs and the RSD% of recoveries from blank samples of fsh. The average percentages of recoveries and the RSD% of recoveries at 0.1 µg/kg level of OCPs standards ranged from 93.1 ± 1.3 to 100.1 ± 3.5%, 92.2 ± 3.2 to 100.2 ± 3.4%, and 91.1 ± 3.2 to 100.3 ± 2.3% from liver, intestine, and parasite samples, respectively. At 1 µg/kg level of the reference material, the recovery percentages ranged from 92.3 ± 2.2 to 98.3 ± 4.1%, 94.1 ± 3.2 to 99.3 ± 3.2%, and 90.2 ± 6.1 to 99.1 ± 5.2% from liver, intestine, and parasite samples, respectively. The readings of the OCP congeners in the fish and parasite samples were corrected according to the obtained recovery. Readings showed that procedure adopted was accurate and met the acceptable criteria of ICH (PAM, Pesticide Analytical Manual 2005) where recoveries were from 70 to 120% and RSD% values were below 20%.

2.21. Sanitization and sterilization

All the solvents and standards used were pure analytical grade, such as organochlorine pesticide standards (EPA Method 508 Chlorinated Pesticide Mix 1, 1000 μg/mL), internal standards (Accustandard, Pentachloronitrobenzene, 1.0 mg/mL) and surrogate standards (2, 4, 5, 6 Tetrachloromxylene, 10 mg/μL and Decachlorobiphenyl, 0.5 mg/mL). The materials used for the extraction were cleaned. The sodium sulfate, Florisil was precleaned with hexane and acetone solvents by passing through a glass column, and then they were conditioned in an oven at 400 ˚C for 4 h. Glassware was pre-cleaned with hexane and acetone, then conditioned overnight in an oven at 200 ˚C. All of the glassware used was cleaned with Alconox detergent (Supelco) in hot deionized water and left to dry in an oven after rinsing with hexane and acetone at 100 ˚C.

2.22. Statistical analysis

The descriptive statistics (Mean±SE) of parameters obtained from the liver and intestine of 16 uninfected and 49 infected fish and their parasites were statistically analyzed as a completely randomized design (CRD) and subjected to analysis of variance (ANOVA) at a signifcance level of $p \leq 0.05$ using Graphpad Prism (version 8.2). After testing the significant differences among the grouped variables, Tukey posthoc test was adopted to ascertain the locations of the significant differences. Statistical correlation among the tested variables was determined at > 0.5.

Table 1
Morphometrics of *Heterotis niloticus* in Lekki Lagoon.

Morphometrics	Minimum	Maximum	Mean±SE	SD
Male TL (cm)	35.00	88.90	62.08±1.59	12.20
Male SL (cm)	38.00	89.00	58.73±1.59	12.22
Male Parasite Load	0.00	44.00	6.17	2.40
Female TL (cm)	50.00	85.50	67.42±4.91	12.03
Female SL (cm)	55.00	78.00	70.47±3.64	8.93
Female Parasite Load	6.00	21.00	12.33	5.20

TL= total length, SL= standard length.

3. Results

3.1. Fish morphometrics and parasite prevalence

The total length of *H. niloticus* ranged from 35.00 - 88.9 cm with a mean value of 62.57±1.51 cm, and the standard length ranged 38.00-89.00 cm with an average length of 58.73±1.54 cm.

Going by the standard length, the male fish (58.73±1.59 cm) were shorter than the females (70.47±3.64 cm), with proportional parasite loads of 6.17 and 12.33, respectively (Table 1).

The parasite's prevalence, *Tenuisentis niloticus* in *H. niloticus* based on sex in the lagoon was 72.88% for males and 100% for females. The total number of parasites recovered from males and females was 239 and 64, respectively, while the mean intensity of infection was 5.56 and 10.67, respectively (Table 2).

Among the male fish in the length cohorts 30- 49.9 cm, the parasite load was 86, while that of cohort 50- 69.9 cm was 98. However, the lengthiest cohort of 70- 89.9 cm had a parasite load of 65. This shows irregularity and a disproportionate relationship between fish length and parasitic infections among the male *H. niloticus* (Table 3).

On the other hand, among the female counterparts, length cohort 30- 49.9 cm hosted no parasite, while cohorts 50- 69.9 cm had 23 parasites, and cohort 70- 89.9 cm had 41 total number of parasites. The relationship shows a somewhat proportionate and length-based parasitic infection among female counterparts. The irregularity observed in the male fish occurred in both sexes' combined statistics due to a higher number of males than the females (Table 3).

3.2. Bioaccumulation of organochlorine chemicals in fish and parasite

As illustrated in Table 4, the concentrations of Alpha-Lindane (α-HCH), Beta-Lindane (β-HCH), and Delta-Lindane (δ-HCH) in the intestine of the uninfected fish were significantly higher than the concentrations in the intestine of the infected fish and the liver of the infected and uninfected ($p<0.05$). The same differential bioaccumulation trend occurred in Aldrin, Heptachlor epoxide, Endosulfan I, Endrin, and Endrin aldehyde. The concentration of Endosulfan sulfate and Dieldrin in the liver and intestine of the uninfected fish was higher than the infected fish ($p<0.05$). Methoxychlor was the only OCP congener at a significantly higher concentration in the liver of the uninfected fish and the intestine of both infected and uninfected individuals.

As presented in Table 5, Alpha-Lindane (α-HCH), Beta-Lindane (β-HCH), Delta-Lindane (d-HCH), Heptachlor epoxide, and Endosulfan I was not detected in the intestine of the infected fish. However, the concentration detected in the parasite was not significantly different from the concentration detected in the intestine of the uninfected fish ($p>0.05$).

The concentrations of Endrin Aldehyde and Dieldrin in the parasites were very much significantly higher than the concentrations in the intestine of the uninfected fish, which was, in turn, significantly higher than the concentration in the infected fish ($p< 0.01$).

Conversely, the concentration of Gamma-Lindane (γ-HCH) in the infected fish was significantly higher than the concentration detected in

Table 2
Prevalence of parasite infection concerning the sex of *H. niloticus* in Lekki Lagoon.

Sex	Number Examined	Number Infected	% Prevalence	Number of Parasites	Mean Intensity
Male	59	43	72.88	239	5.56
Female	6	6	100	64	10.67
Total	65	49	75.4	303	6.18

Table 3
Length-based prevalence of intestinal parasites *Tenuisentis niloticus* of *H. niloticus* in Lekki lagoon.

Standard length (cm)	Number Examined	Number Infected	% Prevalence	Parasite Load	Mean Intensity
Male					
30.0–49.9	15	11	73.33	86	7.82
50.0–69.9	34	22	64.70	98	4.45
70.0–89.9	14	13	92.85	65	5.00
Female					
30.0–49.9	0	0	0.00	0	0.00
50.0–69.9	2	2	100	23	11.50
70.0–89.9	4	4	100	41	10.25
Combined Sex					
30.0–49.9	15	11	73.33	86	7.82
50.0–69.9	36	24	66.67	121	5.04
70.0–89.9	28	17	60.71	106	6.73

Table 4
Comparative concentration of OCP congeners (μg/kg) in the liver and intestine of *H. niloticus*.

Congeners (μg/kg)	LIVER		INTESTINE		
	Infected	Uninfected	Infected	Uninfected	95% CI of diff.
Alpha.-Lindane (α-HCH)	0.001±0.00^{b}	0.014±0.01^{b}	0.000±0.00^{b}	0.042±0.001^{a}	−0.2837 to 0.2554
Beta.-Lindane (β-HCH)	0.002±0.00 ^{b}	0.007±0.01^{b}	0.003±0.001^{b}	0.052±0.001^{a}	−0.2762 to 0.2629
Gamma-Lindane (γ-HCH)	0.000±0.00^{b}	0.003±0.001^{a}	0.001±0.00 ^{a}	0.000±0.00^{b}	−0.2720 to 0.2670
Delta.-Lindane (δ-HCH)	0.001±0.00^{b}	0.003±0.001^{b}	0.001±0.00^{b}	0.078±0.001^{a}	−0.2722 to 0.2669
Heptachlor	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2695 to 0.2695
Aldrin	0.000±0.00^{b}	0.000±0.00 ^{b}	0.000±0.00^{b}	0.534±0.01^{a}	0.2641 to 0.8031
Heptachlor epoxide (Isomer B)	0.001±0.00^{b}	0.005±0.001^{b}	0.003±0.001^{b}	0.035±0.01^{a}	−0.2748 to 0.2643
Endosulfan I	0.001±0.00^{b}	0.002±0.001^{b}	0.001±0.00^{b}	0.084±0.01 ^{a}	−0.2720 to 0.2671
p,p'-DDE (4,4′-DDE)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2695 to 0.2695
Endrin	0.000±0.00^{b}	0.009±0.001^{b}	0.002±0.001^{b}	0.065±0.01^{a}	−0.2141 to 0.3250
Endosulfan II (.beta.-Endosulfan)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2695 to 0.2695
p,p'-DDT (4,4′-DDT)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2695 to 0.2695
Endrin aldehyde	0.000±0.00^{b}	0.000±0.00 ^{b}	0.000±0.00 ^{b}	0.002±0.001^{a}	−0.2675 to 0.2715
Endosulfan sulfate	0.002±0.001^{b}	0.024±0.001^{a}	0.001±0.00^{b}	0.032±0.001^{a}	−0.2834 to 0.2557
p,p'-DDD	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2695 to 0.2695
Dieldrin	0.001±0.00^{b}	0.026±0.01^{a}	0.001±0.00 ^{b}	0.033±0.01^{a}	−0.2632 to 0.2758
Endrin Ketone	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	−0.2699 to 0.2692
Methoxychlor	0.000±0.00 ^{b}	0.042±0.001^{a}	0.000±0.00^{b}	0.000±0.00^{b}	−0.2695 to 0.2695

Values with same superscript are not significantly are not significantly different ($p>0.05$), while those with different superscripts are significantly different ($p<0.05$). p,p'-DDE= p,p$^{'}$- dichlorodiphenyldichloroethylene, p,p'-DDT= p,p$^{'}$- dichlorodiphenyltrichloroethane, p,p'-DDD= p,p$^{'}$- dichlorodiphenyldichloroethane.

Table 5
Deterministic depurative capacity of *Tenuisentis niloticus* on OCP congeners (μg/kg) in the intestine of *Heterotis niloticus*.

Congeners (μg/kg)	Infected	Parasite	CIP	Uninfected	P-value
Alpha-Lindane (α-HCH)	0.000±0.00 ^{b}	0.040±0.001^{a} 0.040± 0.001^{a}	0.042±0.001^{a}	<0.05	
Beta-Lindane (β-HCH)	0.003±0.001^{b}	0.049±0.001 ^{a}	0.049±0.001 ^{a}	0.052±0.001^{a}	<0.05
Gamma-Lindane (γ-HCH)	0.001±0.00^{a}	0.000±0.00^{b}	0.001±0.00^{a}	0.000±0.000^{b}	>0.05
Delta-Lindane (δ-HCH)	0.001±0.00^{b}	0.070±0.001 ^{a}	0.071±0.001 ^{a}	0.078±0.001^{a}	<0.05
Heptachlor	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.00	>0.05
Aldrin	0.000±0.00 ^{b}	0.502±0.01 ^{a}	0.502±0.01 ^{a}	0.534±0.01^{a}	<0.05
Heptachlor epoxide (Isomer B)	0.003±0.001^{b}	0.032±0.01^{a}	0.035±0.01^{a}	0.035±0.01^{a}	<0.05
Endosulfan I	0.001±0.00 ^{b}	0.081±0.001 ^{a}	0.082±0.001 ^{a}	0.084±0.01^{a}	<0.05
p,p'-DDE (4,4′-DDE)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	>0.05
Endrin	0.002±0.001^{b}	0.005±0.001^{b}	0.007±0.001^{b}	0.065±0.001^{a}	<0.05
Endosulfan II (.beta.-Endosulfan)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	>0.05
p,p'-DDT (4,4′-DDT)	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	>0.05
Endrin Aldehyde	0.000±0.00 ^{c}	0.240±0.00 ^{a}	0.240±0.00 ^{a}	0.002±0.001^{b}	<0.01
Endosulfan sulfate	0.001±0.00 ^{b}	0.001±0.00 ^{b}	0.002±0.00 ^{b}	0.032±0.001^{a}	<0.05
p,p'-DDD	0.000±0.00	0.000±0.000	0.000±0.00	0.000±0.000	>0.05
Dieldrin	0.001±0.00^{c}	0.120±0.00 ^{a}	0.121±0.00^{a}	0.033±0.01^{b}	<0.01
Endrin Ketone	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	>0.05
Methoxychlor	0.000±0.00	0.000±0.00	0.000±0.00	0.000±0.000	>0.05

CIP= cumulative concentration of OCPs in the infected fish and the parasite. Numbers with the same superscript are not significantly different, while those with different superscripts are significantly different at the probability of 0.05 and 0.01 for much difference. p,p'-DDE= p,p$^{'}$- dichlorodiphenyldichloroethylene, p,p'-DDT= p,p$^{'}$- dichlorodiphenyltrichloroethane, p,p'-DDD= p,p$^{'}$- dichlorodiphenyldichloroethane.

Table 6
Comparative study of biochemical indicator in the intestine of infected and uninfected *H. niloticus*.

Parameters	Uninfected fish	Infected fish
SOD min/mg pro	161.05 (126.64–225.59)*	158.89 (119.11–210.33)
MDA (nmol/mL)	21.85 (16.42–28.00)*	18.00 (14.40–24.23)
CAT (min/ mg prot.)	1.68 (1.10–2.55)	2.28 (1.60–2.95)
GSH (nmol/mL)	9.81 (8.37–10.62)	9.68 (8.90–10.12)
GPx (nmol/mL)	26.81 (19.89–36.74)	25.19 (22.73–32.19)
Protein (g/l)	9.22(8.11–11.79)	8.55(7.96–9.16)
Cholesterol (g/kg)	2.22(1.45–2.84)*	1.52(0.96–2.36)
Triglycerides (g/kg)	0.93(0.68–1.37)	0.69(0.57–0.87)
High Density Lipids (g/kg)	0.54(0.46–0.84)	0.59(0.53–0.72)
Low Density Lipids (g/kg)	1.25(0.57–1.74)	1.63(0.12–1.25)
Glucose (g/kg)	0.52(0.29–0.96)	0.51(0.25–0.86)

Asterisked numbers are significantly higher ($p<0.05$). SOD= superoxide dismutase, MDA= malondialdehyde, CAT= catalase, GSH= glutathione, GPx= glutathione peroxidase.

the uninfected fish and the parasites in which the chemical was not detected ($p< 0.05$).

3.3. Comparative biochemical markers in infected and uninfected fish

There were significantly higher ($p<0.05$) concentrations of SOD and MDA in the uninfected fish than the infected (Table 6). The concentrations of cholesterol in uninfected fish were also higher than those in infected fish ($p<0.05$). No significant difference occurred among the other biochemical tested among the fish groups ($p>0.05$). Although statistically insignificant, higher levels of CAT and high-density lipids (HDL) were however observed in the infected fish.

Aldrin correlated positively with lipid peroxidation (MDA), meanwhile, the relationship with other biochemical markers was insignificant. Endrin exhibited a strong positive correlation of 0.763 with Deildrin, which negatively correlated (−0.537) with CAT and a strong negative correlation (−0.748) with GSH. Strong negative correlations also occurred between the protein in the fish and SOD (−0.788), CAT (−0.789), and a markedly high one with GPx (−0.939). Protein however, had a strong positive relationship with MDA (0.722).

Strong positive correlations were observed between SOD and CAT (0.747); and GPx (0.831), while a significant negative correlation was observed with MDA (−0.574).

3.4. Comparative microbial load of infected and uninfected fish

In terms of comparative analysis of microbial load between the infected and uninfected fish groups (Table 8), results showed that Staphylococcus and Salmonella were 3 and 1 on the skin, while the intestinal occurrences were 2 and 1 for infected and uninfected fishes respectively. Likewise, the Enterococcus, Bacillus, and Micrococcus distributions on the skin and in the gut of the infected fish were higher than the uninfected. The widest difference occurred among Klebsiella where 3 and 0 individual microbes were observed on the skin of the infected and uninfected fish, which resulted in 13.6 and 0% occurrences, respectively, although no disparity occurred in the guts.

The plasmid bands of the isolated bacteria were profiled and cured (Fig. 2). Four out of the five isolated bacteria were plasmid-encoded, except the 5th bacteria exhibited to plasmid coding before curing. After the plasmids were cured for the bacteria in the nutrient broth for a period of 72 h of incubation at 37 °C, the protein bands were no longer found in the samples 1, 2, and 3, while sample 4 showed a slight appearance of the protein band, indicating the partial impact of the curing. In sample five (5) there was no protein band detected before and after the curing.

Before curing, 10 *Staphylococcus* sp. Furthermore, 12 *Micrococcus* sp. were resistant to Ceftazidime (Table 9). Again, 12 *Staphylococcus* sp., 19 *E. coli*, 19 *Salmonella* sp., 22 *Klebsiella* sp., and 18 *Proteus* sp. exhibited resistance to Cefriazxone. Eighteen (18) individuals of *Salmonella,* and 16 of *Klebsiella* were resistant to Ofloxaxin, while 19 individuals of *Salmonella* sp. and 19 *Klebsiella* sp. exhibited resistance to Ciprofloxacin. The remaining microorganisms were either susceptible or intermediate to the antibiotics. However, after curing, all the bacteria species became susceptible to all the antibiotics. No intermediate or resistant strains were found in any case.

4. Discussion

The sex ratio in the fish population sampled was deviant from what is expected in a natural habitat. The unexpected sex ratio of males outnumbering the female fish may not be a true representation of the sex ratio in the habitat (B. Akinsanya et al., 2020). This is attributable to the fishing techniques adopted by the local fish hunters from whom the fish specimens were procured. The use of small mesh fishing nets may have also caused non-selective fishing, which may impact the population negatively through the removal of the bigger and possibly more resilient individuals in the fish population, thereby rendering the gene pool susceptible to environmental stressors such as pollution, infections, and anthropogenic activities along the shores (Amaeze, 2009; Amare et al., 2014).

The high prevalence of the Acanthocephalan, *Tenuisentis niloticus* in *Heterotis niloticus*- 72.88% in males and 100% in females, was length-dependent, hence the lengthier females harbored more parasites than the males. It is expected that larger fishes would consume more food and maybe more exposed to infections during prolonged foraging. Lengthier fish may also present a larger surface area to accommodate more parasites. The higher parasitic prevalence in the larger and older fish may be due to changes in their diet from weeds, seeds, and plankton to insect larvae, crustaceans, and worms which are more liable to parasitic infections (Olofintoye, 2006; Akinsanya and Kuton, 2016). The current result is at variance with the findings of Oniye et al. (Oniye et al., 2004), who reported more prevalence of infection in the male fish. The Authors linked their observations to the aggressiveness and erratic movements in the male than the female fish, which predisposes the former to higher infection chances than the latter.

The parasites detected in the sampled fish amounted to 303, and this high prevalence of intestinal helminth could be attributed to perturbations at the lagoon which are functions of improper waste disposal along the coastline of the lagoon and the use of agrochemicals within the catchement area. Results showed that of the 18 OCP congeners tested in *H. niloticus,* 6 were undetected and 10 were of higher concentrations in the intestine than the liver. Alpha-lindane (α-HCH), beta-lindane (β-HCH), delta-lindane (δ-HCH), aldrin, heptachlor, epoxide, endosulfan I, endrin, endrin aldehyde, endosulfan sulfate, and dieldrin were higher in the intestine than the concentrations detected in the liver. Only gamma-lindane (γ-HCH) and methoxychlor were higher in the liver than the intestine of the fish. Although bioaccumulation of OCPs may be influenced by many factors, such as lipid content for the compounds with high Kow values. At some point, some of these factors may play the dominant role, which can be deciphered in the event of consistency. In this study, majority of the OCP congeners' concentrations higher in the intestine than the liver is partly attributable to the intestine's first contact with ingested food and the presence of circular folds, villi, and microvilli, which maximize the surface area for absorption. The liver may also have demonstrated some detoxification tendencies, thereby sequestering the concentrations of the OCP congeners. The liver is the most vital organ for detoxification and storage of contaminants (Ardeshir et al., 2017), and this accounts for the negligible bioaccumulation of most congeners tested (with the exception of γ-HCH and methoxychlor) in the liver when compared to the intestine.

Many studies have established the link between bioaccumulation of toxicants in fish and multiple factors which include extrinsic factors such as the physicochemical properties of the ambiance, the cocetration of

Table 7
Correlation among selected OCPs and biochemical markers in the biological media.

	Aldrin	Endrin	Dieldrin	PRO	SOD	MDA	CAT	GSH	GPx
Aldrin	1	−0.107	0.094	0.091	−0.096	**0.645**	−0.457	−0.186	0.005
Endrin	−0.107	1	0.763*	0.421	−0.462	0.293	−0.476	−0.393	−0.450
Dieldrin	0.094	**0.763**	1	0.135	−0.323	0.325	**−0.537**	−0.748	−0.189
PRO	0.091	0.421	0.135	1	**−0.778**	**0.722**	**−0.789**	0.357	−0.939
SOD	−0.096	−0.462	−0.323	**−0.778**	1	**−0.574**	**0.747**	−0.011	0.831
MDA	**0.645**	0.293	0.325	**0.722**	**−0.574**	1	**−0.855**	−0.071	−0.581
CAT	−0.457	−0.476	**−0.537**	**−0.789**	**0.747**	**−0.855**	1	0.097	0.793
GSH	−0.186	−0.393	**−0.748**	0.357	−0.011	−0.071	0.097	1	−0.331
GPx	0.005	−0.450	−0.189	**−0.939**	**0.831**	**−0.581**	**0.793**	−0.331	1

SOD= superoxide dismutase, MDA= malondialdehyde, CAT= catalase, GSH= glutathione, GPx= glutathione peroxidase, PRO= protein.

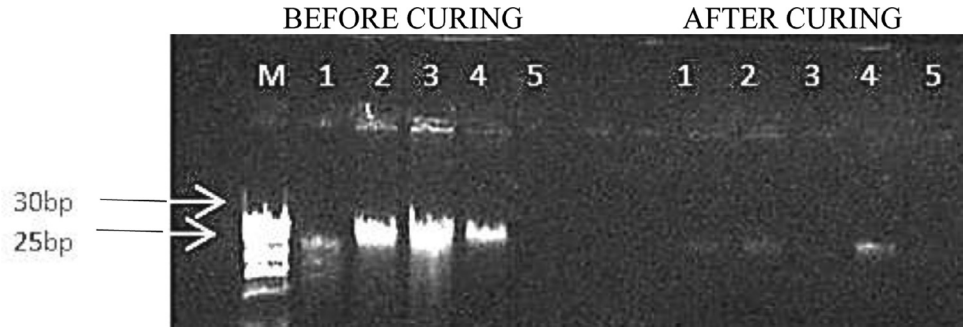

Fig. 2. Plasmid encoding of the bacteria present in samples
Keys: 1- *Bacillus* sp., 2- *Salmonella* sp., 3- *E. coli*, 4- *Proteus* sp., 5- *Micrococcus* sp.

Table 8
Microbial occurrence and percentage on the skin and gut of infected and uninfected *Heterotis niloticus* .

Microorganism	Skin		Gut	
	Infected	Uninfected	Infected	Uninfected
Staphylococcus	3 (13.6%)	1 (11.1%)	2 (12.5%)	1 (14.3%)
Proteus	2 (9.1%)	0 (0.0%)	2 (12.5%)	1 (14.3%)
Enterococcus	4 (18.2%)	2 (22.2%)	3 (18.8%)	1 (14.3%)
Bacillus	3 (13.6%)	2 (22.2%)	2 (12.5%)	0 (0.0%)
Micrococcus	2 (9.1%)	1 (11.1%)	2 (12.5%)	1 (14.3%)
Salmonella	3 (13.6%)	1 (11.1%)	2 (12.5%)	1 (14.3%)
Pseudomonas	2 (9.1%)	2 (22.2%)	1 (6.3%)	0 (0.0%)
Klebsiella	3 (13.6%)	0 (%)	2 (12.5%)	2 (28.5%)
Total	22 (100%)	9 (100%)	16 (100%)	7 (100%)

the toxicant, proximity to the source of pollution and the duration of exposure (P.O. Isibor et al., 2020). The intrinsic factors include the fish sex, age, size, and feeding habits; route of toxicant uptake, and the genetic makeup of the individual and species-specificity (Akan et al., 2012; Isibor and Imoobe, 2017). Having compared bioaccumulation of various OCP congeners in this study on the bases of tissue, size, sex and infection status, comparison of *H. niloticus* with other species may shed some light on the role of species specificity in the bioaccumulation of the chemicals.

In this study, aldrin had the highest mean concentration (0.53 µg/kg) among the OCP congeners. This concentration was less than 1.01 µg/kg reported in *Tilapia guineensis* by Akinsanya et al. (Akinsanya et al., 2015) and even far less than 53.9 µg/kg reported in *Anguilla anguilla* by Ribeiro et al. (Ribeiro et al., 2005). Conversely, Akinsanya *e t al.* (B. Akinsanya et al., 2019) observed a far lower concentration of aldrin (0.003 µg/kg) in *Chrysichthyes nigrodigitatus*. The wide variability in aldrin concentration in the various fish species may be linked to their feeding habits. Solomon et al. (Solomon et al., 2017) pointed out that aside filter feeding, *H. niloticus* grazes on benthic community species hence copius amount of mud which is repository to the lipophilic chemicals is ingested in the gut. This explains why *H. niloticus* could accumulate higher amount of organochlorine pesticides than *Tilapia guineensis* and *Anguilla* which are demersal species with terminal mouthparts with which they feed in the open water. Furthermore, *Chrysichthyes nigrodigitatus* is predominantly a benthopelargic bottom feeder, accumulating settled toxicants through dermal absorption and oral ingestion, thus expected to rank higher than *H. niloticus* in bioaccumulation.

The presence of the enteric parasites *T. niloticus* partly explains the lower concentration of the tested OCP congeners in the infected fish than the uninfected counterparts, as evidenced by the distribution of α-HCH, β-HCH, δ-HCH, aldrin, heptachlor epoxide, endosulfan I, endrin, endrin aldehyde, endosulfan sulfate, and dieldrin. The concentrations of

Table 9
Antibiotic susceptibility before curing.

ISOLATES	CAZ	CRX	GEN	CXM	OFL	AUG	NIT	CPR	ERY
Staphylococcus sp.	10 R	12 R	19 S	23 S	19 S	25 S	23 S	25 S	22 I
Bacillus sp	15 S	21 S	24 S	18 I	23 S	21 S	22 S	24 S	17 I
Pseudomonas sp.	17 S	21 S	20 S	18 I	20 S	25 S	24 S	18 S	24 S
E. coli	20 S	19 R	18 S	23 I	21 I	20 S	24 S	25 I	19 I
Micrococcus sp.	21R	23 S	19 S	24 S	18 S	23 S	20 S	19 I	21 I
Salmonella sp	20 S	19 R	26 S	23 S	18 R	25 S	17 S	19 R	18 I
Klebsiella sp.	25 S	22 R	17 S	24 S	16 R	20 S	26 S	19 R	20 I
Proteus sp.	19 S	18 R	24 S	20 S	25 I	19 S	20 S	24 I	16 I

Key: CAZ- Ceftazidime CRX- Cefriazxone CXM- Cefuroxime GEN- Gentamicine OFL- Ofloxaxin AUG- Augmentin NIT- Nitrofurantin CPR- Ciprofloxacin ERY- Erythromycin NA- Nutrient Agar MCA- MacDonkey Agar EMB- Eosin Methylene Blue SDA-Sabourand Dextrose Agar R-Resistant I- Intermediate S- Susceptible.

Table 10
Antibiotic susceptibility after curing.

ISOLATES	CAZ	CRX	GEN	CXM	OFL	AUG	NIT	CPR	ERY
Staphylococcus sp.	14 S	17 R	24 S	26 S	22 S	25 S	26 S	25 S	25 S
Bacillus sp	19 S	25 S	27 S	22 S	26 S	25 S	25 S	26 S	27 S
Pseudomonas sp.	19 S	23 S	24 S	26 S	25 S	27 S	28 S	26 S	25 S
E. coli	20 S	24 S	25 S	26 S	25 S	24 S	26 S	25 S	26 S
Micrococcus sp.	25 S	23 S	22 S	25 S	26 S	27 S	25 S	26 S	23 S
Salmonella sp	22 S	24 S	26 S	25 S	24 S	26 S	25 S	24 S	26S
Klebsiella sp.	27 S	25 S	26 S	25 S	26 S	25 S	26 S	27 S	26 S
Proteus sp.	26 S	27 S	24 S	25 S	26 S	27 S	25 S	26 S	27 S

Key: CAZ- Ceftazidime CRX- Cefriazxone CXM- Cefuroxime GEN- Gentamicine OFL- Ofloxaxin AUG- Augmentin NIT- Nitrofurantin CPR- Ciprofloxacin ERY- Erythromycin NA- Nutrient Agar MCA- MacDonkey Agar EMB- Eosin Methylene Blue SDA-Sabourand Dextrose Agar R-Resistant I- Intermediate S- Susceptible.

γ-HCH , and methoxychlor were significantly higher in the liver of the uninfected fish than the infected counterparts; α-HCH, β-HCH, aldrin, heptachlor epoxide, endosulfan I, endrin, endrin aldehyde, and dieldrin-lindane were significantly higher in the intestine of the uninfected fish than the infected counterparts, while endosulfan sulfate and dieldrin were significantly higher in both the liver and intestine of the uninfected fish than the infected counterparts.

It is important to note that in the uninfected fish liver where γ-HCH was poorly detoxified, the concentration was higher than the infected. The inefficient detoxification exhibited by the liver of the uninfected fish must have been effectively complimented by the parasitic sequestration of aldrin characterized by the absence of aldrin in the infected counterparts.

Furthermore, the absence of α-HCH, β-HCH, D-HCH, heptachlor epoxide, and endosulfan I in the infected fish, coupled with the insignificant differences in the parasite compared to the uninfected fish further suggests that the parasite may have notably depurated the chemicals except gamma-lindane. Previous studies have demonstrated the biosequestration potentials of enteric parasites in different fish species. Akinsanya *et al.*, (B. Akinsanya et al., 2019) observed that enteric parasites played a significant role in the sequestration of polycyclic aromatic hydrocarbons in silver catfish, *Chrysichthys nigrodigitatus*. Akinsanya et al. (B. Akinsanya et al., 2019; B. Akinsanya et al., 2019) also observed that *Wenyonia acuminata* exhibited marked bioaccumulation affinities for 4,4-DDT, endosulfan 1, aldrin, and heptachlor, irrespective of their concentrations in the water and intestine of *Synodontis clarias* compared to the affinity for BTEX, which was quite negligible.

A comparative analysis of the accumulated OCP congeners is essential in understanding the dynamics of the congeners and the interferences of the endoparasites on the toxicity impacts on the host fish. The phenomenon adopted in this study is based on the hypothesis that a correlation is expected between the sum of a given congener in the infected host and its parasite when compared with the uninfected host. This rationale is based on the simplistic expectation that the uninfected fish bears the burden concentration alone, while the infected counterpart shares the burden with its parasite. Results therefore showed that in the cases of α-HCH, β-HCH, δ-HCH, aldrin, heptachlor epoxide, and endosulfan I the sum of the concentration of each congener in the infected host and the parasite (CIP) was not significantly different from the concentration in the parasite and the uninfected host; which were all significantly higher than the concentrations in the infected host ($p<0.05$). This implies that the expected concentration of each congener as obtained in the uninfected fish was singly met by the parasite. This buttresses the indication that the parasite may have been instrumental to the sequestration of the OCP burden in the host fish. Other studies have also established that the affinity of enteric parasites for most organic chemicals is irrespective of their host's toxicant bureden. Akinsanya et al. (B. Akinsanya et al., 2020) found a consistent affinity for polychlorinated biphenyls in parasitic helminths in a comparative study between *Synodontis filamentosus* and *Tilapia zillii* of Epe Lagoon, Lagos, Nigeria. The observation of the current study, therefore, conforms to previous studies. However, the significantly higher SOD levels, cholesterol, and low density lipids (LDL) in the infected fish than the uninfected are attributable to the parasites' stress impacts on the host fish. The parasite may likely have benefitted the host through its depurative service, while on the other hand inflicting stress through physiological interactions with the host. Conversely, Molbert et al. (Molbert et al., 2020) reported lower oxidative damage in infected chub than uninfected fish, irrespective of their pollutant load. In light of this, they concluded that acanthocephalan parasites could bring benefits to their hosts to cope with organic pollution (Adite et al., 2005; B. Akinsanya et al., 2019; B. Akinsanya et al., 2020; Lans-Ceballos et al., 2018).

In this study, the acanthocephalan parasite, *Tenuisentis niloticus* accumulated some congeners of organochlorine pesticides even higher than the host fish. This finding is similar to that of Akinsanya et al. (B. Akinsanya et al., 2019), who reported that the parasite of *Synodontis clarias; Wenyonia acuminata* had a higher affinity for the OCPs than the host fish. These findings imply that bioaccumulation of OCPs in the parasites does not depend on the bioaccumulation in the host. Fats, lipids, and oil-related substances may foster the accumulation of lipophilic chemicals like OCPs (B. Akinsanya et al., 2019; Isibor and Imoobe, 2017). Therefore, the insignificant differences in the concentrations of cholesterol, triglycerides; and the high and low-density lipids between the uninfected and the infected fish, accompanied by higher concentrations of OCPs in the former than the latter, lend credence to the depurative capability of the parasite, *T. niloticus*. The higher levels of SOD and MDA in the uninfected fish than the infected counterparts further supports this inference. Oxidative damage may have occurred due to no equilibrium between the reactive oxygen species (ROS) generated due to the contaminants' bioaccumulation and the antioxidant defense response. The up-regulation of SOD is strongly linked to oxidative stress (B. Akinsanya et al., 2019), as it is one of the foremost responsive antioxidants in the event of exposure of organisms to stressors. The antioxidant defense system releases SOD to mop-up the oxyradicals (Nabi et al., 2017; Vijayavel et al., 2004) by fostering superoxides' dismutation to H_2O_2, which are destructive to biological membranes.

Furthermore, the significantly higher MDA detected in the uninfected fish implies marked lipid peroxidation. This may be possibly due to the overwhelmed antioxidant enzymes, hence enhanced ROS formation, which might have inflicted injury on the cell membranes, thereby culminating in cellular dysfunction (Nabi et al., 2017). SOD is the first enzyme to deal with oxyradicals (Nabi et al., 2017; Vijayavel et al., 2004) by accelerating superoxide's dismutation (O_2) to H_2O_2, damaging the membrane and biological structures. Reduced glutathione (GSH) is considered one of the essential antioxidant agents involved in protecting cell membranes from lipid peroxidation by scavenging oxygen radicals (yielding glutathione disulfide, GSSG). Moreover, glutathione is the cofactor of many enzymes catalyzing the detoxification and excretion of several toxic compounds. Low GSH concentrations (9.81, 9.68) or activities observed in the liver tissues suggest the toxicity encountered by the fish from the site due to bioaccumulation and organic pollution, which was corroborated by similar findings on GSH levels from Vijayavel et al.

(Vijayavel et al., 2004) and Suhel et al. (Suhel et al., 2006). They worked on *Scylla serrata* and *Wallago attu,* respectively. The effects of oxidative stress may result in immunosuppression in the host fish, thereby rendering them susceptible to parasitic infections (Davies, 1995; Alimba et al., 2015).

The fish's microbial analysis showed the bacteria genera *Staphylococcus, Enterococcus, Bacillus, Pseudomonas, Salmonella, Klebsiella, Escherichia*, and *Proteus,* particularly in the infected fish. Similar bacteria have been reported by other authors (Abolagba and Melle, 2008; Adedeji et al., 2012; Olojo et al., 2010). Some of these bacteria genera are opportunistic pathogens that have been implicated in foodborne infections and are known to harbor plasmid-mediated antibiotic-resistant genes (World Health Organization 2014).

Adequate heating before consumption may help eliminate these pathogens and deactivate their toxins. Fungal species isolated, such as *Aspergillus niger* and *Rhizopus* species, can copiously produce mycotoxins in dangerous foods when consumed by humans (Roberts, 2012). Plasmids are extrachromosomal DNA that confers additional characteristics such as antibiotic resistance on organisms and are capable of autonomous replication (Kane et al., 2015). Before plasmid extraction, some of the organisms showed resistance to some antibiotics used, which could be due to the unregulated disposal of antibiotics in the catchment area (Roberts, 2012; Kaur et al., 2008). However, the microorganisms' susceptibility to the antibiotics after curing suggests that the antibiotics resistant genes were not innate, but rather plasmid-borne.

Recommendations and conclusion

Parasite-host interaction may be favourable from the viewpoint of sequestration of bioaccumulated toxicant in the host. In line with the expectations that stemmed from the stated hypothesis, the study has demonstrated the novelty of *Tenuisentis niloticus* in attenuating mainly endosulfan sulfate and dieldrin burden in *H. niloticus* in Lekki lagoon. The protective role of the parasites on its host found expression in ameliorating the oxidatives stress which may have been inflicted on the fish by the OCP toxicity, although at high parasitic prevalence. It is therefore pertinent to ascertain the parasicitc impact on the fish at the current level of prevalence using a reliable tool such as hispathological analysis.

Results show that the lagoon must have been impacted by anthropogenic activities such as unregulated use of agrochemicals, insecticides, pesticides, etc.

Authors' contribution statement

Author **AB** designed the study, supervised the project, and proof-read the final manuscript, Author **IPO** analyzed and interpreted the data; wrote the original manuscript and proof-read the final, Author **UE** procured the materials and conducted the field and laboratory studies, Author **SJK** provided literature and proof-read the final manuscript.

Declaration of Competing Interest

Authors declare that there is no conflict of interest.

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