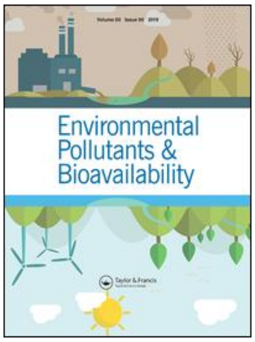

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ORIGINAL RESEARCH

Evaluating the potential health risk of organochlorine pesticides in selected protein foods from Abeokuta southwestern Nigeria

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ABSTRACT
This study evaluated the potential health risk of OCPs in selected protein foods. A total of 66 food samples were collected from selected areas in Abeokuta, southwestern Nigeria. Food samples were analyzed for OCPs using the standard method. OCP data were analysed for descriptive and inferential statistics. Health risk assessment was conducted for non-carcinogenic {Hazard Quotient (HQ), Hazard Index (HI) and Cancer Risk (CR)}. The ΣOCP concentration was observed highest in pork (42.20 ± 33.33 mg kg^{-1}) of which methoxychlor and dieldrin represented 63 and 28%, respectively. The HIs of OCPs in protein foods were generally greater than 1.0 indicating adverse effects. The ΣCR data showed carcinogenic effects in protein foods with values greater than the acceptable limit of 1.0 × 10^{-4}.

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KEYWORDS
Organochlorine pesticides; health effects; cancer; protein foods; risk assessment

1. Introduction

Organochlorine pesticides (OCPs) are persistent organic pollutants (POPs) classified as organic disruptors, because of their ability to mimic thyroid hormones when they enter the human body [1]. OCPs consist three major classes such as dichlorodiphenylethanes (dichlorodiphenyltrichloroethane DDT, dichlorodiphenyldichloroethylene DDE and dichlorodiphenyldichloroethane DDD), cyclodienes (aldrin, dieldrin, endrin, chlordane, endosulfan and heptachlor) and cyclohexane (hexachlorocyclohexane HCH). OCPs have been applied to eradicate pests and vector of diseases [2]. For example, DDT has been used to control lice (vector of typhus) and mosquitoes (vector of malaria), while endrin has been utilized as insecticide, rodenticide and avicide [2,3]. This has invariably led to increased agricultural yields and protection of public health [2]. The application of DDT for malaria reduction program was reported to save more than five million lives [4]. However, the use of OCPs has resulted to environmental pollution of air, water and soil/sediments [2].

The environmental and health concerns of OCPs can be attributed to peculiar characteristics such as persistence (slow rate of degradation) high lipophilicity, bioaccumulation in biota and potential of long range transport [5–7]. DDT is moderately hazardous having high persistence and a half-life of between 2 and 15 years [8]. DDE, which is the metabolite of DDT has also been adopted as a biomarker for DDT exposure in many epidemiological studies [9–11]. Many OCPs are carcinogenic, neurotoxic and immunotoxic [7,12]. They have also been implicated in a number of health problems such as low sperm count, birth defects, reproductive malfunctions and deformities, Parkinson's disease [13–15], endocrine disruption, and developmental disorders [16–18].

Although OCPs have been banned, but are still in use in many countries including Cote D'Ivoire, Ghana, India, Iran, Mexico, Nigeria and parts of China [7,19,20]. This might be linked to factors including effectiveness of the chemicals to control pests at relatively low cost, lack of appropriate regulatory control in management of production and use of OCPs, and laxity in environmental laws [7]. Consequently, considerable amounts of OCPs have been observed in sediments, soil, water, air, plants, animal tissues [21–24] and human samples (blood, adipose tissue and breast milk) [25]. It is, therefore, necessary to monitor and assess the risk of OCPs in environmental samples in order to protect the consumers' health. Human health risk evaluation involves the calculation of the upper limit in excess of lifetime cancer risk and non-carcinogenic hazard of a receptor [26]. This is based on the assumption that an adult might be exposed to chemical substances (e.g. metals, polycyclic aromatic hydrocarbons, OCPs) through ingestion of food. Protein

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foods (beef, cowskin, fish, crab, crayfish, goat meat, pork and snails) are important sources of vitamins and minerals recommended for good health [27,28]. Sea foods are dietary sources of ω-3 polyunsaturated fatty acids (PUFA), for which there is increasing evidence of positive effects on fetal growth and length of gestation period of infants [29]. Fish is rich in lysine suitable for supplementing high carbohydrate food [28]. Crab contains eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are important for preventing atherosclerosis, rheumatoid arthritis, dementia, Alzheimer and cardiovascular diseases [30]. There is a dearth of knowledge on the levels and associated risk of OCPs in protein foods [7,31,32]. The human health risk of OCPs in foodstuffs is yet to be reported in Abeokuta, the capital of Ogun state. It is the most populous city in the state in which the main occupation of the residents is farming. The possibility of past and present applications of OCPs for agricultural activities therefore may not be ruled out. This study seeks to bridge this research gap by evaluating the concentrations and health risk of OCPs in different protein foods from Abeokuta, southwestern Nigeria.

2. Materials and methods

2.1 Sample collection and preservation

A total of 66 protein food samples were purchased from Abeokuta in southwestern Nigeria between October and November 2019. The protein food samples were crabs, (6 samples), crayfish (12 samples), *Clarias gariepinus*, catfish (6 samples), *Tilapia zillii*, tilapia fish (12 samples), beef (6 samples), cowskin (6 samples), goat meat (6 samples), pork (6 samples) and snail (6 samples). A 0.25 kg of each foodstuff (muscle) was purchased from popular markets in Abeokuta, southwestern Nigeria. The samples were wrapped in aluminium foils (to avoid contamination) and placed inside a chest packed with ice cubes [33]. The samples were transported to the CTX-ION Analytics Ltd. Laboratory, Lagos, Nigeria for extraction and determination of OCPs.

2.2 Determination of organochlorine pesticides by GC-microECD

About 15 g tissue (muscle) samples of protein foodstuffs were macerated thoroughly with Teflon pestle homogenizer alongside 10 g anhydrous sodium sulphate [34]. A 2.0 g of each sample was weighed and transferred to a cellulose extraction thimble and placed into a Soxhlet apparatus. Each sample was then extracted with 100 mL hexane for approximately 10 hours.

Sample clean up was done using a glass column packed with 4.0 g silica gel (previously activated for 6 hours at 130 °C in a petri dish, and loosely covered with foil). Exactly 2.0 g of anhydrous sodium sulphate was added to the column after which 10 mL hexane was introduced to the top of the column to wet and rinse the sodium sulphate and silica gel. The sample extract was transferred onto the column and eluted with 20 mL hexane. The extract was collected in a beaker and concentrated down to 2 mL using a rotary evaporator. The extract was analysed for 14 OCPs (aldrin, dieldrin, endosulfan I, endosulfan II, endosulfan sulphate, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, methoxychlor, p,p'-DDD, p,p'-DDE and p,p'-DDT) using Gas Chromatograph equipped with microElectron Capture Detector (μECD) (Agilent 7890B, Santa Clara, CA, USA). The GC-μECD was fitted with a HP-5 capillary column coated with 5% Phenyl Methyl Siloxane (30 m length x 0.32 mm diameter x 0.25 μm film thickness) (Agilent Technologies). A 1.0 μL of the samples were injected in a splitless mode at an injection temperature of 300°C, a pressure of 15 PSI and a total flow of 21 mL min^{-1}. Helium was used as the carrier gas. The purge flow to split vent was set at 15 mL min^{-1} at 0.75 min. Oven was initially programmed at 100°C (1 min), ramped at 15°C/min to 120°C (0 min) and then to 230°C at 15°C min^{-1}. The μECD temperature was set at 300°C with nitrogen used as makeup gas (flow of 60 mL min^{-1}).

Quantification of OCPs involved external calibration curves prepared from the standard solution of each of the OCPs. The OCP standard, 1000 mg L^{-1}·containing 14 congeners was obtained from AccuStandard (New Haven, CT, USA).

During the laboratory analysis, the analytical procedures observed include analysis of blank samples to cancel the matrix effects of extracting reagents and to calculate the limit of detection of the instrument as 3 x standard deviation [33]. All solvents used for extraction were of GC grade (Merck KGaA, Darmstadt, Germany).

2.3 Data analysis

Organochlorine pesticides data were subjected to simple descriptive (mean and standard deviation) and inferential (Duncan Multiple Range Test) statistics using SPSS for Windows (version 22.0).

Table 1. OCP levels in aquatic and terrestrial protein foods.

			mg kg^{-1} (wet weight)			
	Protein foods	N	Mean	Std. Deviation	Minimum	Maximum
Aldrin	*Clarias gariepinus*	6	<0.01a		<0.01	<0.01
	Tilapia zillii	12	<0.01a		<0.01	<0.01
	Crayfish	12	0.21a	0.72	<0.01	2.5
	Crab	6	<0.01a		<0.01	<0.01
Dieldrin	*Clarias gariepinus*	6	0.46a	0.10	0.35	0.6
	Tilapia zillii	12	1.48a	2.53	<0.01	7.61
	Crayfish	12	0.92a	1.92	<0.01	6.59
	Crab	6	1.15a	1.88	0.13	4.96
Endosulfan I	*Clarias gariepinus*	6	0.05a	0.01	0.05	0.07
	Tilapia zillii	12	0.08a	0.03	<0.01	0.13
	Crayfish	12	0.12a	0.09	<0.01	0.22
	Crab	6	0.07a	<0.01	0.05	0.09
Endosulfan II	*Clarias gariepinus*	6	0.17a	0.06	0.07	0.22
	Tilapia zillii	12	0.10a	0.13	<0.01	0.4
	Crayfish	12	0.28a	0.79	<0.01	2.77
	Crab	6	0.46a	0.77	0.06	2.03
Endosulfan Sulphate	*Clarias gariepinus*	6	1.80 c	0.30	1.45	2.26
	Tilapia zillii	12	0.21a	0.16	<0.01	0.47
	Crayfish	12	0.15a	0.14	<0.01	0.36
	Crab	6	1.01b	0.98	0.08	2.37
Endrin	*Clarias gariepinus*	6	0.02a	0.03	<0.01	0.08
	Tilapia zillii	12	0.17ab	0.28	<0.01	0.99
	Crayfish	12	0.14ab	0.17	<0.01	0.52
	Crab	6	0.06ab	0.06	<0.01	0.12
Endrin Aldehyde	*Clarias gariepinus*	6	0.11a	0.04	0.07	0.19
	Tilapia zillii	12	0.18a	0.14	0.04	0.56
	Crayfish	12	0.28a	0.57	<0.01	2.04
	Crab	6	1.16b	2.10	0.05	5.42
Endrin Ketone	*Clarias gariepinus*	6	0.80ab	1.31	0.06	3.42
	Tilapia zillii	12	0.32a	0.18	0.09	0.78
	Crayfish	12	0.39a	0.69	<0.01	2.47
	Crab	6	0.21a	0.21	<0.01	0.52
Heptachlor	*Clarias gariepinus*	6	0.06a	0.12	<0.01	0.31
	Tilapia zillii	12	0.38a	0.79	<0.01	2.31
	Crayfish	12	0.39a	0.82	<0.01	2.83
	Crab	6	0.06a	0.14	<0.01	0.34
Heptachlor Epoxide	*Clarias gariepinus*	6	<0.01a		<0.01	<0.01
	Tilapia zillii	12	0.06a	0.09	<0.01	0.29
	Crayfish	12	0.33a	0.87	<0.01	3.06
	Crab	6	0.17a	0.15	<0.01	0.41
Methoxychlor	*Clarias gariepinus*	6	<0.01a		<0.01	<0.01
	Tilapia zillii	12	0.57a	1.78	<0.01	6.2
	Crayfish	12	2.19ab	3.57	<0.01	9.35
	Crab	6	4.57ab	9.76	<0.01	24.36
p,p′-DDD	*Clarias gariepinus*	6	<0.01a	0.01	<0.01	0.02
	Tilapia zillii	12	<0.01a		<0.01	<0.01
	Crayfish	12	0.20a	0.69	<0.01	2.38
	Crab	6	0.02a	0.01	<0.01	0.03
p,p′-DDE	*Clarias gariepinus*	6	0.29a	0.21	0.14	0.70
	Tilapia zillii	12	0.06a	0.06	<0.01	0.16
	Crayfish	12	0.67a	1.29	<0.01	3.85
	Crab	6	0.48a	0.57	0.07	1.57
p,p′-DDT	*Clarias gariepinus*	6	<0.01a		<0.01	<0.01
	Tilapia zillii	12	0.06a	0.1	<0.01	0.25
	Crayfish	12	0.31a	0.7	<0.01	2.5
	Crab	6	0.14a	0.15	<0.01	0.29
Aldrin	Beef	6	<0.01a		<0.01	<0.01
	Cowskin	6	<0.01a		<0.01	<0.01
	Goat meat	6	<0.01a		<0.01	<0.01
	Pork	6	<0.01a		<0.01	<0.01
	Snail	6	<0.01a		<0.01	<0.01
Dieldrin	Beef	6	1.92b	2.4	0.22	5.12
	Cowskin	6	0.03a	0.05	<0.01	0.09
	Goat meat	6	1.10b	1.88	0.19	4.93
	Pork	6	11.69 c	14.74	<0.01	40.39
	Snail	6	0.08a	0.09	<0.01	0.18
Endosulfan I	Beef	6	0.12a	0.07	0.05	0.23
	Cowskin	6	0.08a	0.03	0.04	0.12
	Goat meat	6	0.08a	0.02	0.05	0.11
	Pork	6	0.10a	0.05	<0.01	0.13
	Snail	6	0.08a	0.08	<0.01	0.21
Endosulfan II	Beef	6	0.14a	0.08	0.05	0.25
	Cowskin	6	0.02a	0.03	<0.01	0.08
	Goat meat	6	0.19a	0.08	0.11	0.32
	Pork	6	1.19b	0.88	<0.01	2.71
	Snail	6	0.13a	0.29	<0.01	0.73

(*Continued*)

Table 1. (Continued).

	Protein foods	N	mg kg^{-1} (wet weight) Mean	Std. Deviation	Minimum	Maximum
Endosulfan Sulphate	Beef	6	0.31a	0.19	0.13	0.65
	Cowskin	6	1.40 c	0.62	0.56	2.12
	Goat meat	6	0.56ab	0.57	0.09	1.46
	Pork	6	1.14bc	1.03	<0.01	2.34
	Snail	6	0.05a	0.05	<0.01	0.12
Endrin	Beef	6	0.25 c	0.18	0.06	0.51
	Cowskin	6	0.03a	0.05	0.01	0.13
	Goat meat	6	<0.01a		<0.01	<0.01
	Pork	6	0.18b	0.26	<0.01	0.68
	Snail	6	<0.01a		<0.01	<0.01
Endrin Aldehyde	Beef	6	0.38b	0.61	0.08	1.63
	Cowskin	6	0.79b	1.11	0.07	2.96
	Goat meat	6	0.03a	0.04	<0.01	0.11
	Pork	6	0.15a	0.11	<0.01	0.33
	Snail	6	0.04a	0.05	<0.01	0.14
Endrin Ketone	Beef	6	0.58ab	1.05	0.09	2.71
	Cowskin	6	1.37b	1.89	0.12	5.01
	Goat meat	6	0.09a	0.01	0.07	0.1
	Pork	6	0.19a	0.12	<0.01	0.35
	Snail	6	0.06a	0.07	<0.01	0.18
Heptachlor	Beef	6	0.37a	0.45	<0.01	0.94
	Cowskin	6	<0.01a		<0.01	0.01
	Goat meat	6	<0.01a		<0.01	0.01
	Pork	6	0.37a	0.19	<0.01	0.49
	Snail	6	<0.01a		<0.01	0.01
Heptachlor Epoxide	Beef	6	0.23a	0.14	<0.01	0.4
	Cowskin	6	<0.01a		<0.01	0.01
	Goat meat	6	<0.01a		<0.01	0.01
	Pork	6	0.18a	0.11	<0.01	0.31
	Snail	6	0.07a	0.1	<0.01	0.2
Methoxychlor	Beef	6	5.46a	6.92	0.09	17.62
	Cowskin	6	0.03a	0.03	<0.01	0.06
	Goat meat	6	0.52a	0.9	<0.01	2.19
	Pork	6	26.38b	18.63	<0.01	56.75
	Snail	6	0.02a	0.03	<0.01	0.07
p,p′-DDD	Beef	6	0.03a	0.06	<0.01	0.15
	Cowskin	6	<0.01a		<0.01	<0.01
	Goat meat	6	0.04a	0.03	<0.01	0.09
	Pork	6	0.03a	0.03	<0.01	0.08
	Snail	6	<0.01a		<0.01	<0.01
p,p′-DDE	Beef	6	0.24a	0.13	0.05	0.41
	Cowskin	6	0.21a	0.34	<0.01	0.87
	Goat meat	6	0.08a	0.05	<0.01	0.14
	Pork	6	0.61a	0.3	<0.01	0.81
	Snail	6	0.13a	0.07	0.06	0.26
p,p′-DDT	Beef	6	0.31a	0.14	0.15	0.53
	Cowskin	6	<0.01a		<0.01	0.01
	Goat meat	6	0.09a	0.2	<0.01	0.49
	Pork	6	<0.01a		<0.01	<0.01
	Snail	6	0.09a	0.21	<0.01	0.51

Similar letters along the rows are not statistically different at p > 0.05 according to Duncan Multiple Range Test

2.4 Health risk assessment

The health risk assessment of OCPs was calculated for Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI) and Cancer Risk (CR) using the formula highlighted by USEPA [35–37].

$$ADD = \frac{CxIRxEFxED}{BWxAT} \quad (1)$$

where ADD is an average daily dose (mg kg^{-1} day^{-1}), C is the concentration of OCPs determined in protein foods (mgkg^{-1}), IR is the ingestion rate of protein foods (24.7 gday^{-1}) [38], ED is exposure duration (years) = 30 years for carcinogenic effects for adults, EF is exposure frequency (day/year) = 350 daysyear^{-1} [33], AT is averaging time or life expectancy = 54.5 years [28,39], AT is equal to ED for non-carcinogenic effects, BW is body weight (kg) = 60kg for an adult [7,28,33].

$$HQ = \frac{ADD}{RfD} HI = \sum_{i=1}^{n} HQi = 1 \ldots n \quad (2)$$

where ADD is an average daily dose (mg kg^{-1} day^{-1}), RfD is the reference dose (mg kg^{-1} day^{-1}) [35], and n is the number of observed elements.

HQ > 1 denotes adverse health effects; HQ < 1 indicates no adverse effects,

$$Cancer\ Risk = ADD\ x\ SF \quad (3)$$

where ADD is average daily dose (mg kg^{-1} day^{-1}), and SF is slope factor (mg^{-1} kg day)

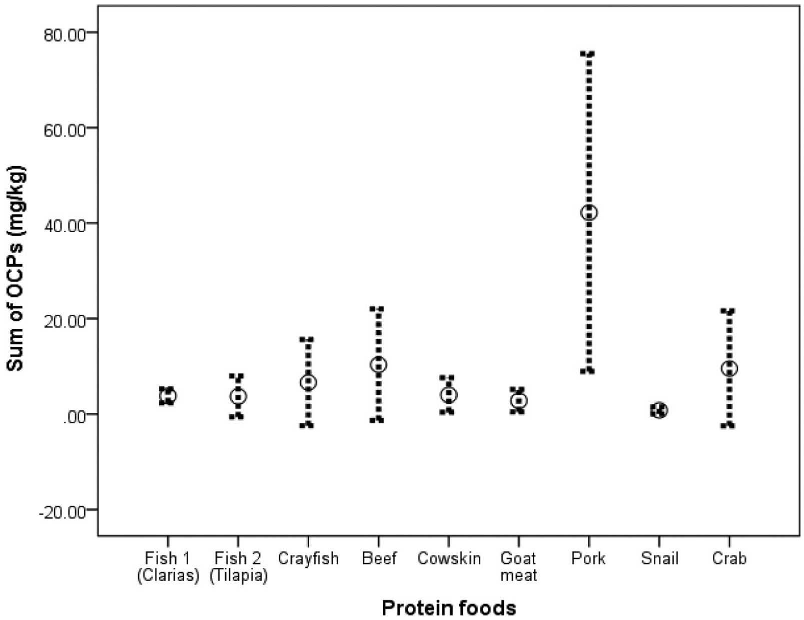

Figure 1. The sum of OCPs in protein foods.

3. Results and discussion

3.1 Concentrations of OCPs in protein foods

The fractions of individual OCP measured in protein food samples are presented in Figure S1 (in the supplementary information). Aldrin was detected only in crayfish, representing only 2% of the total number of food samples, while in terrestrial food samples, aldrin was observed below the detection limit (<0.01 mg kg^{-1}). The prominent OCPs determined in food samples were endrin ketone (89%), endosulfan I (88%), endosulfan sulphate/endrin aldehyde (82%), p,p′-DDE (79%), dieldrin (77%) and endosulfan II (70%). The present data showed that endrin, endosulfan and dieldrin are still widely used by many farmers in Africa, similar to the reports from the past studies [31,40]. These pesticides could remain in the environment for a long period of time and also possessed the potential to bioaccumulate in plants and animals [41].

Tables 1 present the levels of OCPs in aquatic and terrestrial protein foods. Methoxychlor was the highest measured OCP in both aquatic and terrestrial protein food samples. In aquatic food samples (Table 1), the highest level of methoxychlor was measured in crab (4.57 ± 9.76 mg kg^{-1}, wet weight); while for terrestrial tissues (Table 1), methoxychlor was observed highest in pork (26.38 ± 18.63 mg kg^{-1}, wet weight). The high level of methoxychlor observed in pork might be linked to high-fat content [42] and recent application of the pesticide [43]. The use of methoxychlor is seasonal and expected to be higher during the period of insect control on animals [42,43]. The concentrations of endosulfan sulphate, dieldrin and endrin aldehyde were generally greater than 1.0 mg kg^{-1} in crab. In the terrestrial protein foods, the OCPs having the average values greater than 1.0 mg kg^{-1} were dieldrin in beef, goat meat and pork, endosulfan II in pork, endosulfan sulphate and methoxychlor in cowskin and pork, and aldrin ketone in cowskin. Furthermore, dieldrin and endosulfan sulphate revealed levels higher than 1.0 mg kg^{-1} in *Tilapia zillii* and *Clarias gariepinus*. The dieldrin value in *Clarias gariepinus* (0.46 ± 0.10 mg kg^{-1}) was similar to those previous reported by Ezemonye *et al.* [44] in catfish samples (0.38 ± 1.10–0.53 ± 0.90 mg kg^{-1}) collected from three rivers in Edo State, Nigeria. The study, however, documented lower concentrations of dieldrin in *Tilapia zillii*.

There were no significant variations ($p > 0.05$) in the concentrations of most OCPs measured in aquatic protein foods. The exceptions were endosulfan sulphate whose level was statistically ($p < 0.05$) observed highest in *Clarias gariepinus* (1.8 ± 0.30 mg kg^{-1}) and endrin aldehyde (1.16 ± 2.10 mg kg^{-1}) in crab. The United States Federal Drug Agency permissible limit for heptachlor, aldrin, dieldrin, endrin, and methoxychlor in fish is 0.3 mg kg^{-1}, while for DDT, DDE, DDD and endosulfan, the value is 5 mg kg^{-1} [44]. This therefore established that the amounts of dieldrin measured in all the aquatic protein foods, endrin aldehyde in crab, endrin ketone in *Clarias gariepinus, Tilapia zillii* and crayfish, and heptachlor in *Tilapia zillii* and crayfish were higher than the

FDA [45] permissible limit of 0.3 mg kg^{-1}. The past study of Akan *et al*. [46] reported high dieldrin value of 3.1 mg kg^{-1} in fish samples from Lake Chad. Other OCP congeners in protein foods showed values lower than the FDA permissible limits indicating safe consumption. The occurrence of dieldrin in terrestrial protein foods followed similar pattern like those of aquatic protein foods, where the highest significant ($p < 0.05$) amount was observed in pork. Furthermore, the concentrations of dieldrin in beef, goat meat and pork, endosulfan II in pork, endosulfan sulphate in beef, cowskin, goat meat and pork, endrin aldehyde in beef and cowskin, and heptachlor in beef and pork were also higher than the permissible standard of 0.3 mg kg^{-1} [45].

Methoxychlor value in goat meat was slightly higher than the permissible limit of 0.3 mg kg^{-1}, while in meat and pork, the concentrations were more than 18 and 88 times higher than the acceptable limit, respectively. The OCP of major concern in the terrestrial protein foods is methoxychlor having values higher than those reported for fish in past studies [46–48]. In the review work of Taiwo [7], DDT, aldrin and dieldrin were the OCPs of health concerns in fish samples collected from different locations in Africa.

The individual contribution to ΣOCPs in protein foods is shown in Figure S2. Methoxychlor constituted 46% of the total measured OCPs followed by dieldrin (23%), and endosulfan sulphate (7%). The distribution of OCPs in food samples followed the sequence of methoxychlor > dieldrin > endosulfan sulphate > endosulfan ketone > endrin aldehyde/DDE > endosulfan II > heptachlor/heptachlor epoxide > endosulfan I/DDD/DDT/endrin > aldrin.

Figure 1 shows the ΣOCP levels in different protein food. The sequence of distribution of OCPs in protein foods follows the decreasing order of pork > beef > crab > crayfish > cowskin > *Clarias gariepinus* > Tilapia > goat meat > snail. This study established pork as the most contaminated protein food, probably due to its high fat content, which has accumulated OCPs over a period of time. Snail is the least contaminated protein food having ΣOCP concentration less than 1.0 mg kg^{-1}, and thus signifying safest consumption.

3.2 Health risk assessment of OCPs in protein foods

Tables S1a and S1b show the estimated Average Daily Dose (ADD) values of OCPs in protein foods. Methoxychlor was the most dosed OCPs showing the highest concentrations in pork, beef and crab. The ADDs of methoxychlor in these protein foods were generally higher than 1.0 µg kg^{-1} day^{-1}. In contrast, the past study of Taiwo [7] revealed ADD value of ΣDDT greater than 1.0 µg kg^{-1} day^{-1} in fish samples.

The non-carcinogenic adverse health effects of OCPs for Hazard Quotient (HQ) and Hazard Index (HI) in protein foods are presented in Tables 2. In aquatic foods (Table 2), the HQs of dieldrin, heptachlor, heptachlor epoxide (except in *Clarias gariepinus*), aldrin in crayfish, endrin ketone in *Clarias gariepinus*, and endrin aldehyde in crab were greater than the permissible limit of 1.0 indicating non-carcinogenic deleterious health effects through consumption of the protein foods. This was similar to the study of Barnhoorn *et al*. [31], which demonstrated the HQ > 1.0 for dieldrin in fish samples collected from a polluted river in South Africa. A related study by Ezemonye *et al*. [44] reported HQs >1.0 for heptachlor epoxide and aldrin in *Clarias gariepinus* and *Tilapia zillii* taken from three rivers in Edo State. The study also revealed non-carcinogenic adverse effects for dieldrin and endrin in the *Clarias gariepinus* samples.

In terrestrial protein foods (Table 2), the HQs of dieldrin in beef, goat meat and pork, methoxychlor in pork, heptachlor and heptachlor epoxide in beef and pork, endrin ketone and endrin aldehyde in cowskin, and heptachlor epoxide in snail samples were also greater than 1.0. This suggests an adverse health risk on consumption of these protein foodstuffs. A previous study has shown the HQ value greater than 1.0 for heptachlor epoxide in beef samples from Benin City, Nigeria [32].

The HI, which is the sum of HQ for each constituent of OCP in the food samples revealed values greater than 1.0 thereby indicating unsafe consumption. The highest HI value was estimated for pork, while snail and cowskin had the lowest HIs. The pattern of HI of OCPs in protein foods followed the decreasing order of pork > beef > crayfish > tilapia fish > crab > goat meat > catfish > cowskin > snail.

Figure 2 presents the contributions of OCPs to non-carcinogenic adverse health effects. Dieldrin and heptachlor contributed mostly to the total HQ. It formed about 88% to the non-carcinogenic HI in goat meat and 42% in beef. The fractions constituted by dieldrin in *Clarias gariepinus, Tilapia zillii*, crayfish and crab were 48, 44, 21 and 48%, respectively. Similarly, the study of Barnhoorn *et al*. [31] has shown dieldrin as the major contributor to non-carcinogenic effects in fish samples. Also, heptachlor and heptachlor epoxide formed a considerable fraction of adverse health effects in beef with estimated HI values of 31 and 20%,

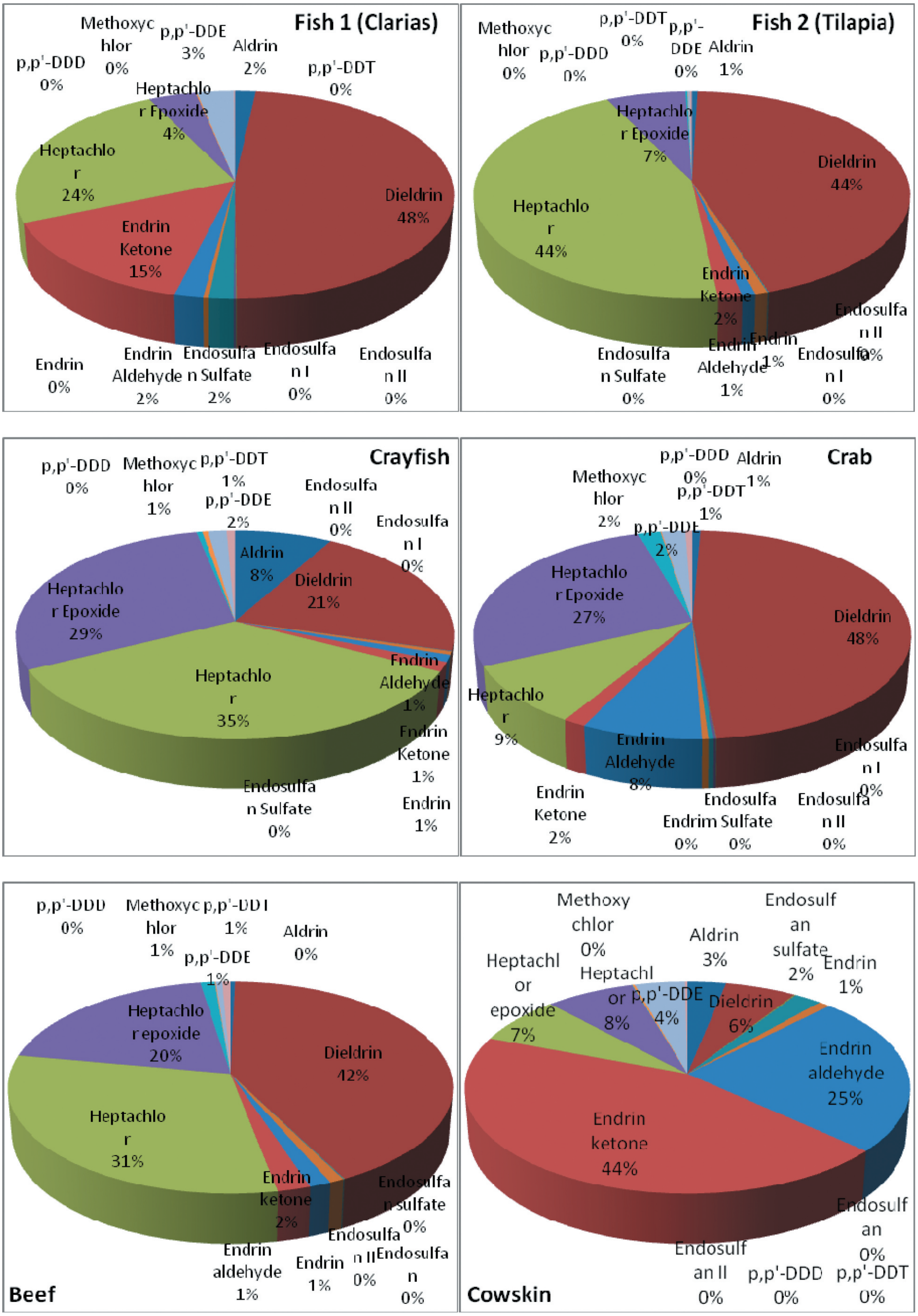

Figure 2. % Contribution to HI by OCPs in protein foods.

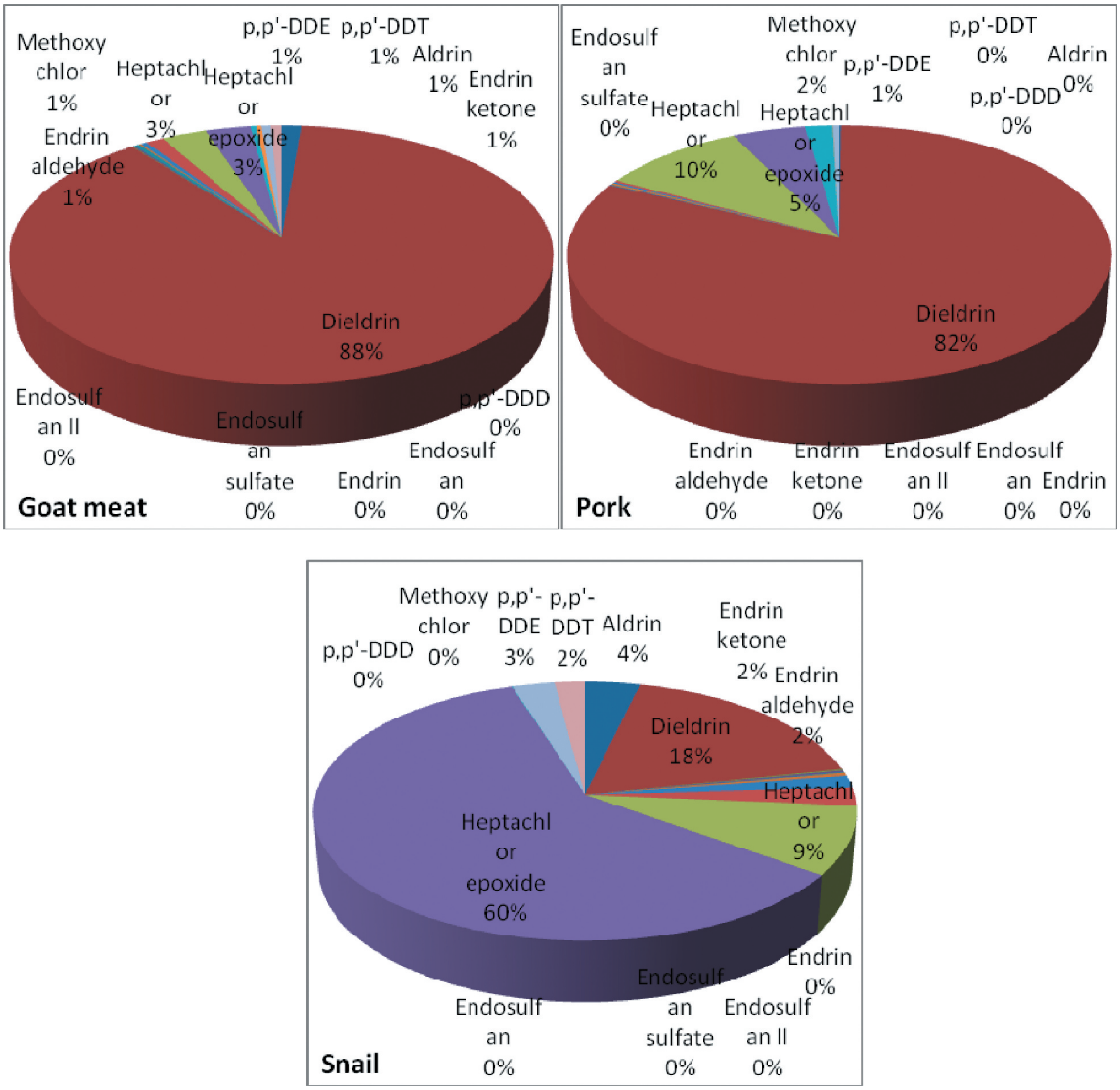

Figure 2. (Continued).

respectively. Heptachlor constituted 24, 44 and 35% of the total HQ in *Clarias gariepinus, Tilapia zillii* and crayfish, respectively.

The cancer risk data of OCPs in protein foodstuffs are shown in Tables 3. The CR values of dieldrin, heptachlor and heptachlor epoxide (except *Clarias gariepinus*) in aquatic protein foods were greater than the USEPA permissible limit of 1.0×10^{-4} [37]. The high CR of dieldrin obtained in this study was similar to the reported value by Barnhoorn *et al*. [31] in *Clarias gariepinus* collected from a polluted river in South Africa. For terrestrial protein samples, the CRs of dieldrin in pork, p,p′-DDE in beef, cowskin and pork, and p,p′-DDT in beef were also greater than the acceptable limit of 1.0×10^{-4} indicating possible development of cancer on exposure to protein foods through ingestion. The ΣCRs in protein foods ranged from 1.8×10^{-3} (*Clarias gariepinus*) to 6.1×10^{-3} (*Tilapia zillii*) for aquatic samples; and 2.0×10^{-4} (snail) to 4.2×10^{-2} (pork) for terrestrial samples. These figures suggested high risk in terms of cancer development by consumers; similar to the recent study of Taiwo [7] on health risk of OCPs in fish samples from different sampling sites in Africa. Furthermore, the CR value greater than 1.0×10^{-4} was documented by Pardío *et al*. [49] in pork samples from Veracruz, Mexico. The high CR value observed for OCPs in pork may be related to the high fat content, and slow metabolism [42].

The contributory fraction of individual OCP to total cancer burden is presented in Figure 3. Like the non-carcinogenic risk, dieldrin was the main contributor to carcinogenic effects in both aquatic

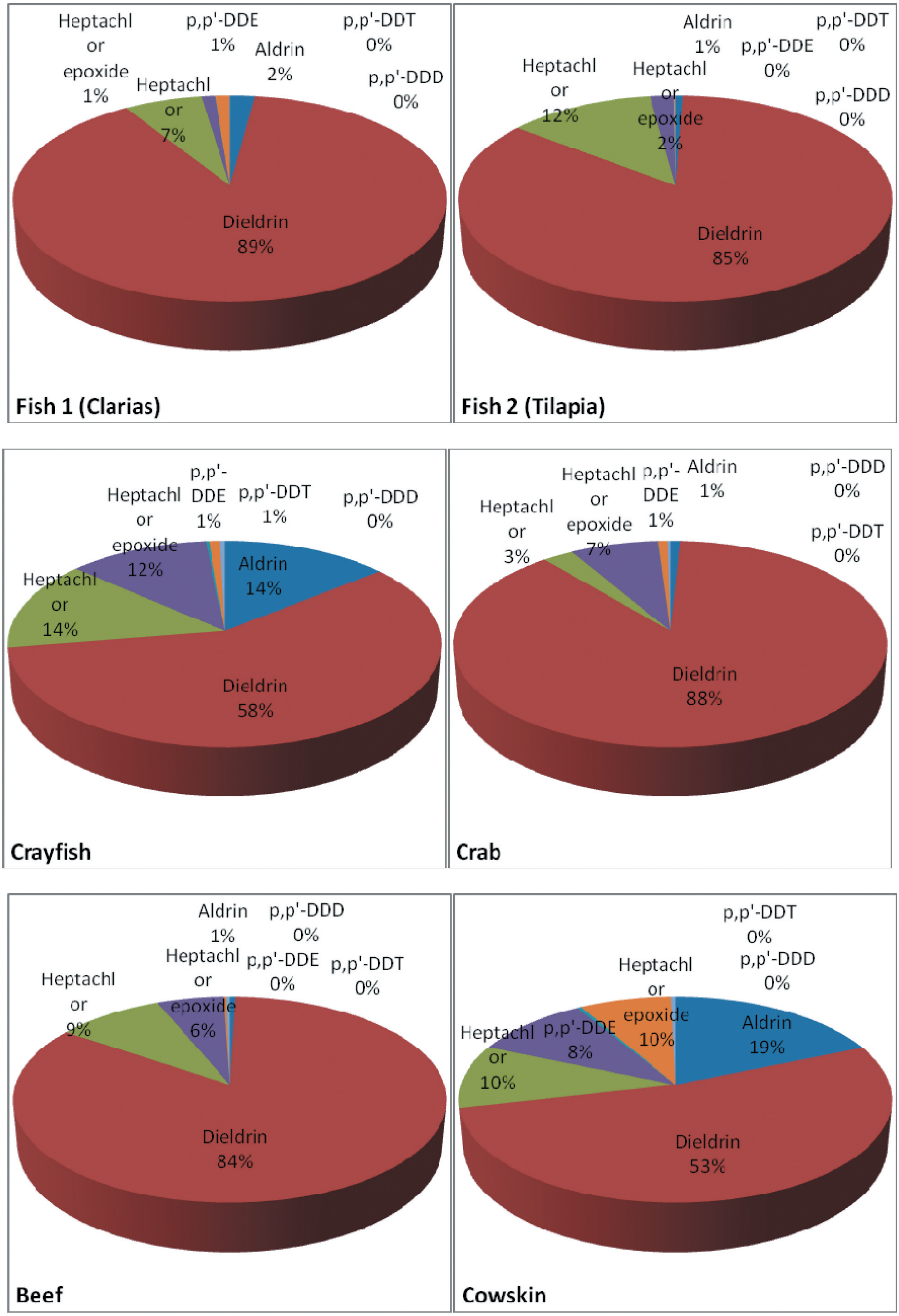

Figure 3. % Contribution to cancer risk by OCPs in protein foods.

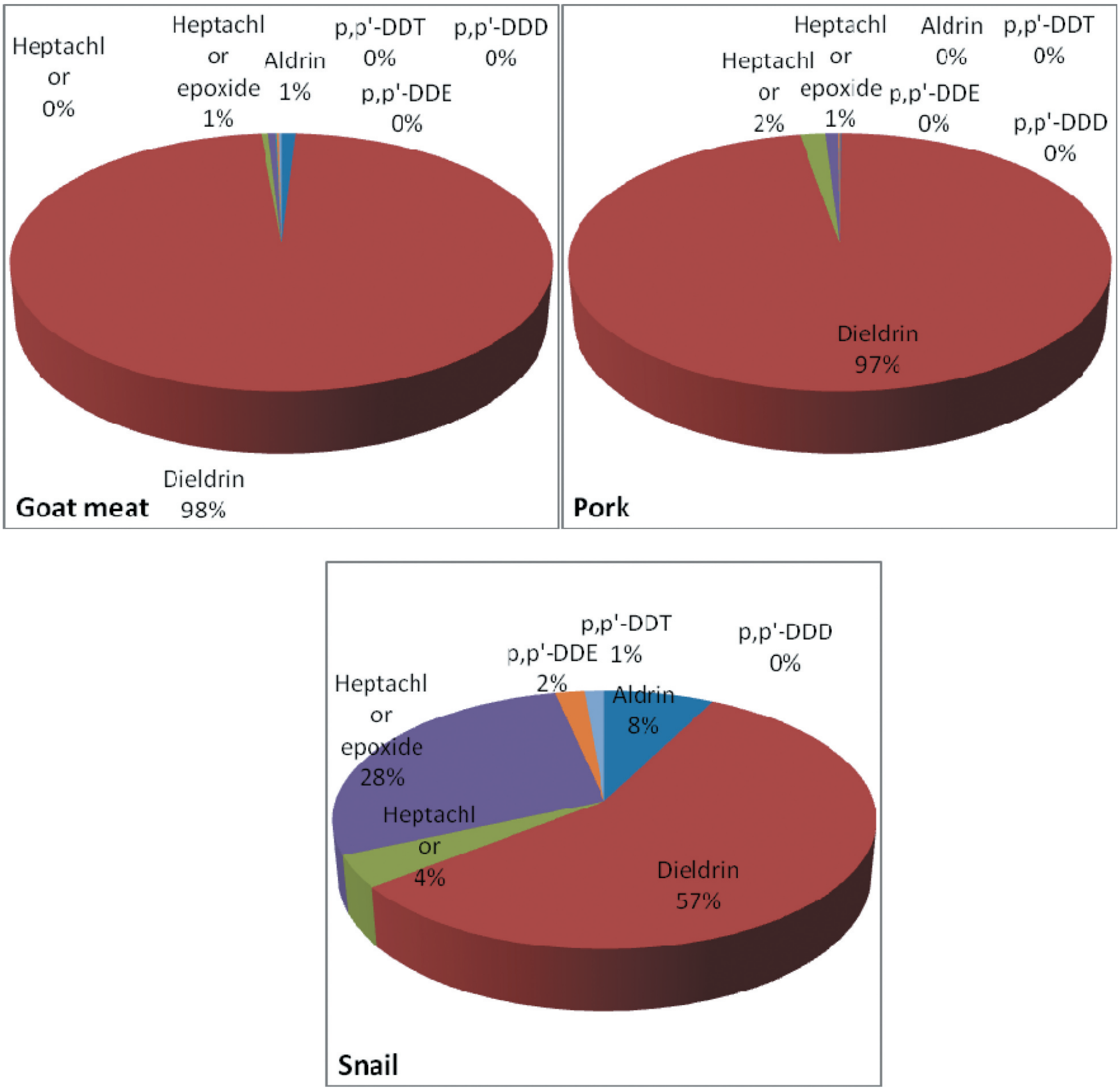

Figure 3. (Continued).

(58–89%) and the terrestrial protein foods (57–98%). Recent studies have shown annual increment in cancer incidence in Nigeria [50–52]. This, therefore, suggests a probable contribution from OCPs contaminated protein foods.

Conclusion

This study evaluated the health risk of OCPs in different protein foods collected from Abeokuta in southwestern Nigeria. Endrin ketone was found in 89% of the food samples, while aldrin was only detected in crayfish, which represented 2% of the total protein foods. Methoxychlor was the highest observed OCP in food samples. The ΣOCP levels in protein foods samples followed the decreasing sequence of pork > beef > crab > crayfish > cowskin > *Clarias gariepinus* > *Tilapia zillii* > goat meat > snail. The Hazard Index (HI) values of OCPs in all the protein foods were found greater than 1.0 indicating adverse health effects. Dieldrin and heptachlor epoxide were the major contributors to the HI in food samples. The total cancer risk data showed carcinogenic effects in all the protein foods with values greater than the acceptable limit of 1.0×10^{-4}. The individual CR values of dieldrin, heptachlor and heptachlor epoxide (except in *Clarias gariepinus*, beef, cowskin, goat meat and snail), p,p′-DDE in beef, cowskin and pork, and p,p′-DDT in beef were also greater than

Table 2. HQ and HI values of OCP in aquatic and terrestrial protein foods.

	Protein foods	RfD mg kg^{-1} day^{-1}	Mean	Std. Deviation	Minimum	Maximum
Aldrin	*Clarias gariepinus*	0.00003	0.13	0.000	0.13	0.13
	Tilapia zillii		0.13	0.000	0.13	0.13
	Crayfish		2.76	9.47	0.13	32.90
	Crab		0.13	0.000	0.13	0.13
Dieldrin	*Clarias gariepinus*	0.00005	3.63	0.79	2.76	4.74
	Tilapia zillii		11.68	19.97	0.08	60.08
	Crayfish		7.26	15.16	0.08	52.03
	Crab		9.08	14.84	1.03	39.16
Endosulfan I	*Clarias gariepinus*	0.006	0.003	0.001	0.003	0.005
	Tilapia zillii		0.01	0.002	0.001	0.01
	Crayfish		0.01	0.01	0.001	0.01
	Crab		0.005	0.001	0.003	0.01
Endosulfan II	*Clarias gariepinus*	0.006	0.01	0.004	0.005	0.01
	Tilapia zillii		0.01	0.01	0.001	0.03
	Crayfish		0.02	0.05	0.001	0.18
	Crab		0.03	0.05	0.004	0.13
Endosulfan Sulphate	*Clarias gariepinus*	0.006	0.12	0.02	0.10	0.15
	Tilapia zillii		0.01	0.01	0.001	0.03
	Crayfish		0.01	0.01	0.001	0.02
	Crab		0.07	0.06	0.01	0.16
Endrin	*Clarias gariepinus*	0.0003	0.03	0.04	0.01	0.11
	Tilapia zillii		0.22	0.37	0.01	1.30
	Crayfish		0.18	0.22	0.01	0.68
	Crab		0.08	0.08	0.01	0.16
Endrin Aldehyde	*Clarias gariepinus*	0.0003	0.14	0.05	0.09	0.25
	Tilapia zillii		0.24	0.18	0.05	0.74
	Crayfish		0.37	0.75	0.01	2.68
	Crab		1.53	2.76	0.07	7.13
Endrin Ketone	*Clarias gariepinus*	0.0003	1.05	1.72	0.08	4.50
	Tilapia zillii		0.42	0.24	0.12	1.03
	Crayfish		0.51	0.91	0.01	3.25
	Crab		0.28	0.28	0.01	0.68
Heptachlor	*Clarias gariepinus*	0.000013	1.82	3.64	0.30	9.41
	Tilapia zillii		11.54	23.99	0.30	70.14
	Crayfish		11.84	24.90	0.30	85.93
	Crab		1.82	4.25	0.30	10.32
Heptachlor Epoxide	*Clarias gariepinus*	0.000013	0.30	0.000	0.30	0.30
	Tilapia zillii		1.82	2.73	0.30	8.81
	Crayfish		10.02	26.42	0.30	92.92
	Crab		5.16	4.55	0.30	12.45
Methoxychlor	*Clarias gariepinus*	0.005	0.001	0.000	0.001	0.001
	Tilapia zillii		0.05	0.14	0.001	0.49
	Crayfish		0.17	0.28	0.001	0.74
	Crab		0.36	0.77	0.001	1.92
p,p′-DDD	*Clarias gariepinus*	0.0005	0.01	0.01	0.01	0.02
	Tilapia zillii		0.01	0.000	0.01	0.01
	Crayfish		0.16	0.54	0.01	1.88
	Crab		0.02	0.01	0.01	0.02
p,p′-DDE	*Clarias gariepinus*	0.0005	0.23	0.17	0.11	0.55
	Tilapia zillii		0.05	0.05	0.01	0.13
	Crayfish		0.53	1.02	0.01	3.04
	Crab		0.38	0.45	0.06	1.24
p,p′-DDT	*Clarias gariepinus*	0.0005	0.01	0.000	0.01	0.01
	Tilapia zillii		0.05	0.08	0.01	0.20
	Crayfish		0.24	0.55	0.01	1.97
	Crab		0.11	0.12	0.01	0.23
HI	*Clarias gariepinus*		7.49			
	Tilapia zillii		26.23			
	Crayfish		34.10			
	Crab		19.04			
Aldrin	Beef	0.00003	0.13	0.000	0.13	0.13
	Cowskin		0.13	0.000	0.13	0.13
	Goat meat		0.13	0.000	0.13	0.13
	Pork		0.13	0.000	0.13	0.13
	Snail		0.13	0.000	0.13	0.13
Dieldrin	Beef	0.00005	15.16	18.95	1.74	40.42
	Cowskin		0.24	0.39	0.08	0.71
	Goat meat		8.68	14.84	1.50	38.92
	Pork		92.29	116.37	0.08	318.88
	Snail		0.63	0.71	0.08	1.42
Endosulfan	Beef	0.006	0.01	0.005	0.003	0.02
	Cowskin		0.01	0.002	0.003	0.01
	Goat meat		0.01	0.001	0.003	0.01
	Pork		0.01	0.003	0.001	0.01
	Snail		0.01	0.01	0.001	0.01
Endosulfan II	Beef	0.006	0.01	0.01	0.003	0.02

(*Continued*)

Table 2. (Continued).

	Protein foods	RfD mg kg^{-1} day^{-1}	Mean	Std. Deviation	Minimum	Maximum
	Cowskin		0.001	0.002	0.000	0.01
	Goat meat		0.01	0.01	0.01	0.02
	Pork		0.08	0.06	0.001	0.18
	Snail		0.01	0.02	0.001	0.05
Endosulfan Sulphate	Beef	0.006	0.02	0.01	0.01	0.04
	Cowskin		0.09	0.04	0.04	0.14
	Goat meat		0.04	0.04	0.01	0.10
	Pork		0.08	0.07	0.001	0.15
	Snail		0.003	0.003	0.001	0.01
Endrin	Beef	0.0003	0.33	0.24	0.08	0.67
	Cowskin		0.04	0.07	0.01	0.17
	Goat meat		0.01	0.00	0.01	0.01
	Pork		0.24	0.34	0.01	0.89
	Snail		0.01	0.000	0.01	0.01
Endrin Aldehyde	Beef	0.0003	0.50	0.80	0.11	2.14
	Cowskin		1.04	1.46	0.09	3.89
	Goat meat		0.04	0.05	0.01	0.14
	Pork		0.20	0.14	0.01	0.43
	Snail		0.05	0.07	0.01	0.18
Endrin Ketone	Beef	0.0003	0.76	1.38	0.12	3.57
	Cowskin		1.80	2.49	0.16	6.59
	Goat meat		0.12	0.01	0.09	0.13
	Pork		0.25	0.16	0.01	0.46
	Snail		0.08	0.09	0.01	0.24
Heptachlor	Beef	0.000013	11.24	13.66	0.30	28.54
	Cowskin		0.30	0.00	0.30	0.30
	Goat meat		0.30	0.00	0.30	0.30
	Pork		11.24	5.77	0.30	14.88
	Snail		0.30	0.00	0.30	0.30
Heptachlor Epoxide	Beef	0.000013	6.98	4.25	0.30	12.15
	Cowskin		0.30	0.000	0.30	0.30
	Goat meat		0.30	0.000	0.30	0.30
	Pork		5.47	3.34	0.30	9.41
	Snail		2.13	3.04	0.30	6.07
Methoxychlor	Beef	0.005	0.43	0.55	0.01	1.39
	Cowskin		0.002	0.002	0.001	0.005
	Goat meat		0.04	0.07	0.001	0.17
	Pork		2.08	1.47	0.001	4.48
	Snail		0.002	0.002	0.001	0.01
p,p′-DDD	Beef	0.0005	0.02	0.05	0.01	0.12
	Cowskin		0.01	0.000	0.01	0.01
	Goat meat		0.03	0.02	0.01	0.07
	Pork		0.02	0.02	0.01	0.06
	Snail		0.000	0.000	0.000	0.01
p,p′-DDE	Beef	0.0005	0.19	0.10	0.04	0.32
	Cowskin		0.17	0.27	0.01	0.69
	Goat meat		0.06	0.04	0.01	0.11
	Pork		0.48	0.24	0.01	0.64
	Snail		0.10	0.06	0.05	0.21
p,p′-DDT	Beef	0.0005	0.24	0.11	0.12	0.42
	Cowskin		0.01	0.000	0.01	0.01
	Goat meat		0.07	0.16	0.01	0.39
	Pork		0.01	0.000	0.01	0.01
	Snail		0.07	0.17	0.01	0.40
HI	Beef		36.028			
	Cowskin		4.140			
	Goat meat		9.856			
	Pork		112.565			
	Snail		3.530			

RfD-Reference dose [35]

Table 3. Cancer risk values of OCP in aquatic and terrestrial protein foods.

	Protein foods	Slope Factor mg^{-1} mg day	Mean	Std. Deviation	Minimum	Maximum
Aldrin	*Clarias gariepinus*	17	3.7E-05	0.0E+00	3.7E-05	3.7E-05
	Tilapia zillii		3.7E-05	0.0E+00	3.7E-05	3.7E-05
	Crayfish		7.8E-04	2.7E-03	3.7E-05	9.2E-03
	Crab		3.7E-05	0.0E+00	3.7E-05	3.7E-05
Dieldrin	*Clarias gariepinus*	16	1.6E-03	3.5E-04	1.2E-03	2.1E-03
	Tilapia zillii		5.1E-03	8.8E-03	3.5E-05	2.6E-02
	Crayfish		3.2E-03	6.7E-03	3.5E-05	2.3E-02
	Crab		4.0E-03	6.5E-03	4.5E-04	1.7E-02
Heptachlor	*Clarias gariepinus*	9.1	1.2E-04	2.4E-04	2.0E-05	6.1E-04
	Tilapia zillii		7.5E-04	1.6E-03	2.0E-05	4.6E-03
	Crayfish		7.7E-04	1.6E-03	2.0E-05	5.6E-03
	Crab		1.2E-04	2.8E-04	2.0E-05	6.7E-04
Heptachlor Epoxide	*Clarias gariepinus*	9.1	2.0E-05	0.0E+00	2.0E-05	2.0E-05
	Tilapia zillii		1.2E-04	1.8E-04	2.0E-05	5.7E-04
	Crayfish		6.5E-04	1.7E-03	2.0E-05	6.1E-03
	Crab		3.4E-04	3.0E-04	2.0E-05	8.1E-04
p,p′-DDD	*Clarias gariepinus*	0.34	7.4E-07	7.4E-07	7.4E-07	1.5E-06
	Tilapia zillii		7.4E-07	0.0E+00	7.4E-07	7.4E-07
	Crayfish		1.5E-05	5.1E-05	7.4E-07	1.8E-04
	Crab		1.5E-06	7.4E-07	7.4E-07	2.2E-06
p,p′-DDE	*Clarias gariepinus*	0.34	2.1E-05	1.6E-05	1.0E-05	5.2E-05
	Tilapia zillii		4.4E-06	4.4E-06	7.4E-07	1.2E-05
	Crayfish		4.9E-05	9.5E-05	7.4E-07	2.8E-04
	Crab		3.5E-05	4.2E-05	5.2E-06	1.2E-04
p,p′-DDT	*Clarias gariepinus*	0.34	7.4E-07	0.0E+00	7.4E-07	7.4E-07
	Tilapia zillii		4.4E-06	7.4E-06	7.4E-07	1.8E-05
	Crayfish		2.3E-05	5.2E-05	7.4E-07	1.8E-04
	Crab		1.0E-05	1.1E-05	7.4E-07	2.1E-05
ΣCR	*Clarias gariepinus*		1.8E-03			
	Tilapia zillii		6.1–03			
	Crayfish		5.5E-03			
	Crab		4.5E-03			
Aldrin	Beef	17	3.7E-05	0.0E+00	1.3E-07	1.3E-07
	Cowskin		3.7E-05	0.0E+00	1.3E-07	1.3E-07
	Goat meat		3.7E-05	0.0E+00	1.3E-07	1.3E-07
	Pork		3.7E-05	0.0E+00	1.3E-07	1.3E-07
	Snail		3.7E-05	0.0E+00	1.3E-07	1.3E-07
Dieldrin	Beef	16	6.7E-03	3.3E-05	3.0E-06	7.0E-05
	Cowskin		1.0E-04	6.8E-07	1.4E-07	1.2E-06
	Goat meat		3.8E-03	2.6E-05	2.6E-06	6.7E-05
	Pork		4.1E-02	2.0E-04	1.4E-07	5.5E-04
	Snail		2.8E-04	1.2E-06	1.4E-07	2.4E-06
Heptachlor	Beef	9.1	7.3E-04	1.1E-05	2.4E-07	2.2E-05
	Cowskin		2.0E-05	0.0E+00	2.4E-07	2.4E-07
	Goat meat		2.0E-05	0.0E+00	2.4E-07	2.4E-07
	Pork		7.3E-04	4.5E-06	2.4E-07	1.2E-05
	Snail		2.0E-05	0.0E+00	2.4E-07	2.4E-07
Heptachlor Epoxide	Beef	9.1	4.5E-04	3.3E-06	2.4E-07	9.6E-06
	Cowskin		2.0E-05	0.0E+00	2.4E-07	2.4E-07
	Goat meat		2.0E-05	0.0E+00	2.4E-07	2.4E-07
	Pork		3.6E-04	2.6E-06	2.4E-07	7.4E-06
	Snail		1.4E-04	2.4E-06	2.4E-07	4.8E-06
p,p′-DDD	Beef	0.34	2.2E-06	3.8E-05	6.4E-06	9.6E-05
	Cowskin		7.4E-07	0.0E+00	6.4E-06	6.4E-06
	Goat meat		3.0E-06	1.9E-05	6.4E-06	5.8E-05
	Pork		2.2E-06	1.9E-05	6.4E-06	5.1E-05
	Snail		0.0E+00	0.0E+00	0.0E+00	6.4E-06
p,p′-DDE	Beef	0.34	1.8E-05	8.3E-05	3.2E-05	2.6E-04
	Cowskin		1.6E-05	2.2E-04	6.4E-06	5.6E-04
	Goat meat		5.9E-06	3.2E-05	6.4E-06	8.9E-05
	Pork		4.5E-05	1.9E-04	6.4E-06	5.2E-04
	Snail		9.6E-06	4.5E-05	3.8E-05	1.7E-04
p,p′-DDT	Beef	0.34	2.3E-05	8.9E-05	9.6E-05	3.4E-04
	Cowskin		7.4E-07	0.0E+00	6.4E-06	6.4E-06
	Goat meat		6.6E-06	1.3E-04	6.4E-06	3.1E-04
	Pork		7.4E-07	0.0E+00	6.4E-06	6.4E-06
	Snail		6.6E-06	1.3E-04	6.4E-06	3.3E-04
ΣCR	Beef		7.9E-03			
	Cowskin		2.0E-04			
	Goat meat		3.9E-03			
	Pork		4.2E-02			
	Snail		4.9E-04			

the acceptable limit of 1.0×10^{-4}. The ΣCR was mostly contributed by p,p′-DDE and dieldrin. The health risk data indicated that despite the ban of OCPs in many developing countries; the present concentrations in protein foods are of serious health concerns.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Olisah C, Okoh OO, Okoh AI. Distribution of organochlorine pesticides in fresh fish carcasses from selected estuaries in Eastern Cape Province, South Africa, and the associated health risk assessment. Mar Pollut Bullet. 2019;149:110605.

[2] EFSA. Annual report on pesticide residues according to article 32 of regulation (EC) No 396/2005. The EFSA 2010; J. 8, 1646 [Cited 2020 Mar 17]. Available from: http://www.efsa.europa.meu/en/efsajournal/pub/1646.htm

[3] Snedeker S. Pesticides and breast cancer: a review of DDT, DDE and dieldrin. Environ Health Perspect. 2001;109(1):35–47.

[4] Baird C, Cann M. Environmental chemistry. 3rd ed. New York: W.H. Freeman and Company; 2004.

[5] Grimalt JO, Fernandez P, Berdie L, et al. Selective trapping of organochlorine compounds in mountain lakes of temperate areas. Environ Sci Technol. 2001;35:2690–2697.

[6] Bentzen TW, Follman EH, Amstrup SC, et al. Dietary biomagnification of organochlorine contaminants in Alaskan polar bears. Can J Zool. 2008;86:177–191.

[7] Taiwo AM. A review of environmental and health effects of organochlorine pesticide residues in Africa. Chemos. 2019;220:1126–1140.

[8] Su Y, Dai Y, Lin Y, et al. Serum organochlorine pesticide residues and risk of gallstone disease: a case-control study in Xiamen. Annal Epidemiol. 2012;22(8):592–597.

[9] Romieu I, Hernandez-Avila M, Lazcano-Ponce E, et al. Breast cancer, lactation history, and serum organochlorines. Am J Epidemiol. 2000;152:363–370.

[10] Jaga K, Dharmani C. Global surveillance of DDT and DDE levels in human tissues. Int J Occup Med Environ Health. 2003;16:7–20.

[11] Cohn BA, Wolff MS, Cirillo PM, et al. DDT and breast cancer in young women: new data on the significance of age at exposure. Environ Health Perspect. 2007;115:1406.

[12] Kaiser J. Endocrine disrupters: panel cautiously confirms low-dose effects. Sci. 2000;290:695–697.

[13] Sosan MB, Akingbohungbe AE, Ojo IAO, et al. Insecticide residues in the blood serum and domestic water source of cacao farmers in Southwestern Nigeria. Chemos. 2008;72(5):781–784.

[14] Tanner CM, Kamel F, Ross GW, et al. Rotenone, Paraquat, and Parkinson's Disease. Environ Health Perspect. 2011;119:866–872.

[15] Leena S, Choudhary SK, Singh PK. Pesticide concentration in water and sediment of river ganga at selected sites in middle Ganga plain. Inter J Environ Sci. 2012;3(1):260–274.

[16] Mesnage R, Clair E, de Vendômois JS, et al. Two cases of birth defects overlapping stratton-parker syndrome after multiple pesticide exposure. Occup Environ Med. 2010;67(5):359.

[17] Cocco P, Satta G, Dubois S, et al. Lymphoma risk and occupational exposure to pesticides: results of the epilymph study. Occup Environ Med. 2013;70:91–98.

[18] Gill HK, Garg H. Pesticides: environmental impacts and management strategies. In: Soloneski S, editor. Pesticides - toxic aspects. InTech, London, UK; 2014. p. 188–230. DOI:http://doi.10.5772/57399.

[19] Williams AB. Organochlorine pesticide residues in muscle tissues of ethmalosa fimbriata and psettias sebae from Lagos Lagoon, Nigeria. Int J Acad Res. 2013;5:166–172.

[20] Kafilzadeh F. Assessment of organochlorine pesticide residues in water, sediments and fish from Lake Tashk, Iran. Ach Life Sci. 2015;9:107–111.

[21] Silva DMLD, Camargo PBD, Martinelli LA, et al. Organochlorine pesticides in Piracicaba river basin (São Paulo/Brazil): a survey of sediment, bivalve and fish. Químic Nova. 2008;31:214–219.

[22] Hu G, Dai J, Mai B, et al. Concentrations and accumulation features of organochlorine pesticides in the Baiyangdian Lake freshwater food web of North China. Arch.Environ.Contam.Toxicol. 2010;58:700–710.

[23] Behfar A, Nazari Z, Rabiee MH, et al. The organochlorine pesticides residue levels in Karun river water. Jund J Nat Pharm Prod. 2013;8:41–46.

[24] Jeyakumar T, Kalaiarasi I, Rajavel A, et al. Levels of organochlorine pesticide residues in water and sediment from selected agricultural sectors of Kanyakumari District, Tamil Nadu, India. Int J Environ Res. 2014;8:493–500.

[25] Padhi S, Pati B. Severity of persistence and toxicity of hexachlorocyclohexane (HCH) to the environment-A current approach. Scho Res J Interdiscip Stud. 2016;4:3158–3168.

[26] Yahaya A, Okoh OO, Okoh AI, et al. Occurrences of organochlorine pesticides along the course of the Buffalo River in the Eastern Cape of South Africa and its health implications. Inter J Environ Res Pub Health. 2017;14(11):1372.

[27] Alturiqi AS, Albedair LA. Evaluation of some heavy metals in certain fish, meat and meat products in Saudi Arabian markets. Egypt J Aqua Res. 2012;38(1):45–49.

[28] Taiwo AM, Oyebode AO, Salami FO, et al. Carcinogenic and non-carcinogenic evaluations of heavy metals in protein foods from southwestern Nigeria. J Food Composit Anal. 2018;73:60–66.

[29] Makrides M, Duley L, Olsen SF. Marine oil, and other prostaglandin precursor, supplementation for pregnancy uncomplicated by pre-eclampsia or intrauterine growth restriction. Cochrane Database Syst Rev. 2006;3:CD003402.

[30] Mohanty BP, Ganguly S, Mahanty A, et al. DHA and EPA content and fatty acid profile of 39 food fishes from India. Bio Med Res Int. 2016; 1–14.

[31] Barnhoorn IE, Van Dyk JC, Genthe B, et al. Organochlorine pesticide levels in Clarias gariepinus from polluted freshwater impoundments in South Africa and associated human health risks. Chemos. 2015;120:391–397.

[32] Tongo I, Ezemonye L. Human health risks associated with residual pesticide levels in edible tissues of slaughtered cattle in Benin City, Southern Nigeria. Toxicol Rep. 2015;2:1117–1135.

[33] Taiwo AM, Ihedioha EC, Nwosu SC, et al. Levels and health risk assessment of polycyclic aromatic hydrocarbons in protein foods from Lagos and Abeokuta, Southwestern Nigeria. J Food Composit Anal. 2019;79:28–38.

[34] Wang GS, Lee A, Lewis M, et al. Accelerated solvent extraction and gas chromatography/mass spectrometry for determination of polycyclic aromatic hydrocarbons in smoked food samples. J Agric Food Chem. 1999;47:1062–1066.

[35] USEPA (United States Environmental Protection Agency). Risk assessment guidance for superfund: process for conducting probabilistic risk assessment (part A). 2001; EPA 540-R-02-002. vol. 3.

[36] USEPA (United States Environmental Protection Agency). Integrated risk information system (IRIS) database. US environmental protection agency, Washington DC: National Center for Environmental Assessment.2002.

[37] USEPA (United States Environmental Protection Agency). Framework for metal risk assessment (EPA 120-R-07-001 Washington DC). 2007.

[38] FAO. The state of world fisheries and aquaculture 2008. FAO fisheries and aquaculture department. Food and Agriculture Organisation of the UN, Rome. 2008.

[39] WHO. Country Statistics, Nigeria. 2015. [Cited 2020 Mar 10]. Available from: www.who.int/country/nga/en

[40] Darko G, Akoto O, Oppong C. Persistent organochlorine pesticide residues in fish, sediments and water from Lake Bosomtwi, Ghana. Chemos. 2008;72:21–24.

[41] Briz V, Molina-Molina JM, Sánchez-Redondo S, et al. Differential estrogenic effects of the persistent organochlorine pesticides dieldrin, endosulfan and lindane in primary neuronal cultures. Toxicol Sci. 2011;120 (2):413–427.

[42] Alavanja MC, Hoppin JA, Kamel F. Health effects of chronic pesticide exposure: cancer and neurotoxicity. Ann Rev Public Health. 2004;25:155.

[43] Persistent Organic Pollutants Review Committee. Methoxychlor. Draft risk profile. 2020. 39p. [Cited 2020 Aug 02]. Available from: https://echa.europa.eu/documents/10162/b65a738e-b50f-64e5-cbb0-f2711d49c25 e.

[44] Ezemonye L, Ogbeide O, Tongo I. Distribution and ecological risk assessment of pesticide residues in surface water, sediment and fish from Ogbesse River, Edo State, Nigeria. J Environ Chem Ecotoxicol. 2015;7:20–30.

[45] FDA. Environmental chemical contaminant and pesticide tolerances, action levels and guidance levels for fish and fishery products (compliance policy guide sec.575.100. Pesticide Chemical Residues in Food e Enforcement Criteria. 2001; CPG 7141.01.

[46] Akan JC, Mohammed Z, Jafiya L, et al. Organochlorine pesticide residues in fish samples from Alau Dam, Borno state, North Eastern Nigeria. Environ Anal Toxicol. 2013;3:1e7.

[47] Gbeddy G, Glover E, Doyi I, et al. Assessment of organochlorine pesticides in water, sediment, African cat fish and nile tilapia, consumer exposure and human health implications, Volta lake, Ghana. J Environ Anal Toxicol. 2015;5:1e8.

[48] Adeyemi MM, Abdulmalik H. Determination of organochlorine pesticides in some imported frozen fish species consumed within Kaduna Metropolis. IOSR J Environ Sci Toxicol Food Technol. 2017;11(4):1e5.

[49] Pardío V, Martínez D, Flores A, et al. Human health risk of dietary intake of organochlorine pesticide residues in bovine meat and tissues from Veracruz, México. Food Chem. 2012;135(3):1873–1893.

[50] Jedy-Agba E, Curado MP, Ogunbiyi O, et al. Cancer incidence in Nigeria: a report from population-based cancer registries. Cancer Epidemiol. 2012;36(5):e271–e278.

[51] Amin SM, Ewunonu HAS, Oguntebi E, et al. Breast cancer mortality in a resource-poor country: A 10-year experience in a tertiary institution. Sahel Med J. 2017;20(3):93.

[52] Sowunmi A, Alabi A, Fatiregun O, et al. Trend of cancer incidence in an oncology center in Nigeria. West Afri J Radiol. 2018;25(1):52.