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REVIEW

Toxicology

Organochlorine pesticide contamination of foods in Africa: incidence and public health significance

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ABSTRACT. Organochlorine pesticides (OCPs) have been used worldwide, particularly in Africa, for several decades. Although many are banned, several African countries still use OCPs especially for the prevention and control of malaria. OCPs are characterized by their bio-accumulation in the environment, especially in the food chain, where they find their way into the human body. Despite no clear epidemiological studies confirming hazardous effects of these chemicals on human health, many studies have reported positive associations between the use of OCPs and neurological and reproductive disorders, and cancer risk. There is a clear gap in published reports on OCPs in Africa and their potential health hazards. Thus, the aim of this review is to summarize the incidence of OCP contamination in various foods in Africa, to demonstrate the potential transmission of these chemicals to people and to discuss their possible health hazards.

KEY WORDS: Africa, food, health hazards, OCPs

Organochlorine pesticides (OCPs) have been extensively used worldwide for several decades, because of their prolonged period of action, low cost and toxicity against various pests [73]. Several OCPs—including aldrin, dieldrin and dichlorodiphenyltrichloroethane (DDT)—became widely used in agriculture in the 1950s. Initially, DDT was thought to be unsafe only for insects, but toxicity and extensive biomagnification were soon highlighted in other species, notably wild birds, many of which had dramatic population declines related to use of this chemical [5]. Lipophilic chlorine residues from OCPs accumulate within animals, and biomagnification is also seen in species at the top of the food chain. An international environmental treaty, the Stockholm Convention on Persistent Organic Pollutants (POPs), was adopted in May 2001 [85] and currently has 179 parties. The 12 initial POP chemicals banned under this treaty included the following OCPs: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene.

Although a number of OCPs have been banned for use in agriculture, others are still currently used in many countries as agricultural pesticides. DDT use continues under an exemption for approved disease vector control in many African countries. In this situation, chemicals are applied to bed nets (insecticide treated nets) or sprayed in homes (indoor residual spraying, IRS). Stockpiled or obsolete chemicals are likely to exist in some locations, with unmonitored and potentially inappropriate storage conditions. It is only possible to detect these by assessment of environmental samples for contamination.

Humans can be exposed to OCPs via several routes including breathing polluted air, dermal penetration or ingestion of contaminated foods and drinking water. OCP-contaminated foods (fruit, vegetables, cereals and various meats) are considered the main source of human exposure to pesticides [39]. Maternal transfer is also possible across the placenta to the fetus or via breast milk to infants. Residue levels of these compounds in living organisms depend on each organism's habitat and position in the food chain [95]. OCPs contamination of food and their public health implications attracted the attention of many researchers and scientists to report intensive information about this worldwide problem [42, 44, 45, 73, 83, 84]. Despite suspected adverse human health effects due to OCP exposure in Africa, available information is scarce. Thus, based on a literature search of peer-reviewed manuscripts published between 1st January 2000 and 11th August 2015, this review aims to highlight and summarize the incidence of OCP contamination of food in different African countries (Fig. 1). Furthermore, the presence of OCP residues in human fluids and related health effects were ascertained.

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Fig. 1. A declarative map for the reported OCPs in some African countries.

OCP CONTAMINATION OF FOODS IN AFRICAN COUNTRIES

Ingestion of contaminated foods is a major source of human exposure to chemical residues. Although no complete diets have been assessed, several publications describe detection of OCPs in foods destined for human consumption. In this section, we will summarize the incidence of OCP contamination of foods in some African countries.

Benin

Fish and shellfish: Studies conducted in Benin have focused mainly on fish species in the Ouémé River and Lake Nokoué. Pazou and colleagues detected several OCPs in fish with different concentrations (*ng*/g lipid weight (lw)), including DDTs (1,642), endosulfans (7,926), aldrin (24), dieldrin (57), endrin (13) and lindane (13), respectively [72, 91–93]. Interestingly, an earlier study in the same river detected lindane as the most prevalent OCP (105 μg/g) [71]. Shellfish in Lake Nokoué and Cotonou Lagoon contained DDTs (maximum 18.5 *ng*/g dw detected), α-endosulfan and aldrin (Table 1) [72, 91–93].

Vegetables: Vegetables grown in the river's floodplains in Benin also contained several OCPs in variable concentrations (μg/g dry weight (dw)), DDTs (1,578), drins (57) and lindane (444), respectively (Table 1) [72, 91–93]

Cameroon

Leaf crops and Tomatoes: In Cameroon, assessment of pesticide levels in local leaf crops (ndole/keleng keleng) and tomatoes detected only endosulfan in the tomatoes and even then at a level below the acceptable daily intake (ADI), at 0.02 mg/kg [37].

Cereal crops: A study on maize, millet and cowpea detected lindane, at 9.53 mg/kg in maize, above the maximum residue limit (MRL) (Tables 1 and 2) [80].

Egypt

Agricultural crops: Although use has been banned in Egypt since the 1980s, OCPS are still detected in various foods in the country. For farmed cucumbers, the method of farming has been shown to affect pesticide contamination levels (greenhouse cucumbers >conventional >organic farming), as has season (winter/spring range of OCPs 0.0–0.362 mg/kg compared to summer/fall range 0.219–1.628 mg/kg) [56]. A similar study also showed organic potatoes to contain lower levels of contaminants than conventionally farmed specimens [57]. Further elucidation of potato contamination compared different washing and cooking methods, and showed that deep-fried chips contained lower OCP contaminant levels than pommes frites, with both lower than uncooked potatoes [79]. In addition, potato skin samples contained the highest levels. Many locally produced foods in Ismailia city were assessed for various contaminants, but dicofol was found only in cucumbers, and then at a level (0.021 mg/kg) well below recommended safe limits (Table 1) [51]. Another study on samples from several Egyptian markets ascertained dicofol as the most

Table 1. Reported levels of OCPs in various foods in African countries

Country	Foodstuff	Pesticide concentration (*ng*/g dw, except where specified)		Reference
		DDTs	Other	
Benin	Fish (6 species)	3.88–11.3	α-endosulfan (0.50–3.39), Σaldrin (0.12–0.95), lindane (γ-HCH, ND–0.532)	[91]
	Shellfish	0.20–18.5	α-endosulfan (ND-0.90), Σaldrin (ND-0.371), lindane (ND)	
	Fish (*ng*/g lw)	74–1,185	α-endosulfan (23–7,926), aldrin (<1–24), dieldrin (2–57), endrin (<13), lindane (<13)	[92]
	Fish (*ng*/g lw)	242–1,239	Σendosulfan (9–215), dieldrin (0–10)	[93]
	Vegetables(*µ*g/kg dw)	647–1,578	Σdrins (15–57), lindane (7–444)	
	Fish (*ng*/g lw)	129–1,642	Σendosulfan (0–215), lindane (0–6.5), dieldrin (0–9)	[72]
	Fish (*µ*g/g)	30	Lindane (105), dieldrin (77), heptachlor (40)	[71]
Cameroon	Maize	-	Lindane (9.53), endosulfan (0.06)	[80]
	Millet	-	Lindane (0.08), α-endosulfan (0.05), β-endosulfan (0.02)	
	Cowpea	-	Lindane (0.24), α-endosulfan (0.08)	
	Ndole/keleng keleng (local leaves)	-	<LOQ	[38]
	Tomatoes	-	Endosulfan 0.02	
Egypt	Raw buffalo milk (local vendors, dairy farms and shops)	-	Alachlor (<0.001), dieldrin (<15), HCB (<0.200), lindane (<0.192), mehoxychlor (<0.200)	[78]
	African catfish (*Claria gariepinus*) (*µ*g/kg fw)	*p,p'*-DDE (0.70–0.90)	Alachlor (0.23–0.25), lindane (1.38–2.10), dieldrin (0.72–1.20), aldrin (ND), heptachlor (0.30–0.50), HCB (ND)	[90]
	Nile tilapia (*Oreochromis niloticus*) (*µ*g/kg fw)	*p,p'*-DDE (ND)	Alachlor (ND), lindane (0.41–0.57), dieldrin (ND), aldrin (0.17–0.28), heptachlor (0.18–0.19), HCB (3.04–3.10)	
	Nile tilapia (*µ*g/kg)	*p,p'*-DDE (0.012–0.084), *p,p'*-DDD (ND–0.087), *p,p'*-DDT (ND–0.010)	α-HCH (ND–0.059), heptachlor (ND–0.003), aldrin (ND–0.060), heptachlor epoxide (0.021–0.113), endrin (ND–0.026)	[11]
	Buffalo liver (*ng*/g lw)	ND–18.41	ΣHCHs (34.97–89.21), Σdrins (14.92–30.27), HCB (ND–10.15), ΣCHLs (ND-19.08)	[53]
	Buffalo kidney (*ng*/g lw)	ND–35.67	ΣHCHs (41.97–247.73), Σdrins (11.19–68.13), HCB (ND–96.47), ΣCHLs (ND-45.09)	
	Buffalo tongue (*ng*/g lw)	ND–62.83	ΣHCHs (59.24–351.57), Σdrins (22.92–84.00), HCB (ND–23.18), ΣCHLs (ND)	
	Mussels (*µ*g/g dw)	0.94–31	ΣHCHs (<LOD-11), ΣCHLs (<LOD-35), dieldrin (<LOD–12), endosulfan (<LOD–9.3), methoxychlor (<LOD–4.0), mirex (<LOD–0.89), ΣHCBs (<LOD–0.50)	[47]
	Cucumbers (*µ*g/g)	-	ΣOCPs 0.0–1.628	[56]
	Potato tubers: conventionally farmed (*µ*g/g)	-	ΣOCPs 0.685	[57]
	Potato tubers: organically farmed (*µ*g/g)	-	ΣOCPs 0.308	
	Cucumbers (*µ*g/g)	-	Dicofol 0.021	[51]
	Vegetables (pepper highest) (*µ*g/g)	-	Dicofol <3.40	[29]
	Fruits (strawberry highest) (*µ*g/g)	-	Dicofol <3.30	
	Potato tubers (skin and pulp) (*µ*g/g)	0.537	HCB (0.014, <0.026), lindane (0.141, <0.221)	[79]
	Pommes frites (*µ*g/g)	0.061 (<0.094)	HCB (0.006, <0.011), lindane (0.021, <0.121)	
	Potato chips (*µ*g/g)	0.022 (<0.033)	HCB (0.003, <0.006), lindane (0.006, <0.0084)	
Ethiopia	Fish (*ng*/g ww)	Means 19–56 (range 1.65–409.6)	ΣCHLs (0.85–2.15, range 0.75–3.56), Σendosulfan (ND–25.90, range ND–42.5)	[27]
	Fish (4 species) (*ng*/g ww)	0.77–61.9	ΣHCHs (0.16–5.10), ΣCHLs (0.17–4.00), ΣHPTs (0.19–2.27)	[94]
	Various foods (pepper, maize, teff, coffee pulp/beans) (*µ*g/g)	*p,p'*-DDE (0.00–0.086), *p,p'*-DDD (0.049–0.128), *o,p'*-DDT (0.085–0.193), *p,p'*-DDT (0.099–0.461)	α-endosulfan (0.0042–0.0332), β-endosulfan (0.002–0.063)	[62]
	Milk: cow (*µ*g/kg)	<1,230	Aldrin (<11.6), α-endosulfan (<77.6), β-endosulfan (ND)	[28]
	Milk: goat (*µ*g/kg)	<874.4	Aldrin (ND), α-endosulfan (<142.1), β-endosulfan (<87.0)	
	Cow milk (*µ*g/kg)	0.389	-	[36]
	Beef (*µ*g/g)	Means *o,p'*-DDT (ND–3.23), *p,p'*-DDT (0.37–4.32)	Means endosulfan-I (ND-0.06), aldrin (ND–0.012), dieldrin (ND-0.04), endrin (ND-0.011), lindane (ND–0.05)	[49]
	Khat (*µ*g/kg)	*p,p'*-DDT (ND-1,223.8)	-	[24]

Table 1 Continued.

Country	Foodstuff	Pesticide concentration (*ng*/g dw, except where specified)		Reference
		DDTs	Other	
Ghana	Cereal-based complementary foods (locally produced) (*µ*g/g)	-	Means β-HCH (<0.017), lindane (<0.022), δ-HCH (<0.008), heptachlor (<0.006), γ-chlordane (<0.013), α-endosulfan (<0.008), β-endosulfan (<0.021)	[3]
	Cowpea (*µ*g/g)	-	Total OCPs (including HCHs, heptachlor, drins, γ-chlordane, endosulfans, DDTs, methoxychlor) 0.314	[4]
	Maize (*µ*g/g)	-	Total OCPs (including HCHs, heptachlor, drins, γ-chlordane, endosulfans, DDTs, methoxychlor) 0.354	
	Okra (*µ*g/kg)	-	OCPs (including lindane, heptachlor, drins, DDTs, endosulfan, methoxychlor) 3.10–7.60	[35]
	Fish (*ng*/g)	*p,p'*-DDT (ND–0.93), *p,p'*-DDE (ND-0.50)	Lindane (0.02–0.54), δ-HCH (0.01–0.98), aldrin (0.29–4.26), dieldrin (0.01–0.06), α-endosulfan (0.01–7.52), endosulfan sulfate (0.01–2.76), endrin (ND–0.67), endrin aldehyde (ND–0.77), endrin ketone (ND–0.26)	[48]
	Fish (redbelly tilapia and catfish) (*ng*/g lw)	Average 440.90	Average HCB (2.10), ΣHCHs (0.72), ΣCHLs (7.19)	[1]
	Fruits (locally produced pawpaw, locally produced tomato, imported apples)	*p,p'*-DDE (0.05, <LOD, 0.01), *o,p'*-DDD (ND, <LOD, <LOD), *o,p'*-DDT (0.03, ND, ND), *p,p'*-DDT (0.02, 0.01, 0.09)	Lindane (0.04, 0.02, 0.02), δ-HCH (0.06, 0.02, 0.04), heptachlor (0.02, 0.02, 0.05), aldrin (<LOD, ND, <LOD), heptachlor epoxide (<LOD, 0.06, <LOD), γ-chlordane (ND, <LOD, <LOD), α-endosulfan (0.02, <LOD, <LOD), endrin (0.01, <LOD, <LOD), β-endosulfan (0.02, ND, ND), endrin aldehyde (0.02, 0.01, 0.11), endrin ketone (0.02, 0.02, 0.01), methoxychlor (0.03, <LOD, <LOD)	[16]
	Milk	*p,p'*-DDE (0.01–4.62), *p,p'*-DDT (0.44–28.62)	Range lindane (<LOD), aldrin (<LOD–0.05), endosulfan (0.02–0.12), dieldrin (0.04–4.62)	[25]
	Yoghurt	*p,p'*-DDE (0.01–2.05), *p,p'*-DDT (0.71–19.20)	Range lindane (<LOD–0.05), aldrin (<LOD–0.15), endosulfan (<LOD–0.34), dieldrin (<LOD–0.34)	
	Cheese	*p,p'*-DDE (0.16–485.76), *p,p'*-DDT (1.33–119.0)	Range lindane (<LOD–4.41), aldrin (0.01–7.88), endosulfan (0.14–9.06), dieldrin (0.88–30.49)	
	Lettuce (*µ*g/g)	0.4 (0.02–0.9)	Lindane (average 0.3, range 0.03–0.9), endosulfan (0.4, 0.04–1.3)	[6]
	Tomatoes (*ng*/g fw)	-	Heptachlor epoxide 1.65	[66]
Morocco	Tomatoes (*ng*/g)	-	Dicofol (0.001–0.400), endosulfan (0.003–1.123)	[76]
	Clams and eels (*ng*/g lw)	<2,000	-	[61]
Nigeria	White maize (*µ*g/kg)	-	OCPs (means 7.9–52.0)	[68]
Sene-Gambia	Bivalves and gastropods	0.8–16.6	∑14 OCPs 1.9–17.8	[19]
	Fish and shrimps (*ng*/g fat)	11.1–199.2	∑HCHs (ND–13.3), ∑endosulfans (ND–49.7)	[55]
South Africa	Chicken eggs (*ng*/g ww)	Median 11,000 (range 5,200–48,000)	-	[20]
	Fish (fat) (mg/kg fat)	0.322–81.491	-	[15]
	Bovine milk (*µ*g/kg mf)	0.15	-	[77]
	Leafy vegetables (*µ*g/kg)	43.0	-	[87]
	Chicken meat (*µ*g/kg)	700	-	
Tanzania	Tilapia fish (*Oreochromis* sp) (*ng*/g lw)	7.2–319	HCB (0.6–4.0), ∑HCHs (0.6–4.0), ∑CHLs (<LOD–2.1), ∑CHBs (<LOD–0.9), ∑endosulfan (<LOD–405)	[74]
	Fish fillet (Nile tilapia and Nile perch) (mg/kg fw)	0.03	Endosulfan 0.2	[41]
	Spinach (*µ*g/kg)	2.89	Lindane 0.08	[65]
	Rice (*µ*g/kg)	0.76	Lindane 0.08	
	Beef meat (*µ*g/kg)	0.76	Lindane 0.14	
	Stiff porridge (*µ*g/kg)	0.03	Lindane 0.06	
	Beans (*µ*g/kg)	0.13	Lindane 0.04	
	Fish fillet (Nile tilapia and Nile perch) (*µ*g/kg)	-	Lindane 0.05	
	Various aquatic biota (fish and crab species) (*µ*g/kg fw)	6.6–54	-	[64]
Togo	Cowpea grains (*µ*g/kg)	-	OCPs (including dieldrin, endrin, heptachlor epoxide, endosulfan) 13.16–98.79	[59]
	Maize grains (*µ*g/kg)	-	OCPs (including dieldrin, endrin, heptachlor epoxide, endosulfan) 0.53–65.70	

Table 1 Continued.

Country	Foodstuff	Pesticide concentration (ng/g dw, except where specified)		Reference
		DDTs	Other	
Tunisia	Dover sole (*Solea solea*) (*ng*/g lw)	54.2–512	HCB (1.7–18.0), ∑HCHs (ND–58.0), ∑OCPs (65–752)	[17]
	Mullet (*Mugil cephalus*) (*ng*/g lw)	14.3–47.3	HCB (1.27–15.1), ∑HCHs (0.57–20.5), ∑OCPs (19.6–157)	[7]
	Sea bass (*Dicentrarchus labrax*) (*ng*/g lw)	25.4–227	HCB (1.62–28.5), ∑HCHs (2.69–33.6), ∑OCPs (47.9–265)	
Uganda	Nile perch and Nile tilapia (*pg*/g lw)	-	∑HCHs ND-73,000	[82]
	Fresh cow's milk (mg/kg mf)	Mean 0.052 (range 0.018–0.152)	Lindane (0.026, 0.001–0.086), aldrin (0.009, 0.002–0.018), dieldrin (0.007, 0.001–0.018), α-endosulfan (0.002, 0.001–0.004), β-endosulfan (<LOD)	[43]
	Pasteurized cow's milk (mg/kg mf)	Mean 0.041 (range 0.012–0.088)	Lindane (0.022, <LOD–0.066), aldrin (0.006, 0.005–0.008), dieldrin (0.005, 0.001–0.021), α-endosulfan (<LOD), β-endosulfan (<LOD)	
	Fish (μg/kg fw)	ND-68	-	[81]
	Nile perch (belly flap oil) (μg/kg oil)	Mean 43.74	-	[69]
	Nile tilapia and African catfish (mg/kg ww)	*p,p'*-DDE (<0.01), *p,p'*-DDT (0.002)	Endosulfan sulphate <0.002	[13]
	Nile tilapia (μg/kg)	Mean *p,p'*-DDE (0.80), *p,p'*-DDT (0.59)	Mean lindane (0.74), aldrin (0.28), α-endosulfan (1.70), dieldrin (0.30)	[46]
	Nile perch (μg/kg)	Mean *p,p'*-DDE (0.86), *p,p'*-DDT (0.81)	Mean lindane (0.87), aldrin (0.48), α-endosulfan (1.45), dieldrin (0.18)	

ND=below limit of detection, ww or fw=wet weight or fresh weight, dw=dry weight, lw=lipid weight, mf=milk fat, LOQ=limit of quantification, LOD=limit of detection. CHLs=chlordanes, DDTs=DDT+DDE+DDD, HCB=hexachlorobenzene, HCH=hexachlorocyclohexanes, HPTs=heptachlor.

Table 2. Maximum Residue limits (MRLs) recorded by different organizations and reported in this review

Organization	Pesticide	MRLs (ppb)	Reported in
Codex Alimentarius Commission	Lindane	200	[90]
US EPA	DDT	20	[90]
EU	DDT	100	[90]
EU	DDT in cereals	50	[24]
EU	Endosulfan in meat	50	[74]
FAO/WHO	DDT in fish	200	[64]
Canadian Limits	DDT in fish	500	[64]
WHO	DDT in water	2	[59]
German Food Law	Lindane	500	[46]
German Food Law	Aldrin + dieldrin	200	[46]
German Food Law	Endosulfan + endosulfan sulphate	100	[46]
German Food Law	ΣDDTs	500	[46]
AFFA	ΣDDTs	1,000	[46]
US FDA	ΣDDTs	5,000	[46]
Codex Alimentarius Commission	ΣDDTs	5,000	[81]
CREM/CBI	ΣDDTs	5,000	[69]
CREM/CBI	Total endosulfan	10	[69]

US EPA: U.S. Environmental Protection Agency, EU: European Union, WHO: World Health Organization, AFFA: Agriculture, Fisheries and Forestry-Australia, US FDA: U.S. Food and Drug Administration, CREM/CBI: Consultancy and research for environmental management/centre for the promotion of imports from developing countries.

frequently occurring pesticide residue (5.1% of samples), notably in peppers and strawberries [29].

Fish and shellfish: Mussels from Abu Qir Bay contained several OCPs, with DDT concentrations up to 31 μg/g dw (Table 1), but a risk assessment showed no expected adverse effects on people through mussel consumption [47]. A study of fish in Assiut city region found higher levels of various OCPs in catfish compared to tilapia, though all were below recommended MRLs (Table 2) [90]. Tilapia fish from the Manzala Lake on the north eastern edge of the Nile Delta contained several OCPs, including DDTs, although levels were below FAO/WHO maximum permissible limits [11].

Edible offal: Even within a single animal species, OCP levels may vary by tissues; for example, buffalo tongue has been shown to contain higher concentrations than liver or kidney [53]. In this study, HCHs were the predominant OCP detected (up to 351.57 *n*g/g lw in tongue samples) (Table 1).

Milk: Assessment of raw buffalo milk in the Egyptian city of Assiut showed some variation in pesticide level between sources, with the number of OCPs detected lower in milk samples from local vendors, although this was combined with high mean values for HCH (88% of samples) and pesticide types other than OCPs (Table 1) [78].

Ethiopia

Milk: As in Egypt, milk samples in Ethiopia were found to contain several pesticides, with highest concentrations seen in malaria areas, and overall cow and goat samples contained an average DDT level of 328.5 μg/kg (Table 1) [28]. Analysis of cow milk samples focusing on the south west of the country also detected DDTs, with *p,p'*-DDT predominating [36].

Edible offal: Cattle samples from the West Shoa Zone contained several OCPs, with levels reducing by tissue: liver >kidney >meat [49]. Heat treatment (boiling for 90 min) was shown to reduce contamination levels by 29–62.2%, depending on the OCP.

Fish: In the Ethiopian Rift Valley lakes, various fish species have been assessed for OCP contamination. In Lake Awassa, DDTs were the most predominant OCP, with the greatest degree of contamination (up to 56 *n*g/g ww) seen in fish at the highest trophic level, the African big barb [27]. Levels in this region were shown to exceed safety limits published by the US EPA for children under 1 year of age. In a similar study in Lake Ziway fish, DDTs again predominated (up to 61.9 *n*g/g ww), and calculated cancer risk estimates and hazard ratios indicated a potential cancer risk from consumption of the fish (Table 1) [94].

Other food substrates: Samples of various foods from a local market in the Jimma Zone showed a third to be contaminated with pesticides at levels above recommended MRLs, predominantly DDTs and endosulfans, with red peppers and green coffee beans the most contaminated [62]. Khat leaves (chewed locally) were found to have levels of DDTs over 1,000 times the EU MRL in some locations (Tables 1 and 2) [24].

Ghana

Cereal crops: In Ghana, assessment of 10 brands of processed cereal-based complementary foods detected levels of several OCPs exceeding recommended MRLs and indicated possible adverse health effects particularly on infants and young children [3]. Cowpea and maize samples from farms in Ejura contained several OCPs at levels exceeding MRLs (Table 2) and again showed potential for chronic toxicity when consumed [4].

Fruits and vegetables: Fruits purchased in Accra Metropolis were analyzed, and both locally-produced fruits (pawpaw and tomato) and imported apples were found to have pesticide contamination, mainly with OCPs, with 32.8% of samples exceeding MRLs (Table 2) [16]. Okra grown on a farm adjoining one using pesticides, though not directly subjected to pesticide application, was shown to be contaminated by several OCPs [35]. Lettuce from various markets and sellers in three Metropolitan Districts contained lindane, endosulfan and DDT in over 30% of samples, exceeding MRLs [6]. Half of tomatoes sampled from a vegetable-farming community in Offinso District contained heptachlor epoxide [66].

Fish: Although fish from the Densu river basin contained several OCPs, with α-endosulfan predominating, MRLs were not exceeded [48]. A study sampling fish from several lakes in Ghana determined DDTs to have the highest concentration, with the highest level found in a catfish (2,205.50 *n*g/g lw) (Table 1) [1].

Dairy products: Examination of dairy products in the Kumasi metropolis showed pesticide contamination, with 75% containing aldrin [25]. Of note in these samples was the high ratio of DDT to DDE concentrations, suggesting recent exposure to DDT, although regional variations were present (Table 1).

Morocco

Vegetables: Tomatoes cultivated in greenhouses in the Souss Massa Valley of Morocco showed endosulfan as the predominant OCP (1.2 mg/kg), but only 2 of 120 samples exceeded MRLs established by European Union legislation (Table 2) [76]. Dicofol was also detected in samples.

Fish and shellfish: A separate study focused on clams and eels sampled from the Moulay Bousselham lagoon on the west coast of the country [61]. DDTs were shown to accumulate, particularly in samples taken from near channels draining agricultural land. Notably, higher concentration was observed in eels, particularly in large specimens.

Nigeria

Cereal crops: White maize samples from markets in the Lagos State were analyzed for OCP residues [68]. 96% of samples contained at least one OCP, with the mean OCP concentration up to 52.0 μg/kg; this resulted in MRLs being exceeded in up to 7% of the samples. The study highlighted particular concern for levels of aldrin and dieldrin in the diet (Table 1).

The Gambia and Senegal

Fish and shellfish: Sampling of fish and shrimps from local markets in The Gambia and Senegal showed contamination of OCPs, mostly DDTs [55]. DDT levels in fish and shrimp (mean 95.2 *n*g/g fat) were less than the European Union MRL of 1,000 *n*g/g edible fat. Analysis of molluscs from southwestern Senegal also confirmed contamination with OCPs, including lindane, HCB, cyclodienes (heptachlor and *trans*-nonachlor) and DDTs [19]. In these molluscs, OCP levels were similar to those found in surface sediments. DDTs were the most abundant OCP (up to 15.6 *n*g/g dw) (Table 1).

South Africa

Chicken eggs: In the Limpopo Province of South Africa where DDT is used for IRS, chicken eggs were found to contain DDTs up to 48,000 *n*g/g ww [20].

Fish: In the same region, DDTs were detected in 2 fish species, with concentrations and pollutant profile varying depending on sampling location [15].

Vegetables: Leafy vegetables in the same region were shown to have a predominance of *o,p'*-DDT and *o,p'*-DDD, while *p,p'*-DDE predominated in chicken samples; both food types exceeded safe consumption limits by WHO guidelines [87].

Milk: KwaZulu-Natal Province is another malaria control area, but DDTs detected in cow milk samples in this region were lower than FAO-stipulated MRLs (Table 1) [77].

Tanzania

Fish and Shellfish: Tilapia fish from 4 lakes in Tanzania showed geographical variation in pollutants, with endosulfanes highest in Lake Victoria (mean 94 *n*g/g lw) and DDTs highest in Lake Tanganyika (mean 274 *n*g/g lw); levels were below EU MRLs [74]. Assessment of various OCPs in Nile tilapia and Nile perch from Lake Victoria detected only DDTs and endosulfans, mostly less than calculated ADI limits [41]. Crustaceans collected from coastal and estuarine sites near Dar es Salaam contained DDTs at levels deemed safe for human consumption, with levels depending on mode of feeding and age of the specimen (Table 1) [64].

Vegetables: An interesting study analyzed "table-ready" foods (ready for consumption), and although levels did not pose a health risk according to recommended limits, there was concern over the presence of DDTs in foods, particularly spinach (2.89 μg/kg) [65].

Togo

Cereal crops: Assessment of cowpea grains and maize grains in Togo detected several OCPs, including dieldrin, endrin, heptachlor epoxide and endosulfan [59].Although levels in maize (up to 65.70 μg/g) were below the MRL set by the World Health Organization (WHO) (Table 2), those in cowpea grains exceeded this level (up to 98.79 μg/g) (Table 1).

Tunisia

Fish: Fish contaminated by OCPs in Tunisia have been investigated in a number of species—Dover sole, mullet and sea bass—in the Bizerte Lagoon in the northern part of the country [7, 17]. In the Dover sole study, the dominant chemicals were HCB, *p,p'*-DDE and *o,p'*-DDD. The report suggests many sources for the pollution, including surface run-off and wastewater discharges from intensively cultivated areas. DDTs were present in greater levels than HCHs or HCB. The distribution pattern of pesticide accumulation differed between fish species, with Dover sole containing the highest levels overall (752 *n*g/g lw for all OCPs, compared to 265 *n*g/g lw in sea bass and 157 *n*g/g lw in mullet) (Table 1).

Uganda

Fish: Nile perch and Nile tilapia sampled from the northern shore of Lake Victoria in Uganda contained HCHs, at levels considered safe for human consumption [82]. Assessment of other OCPs in these fish also showed residues below recommended MRLs [46]. In southwestern Uganda, 5 fish species from Lake Edward were analyzed for DDT, and a maximum level of 68 μg/kg fw was detected; most samples were below FAO/WHO MRLs (Table 2) [81]. Fish farms in Uganda export internationally, and analysis of such farmed Nile tilapia and African catfish detected OCPs, although within prescribed limits [13]. Interestingly, DDT and endosulfan were only detected in catfish, suggesting this species is more prone to contamination than tilapia. Belly flap oil from Nile perch in Lake Victoria was found to contain several OCPs, predominantly DDTs [69]. Concentrations of these increased with fish size, and notably levels of endosulfan in the group of largest fish exceeded MRLs.

Milk: Cow's milk from Kampala markets showed pasteurized samples to contain lower levels of OCPs than fresh samples, however, most were above international residue limits and thus likely pose a risk to human health from consumption (Table 1)[43].

Comparing the OCP situation in African countries with that outside Africa, it notes worthy that DDT use has been banned since the 1970s/1980s in Europe, North America and the temperate industrial regions of the northern hemisphere. DDT use was continuous in some parts of Asia and Africa as well as in central and south America [42]. For instance, approximately a 100-fold reduction in the concentration of DDT and HCH is recorded in farm products during the last two decades in India [45]. Correspondingly, in Japan, DDT and HCH concentrations were less than in developing countries, as their concentrations in most food stuffs were less than 0.05% of the recommended MRLs [58].

In general, analysis of the cited literature in this mini-review showed a clear bias in reporting of pesticide contamination in peer-reviewed publications, with some African countries highly represented, such as Egypt, Ethiopia, Ghana and South Africa. Data about national pesticide usage—current and historical—are not always readily available, and it is unlikely that published reports accurately reflect the extent of pesticide contamination in each country. Of note was the detection in foods of certain pesticide residues in areas where use of specific pesticides has been banned. Some of these may be due to persistence in the environment, but it is suspected that some instances relate to inappropriate or illegal use of pesticides [79].

PUBLIC HEALTH IMPORTANCE OF OCPS

It is well-established that some OCPs are still used in African countries for various reasons including disease control, malaria

Table 3. Reported levels of OCPs in human serum samples in African countries

Country	Pesticide	Concentration detected (*ng*/g lw)	Reference
Benin	*p,p'*-DDT	497	[12]
	p,p'-DDE	21	
	β-HCH	3	
	Trans-nonachlor	2	
Congo Republic	ΣOCPs	660	[52]
Egypt	DDE	40	[2]
Gambia	ΣDDTs	<10	[55]
Ghana	HCB	30	[66]
	p,p'-DDE	380	
Guinea Bissau	ΣDDTs	131	[52]
Senegal	ΣDDTs	124	[52]
Sierra Leone	ΣDDTs	574	[52]
South Africa	ΣHCHs	956	[23]
Sudan	Heptachlor	170	[30]
	ΣDDE	618	
	α-HCH	92	
	Dieldrin	82	
Tunisia	*p,p'*-DDE	169	[18]
	HCB	49	
	p,p'-DDE	128	[10]
	HCB	20	

lw=lipid weight. DDTs=DDT + DDE + DDD, HCB=hexachlorobenzene, HCH=hexachlorocyclohexanes.

in particular [88]. These and obsolete pesticide stocks can contaminate food, water, soil and air, and pose serious health threats to Africa's rural and urban populations [86]. Thus, OCPs, exposure is a public health concern among African populations. It is not surprising that, according to WHO, one-third of disease burden in Africa is attributable to environmental hazards [75]. However, there is a lack of clear epidemiologic data relating specific pesticide exposures to adverse health effects among African populations. In this section, we will highlight recent studies (published between 2000/01/01 and 2015/07/13) confirming human exposure to OCPs with serum and breast milk concentrations and possible related adverse health effects.

DETECTION OF OCP RESIDUES IN HUMAN SERUM IN AFRICAN COUNTRIES

Benin

Azandjeme *et al.* [12] measured the distribution of serum concentrations of 14 OCPs in 118 diabetic subjects (54.2% men and 45.8% women; 43% lived in urban areas, 14.4% were obese, and 39.8% had high economic status) in Benin. The four detected OCPs were *p,p'*-DDT (497.1 ± 4.5), *p,p'*-DDE (20.6 ± 7.9), β-HCH (2.9 ± 3.4) and trans-nonachlor (2.0 ± 2.3) *ng*/g of total serum lipids. OCP levels were significantly higher in obese, wealthier and more educated subjects, and in those living in urban areas as compared to the other groups, particularly for *p,p'*-DDE, *p,p'*-DDT and β-HCH (Table 3).

Egypt

Ahmed *et al.* [2] conducted an investigation to detect residues of DDE in blood serum samples collected from fasting females in Port Said, Egypt, between July 1999 and July 2000. Included in the study were 43 women diagnosed with invasive adenocarcinoma of the breast, 21 suffering benign breast disease and 11 healthy individuals. Mean residues of DDE detected in the three groups examined were 41 ± 5.2, 48 ± 6.2 and 31 ± 2.5 *ng*/g for breast cancer cases, benign breast disease cases and controls, respectively, indicating significantly lower residues in blood serum from control females (Table 3). In addition, Elserougy *et al.* [31] found a high odds ratio (8.3) in *o,p'*-DDD between maternal and umbilical sera of mothers, suggesting potential placental transfer of OCPs between mothers and their children during pregnancy.

Sene-Gambian Region

Manirakiza *et al.* [55] measured the OCP concentrations in human serum samples from the Sene-Gambian region. α-HCH, *p,p'*-DDE, *o,p'*-DDT and *p,p'*-DDT were detected in all 16 pooled serum samples, whereas endosulfansulfate, methoxychlor, mirex, heptachlorepoxide and endrin were detected in 15 samples. For each OCP detected, most of the concentrations were below 10 *ng*/m*l* lipid (Table 3).

Ghana

Ntow [66] collected serum samples from inhabitants of Akumadan, a prominent vegetable-farming community in Ghana. High HCB and *p,p'*-DDE residues were found in serum; mean values were 30 *n*g/g and 380 *n*g/g, respectively. Additionally, DDTs and dieldrin residues were significantly higher ($P<0.05$) in males' than in females' pooled samples of human serum (n=115) from vegetable farmers in Ghana, during 2005 [67] (Table 3).

Guinea-Bissau

Linderholm *et al.* [50] collected serum samples from an open cohort of police officers in Guinea-Bissau, (n=33) at five time points between 1990 and 2007, totaling 147 samples. They observed that the major OCP in all samples was *p,p'*-DDE followed by *p,p'*-DDT. Levels of *p,p'*-DDE, *p,p'*-DDT, β- and γ-HCH significantly decreased over time.

South Africa

Channa *et al.* [23] reported on the concentrations of α-, β- and γ-HCH and HCB detected in maternal blood plasma from delivering women (n=241) in three coastal sites of the KwaZulu-Natal Province, South Africa. γ-HCH was the most dominant pesticide at all three sites. Significantly higher levels of γ-HCH (mean 956 *n*g/g lipids) were found in site 3 (Empangeni town vicinity) compared to the other two sites. HCB, α-HCH and β-HCH were detected in less than 31% of the samples from all sites. Additionally, investigators concluded that the high levels of γ-HCH in maternal plasma samples at site 3 indicate current and on-going exposure, which is of great concern for reproductive health and perinatal exposure (Table 3).

Sudan

Elbashir *et al.* [30] collected 96 human blood samples from six locations representing areas of intensive pesticide use, including irrigated cotton schemes (Wad Medani, Hasaheesa, Elmanagil and Elfaw) and sugarcane schemes (Kenana and Gunaid) in Sudan. Residues of *p,p'*-DDE, heptachlor epoxide, γ-HCH and dieldrin were detected in blood from all locations surveyed. The levels of total organochlorine burden detected were higher in blood from people in the irrigated cotton schemes (mean 261 *n*g/m*l*) than from the irrigated sugarcane schemes (mean 204 *n*g/m*l*). The highest levels of heptachlor epoxide (170 *n*g/m*l*) and γ-HCH (92 *n*g/m*l*) were observed in blood samples from Hasaheesa, while the highest levels of DDE (618 *n*g/m*l*) and dieldrin (82 *n*g/m*l*) were from Wad Medani and Kenana, respectively (Table 3).

Tunisia

Ben Hassine *et al.* [18] detected *p,p'*-DDE and HCB in >95% of human serum samples (n=113) from Bizerte, northern Tunisia, collected between 2011 and 2012. The mean levels of *p,p'*-DDE and HCB in serum were 168.8 and 49.1 *n*g/g lipid, respectively. However, in another study, slightly lower concentrations (127.59 and 19.98 *n*g/g lipid) were recorded for *p,p'*-DDE and HCB in serum samples from 54 Tunisian women [10]. These authors observed that age, working outside the home and cereal consumption were positively correlated with serum levels of *p,p'*-DDE (Table 3).

Luzardo *et al.* [52], measured levels of 36 POPs in the serum of recent immigrants (n=575) from 19 Sub-Saharan countries entering the Canary Islands, Spain. OCP levels increased with age. The most frequently detected compound was *p,p'*-DDE (100% of the samples); its parent compound (*p,p'*-DDT) was detected in 72.2% of the samples. Participants from the Republic of the Congo and Sierra Leone had the highest levels of OCP contamination (median 660 *n*g/g lipid and 574 *n*g/g lipid, respectively). Those from Guinea Bissau and Senegal had the lowest levels (median 134 *n*g/g lipid and 124 *n*g/g lipid, respectively).

DETECTION OF OCP RESIDUES IN HUMAN BREAST MILK IN AFRICAN COUNTRIES

During pregnancy, the placenta appears to allow transport of OCPs to the developing fetus [31]. Maternal breast milk is also a potentially significant source of some pesticides for breast-fed infants [63]. Conversely, pregnancy and lactation are routes by which OCPs can be decreased in the maternal body (by vertical transmission), and levels in maternal serum have been shown to reduce with each parity. Due to concerns regarding susceptibility to toxic effects of DDTs in young children, the focus of OCPs in breast milk samples has been mainly on assessment of levels of DDT and its metabolites [54].

Egypt

Elserougy *et al.* [31] detected lindane in breast milk of 38 healthy participants submitted to cesarean delivery with a mean value of 90 *n*g/g. DDTs were also detected in about 65% of breast milk specimens (Table 4).

Ghana

Both DDE and HCB were detected with mean concentrations of 490 *n*g/g lw and 40 *n*g/g lw, respectively, in breast milk samples taken from residents of a farming community, in Ghana [66]. Additionally, Ntow *et al.* [67] determined OCP concentrations in pooled samples of human breast milk (n=109) from vegetable farmers during 2005. The mean concentrations of ΣDDTs, ΣHCHs, dieldrin and HCB were 78.3, 46.4, 122.8 and 4.9 *n*g/g lw, respectively (Table 4).

Mozambique

Concentrations of DDTs in breast milk were higher in samples collected in 2006 (930 *n*g/g lw) compared with those from 2002

Table 4. Reported levels of OCPs in human breast milk samples in African countries

Country	Pesticide	Concentration detected (*ng*/g lw, except where specified)	Reference
Egypt	Lindane	90	[31]
Ghana	HCB	40	[66]
	p,p'-DDE	490	
	ΣDDTs	78	[67]
	ΣHCHs	46	
	Dieldrin	123	
	HCB	5	
Mozambique	ΣDDTs	930	[54]
South Africa	ΣDDT (*ng*/g)	ND–8,540	[70]
	ΣDDE	1–14,580	
	ΣDDD	ND–5,910	
	ΣDDTs (mg/kg mf)	8–140	[21]
	ΣDDTs (*µ*g/g mf)	1.3–10	[77]
Tunisia	ΣDDTs	1,164	[40]
	HCB	289	
	p,p'-DDE	661	[32]
	p,p'-DDT	438	
	p,p'-DDE	77	
	p,p'-DDT	106	
	ΣDDTs	1,931	[34]
	ΣHCHs	65	
	HCB	85	
	Dieldrin	25	
	HCB	260	[33]
	ΣHCHs	67	
	Dieldrin	59	
	ΣDDTs	3,863	

ND=below limit of detection, lw=lipid weight, mf=milk fat, LOQ=limit of quantification, LOD=limit of detection. DDTs=DDT + DDE + DDD, HCB=hexachlorobenzene, HCH=hexachlorocyclohexanes.

(370 *ng*/g lw) in two populations of mothers in Manhiça, Mozambique. The 2006 samples were obtained several months after implementation of indoor residual spraying with DDT for malaria vector control in dwellings, while the earlier samples were taken for reference prior to DDT use [54] (Table 4).

South Africa

A recent study investigated the levels of DDT in 163 breast milk samples from four South African villages, three of which use DDT in IRS to control malaria. Mean ΣDDT levels in breast milk were 18, 11 and 9.5 mg/kg mf from the DDT-sprayed villages, respectively, including the highest ΣDDT level ever reported for breast milk from South Africa (140 mg/kg mf) [21].

Tunisia

Ennaceur *et al.* [33] measured the levels of 13 OCPs in breast milk from 87 Tunisian mothers throughout their lactation periods. All samples contained detectable residues of DDT, and the mean concentrations of ΣDDTs, HCB, ΣHCHs and dieldrin were 3.863, 0.260, 0.067 and 0.059 *ng*/g lw, respectively. Additionally, OCPs were determined in breast milk samples (n=36) of primipara and multipara mothers from Bizerte in 2010 [40]. The mean concentrations of ∑DDTs and HCB in breast milk were 1,163.9 and 286.8 *ng*/g lw, respectively (Table 4).

It is clear from the previously mentioned information in this section that breast milk is a major source for OCPs by infants in areas where the pesticides are used. Infants depend on breast milk as their main source of nutrition and are therefore at high risk of adverse effects related to OCPs, such as neurological and reproductive disorders [14].

POSSIBLE HUMAN HEALTH HAZARDS FROM OCP EXPOSURE

In Africa, very few health effect studies of worker populations—including farm workers and those administering IRS—have directly assessed the adverse effects associated with single or multiple pesticide use and exposure among general African populations, and no studies have examined the toxicological consequences of interactions resulting from cumulative exposures to several pesticides in these populations. Most of the published studies on farmworker populations rely on self-reported information to diagnose adverse effects and therefore may not provide the most objective data.

OCPs are suggested to be endocrine disrupting chemicals [60], believed to produce a wide variety of adverse health outcomes in people, such as reduced fertility and fecundity, spontaneous abortion, skewed sex ratios within the offspring of exposed communities [89], and male and female reproductive tract abnormalities [22].

In South Africa, Aneck-Hahn *et al.* [8], conducted a cross-sectional study on healthy male subjects (n=311) between 18 and 40 years of age in Limpopo Province, an endemic malaria area where DDT is sprayed annually. The results showed a significant positive association between percent sperm with cytoplasmic droplets, low ejaculate volume and *p,p'*-DDT concentration. Additionally, 28% of the study group presented with oligozoospermia and 32% with asthenozoospermia. In another study, de Jager *et al.* [26] suggested a weak link between non-occupational environmental DDT exposure and a negative impact on sperm chromatin integrity in young South African males.

Positive associations of OCPs with a wide variety of human cancers have been reported (Høyer *et al.*, 2000). For instance, Ahmed *et al.* [2] reported higher residual levels of DDE in the sera of invasive adenocarcinoma cases compared with control subjects. In Tunisia, Arrebola *et al.* [9] found a positive association between breast cancer risk and β-HCH, HCB, heptachlor and *p,p'*-DDE.

From the aforementioned reports, it is clear that OCP exposure might have implications on public health. However, it notes worthy that analysis of public health implications of OCPs due to food consumption must be quoted carefully due to many reasons, such as: 1) Most studies take a single sample from each food type for analysis, but the distribution pattern of contamination within a foodstuff may vary. An example is higher pesticide residues present in the skin compared to the pulp of potato tubers [79]. 2) Concentrations of pesticides in soil samples can be important indicators as vegetables can accumulate these chemicals efficiently, with levels 4−45 times higher in the plant than in the soil [38]. 3) The method of farming and season also result in different residue concentrations in plants [57]. 4) Food preparation, particularly cooking, alters pesticide content and therefore human risk from consumption [49, 79]. 5) Another complicating factor in interpretation is a lack of standardization of reporting concentrations. As OCPs are lipophilic, it is often useful to report results according to lipid weight of samples, but for human risk analysis, dry weight or wet weight of foods is more relevant to estimate daily consumption values. Even within countries and sampling areas, there may be great variation in levels of residue concentrations in samples, making general risk assessments difficult.

In many instances, high percentages of foods tested contained pesticide residues, often above MRLs set either at national or international levels. This shows that a potential risk exists for people consuming such foodstuffs. Some reports state the "violation percentage" of foods, that is, those containing levels greater than permissible limits. These stated limits vary, for example, European versus International (e.g. Codex Alimentarius Commission or Joint FAO/WHO Meeting on Pesticide Residues) limits, making comparative interpretation difficult. Where multiple chemicals are analyzed concurrently, samples are often shown to contain residues from many compounds [53]. The toxic effects of such chemical cocktails are difficult to ascertain. Age or life stage of the consumer may also be relevant to the exposure risk or toxic effects−for example, children may be exposed to higher levels of DDTs from breast milk and may also be more susceptible to the endocrine disruptive effects of such chemicals [63].

CONCLUSION

Food contamination is the main route of exposure to OCPs for people. However, levels of OCP residues in food and possible human health risk assessment must be analyzed carefully for several reasons. These reasons include the sample size, the type of the plant, the consumed parts of the plant, the feeding habits of the people in each country, the method of farming and the season, food preparation methods, and the lack of standardization of reporting concentrations, age and health conditions of the consumers.

In addition, this review declares without doubt that Africa's environmental health issues are complex and need more effort and collaborations between governmental authorities and research institutes for continuous surveillance programs in order to draw a clear map about the pesticide situation in Africa, in particular OCPs.

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