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REVIEW ARTICLE

Pesticide residues in fruits and vegetables in Ghana: a review

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Abstract Pesticides are known to improve agriculture yield considerably leading to an increase in its application over the years. The use of pesticides has shown varying detrimental effects in humans as well as the environment. Presently, enough evidence is available to suggest their misuse and overuse in the last few decades in most developing nations primarily due to lack of education, endangering the lives of farmers as well as the entire population and environment. However, there is paucity of data especially over long durations in Ghana resulting in the absence of effective monitoring programs regarding pesticide application and subsequent contamination in fruits and vegetables. Therefore, this review discusses comprehensively pesticide type and use, importation, presence in fruits and vegetables, human exposure, and poisoning in Ghana. This is to alert the scientific community in Ghana of the need to further research into the potential implications of pesticide residues in food commodities in order to generate a comprehensive and reliable database which is key in drafting policies simultaneous with food regulation, suitable monitoring initiatives, assessment, and education to minimize their effects thereon.

Keywords Pesticides · Monitoring · Human exposure · Poisoning · Fruits and vegetables · Ghana

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Introduction

Fruits and vegetables are vital to human health as they are known for boosting the immune system. Many studies have identified phytochemicals, minerals, and others in fruits and vegetables to be very essential in human development. Health professionals as well as nutritionists keep encouraging people to live on fruits and vegetables to avoid killer diseases such as cancer and cardiovascular diseases. While many think of the gains associated with the consumption of fruits and vegetables, there is growing concern on the cultivation of these with agrochemicals, fertilizers, and pesticides.

Pesticides, in particular, are compounds with known inherent toxicity. Their heavy application could result in diffuse pollution that can bring about disturbance of the natural balance, widespread pest resistance, environmental pollution, and hazards to humans and wildlife (Claeys et al. 2011; Hjorth et al. 2011). Thus, the presence of pesticide residues in food commodities is a source of great worry; what makes it more complex is that some of these fruits and vegetables are consumed fresh or semi-processed which may contain elevated levels of chemicals compared to other food crops of plant origin. Exposure to pesticides through diet is thought to be five orders of magnitude higher than other exposure routes, for example, air and drinking water (Claeys et al. 2011; Chen et al. 2011).

Currently, the application of various pesticides in agriculture has escalated, resulting in better food production to meet population demands globally; nevertheless, the fact that the environment and farms produce contamination via residues cannot be denied. Moreover, developing countries in the tropics are guilty of increased usage of pesticides, for example, in fruit and vegetable baskets for export, to meet the supply and demand throughout the year from developed nations. Accordingly, residues of pesticides remaining in the soil, water, and crops eventually enter the food chain and are therefore ingested by humans (Ecobichon 2001; Carvalho 2006; Hjorth et al. 2011). Consequently, human health impacts ranging from short-term (e.g., headaches and nausea) to chronic (e.g., cancer, reproductive harm, and endocrine disruption) may occur (Berrada et al. 2010).

In fruits and vegetables, pesticides are used for better quality and high yield of crops. Some are applied to crops during the entire period of growth and sometimes at the fruiting stage; others are used to protect the produce after harvesting. These are absorbed by the vegetables, which turn out to be noxious when consumed by humans. It is believed that more than 1000 compounds are applied to agricultural crops to control undesirable weeds, molds, insects, and pests. Additionally, pesticide experts think that pesticide residues in various fruits and vegetables could be more than the prescribed guideline values of the European Union (EU), World Health Organization (WHO), and Food and Agricultural Organization (FAO). The content of pesticides in various fruits and vegetables does not depend only on the sprayed amount over them but also on the content present in the soil or water used for irrigation. Without pesticides, crop yields would fall, costs would surge, and many fruit and vegetables would end up with more maggots and molds (Sharma et al. 2010 and references therein; Chen et al. 2011).

In most developing countries like Ghana, organophosphorus and synthetic pyrethroids are the most commonly applied insecticides for pest and disease vector eradication. Other banned, cheap pesticides, organochlorines like DDT and HCHs, are also utilized in many countries (e.g., Philippines, Brazil, Bangladesh) in the tropics. As a consequence of poor handling practices and use of toxic pesticides by farmers as well as inadequate management and regulation of these chemicals in developing nations, the occurrence of pesticide poisoning in these nations far outweighed that of the developed world. Risk to public health is higher as well (Carvalho 2006; Chen et al. 2011).

Given the potential risk of pesticides to public health, the use of pesticides in agriculture is subjected to constant monitoring. The surveillance focuses on the proper use of pesticides in terms of authorization and registration and on compliance with maximum residue limits (MRLs). For that matter, numerous studies have been documented in the literature about pesticide contamination of fruits and vegetables. In this regard, surveillance studies have been executed to understand the level of contamination, if any, to initiate measures to mitigate pesticide poisoning; however, these concerns are not well addressed in most developing nations including Ghana. The most interesting issue is that in most African countries, pesticide management capacities vary widely; this situation is poorly documented to provide reliable data and information for programs to improve pesticide management confidence (Bempah and Donkor 2011; Bempah et al. 2011a, b; Suglo and Pwamang 2012).

The literature has limited number of publications on continuous monitoring of pesticide residues in fruits and vegetables in Ghana. In the last 20 years (1994–2014), over 30 scientific studies associated with pesticide residues in water, soil, fish, fruits, vegetables, crops, and humans in Ghana have been reported (e.g., Mawuenyegah 1994; Ninsin 1997; Osafo and Frempong 1998; Botchwey 2000; Ntow 2001, 2005; Ntow et al. 2006; Darko and Akoto 2008). These studies differ widely in their design features, such as site selection strategy, duration of work, sample collection method, species or type of crop, and method of analysis. Moreover, currently, there is no national program on the monitoring of pesticide residues in crops in Ghana. Most of the works have been on organochlorine pesticides which were phased out years ago, but their residues may still be present in the environment. The usual duration of the study is from 1 to 11 months because of the differences among the design, sampling dates, and methods of analysis. Accordingly, it is difficult to combine data from different studies to come up with an overall national assessment. However, data from individual studies can be used to assess the trend of pesticides in a particular locality.

This review and critical discussion suggest that Ghana is lagging behind in terms of monitoring programs as pesticide contamination of fruits and vegetables are on the rise. This is due to the increased application of these chemicals, although it is well known that pesticides boost agricultural production. Therefore, this review is to provoke discussions and scientific studies to stimulate research on potential implications of pesticide residues in fruits and vegetables in Ghana like in any other developing nation where its use is on the increase. Additionally, the review also seeks to bring to light some actions that could enhance pesticide use, control, compliance, education, and advice to the public on the consumption of fruits and vegetables.

Geographical location of Ghana

Ghana, the country under review, is located on the west coast of Africa, about 750 km north of the equator between the latitudes 4° and 11.5° north and longitudes 3.11° west and 1.11° east. It is bordered on the north by Burkina Faso, on the west by La Cote D'Ivoire, on the east by Togo, and on the south by the Gulf of Guinea (Atlantic Ocean) (Fig. 1). The Greenwich Meridian (zero line of longitude) passes through

Ghana, making it the closest landmark to the center of the world.

Agriculture in Ghana

Ghana is one of the most thriving democratic countries on the continent. It has often been referred to as an “island of peace” in one of the most chaotic regions on earth. The country’s economy is dominated by agriculture, which employs about 40 % of the working population. Thus, the livelihood of most Ghanaians depends either on agriculture or agricultural related businesses. It employs people from production and manufacturing to agricultural service providers. Peasant as well as commercial farmers all derive their sustenance from this sector (Asare 2012).

Furthermore, to avoid the dependency of Ghana on cocoa alone, the government of Ghana for some time now has encouraged the production of some high-valued crops like cashew nut, pineapple, banana, mangoes, kola nuts, tomatoes, groundnuts, etc., considered as non-traditional cash crops. These emerging cash crops are now making great contribution in terms of foreign exchange to Ghana (Asare 2012).

The use of pesticides in these emerging, as well as the traditional cash crop, production is boosting crop yield yearly. For example, in the cocoa sector, the use of pesticides in 2012 helped the country to produce over one million metric tons of cocoa, an unprecedented production capacity in the history of Ghana. The similar increase was observed for cashew nut; in 2011, Ghana exported 280,834 metric tons of raw cashew nut valued at US$379 million, a rise from the 82,732 metric tons in May 2010 (Asare 2012; Global Agricultural Information Network, Gain Report 2012).

Patterns of agricultural production

Crop production

Ghana has several staple crops like maize, rice, sorghum, millet, cowpea, yam, plantain, cassava, etc. Some of the horticultural crops are pineapple, banana, mango, papaya, citrus, tomato, garden egg, okra, pepper, onions, and shallots, whereas the commercial crops are cocoa, oil palm, cotton, sheanut, coffee, rubber, and coconut.

Land areas available for planting different crops increased only marginally between 2000 and 2008, that is, about 17.3 % or an increase of about 1.9 % per year over the period (SRID 2008). Overall, increase in the production of all arable crops between 2000 and 2008 is also about 41.1 or 4.6 % per year over the period (Suglo and Pwamang 2012; SRID 2008). Studies of the components of agricultural growth suggest that most agricultural growth has been mainly due to land area expansion as opposed to yield increase (Ministry of Food and Agriculture 2010).

Trends and patterns of pesticide use in Africa

Data on pesticide use and sales in the world is hard to find. However, in 2006 and 2007, the world used approximately 5.2 billion pounds (2.358 million tons) of pesticides, with herbicides constituting the biggest part of the world pesticide use at 40 %, followed by insecticides (17 %) and fungicides (10 %) (EPA 2011). It has been estimated that millions of tons of pesticides are being applied worldwide each year and keep on increasing with the passage of time. Similar trends have also been observed in Africa where mainly insecticides, herbicides, fungicides, and bactericides are employed that are all imported. In terms of import value, Ghana ranks second to South Africa followed by Morocco, Kenya, and Nigeria in Africa (Suglo and Pwamang 2012).

Table 1 shows pesticide consumption data for some African countries. Several tons of pesticides are used annually by most nations (FAOSTAT 2015). Available data further reveals that between 2000 and 2004, lower quantities of pesticides were applied, a case in point is Ghana; but thereon, trends have shot up in most nations except Gambia where there is inconsistency because of lack of data. Compared to other continents, pesticide use in Africa has been very low due to several factors like poverty, instability, unreliable rains, and varied soils that do not allow modernization of agriculture (Mansour 2004).

Importation of pesticides in Ghana and uses

Table 2 shows tons of pesticides used in Ghana from 1995 to 2009. The use of pesticides to control pests in Ghana has been in existence for decades. Data available indicates that in 2009, 3448.71 t of insecticides, 9979.25 t of herbicides, and 1273.59 t of fungicides and bactericides were used in Ghana. From 2000 to date, the amount of pesticides has increased. The total pesticide consumption of Ghana in 1995 was 131.6 t; this rose to 8729.04 t in 2004, several orders of magnitude higher, peaking 14,701.55 t in 2009 (FAOSTAT 2015).

Ghana import values for pesticides

Total pesticide import values for Ghana between 2001 and 2013 (Fig. 2) reveal continuous upward trends in pesticide usage except 2006 to 2007 and 2012 to 2013. The highest importation of total pesticides was recorded in 2011, valued at about 370 million dollars (FAOSTAT 2015). Though the country has no capability to manufacture pesticides, it is able to formulate and package imported pesticides. Few

Fig. 1 Map of Ghana

insecticides are formulated and packaged for the cocoa subsector. The only herbicide formulated and packaged in Ghana is glyphosate by a Chinese company (Wynca) in the Ashanti region. Chemico Ltd., in Tema is the second company that formulates and packages a variety of pesticides (Suglo and Pwamang 2012).

Insecticides, herbicides, and fungicides form the largest portion of agrochemicals imported into the country like any other African nation (Table 1). The importation of both liquid insecticide and herbicide formulation increased significantly in 2011. The liquid and solid formulations of insecticide increased by 58 and 19.4 %, respectively. The importation of solid fungicide, which recorded a decline in 2010, increased by 145 % in 2011; however, liquid fungicides declined by 92.5 %. The number of major importers of agrochemicals increased from 12 to 24 in 2011. These figures exclude imports by Ghana COCOBOD, which is a significant consumer of agrochemicals (Suglo and Pwamang 2012).

With regard to horticultural crops grown for local consumption like tomatoes, garden eggs, okra, pepper, onions and shallots, and citrus and watermelon, farmers use significant volumes of pesticides with frequent abuse and misuse. These produce are normally for the local markets. On the contrary, in the case of horticultural crops (pineapple, mango, papaya, citrus, yam, and butternut) for export, pesticides are applied with restriction on crops to a very large extent as a result of stringent food safety demands made by trading partners that promote the adoption of integrated pest management (IPM) (Suglo and Pwamang 2012). The main crops and uses of pesticide products registered in Ghana as of the 30th of June 2013 are given in Fig. 3. The numbers indicate the registered pesticides normally used per crop.

Pesticide registration

The part II of the Environmental Protection Agency Act (Act 490) which is the pesticides regulation in Ghana is being administered by the Chemicals Control and Management Center (CCMC) of Environmental Protection Agency since 1994. This Act regulates registration, licensing, issuing of permit for exports and imports of chemicals, and inspection and monitoring of industrial/consumer chemicals and agrochemicals in Ghana. The list includes the active ingredients, number of active brands, and type of crops/pests it controls with World Health Organization (WHO) hazard class as registered in Ghana as of the 30th of June 2013 (Table S1).

Th toxicity of the formulated chemical product is classified according to WHO hazard classes. Pesticide belonging to WHO class I A is extremely hazardous, class I B is highly hazardous, class II is moderately hazardous, class III is slightly hazardous, and class U is unlikely to present acute serious hazards in normal use (WHO 2009). Nearly 90 % of the banned pesticides fall into categories IA/IB/II of the WHO hazard grades.

Thus, in Ghana, 52 % of pesticides registered are in class III, 33.6 % in class II, 11.2 % in Class U, and 3.2 % in class IB. Table 3 shows the summary of registered pesticides as of 30 June 2013, with insecticides constituting the biggest part of the pesticide use at 46.5 %, followed by herbicides (39.7 %) and fungicides (10.8 %).

Pesticides in fruits and vegetables in Ghana

Farmers around the world including Ghana use pesticides as an insurance policy against the possibility of a devastating crop loss from pests and diseases. Accordingly in Ghana, for decades, pesticides have been employed not only in agriculture to control and eradicate crop pests but also in the public health sector for disease vector control. Nevertheless, there has been a rapid increase in the quantity and use of pesticides (insecticide, fungicides, herbicides, bactericides, rodenticides, and plant growth regulator) in agriculture over the past years (957,474.2 t in 1992 to 1,912,994 t in 2007) (FAOSTAT 2015). Moreover, this growth trend is expected to heighten for the next decades. Agricultural pesticides are used in cocoa, coffee, and cotton farming; in vegetable and fruit production; and for other mixed crop farming systems involving cereals (mostly maize), tuber crops (e.g., yam, cassava), legumes (e.g., cowpeas), sugarcane, rice, etc. The majority of these pesticides are employed in the forest areas or farming regions noted for the production of these crops located in Ashanti, Brong Ahafo, and eastern and western regions of Ghana (Ntow 2005; Amoah et al. 2006).

Dinham (2003) estimates that 87 % of farmers in Ghana use chemical pesticides to control pests and diseases on vegetables and fruits. Ntow et al. (2006) gave the proportions of pesticides used extensively on vegetable farms, in small or large amounts by farmers, as herbicides (44 %), fungicides (23 %), and insecticides (33 %). Herbicides are the predominant pesticide type use in vegetable production in Ghana probably due to the farmers' perception of weed control. The reason was as long as it is profitable, and no better alternatives are available; the spraying of pesticide is a good investment (Hardy 1995). More so, the chemical control method is very effective, rapid in curative action, adaptable in most situations, and flexible in meeting changing agronomic, ecological, and economical conditions (Metcalf 1975; Newsom et al. 1976).

Among the different types of pesticides known, organochlorine pesticides were extensively used by farmers in the 1980s, because of their cost effectiveness and broad spectrum activity. Lindane was widely used in Ghana on cocoa plantations and farms and for the control of stem borers in maize (Ministry of Agriculture 1990). Endosulfan was popularly used in cotton-growing areas, on vegetables farms, and on coffee plantations (Gerken et al. 2001). On the other hand, DDT, lindane, and endosulfan were also employed to control the ectoparasites of farm animals and pets in Ghana (Ntow et al. 2006), but at the moment, these pesticides are not used in agricultural production because of their toxicity and persistence in the environment.

The impact of pesticides have been reported in fruits and vegetables at different intervals throughout Ghana (e.g., Mawuenyegah 1994; Ninsin 1997; Botchwey 2000; Ntow 2001; Aboagye 2002; Amoah et al. 2006; Kotey et al. 2008; Darko and Akoto 2008; Essumang 2008; Armah 2011; Botwe et al. 2011; Bempah et al. 2011a, b, 2012a, b; Akoto et al. 2013). The data gathered from the literature has been sorted out chronologically. Tables 4 and 5 demonstrate that majority of the samples are contaminated by chlorinated pesticides, exceeding the maximum residue limits (MRLs) which can cause hazard to consumers.

The organochlorines (OCs) appeared to be the most detected and studied in the literature revealing either its past usage or persistence in the soils reflected in the vegetables and fruits indicated earlier. Perhaps farmers clandestinely obtained these chemicals and are currently applying them secretly even though it is prohibited in the Ghanaian environment. The organophosphorus (OPs) dichlorvos and chlorpyrifos were also found to be the most popular pesticide applied among the vegetable growers, excluding lambda cyhalothrin. The utilization of synthetic pyrethroids (SPs) is now on the rise by most fruit and vegetable farmers in Ghana. The findings by different groups elucidate this (e.g., Darko and Akoto 2008; Essumang 2008; Armah 2011; Bempah and Donkor 2011; Akoto et al. 2013).

Unfortunately, fruits and vegetable farming and their consumption are concurrently progressing steadily in the Ghanaian environment. Yet, the impact of pesticides, particularly OPs and SPs, in the Ghanaian environment has not received the fullest attention with the increase in its usage. In June 2013, the percentage of OPs and SPs registered is only 23 % of the total of 406 and being 50.8 % only of the total insecticides registered (EPA, Ghana 2013). A general summary of the inventory regarding OPs and SPs pesticides that are frequently being used in fruits and vegetable farming in Ghana is presented in Table 6.

The non-conforming results of pesticide residue on the fruits and vegetables detected because of the different types of pesticides applied by farmers further suggested a great potential for systemic toxicity in children considering that they

Table 1 Pesticide use (tons) in some African countries from 2000 to 2012

Country	Type of pesticide	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Algeria	Insecticides	–	–	–	–	4453.23	996.55	762.58	2280.47	1262.6	1603.6	655.998	1483	1267
	Herbicides	–	–	–	–	300.26	446.17	530.4	591.38	948.04	596.01	768.448	978	1050
	Fungicides and bactericides	–	–	–	1913.76	1831.89	1013.44	1298.75	1238.23	2011.69	1872.32	3000	3081	–
Burkina Faso	Insecticides	–	–	–	101.42	1.06	429.08	505.96	1285.7	893.2	522.72	109.69	186	–
	Herbicides	–	–	–	1.56	25.2	37.74	56.42	487.41	53.76	520.91	333.2	657	–
Cameroon	Insecticides	85	113	2084.59	2481.98	2718.73	2016.25	2986.24	2964.88	2458.59	2020.29	3467.28	3670.7	–
	Herbicides	103	117	1442.29	2090.42	2055.04	1841.18	2067.76	2769.4	2518.26	2353.1	3470.2	4000.2	–
	Fungicides and bactericides	357	451	2264.25	2474.4	1954.44	2173.4	2308.76	1867.62	1958.55	1874.95	2457.46	3076.4	–
Egypt	Insecticides	–	–	–	–	–	3477	4905	4777	3603	3304	4390	5148	4808
	Herbicides	–	–	–	–	–	882	1805	1756	2055	2539	2854	2479	2809
	Fungicides and bactericides	–	–	–	–	–	1112	3071	2572	3869	3170	4346	5318	6374
Ethiopia	Insecticides	38	153	–	–	–	45.9	608.9	666.4	457.8	370.9	638.4	–	–
	Herbicides	533	454	–	–	–	1197.6	1821.3	1713.5	1635.3	3105.9	3109.7	–	–
	Fungicides and bactericides	30	15	–	–	–	146.7	143.8	197	171.9	222.4	377.1	–	–
Gambia	Insecticides	269	226	244	340	502	629	1170	408	–	–	–	–	–
	Herbicides	–	–	–	–	1	46	–	24	–	–	–	–	–
	Fungicides and bactericides	–	–	–	–	11	80	295	41	–	–	–	–	–
Ghana	Insecticides	47	47	1090	–	1278.68	2684.54	11,728	1015.34	3642	3448.71	–	–	–
	Herbicides	22	22	1345	–	2368.24	831.54	10,703	2569.79	7531	9979.25	–	–	–
	Fungicides and bactericides	12.57	13	582	–	634.12	1138.8	1318	1041.1	1740	1273.59	–	–	–
Libya	Insecticides	–	–	–	–	–	7271	3214	1796	2505	3379	1055	–	–
	Herbicides	–	–	–	–	–	362	947	161	262	363	222	–	–
	Fungicides and bactericides	–	–	–	–	–	334	181	445	27	350	–	–	–
Madagascar	Insecticides	59.45	22.32	200.6	12.94	13.38	53.11	29.48	33.72	34.97	43.06	99.19	156.82	159.28
	Herbicides	31	22.24	23.24	26.41	29.88	39.31	39.77	26.89	32.56	35.55	68.91	74.44	114.17
	Fungicides and bactericides	25	41.02	17	79.24	15.4	21.64	34.73	33.12	36.59	35.6	73.07	78.2	103.42
Mauritius	Insecticides	439	605	755	809	642	707	1288	648	645	837	948	904	843
	Herbicides	947	1042	1005	1212	1220	1192	911	1105	1394	1280	1206	1111	1047
	Fungicides and bactericides	163	177	199	201	210	242	188	212	210	207	229	257	196
Mozambique	Insecticides	–	–	6.04	99.63	185.25	254.54	439.24	172.34	437.12	180.23	398.46	200	–
	Herbicides	–	–	5.63	152.13	315.35	451.68	378.15	320.37	391.17	617.29	648.42	442.24	–
	Fungicides and bactericides	–	–	5.73	7.07	71.95	61.79	74.13	54.6	60.22	115.35	139.88	121.76	–
Rwanda	Insecticides	36	69	–	73.63	94.07	69.82	64.06	75	50.54	95.04	63.23	67.8	91.2
	Herbicides	4	1	–	3.37	5.57	–	–	7	0.01	1.35	1.24	9.2	10.29
	Fungicides and bactericides	107	1	–	63.68	59.9	153.1	224.66	316.11	271.2	1091.21	889.38	104.6	816.3
Togo	Insecticides	–	–	–	261.73	445.74	67.7	26.23	70.57	10.15	21.47	49.81	25.8	–
	Herbicides	–	–	–	92.99	86.73	98.25	127.35	113.52	97.48	93.03	113.43	88.83	–
	Fungicides and bactericides	–	–	–	15.85	11.06	9.8	8.87	11.08	11.05	12.06	11.52	11.24	–

Source: FAOSTAT, 2015

are the most vulnerable population subgroup (Bempah et al. 2011a, b). Moreover, the higher levels observed on the various fruits and vegetables could also be attributed to the farmers' poor knowledge in pesticide application, thus over abusing the chemical. The farmers' non-conforming attitude to extension officers' advice on the usage of these chemicals could play a key role. Additionally, the differences in the numbers by the different groups could arise from the source of food commodity and location of sampling, period of sampling, sample size, and method of analysis (Bonzongo et al. 2004). Further, the samples exceeding the MRLs could suggest poor agricultural practices on the part of farmers. The higher values of pesticide residues in these food commodities may also be a consequence of the

Table 2 Tons of pesticides used in Ghana from 1995 to 2009

Pesticides/year	1995	1996	1997	1998	1999	2000	2001	2002	2004	2005	2006	2007	2008	2009
Insecticides	32.4	1167.5	337	112.78	56.56	47	47	1090	1278.68	2684.54	11,728	1015.34	3642	3448.71
Chlorinated hydrocarbons	11.3	825.4	143	23.16	25.32	29	29	–	–	–	–	–	–	–
Organophosphates	0.9	1.3	64	77.75	18.4	8	8	–	152.72	–	–	92.12	–	–
Carbamates insecticides	17.3	325	122	0.09	0.06	–	–	–	6.27	–	–	5	–	–
Pyrethroids	0.2	1.9	7	11.7	11.58	7	7	–	808.16	–	–	513.58	–	–
Botanic production and biological	0.9	0.3	–	–	–	–	–	–	–	–	–	-	–	–
Other insecticides	1.8	13.6	1	0.08	1.2	3	3	–	311.53	–	–	404.64	–	–
Herbicides	8	287	68	54	37	22	22	1345	2368.24	831.54	10,703	2569.79	7531	9979.25
Phenoxy hormone products	2.9	7	3	3	1	–	–	–	27.4	352.16	–	348.22	–	–
Triazines	0.4	22	23	4	2	–	–	–	379.46	479.38	–	758.62	–	–
Amides	0.2	227	10	14	9	6	6	–	–	–	–	–	–	–
Carbamates herbicides	0.2	1	4	1	–	1	1	–	–	–	–	–	–	–
Dinitroanilines	0.6	5	–	1	–			–	–	–	–	–	–	–
Urea derivates	–	–	6	5	1	1	1	–	8	–	–	–	–	–
Sulfonyl ureas	0.1	2	–	–	–	–	–	–	–	–	–	–	–	–
Bipiridils	0.2	19	7	1	3	–	–	–	–	–	–	–	–	–
Uracil	–	–	3	5	2	1	1	–	5.4	–	–	–	–	–
Other herbicides	3.4	4	12	20	19	13	13	–	1947.98	–	–	1462.95	–	–
Fungicides and bactericides	25	121	95	131	16.57	12.57	13	582	634.12	1138.8	1318	1041.1	1740	1273.59
Inorganics	–	–	24	50	–	–	–	–	153.4	–	–	147	–	–
Dithiocarbamates	10	121	50	43	16.52	12.5	13	–	79	–	–	126	–	–
Benzimidazoles	1	–	9	9	–	–	–	–	–	–	–	–	–	–
Triazoles, diazoles	1	–	–	–	–	0.01	0	–	–	–	–	–	–	–
Diazines, morpholines	–	–	12	29	0.05	0.06	0	–	–	–	–	–	–	–
Other fungicides	13	–	–	–	–	–	–	–	401.72	–	–	768.1	–	–
Seed treatment fungicides	–	–	–	–	–	–	–	51	22.77	–	223	–	–	–
Botanic production and biological seed treatment fungicide	–	–	–	–	–	–	–	51	22.77	–	223	–	–	–
Seed treatment insecticides	–	–	–	–	–	–	–	–	44	–	–	–	–	–
Others—seed treatment insecticides	–	–	–	–	–	–	–	–	44	–	–	–	–	–
Plant growth regulators	–	–	2	–	4	0.06	0	–	16.71	–	–	–	–	–
Rodenticides and anticoagulants	0.8	–	–	–	–	–	–	–	–	–	–	–	–	–
TOTAL	131.6	3151	1002	595.56	224.26	163.2	164	3119	8712.33	5486.42	24,195	9252.46	12,913	14,701.55

Source: FAOSTAT, 2015

absence of updated food regulations, because food laws in Ghana are very old and keep silent about the pesticide residue limits in many food commodities.

Pesticides and human exposure

In spite of their huge benefits, pesticides do present risks to human health and the environment. These risks are a consequence of their inherent toxicities. Some growers sometimes harvest crops immediately after treatment with pesticides, ignoring the preharvest interval. Accordingly, an examination encompassing 30 organized farms and 110 kraals distributed throughout the 10 regions of Ghana, by Awumbila and Bokuma (1994), established that among the 20 different pesticides applied, lindane was the most widely distributed and employed. The usual method of application was by hand dressing, and no post application interval was observed before slaughter or sale of milk for human consumption (Awumbila and Bokuma 1994). Therefore, there is the potential for significant risk to human health, particularly to the applicators and consumers of

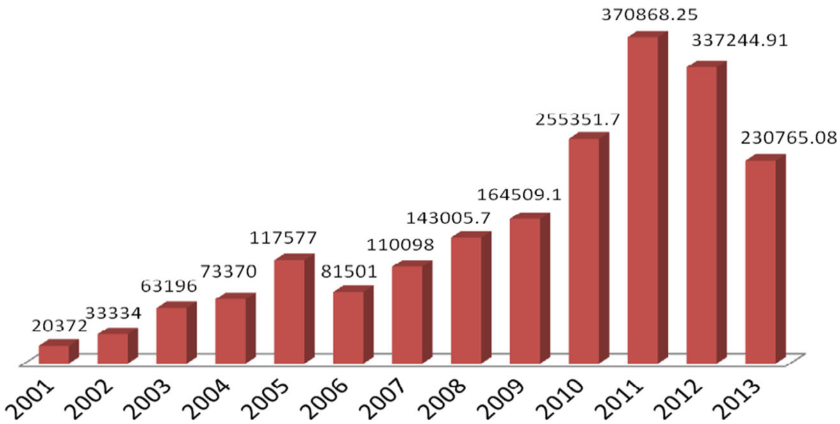


Fig. 2 Total pesticide import value in Ghana from 2001 to 2013 (US$ 1000) (FAOSTAT, 2015)

agricultural products. Similarly, Clarke et al.'s (1997) study on the knowledge, attitudes, and practices of 123 farm workers on three irrigation projects in Accra Plains regarding the safe handling and use of pesticides demonstrated that the majority of the workers were aware of pesticide absorption routes and potential symptoms after exposure. However, knowledge on safety measures and personal protective equipment was poor to moderate.

Many other studies of pesticide applications in Ghana are documented especially on the control of foliar insect pests of pineapple with chlorpyrifos, dimethoate, diazinon, cymethoate, and fenitrothion (Abutiate 1991; Kyofa-Boamah and Blay 2000) and postharvest treatment with the fungicides maneb, carbendazim, imazil, and copper hydroxide (Abutiate 1991; Kyofa-Boamah and Blay 2000; Cudjoe et al. 2002). In addition, herbicides, glyphosate, fluazifop-butyl, ametryne, diuron, or bromacil are applied on fields to kill weeds (Aboagye 2002). In all of these, there have been many reported cases of exposure where the health of the farmers was in danger. Further, it is believed that more exposure is expected as the utilization of these chemicals is on the rise. For instance, nowadays, the majority of the farmers in vegetable cultivation in Ghana spray insecticides such as lambda-cyhalothrin (Karate 2.5 EC/ ULV), cypermethrin (Cyperdin, Cymbush), dimethoate (Perferkthion 400 EC), and endosulfan (Thionex 35 EC/ ULV, Thiodan 50 EC) on tomatoes, peppers, okras, eggplants (garden eggs), cabbages, and lettuces (Aboagye 2002).

Finally, temephos has been used to control black flies (*Simulium spp*. Diptera: Simulidae), which transmit Onchecerciasis to humans by the Onchocerciasis Program in the Volta basin and Tano and Pra rivers (Osei-Atweneboana et al. 2001; Ntow 2005). Additionally, it is used for controlling domestic pests like cockroaches, mosquitoes, ectoparasites (ticks), and other insects. Moreover, due to the severity of pest problems, temephos is likely to be employed in the systematic treatment of most rivers across west Africa in the foreseeable future.

Pesticides poisoning

In Ghana, pesticide poisoning resulting from human consumption of pesticide-contaminated food commodities has been documented. The Northern Presbyterian Agricultural

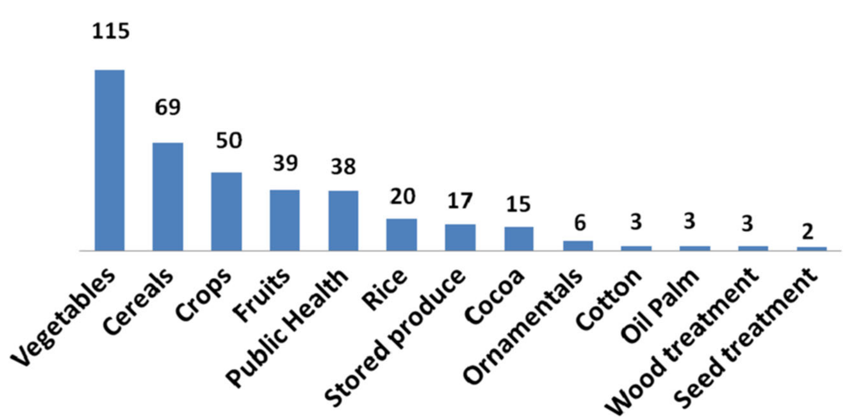


Fig. 3 Number of registered pesticide products used per main crop (EPA, Ghana, 2013)

Table 3 Summary of registered pesticides as of 30 June 2013

Category	FRE[a]	PCL[b]	Banned	Total
Insecticides	153	10	26	189
Fungicides	40	4	0	44
Herbicides	88	73	0	161
Plant growth regulator	6	0	0	6
Rodenticides	3	2	0	5
Molluscicide	1	0	0	1
Total	291	89	26	406

Source: EPA, Ghana

[a] Fully registered pesticides

[b] Provisionally cleared pesticides

Services (NPAS), in 2012, established that 15 farmers died after eating food polluted with pesticides, and 63 others were admitted at the hospital. Others reported experiencing burning sensations on their skin, headaches, itchy or watery eyes, body weakness, nausea, sexual weakness, dizziness, and breathing difficulties after application. Likewise, a survey of 183 farmers in 14 villages in the Upper East region gave similar findings (NPAS 2012). Additionally, the presence of organochlorine pesticide residues, particularly DDT, has been ascertained in the breast milk and human blood of vegetable farmers. Although these pesticides are prohibited in Ghana, their detection could be the result of past usage in the environment (Ntow et al. 2008; Osei Tutu et al. 2011). Moreover, between 1989 and 1997, 1215 toxicological cases were examined, 963 cases tested positive for chemical poisoning, with 30 % being directly related to the misuse of pesticides. The main causes for these deaths were carbamates (126 cases), organophosphates (66 cases), and organochlorine (74 cases) (Adetola et al. 1999). Furthermore, in March 1999, three children in Ghana died after consuming fruits containing high residues of carbamates (Gerken et al. 2001).

Health risk assessment

Consumption data play a key role in the dietary risk assessment residues in food commodities. Thus, prediction of exposure to pesticide residues through diet is very critical for sanctioning the use of pesticides and for gaining official acceptance on pesticide residue levels that occur in food commodities. For some time now, several models have been developed to give an accurate risk assessment. The risk assessment of pesticide residues in food is based on toxicological evaluation of the single compounds, and no internationally accepted procedure exists for the evaluation of cumulative exposure to multiple pesticide residues in food crops, vegetables, and fruits. In general, food is the major exposure route. Exposure to pesticide residues through the diet is considered to be five orders of magnitude higher than other exposure pathways like air and drinking water (Knezeviv et al. 2012; Lozowicka et al. 2013;). In general, possible exposure to pesticide residues is an integral part of the risk assessment process to ascertain that the acceptable daily intake (ADI) of the pesticide concerned is not exceeded. If the pesticide residue ingested by the consumer is not exceeding the corresponding ADI, the consumer is regarded to be safe and vice-versa. In reality, this gives the overall assessment of human exposure to pesticides through food supply and the magnitude of the risk.

In Ghana, studies as regards health risk assessment of dietary intake of fruits and vegetables are very scarce. Searching through the literature, only four publications could be found in this all-important area of evaluation of health status of consumers. Table 7 summarizes health risk assessment of pesticide residues in fruits and vegetables on the basis of ADI studies so far reported in the literature. Health risk estimations were calculated based on an integration of pesticide analysis data and exposure assumptions. Most of the studies used the default US Environmental Protection Agency's guidelines: (a) hypothetical body weight of 10 kg for children and 70 kg for adults and (b) maximum absorption rate of 100 % and bioavailability rate of 100 % (USEPA 1989, 1996). Food consumption rates were based on the International Food Policy Research Institute (IFPRI) data (IFPRI 2004).

Food consumption rate for fruits in Ghana is 0.064 kg/person/day (IFPRI 2004) and the vegetables tomatoes, eggplants, and pepper are 0.03, 0.047, and 0.003 kg/person/day respectively (FAO 2002). For each type of exposure, the estimated lifetime exposure dose (mg/kg/day) was obtained by multiplying the residual pesticide concentration (mg/kg) in the food of interest times the food consumption rate (kg/day), and then dividing the product by the body weight (kg). The hazard indices for adults and children were calculated as ratios between estimated pesticide exposure doses and the reference doses which are considered to be safe levels of exposure over the lifetime (USEPA 1989, 1996).

The health risk estimates for systemic effects associated with pesticide residues in various fruits and vegetables are presented in Table 7. The tables comprise the acceptable daily intake, computed average maximum daily intake values, and corresponding hazard indices during the study period for both adults and children. On the whole, no health hazard was found associated with the consumption of pepper as the indices for all the residues were less than unity. For tomatoes, methyl-chlorpyrifos, ethyl-chlorpyrifos, and omethioate showed risk whereas methyl-chlorpyrifos, ethyl-chlorpyrifos, omethioate, dichlorvos, and monocrotophos indices in

Table 4 Pesticides detected in vegetables in Ghana

Matrix	Area	Year, duration (months)	Samples	Detected	Concentration (mg/kg)	Detection frequency (%)	Detection technique	Reference
Tomato	Akumda, Ashanti region		76	HCB Lindane p, p'-DDE Heptachlor epoxide α-endosulfan β-endosulfan endosulfan-sulfate	<0.1 <2.5 <0.1 0.13–3.13 <0.05 <0.01 <0.01	39 18 6 42 18 9 27	GC (ECD)	Ntow (2001)
Vegetable (lettuce)	Accra, Kumasi, and Tamale	2002, (3)	60	Lindane Endosulfan Lambda-cyhalothrin Chlorpyrifos DDT	0.03–0.9 0.04–1.3 0.01–1.4 0.4–6.0 0.02–0.9	31 36 11 78 33	GC (FID, ECD)	Amoah et al. (2006)
Shallots	Volta region	2006, (3)	16	Chlorpyrifos	0.0004–0.3329	55		Kotey et al. (2008)
Vegetable (Tomatoes, eggplant, pepper)	Kumasi	2006, (7)	50 50 50	Methyl chlorpyrifos Ethyl chlorpyrifos Dichlorvos Dimethoate Malathion Monocrotophos Omethioate Methyl-parathion Ethyl-parathion Methyl chlorpyrifos Ethyl chlorpyrifos Dichlorvos Dimethoate Malathion Monocrotophos Omethioate Methyl-parathion Ethyl-parathion Methyl chlorpyrifos Ethyl chlorpyrifos Dichlorvos Dimethoate Malathion Monocrotophos Omethioate Methyl-parathion Ethyl-parathion	Tomatoes 0.044–0.524 0.171–0.251 0.044–0.274 0.228–0.978 0.074–2.620 0.019–0.107 0.040–0.076 0.010–0.073 0.026–0.217 Eggplant 0.015–0.084 0.065–0.236 0.120–0.291 0.162–0.422 0.176–0.340 0.040–0.148 0.054–0.356 0.031–0.058 0.042–0.145 Pepper – 0.001–0.039 0.001–0.213 0.011–0.244 0.042–0.218 – 0.001–0.036 0.013–0.068 0.061–0.264	30 42 48 42 32 12 36 10 16 8 10 42 26 18 2 16 12 10 – 16 26 18 24 – 20 16 12	GC (FID)	Darko and Akoto. (2008)
Tomato	Kumasi, Cape Coast		200	Folpet Alpha endosulfan Beta-endosulfan Lambda cyhalothrin Cypermethrin Pirimiphos-methyl Chlorpyrifos Fenitrothion	0.22–0.52 0.08–0.30 0.03–0.43 0.05–1.45 0.35–3.45 0.03–0.15 0.18–10.75 0.04–0.09		GC (ECD, PFD)	Essumang. et al. (2008)

Table 4 (continued)

Matrix	Area	Year, duration (months)	Samples	Detected	Concentration (mg/kg)	Detection frequency (%)	Detection technique	Reference
Cabbage	Cape Coast, Ghana	2010, (5)	40	Allethrin	0.270–9.566			Armah (2011)
				Bifenthrin	0.004–0.036			
				Lambda-	0.036–0.104			
				cyhalothrin	0.068–0.246			
				Permethrin	0.018–0.138			
				Cyfluthrin 3	0.021–1.168			
				Cypermethrin	0.011–0.077			
				Cypermethrin 2	0.056–0.482			
				Fenvalerate 2	2.751–7.052			
				Deltamethrin	0.531–1.661			
				Ethoprophos	0.010–2.077			
				Phorate	0.001–0.075			
				Diazinon	0.010–0.255			
				Fonofos	0.010–0.073			
				Pirimiphos-	0.006–0.089			
				methyl	0.008–0.242			
				Chlorpyrifos	0.006–0.051			
				Malathion	0.047–0.423			
				Parathrin-ethyl	0.027–0.059			
				Chlorfenvinphos	0.010–0.406			
				Dimethoate				
				Fenitrothion				
Cowpea	Ejura, Ghana	2012, (1)	10,	β-HCH	0.003–0.040		GC (ECD, PFPD)	Akoto et al. (2013)
				γ-HCH	0.001–0.002			
				δ-HCH	0.003–0.004			
				Heptachlor	0.008–0.012			
				Aldrin	0.001–0.004			
				γ-Chlordane	0.002–0.003			
				α-endosulfan	0.001–0.001			
				β-endosulfan	0.006–0.123			
				endosulfan-	0.002–0.009			
				sulfate	0.034–0.077			
				p,p′-DDE	0.108–0.118			
				p,p′-DDD	0.002–0.003			
				p,p′-DDT	0.002–0.004			
				Methoxychlor	0.001–0.002			
				Endrin	0.001–0.005			
				Dieldrin	0.004–0.011			
				Dimethoate	0.003–0.008			
				Methamidophos	ND			
				Ethoprophos	ND			
				Phorate	ND			
				Diazinon	ND			
				Pirimiphos-	0.009–0.021			
				methyl	0.001–0.027			
				Chlorpyrifos	0.002–0.005			
				Malathion	0.002–0.002			
				Fenitrothion	0.002–0.020			
				Parathrin-ethyl	0.005–0.012			
				Chlorfenvinphos	ND			
				Profenofos	0.002–0.003			
				Fonofos	0.001–0.008			
				Bifenthrin	0.001–0.083			
				Fenpropathrin	0.001–0.003			
				Lambda-	0.002–0.018			
				cyhalothrin	0.001–0.008			
				Permethrin	0.002–0.011			
				Cyfluthrin	0.005–0.015			
				Allethrin	0.003–0.013			
				Cypermethrin				
				Fenvalerate				
				Deltamethrin				

Table 5 Pesticides detected in fruits and vegetables in Ghana

Matrix	Area	Year, duration (months)	Samples	Detected	Concentration, mg/kg					Detection technique	Reference
Vegetable (tomato, cabbage, pepper, onion, eggplants)	Ghana		15		Tomato	Cabbage	Pepper	Onion	Eggplants	GC-MS	Botwe et al. (2011)
				DDT	0.02–0.04	0.61–0.29	<0.01	0.01–0.03	0.00–0.02		
				Endosulfan	0.12–0.30	3.78–2.28	<0.01	1.01–2.69	<0.01		
				HCH	0.16–0.28	0.50–0.74	0.20–0.48	0.06–0.10	<0.01		
				Methoxychlor	27.83–28.59	0.71–0.99	5.28–9.58	46.61–47.27	0.97–1.03		
				Dimethoate	0.00–0.02	0.17–0.29	<0.01	1.63–1.89	0.15–0.29		
				Lambda-cyhalothrin	0.04–0.06	<0.01	0.00–0.02	0.08–0.14	<0.01		
Fruits and vegetables (pawpaw, tomato, apple)	Accra, Ghana	2007, (10)	320		Pawpaw	Tomato		Apple		GC-ECD	Bempah et al. (2011); Bempah & Donkor (2011)
				Heptachlor epoxide	ND	0.02–0.04		0.01–0.05			
				Aldrin	ND	ND		ND			
				γ-Chlordane	ND	ND		ND			
				o,p-DDD	ND	ND		ND			
				δ-HCH	<0.01–0.06	0.01–0.02		0.01–0.02			
				γ -HCH	0.02–0.04	<0.01–0.02		0.01–0.02			
				p,p′-DDE	0.01–0.05	ND		<0.01–0.01			
				Methoxychlor	0.01–0.03	ND		ND			
				Endrin	<0.01–0.01	ND		ND			
				Endrin aldehyde	0.01–0.02	<0.01–0.01		0.03–0.11			
				Endrin ketone	0.01–0.02	<0.01–0.02		<0.01–0.01			
				α-endosulfan	<0.01–0.01	ND		ND			
				β-endosulfan	0.01–0.02	ND		ND			
				o,p’-DDT	0.01–0.03	ND		ND			
				p,p’-DDT	<0.01–0.02	<0.01–0.01		0.03–0.09			
				Heptachlor	<0.01–0.01	0.01–0.02		ND			
Fruits and vegetables	Kumasi, Ghana	2009, (11)	350	Fruits	Papaya	Watermelon		Banana		GC (ECD)	Bempah et al. (2011)
				Lindane	0.092–0.105	–		–			
				Methoxychlor	0.004–0.012	–		0.004–0.012			
				Aldrin	0.009–0.019	–		–			
				Dieldrin	0.002–0.040	–		0.013–0.203			
				Endrin	–	–		0.004–0.012			
				p,p′-DDE	–	0.004–0.008		–			
				p,p′-DDT	0.008–0.014	0.008–0.014		0.005–0.062			
				Permethrin	0.005–0.032	0.080–0.025		–			
				Cyfluthrin	–	0.006–0.010		0.006–0.022			
				Cypermethrin		–		0.007–0.012			
				Fenvalerate		–		–			
				Deltamethrin		0.007–0.023		0.008–0.040			

Table 5 (continued)

Matrix	Area	Year, duration (months)	Samples	Detected	Concentration, mg/kg				Detection technique	Reference
					0.030–0.040 0.018–0.021 –					
				Fruits Lindane Methoxychlor Aldrin Dieldrin Endrin p,p′-DDE p,p′-DDT Permethrin Cyfluthrin Cypermethrin Fenvalerate Deltamethrin	Mango 0.006–0.022 0.004–0.006 – – – 0.005–0.011 0.018–0.021 0.002–0.031 – 0.004–0.012 0.006–0.004 –	Pear 0.006–0.012 – 0.010–0.016 – – – – 0.004–0.008 – 0.004–0.008 – 0.007–0.010		Pineapple 0.121–0.153 0.007–0.052 0.004–0.008 0.007–0.018 0.004–0.008 – – 0.025–0.066 0.018–0.021 0.019–0.025 – 0.026–0.062		
				Vegetables Lindane Methoxychlor Aldrin Dieldrin Endrin p,p′-DDE p,p′-DDT Permethrin Cyfluthrin Cypermethrin Fenvalerate Deltamethrin	Tomato 0.104–0.155 0.010–0.017 0.080–0.015 – – 0.006–0.002 0.018–0.021 – 0.006–0.020 – 0.011–0.017	Lettuce 0.08–0.015 0.005–0.007 0.009–0.021 – – 0.050–0.005 0.011–0.051 – 0.030–0.080 0.013–0.016 0.006–0.024	Cabbage 0.095–0.102 0.031–0.022 – 0.030–0.052 0.005–0.009 0.006–0.010 0.030–0.040 0.022–0.078 0.010–0.018 – 0.003–0.017 0.009–0.020	Carrot – 0.006–0.012 0.008–0.040 – 0.016–0.031 – 0.005–0.013 0.030–0.052 – 0.010–0.018 0.004–0.008 0.009–0.063		
				Vegetables Lindane Methoxychlor Aldrin Dieldrin Endrin p,p′-DDE p,p′-DDT Permethrin Cyfluthrin Cypermethrin Fenvalerate Deltamethrin	Okra 0.006–0.012 – – – 0.016–0.031 0.008–0.021 0.030–0.052 – 0.007–0.021	Green Pepper – .006–0.032 .018–0.021 .052–0.062 – – – .005–0.013 –	Onion 0.016–0.020 0.025–0.066 – – – 0.016–0.031 0.030.0.040 – 0.005–0.013 –	Cucumber – 0.018–0.021 – 0.005–0.013 – 0.053–0.082 0.004–0.008 0.008–0.016 – 0.006–0.013 0.008–0.016 –		

Table 5 (continued)

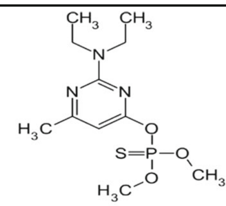
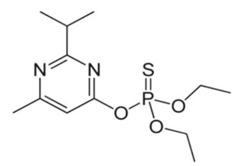
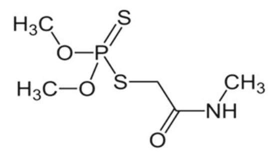
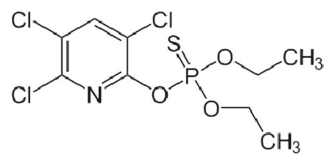
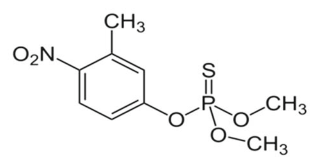
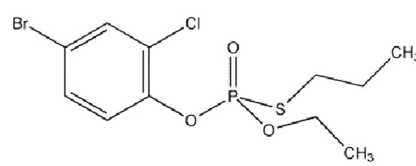
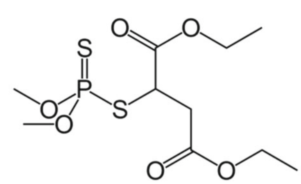
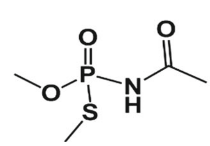
Matrix	Area	Year, duration (months)	Samples	Detected	Concentration, mg/kg				Detection technique	Reference
					0.006–0.014	–	0.013–0.042			
					0.019–0.041	.007–0.015	0.021–0.045			
					–	.022–0.034				
Fruits and vegetables	Accra, Ghana	2010, (8)	240		Carrot	Cabbage	Lettuce	Tomato	GC-ECD	Bempah et al. (2012)
				Lindane	0.075–0.005	0.173–0.036	0.075–0.005	0.001–0.112		
				Heptachlor/epoxide	–	0.062–0.009	0.011–0.007	0.004–0.107		
				Endrin	–	0.022–0.001	–	0.007–0.011		
				Dieldrin	–	–	–	0.001–0.012		
				o,p'-DDE	0.075–0.005	0.502–0.053	0.004–0.190	0.001–0.372		
				p,p'-DDE	0.205–0.004	0.126–0.034	0.045–0.366	0.036–0.241		
				o,p-DDD	0.090–0.003	0.173–0.091	0.001–0.090	0.001–0.160		
				o,p'-DDT	0.055–0.004	0.227–0.091	–	0.006–0.419		
				p,p'-DDT	0.042–0.022	–	–	0.004–0.218		
Fruits and vegetables	Greater Accra, Ghana	2009, (11)	309	Fruits	Tomato	Lettuce		Cabbage	EC (ECD)	Bempah et al. (2012)
				Lindane	0.004–0.010	0.004–0.006		0.095–0.102		
				Methoxychlor	0.002–0.008	0.031–0.022		0.031–0.022		
				Aldrin	–	0.006–0.012		–		
				Dieldrin	0.002–0.040	–		0.030–0.052		
				Endrin	–	0.080–0.015		0.005–0.009		
				p,p′-DDE	0.007–0.015	0.025–0.066		0.006–0.010		
				p,p′-DDT	0.008–0.014	0.018–0.021		0.030–0.040		
				Diazinon	0.003–0.013	0.002–0.006		0.010–0.019		
				Dimethoate	0.007–0.019	0.018–0.024		–		
				Pirimiphos-me	0.012–0.025	–		0.001–0.006		
				Chlorpyrifos	0.018–0.025	0.001–0.021		0.003–0.009		
				Profenofos	0.005–0.011	–		0.002–0.010		
				Malathion	0.005–0.062	0.001–0.006		0.004–0.008		
				Fruits	Carrot	Cucumber		Onion		
				Lindane	–	–		0.016–0.020		
				Methoxychlor	0.006–0.012	0.018–0.021		0.025–0.066		
				Aldrin	0.008–0.040	–		0.004–0.008		
				Dieldrin	–	0.005–0.013		–		
				Endrin	0.006–0.032	–		–		
				p,p′-DDE	–	–		0.016–0.031		
				p,p′-DDT	0.004–0.008	0.005–0.013		0.030–0.040		
				Diazinon	0.003–0.011	0.003–0.011		0.004–0.010		
				Dimethoate	0.018–0.024	–		0.002–0.008		
				Pirimiphos-me	–	0.006–0.021		–		
				Chlorpyrifos		–		0.041–0.062		
				Profenofos		0.0010.009		0.008–0.044		
				Malathion		0.008–0.012		–		

Table 5 (continued)

Matrix	Area	Year, duration (months)	Samples	Detected	Concentration, mg/kg			Detection technique	Reference
					0.038–0.044				
					0.010–0.016				
					0.005–0.011				
				Vegetables	Papaya	Watermelon	Banana		
				Lindane	0.092–0.105	0.004–0.006	–		
				Methoxychlor	0.004–0.012	–	0.004–0.012		
				Aldrin	0.001–0.008	–	–		
				Dieldrin	0.002–0.040	–	0.013–0.203		
				Endrin	–	–	0.004–0.012		
				p,p′-DDE	–	0.004–0.008	–		
				p,p′-DDT	0.008–0.014	0.006–0.010	0.005–0.062		
				Diazinon	–	–	–		
				Dimethoate	0.002–0.012	0.004–0.006	–		
				Pirimiphos-me	–	–	–		
				Chlorpyrifos	0.004–0.010	0.002–0.005	0.004–0.012		
				Profenofos	0.001–0.005	–	–		
				Malathion	–	–	–		
				Vegetables	Mango	Pear	Pineapple		
				Lindane	0.006–0.022	0.006–0.012	0.121–0.153		
				Methoxychlor	0.004–0.006	–	0.007–0.052		
				Aldrin	–	0.003–0.009	0.004–0.008		
				Dieldrin	–	–	0.007–0.018		
				Endrin	–	–	0.004–0.008		
				p,p′-DDE	0.005–0.011	–	–		
				p,p′-DDT	0.018–0.021	–	–		
				Diazinon	–	–	0.001–0.009		
				Dimethoate	0.004–0.018	–	0.002–0.008		
				Pirimiphos-me	0.002–0.006	–	0.008–0.018		
				Chlorpyrifos	0.003–0.007	0.012–0.025	0.041–0.062		
				Profenofos	–	–	–		
				Malathion	–	–	0.002–0.008		

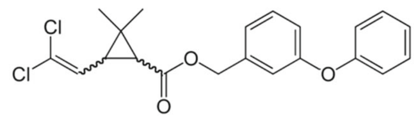
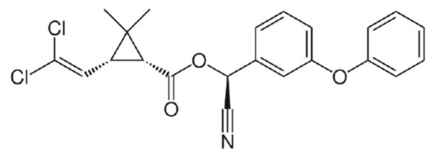
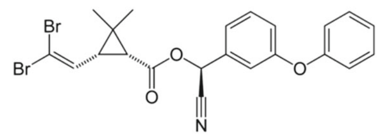
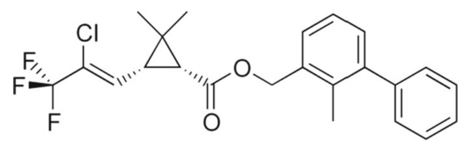
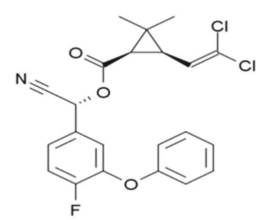
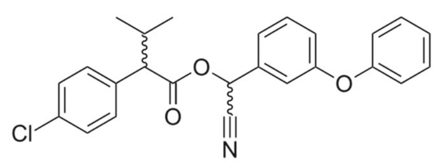
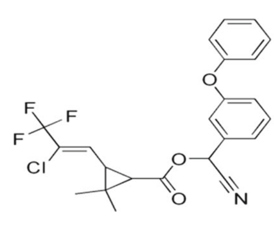
eggplant were more than one (Darko and Akoto 2008). In the case of Bempah et al.'s (2011a, b) risk studies in Kumasi on fruits and vegetables, the hazard index values showed that only endrin demonstrated health risk with vegetables indicating a great potential for systemic toxicity in children. Likewise, data analysis of health

Table 6 Organophosphorus and synthetic pyrethroid pesticides used in Ghana

No.	Common name	IUPAC name	Structural formula	Molecular formula
1.	Pirimiphos-methyl	*O*-[2-(Diethylamino)-6-methylpyrimidin-4-yl] *O,O*-dimethyl phosphorothioate		$C_{11}H_{20}N_3O_3PS$
2.	Diazinon	*O*,*O*-Diethyl *O*-[4-methyl-6-(propan-2-yl)pyrimidin-2-yl] phosphorothioate		$C_{12}H_{21}N_2O_3PS$,
3.	Dimethoate	*O,O*-dimethyl *S*-[2-(methylamino)-2-oxoethyl] dithiophosphate		$C_5H_{12}NO_3PS_2$
4.	Chlorpyrifos	*O*,*O*-Diethyl *O*-3,5,6-trichloropyridin-2-yl phosphorothioate		$C_9H_{11}Cl_3NO_3PS$
5.	Fenitrothion	*O*,*O*-Dimethyl *O*-(3-methyl-4-nitrophenyl) phosphorothioate		$C_9H_{12}NO_5PS$,
6.	Profenofos	*(RS)-(O-4-bromo-2-chlorophenyl O-ethyl S-propyl phosphorothioate)*		$C_{11}H_{15}BrClO_3PS$
7.	Malathion	Diethyl 2-[(dimethoxyphosphorothioyl)sulfanyl]butanedioate,		$C_{10}H_{19}O_6PS_2$
8.	Acephate	*N*-(Methoxy-methylsulfanylphosphoryl)acetamide,		$C_4H_{10}NO_3PS$

risk estimates in Accra Metropolis revealed that γ-HCH, δ-HCH, β-endosulfan and *o,p'*-DDT, *p,p'*-DDE, and *p,p'*-DDE did not pose a direct hazard to human health, although present in pawpaw. Nonetheless, heptachlor, α-endosulfan, endrin, endrin aldehyde, and endrin ketone levels exceeded the reference dose for children, indicating a great potential for systemic toxicity in children as they are the most vulnerable population subgroup. On

Table 6 (continued)

9.	Permethrin	3-Phenoxybenzyl (1*RS*)-*cis*,*trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylate,		$C_{21}H_{20}Cl_2O_3$
10.	Cypermethrin	Cyano-(3-phenoxyphenyl) methyl]3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate		$C_{22}H_{19}Cl_2NO_3$
11.	Deltamethrin	[(*S*)-cyano-(3-phenoxyphenyl)-methyl] (1*R*,3*R*)-3-(2,2-dibromoethenyl)-2,2-dimethyl-cyclopropane-1-carboxylate,		$C_{22}H_{19}Br_2NO_3$
12.	Bifenthrin	2-Methyl-3-phenylphenyl)methyl (1*S*,3*S*)-3-[(*Z*)-2-chloro-3,3,3-trifluoroprop-1-enyl]- 2,2-dimethylcyclopropane-1-carboxylate		$C_{23}H_{22}ClF_3O_2$
13.	Cyfluthrin	[(R)-cyano-[4-fluoro-3-(phenoxy)phenyl]methyl] (1R,3R)-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate		$C_{22}H_{18}Cl_2FNO_3$
14.	Fenvelarate	(RS)-*alpha*-Cyano-3-phenoxybenzyl (RS)-2-(4-chlorophenyl)-3-methylbutyrate		$C_{25}H_{22}ClNO_3$
15.	Lambda-cyhalothrin	3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethyl-cyano(3-phenoxyphenyl)methyl cyclopropanecarboxylate		$C_{23}H_{19}ClF_3NO_3$,

the other hand, in tomato, γ-HCH, δ-HCH, and *p,p*'-DDT were under the safe limit but heptachlor, heptachlor epoxide, endrin aldehyde, and endrin ketone appeared to have some health risk associated with them, especially to children. Similarly for imported apples, health risk was found with endrin aldehyde, *p,p'*-DDT, heptachlor epoxide, and endrin ketone, implying a great potential for systemic toxicity (Bempah et al. 2011a, b).

Table 7 Health risk assessment of various pesticide residues in fruits and vegetables studies in Ghana

Study Area	Commodity	Detected pesticides	ADI (mg/kg/day)	EADI (mg/kg/day)	HRI	Health risk assessment	Reference
Kumasi	Tomato	Chlorpyrifos-	0.001	0.006	6.00	Yes	Darko and Akoto, 2008
		methyl	0.001	0.0079	7.90	Yes	
		Chlorpyrifos	0.004	0.0008	0.20	No	
		Dichlorvos	0.010	0.0093	0.93	No	
		Dimethhoate	0.020	0.0045	0.23	No	
		Malathion	0.0006	0.0023	3.83	Yes	
		Monocrotophos	0.0003	0.0004	1.33	Yes	
		Omethioate	0.020	0.0008	0.04	No	
		Parathion-methyl	0.005	0.0030	0.60	No	
		Parathion					
	Eggplant	Chlorpyrifos-	0.001	0.0013	1.30	Yes	
		methyl	0.001	0.0046	4.60	Yes	
		Chlorpyrifos	0.004	0.0072	1.80	Yes	
		Dichlorvos	0.010	0.0100	1.00	No	
		Dimethhoate	0.020	0.0141	0.71	No	
		Malathion	0.0006	0.0028	4.67	Yes	
		Monocrotophos	0.0003	0.0052	17.3	Yes	
		Omethioate	0.020	0.0019	0.09	No	
		Parathion-methyl	0.005	0.0029	0.58	No	
		Parathion					
	Pepper	Chlorpyrifos-	0.001	0.0000	0.00	No	
		methyl	0.001	0.0000	0.00	No	
		Chlorpyrifos	0.004	0.0000	0.00	No	
		Dichlorvos	0.010	0.0001	0.01	No	
		Dimethhoate	0.020	0.0000	0.00	No	
		Malathion	0.0006	0.0000	0.00	No	
		Monocrotophos	0.0003	0.0000	0.00	No	
		Omethioate	0.020	0.0000	0.00	No	
		Parathion-methyl	0.005	0.0000	0.01	No	
		Parathion					
Accra Metropolis	Pawpaw	γ-HCH	0.0030	1.74×10^{-4} (adult)	0.06	No	Bempah et al., 2011
		δ-HCH	0.0030	2.74×10^{-4} (adult)	0.09	No	
		Heptachlor	0.0001	6.40×10^{-5} (adult)	0.64	No	
		α-endosulfan	0.0060	4.57×10^{-5} (adult)	0.46	No	
		β-endosulfan	0.0060	1.00×10^{-4} (adult)	0.02	No	
		p,p'-DDE	0.0200	4.57×10^{-5} (adult)	0.002	No	
		Endrin	0.0002	3.66×10^{-5} (adult)	0.46	No	
		o,p'-DDT	0.0200	2.74×10^{-5} (adult)	0.001	No	
		Endrin aldehyde	0.0002	9.14×10^{-5} (adult)	0.46	No	
		p,p'-DDT	0.0200	5.48×10^{-5} (adult)	0.003	No	
		Endrin ketone	0.0002	5.48×10^{-5} (adult)	0.27	No	
	Tomato	γ-HCH	0.0030	7.30×10^{-5} (adult)	0.02	No	
		δ-HCH	0.0030	1.09×10^{-4} (adult)	0.04	No	
		Heptachlor	0.0001	2.74×10^{-5} (adult)	0.27	No	
		Heptachlor epoxide	0.0001	2.01×10^{-4} (adult)	2.01	Yes	
		Endrin aldehyde	0.0002	1.41×10^{-4} (adult)	0.27	No	
		p,p'-DDT	0.0200	9.14×10^{-6} (adult)	0.0005	No	
		Endrin ketone	0.0002	2.74×10^{-5} (adult)	0.27	No	
	Apple	γ-HCH	0.0030	6.40×10^{-4} (adult)	0.02	No	
		δ-HCH	0.0030	1.66×10^{-5} (adult)	0.01	No	
		Heptachlor epoxide	0.0001	9.14×10^{-6} (adult)	0.05	No	
		p,p'-DDE	0.0200	9.14×10^{-6} (adult)	0.0005	No	
		Endrin aldehyde	0.0002	2.93×10^{-4} (adult)	1.46	Yes	
		p,p'-DDT	0.0200	2.37×10^{-4} (adult)	0.01	No	
		Endrin ketone	0.0002	2.74×10^{-5} (adult)	0.27	No	
Kumasi	Fruits	γ-HCH	0.005	1.63×10^{-3}	0.326	No	Bempah et al., 2011
		Methoxychlor	0.005	7.00×10^{-5}	0.014	No	
		Aldrin	–	–	–	–	
		Dieldrin	–	–	–	–	
		Endrin	0.0003	3.00×10^{-5}	0.100	No	
		p,p'-DDE	0.020	4.00×10^{-5}	0.006	No	
		p,p'-DDT	0.020	3.00×10^{-4}	0.015	No	
		Permethrin	0.250	1.50×10^{-4}	0.001	No	
		Cyfluthrin	0.025	8.00×10^{-5}	0.003	No	

Table 7 (continued)

Study Area	Commodity	Detected pesticides	ADI (mg/kg/day)	EADI (mg/kg/day)	HRI	Health risk assessment	Reference
		Cypermethrin	0.050	7.00×10^{-5}	0.007	No	
		Fenvalerate	–	–	–	–	
		Deltamethrin	0.010	1.30×10^{-4}	0.013	No	
	Vegetables	γ-HCH	0.005	8.00×10^{-4}	0.160	No	Bempah et al., 2011
		Methoxychlor	0.005	6.50×10^{-4}	0.130	No	
		Aldrin	–	–	–	–	
		Dieldrin	–	–	–	–	
		Endrin	0.0003	3.10×10^{-4}	1.030	Yes	
		p,p′-DDE	0.020	1.10×10^{-3}	0.054	No	
		p,p′-DDT	0.020	3.40×10^{-4}	0.017	No	
		Permethrin	0.250	4.90×10^{-4}	0.002	No	
		Cyfluthrin	0.025	1.60×10^{-4}	0.006	No	
		Cypermethrin	0.050	2.80×10^{-4}	0.028	No	
		Fenvalerate	–	–	–	–	
		Deltamethrin	0.010	3.10×10^{-4}	0.031	No	
Accra Metropolis	Pawpaw	γ-HCH	0.0030	1.20×10^{-3}	0.41	No	Bempah et al., 2011
		δ-HCH	0.0030	(children)	0.64	No	
		Heptachlor	0.0001	1.92×10^{-3}	4.48	Yes	
		α-endosulfan	0.0060	(children)	3.20	Yes	
		β-endosulfan	0.0060	4.50×10^{-4}	0.12	No	
		p,p′-DDE	0.0200	(children)	0.016	No	
		Endrin	0.0002	3.20×10^{-4}	1.28	Yes	
		o,p′-DDT	0.0200	(children)	0.01	No	
		Endrin aldehyde	0.0002	7.04×10^{-4}	1.20	Yes	
		p,p′-DDT	0.0200	(children)	0.02	No	
		Endrin ketone	0.0002	3.20×10^{-4}	1.92	Yes	
				(children)			
				2.56×10^{-4}			
				(children)			
				1.92×10^{-4}			
				(children)			
				6.40×10^{-4}			
				(children)			
				3.84×10^{-4}			
				(children)			
				3.84×10^{-4}			
				(children)			
	Tomato	γ-HCH	0.0030	5.20×10^{-4}	0.17	No	
		δ-HCH	0.0030	(children)	0.26	No	
		Heptachlor	0.0001	7.68×10^{-4}	1.92	Yes	
		Heptachlor epoxide	0.0001	(children)	14.10	Yes	
		Endrin aldehyde	0.0002	1.92×10^{-4}	1.92	Yes	
		p,p′-DDT	0.0200	(children)	0.0032	No	
		Endrin ketone	0.0002	1.41×10^{-4}	1.92	Yes	
				(children)			
				1.92×10^{-4}			
				(children)			
				6.40×10^{-5}			
				(children)			
				1.92×10^{-4}			
				(children)			
	Apple	γ-HCH	0.0030	4.48×10^{-3}	0.15	No	
		δ-HCH	0.0030	(children)	0.09	No	
		Heptachlor epoxide	0.0001	2.56×10^{-4}	0.32	No	
		p,p′-DDE	0.0200	(children)	0.32	No	
		Endrin aldehyde	0.0002	6.40×10^{-3}	10.24	Yes	
		p,p′-DDT	0.0200	(children)	0.08	No	
		Endrin ketone	0.0002	6.40×10^{-3}	1.92	Yes	
				(children)			
				2.05×10^{-4}			
				(children)			
				1.66×10^{-3}			
				(children)			
				1.92×10^{-4}			
				(children)			

Overall, the results suggest that there exists a likelihood increase in potential risk for systemic health effects associated with pesticide use in fruit production in Ghana if this is not regulated.

Conclusions and recommendations

Pesticides are generally recognized as a significant factor in enhancing the country's ability to meet the need for sufficient, safe, and affordable food. The monitoring initiatives and studies of pesticide contaminants in fruits and vegetables have demonstrated environmental deterioration with the passage of time due to increased usage of pesticides. Several kinds of pesticides are applied throughout Ghana like in many other developing nations. Nonetheless, there are no complementary health and long-term monitoring programs in place as regards the health of the farm workers or farmers as well as other environmental regulation and policy initiatives to bring sanity into the farming dependency on pesticide application practices. This review makes it clearer that studies so far reveal insufficient data regarding regular monitoring, exposures, and poisoning. Also, to the best of our knowledge, there are no national programs to offset any imminent fruit and vegetable poisoning. Accordingly, long-term regular monitoring studies into the various pesticides applied in fruits and vegetables grown and marketed across the country are really needed. Data up to now is limited more to organochlorines with scanty information on organophosphates, carbamates, and synthetic pyrethroids; thus, investigation into this requires immediate action. Additionally, environmental impact, fate, and degradation studies especially the dissipation behavior of these chemicals in fruit and vegetable growth are yet to be reported for Ghana. A comparative examination study into the fate of pesticides in fruits and vegetables after harvesting from farm sites to market centers to be sold to consumers is relevant. This would tell whether pesticide residual levels change in the course of transport to the markets.

In reality, few cases of pesticide exposures have been documented in Ghana since 1980 compared to those in the developed world where state-of-the-art analytical equipment and competent laboratories are available to determine specific pesticides in parts per billion (ppb) and parts per trillion (ppt). Hence, there is an urgent need to develop more accredited testing facilities for pesticide residue determinations in the country for fruits and vegetables and in biological fluids of the field workers to benchmark the pesticide residue levels. Besides, studies evaluating the actual exposure of consumers and farmers to these compounds and their evolving trends with time are important. Moreover, the estimation of the potential health risks associated with the exposure to violated pesticides as well will be very interesting, as this aspect has not been thoroughly explored, depicted in Table 7.

Further, the review clearly indicates most of the studies corroborate the pesticide residues in the environment in the absence of necessary regulations of pesticide pollution control. Moreover, based on this review of pesticide exposure on fruits and vegetables in Ghana, the institutionalization of policies and programs in this field should be given top priority by the government. Furthermore, an extensive information and education campaign (IEC) should be organized to educate the farmers on route of entry of contaminants into the body and food and the need to adhere to dossier on the pesticide containers and strict implementation of existing food safety laws. Hence, it is necessary for Ghana to harmonize its food regulation with Codex Alimentarius Commission (CAC) standards by adapting similar guidelines for enacting standards and pesticide residue limits.

Simultaneous with the initiative in pesticide regulations, it is imperative to focus on food regulation as well. A national long-term monitoring program for pesticide residue should be carried out in Ghana to generate a comprehensive and reliable data that could be used as basis in drafting appropriate policies pertaining to pesticide regulation. Monitoring the use of pesticides is required to detect health and environmental impacts and to provide advice on reducing risks.

Results of this review studies and monitoring initiatives on pesticides further demonstrate that pesticide exposure occurs in Ghana as a consequence of lack of awareness and high illiteracy rate among rural populations about the safe use of pesticides among field workers. Keeping in view the present scenario, it is strongly recommended that an extensive IEC for safe use of pesticides should be carried out. IEC should be done through all forms of media, i.e., radio, TV, newspapers, agriculture staff, schools; launching of contest on best management practices (BMP) as well as integrated pest management (IPM) by agricultural extension staff of all districts to encourage farmers to do things right and safe so as to enhance the production of high-quality fruits and vegetables in the markets can also be a way.

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