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Pesticide residues in commonly consumed food from five localities of Burkina Faso: occurrence and health risk assessment

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Abstract Monitoring data for pesticides are generally scarce in many countries of the world, especially in developing countries. In Burkina Faso, there are few scientific data on the occurrence and concentrations of pesticide residues in staple foods found in local markets. Using QuEChERS extraction method and gas chromatography–mass spectrometry, samples of commonly eaten foods from five localities of Burkina Faso were evaluated by targeting more than 40 pesticides. It appears that 58.1% of all the collected samples exhibited at least one or more pesticide residues. Among those, 36.5% of the samples had at least one pesticide with a concentration above the maximum residue level (MRL) value. Unfortunately, no MRL data was available for dried fish which is a widely consumed food in this part of Africa. Simazine was found in tomatoes, pyrethroids in cereals, while dried fish contained most of the pesticides detected. The assessment of long-term health risks revealed that dieldrin quantified in dried fish showed more than 250% of acceptable daily intake which was then labelled as unacceptable high risk. For hazardous foods, more sampling should be carried out for a better assessment of the health risks involved.

Keywords Burkina Faso · Food quality control · QuEChERS method · Residual pesticides · Human health risk assessment

Abbreviations

ADI	Acceptable daily intake
ARfD	Acute reference dose
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization
GC	Gas chromatography
HQ	Hazard quotient
MRL	Maximum residue level
PSA	Primary–secondary amine
QuEChERS	Quick, easy, cheap, effective, rugged, and safe
US EPA	US Environmental Protection Agency

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Introduction

The use of pesticides is one of the main agricultural practices in order to increase crop yields and reduce losses (Kmellár et al., 2010). Although pesticides play an important role in increasing food production, the intensive and widespread use of these chemicals can lead to soil pollution, thereby increasing environmental and health risks (Bhandari et al., 2020). Many studies showed that human exposure to pesticides leads to several health disorders such as Alzheimer's disease (Tang, 2020), carcinogenicity (George & Shukla, 2011), neurotoxicity (Richardson et al., 2019), reproductive toxicity (El-Nahhal, 2020), and metabolic toxicity (He et al., 2020). Considering the potential toxicity of pesticides, there is a need for food safety control by monitoring pesticide residues in the environment.

The general population is mainly exposed to pesticide residues through food and water. To protect the consumer's health around the world, regulatory bodies such as Codex alimentarius from WHO/FAO (WHO, 2018), the US Environmental Protection Agency (US EPA, 2000), or European Food Safety Authority (EFSA) (Brancato et al., 2018) have established legal directives to control levels of pesticides thanks to the maximum residue levels (MRLs). They limit the types and concentrations of residues permitted or accepted on foods (Kang et al., 2020; Zarrouk et al., 2020). Unfortunately, many farmers do not follow these legal practices. Therefore, the assessment of pesticide residues in food is critical for assessing the potential risks associated with the consumption of pesticide-contaminated foods (Damalas & Eleftherohorinos, 2011).

Pesticide monitoring data are generally very limited in many countries and especially in developing countries due to problems of inadequate facilities and financial constraints (Ravichandra, 2018). In recent years, a few studies assessing the exposure and risk of pesticide residues on human health in Burkina Faso have been published. Most of these studies deal with the unsafe agricultural practices (Perroud, 2018) or with the occurrence of pesticides on the growing land, such as gardens (Lehmann et al., 2017, 2018; Son, 2018; Tarnagda et al., 2017). However, there are very few data on the occurrence of pesticide residues in foods proposed in local markets for consumption. Those residues may cause acute and/or chronic toxicity with harmful impacts on human health (Bempah et al., 2016). Therefore, monitoring and assessing the levels of residual pesticides in food may provide the basis for risk assessment of human exposure to these chemicals.

In the present study, we investigated the residual pesticides in widely eaten foods such as rice, maize, tomatoes, or dried fish, in the urban and semi-urban areas of Burkina Faso. More than 40 pesticides were evaluated from almost 150 samples collected in five (5) localities, using QuEChERS extraction methods and analysis by gas chromatography–mass spectrometry (GC–MS). Based on the levels of residual pesticides found in the samples, the hazard quotients (HQ) were calculated in relation with the acceptable daily intakes (ADIs) and acute reference doses (ARfDs) derived from toxicological studies. The relevant results highlighted in this study suggest that more extensive and periodic sampling should be carried out to monitor pesticide levels in food in order to protect consumer health.

Materials and methods

Quantification of residual pesticides in samples

Chemicals and reagents

Pesticide analytical standards comprising 16 OCP (2,4′-DDT, lindane, aldrine, Op′DDT, methoxychlor, mirex, PCB 209, dieldrin, heptachlor, alpha-endosulfan, beta-endosulfan, HCB, chlordimeform, chlorothalonil, methazachlor, pretilachlor), 7 OPP (diazinon, dimethoate, mevinphos, heptenophos, monocrotophos, ethoprophos, azinphos ethyl), 12 CP (quintozene, imazalil, methomyl, proposcur, carbofuran, diflubenzamide, triadimefon, penconazole, propiconazole, azoxystrobine, simazine, benalaxyl), and 8 PP (cypermethrin, deltamethrin, L-cyhalothrin, cyfluthrin, alpha cypermethrin, tetramethrin, permethrin, bifenthrin) were of high purity (> 97%) and purchased from Sigma–Aldrich (St. Louis, MO, USA) and Merck (Darmstadt, Germany). Formic acid analytical grade, sodium citrate tribasic dehydrate, and sodium chloride (NaCl) were also from Sigma–Aldrich (St. Louis, MO, USA). Acetonitrile (MeCN) suitable for QuEChERS was from Scharlau Chemie (Barcelona, Spain). Anhydrous magnesium sulphate ($MgSO_4$) was procured from VWR Chemicals (Leuven, Belgium) and primary secondary amine (PSA) sorbent from Agilent Technologies (DE, USA).

Sampling and extraction

Data from the routine quality control of food products by the National Public Health Laboratory (NPHL) and the assessment of dietary diversity scores by the Ministry of Agriculture of Burkina Faso were used to identify foods of interest for this study (Ministère de l'agriculture, de l'hydraulique et des ressources halieutiques, Burkina Faso, 2008). These were maize (19 samples), dried fish (38 samples), rice (36 samples), and tomatoes (55 samples) which were collected in December 2020 in five (5) localities which are Bobo Dioulasso, Cinkanse, Dakola, Niangoloko, and Ouagadougou. These products were randomly picked from household supply points such as shops and markets. All samples were stored at – 20 °C until the analysis.

The standard method EN 15662 of the European Committee for Standardization of Food of Plant Origin, known as the QuEChERS (quick, easy, cheap, effective, rugged, and safe) method, was used with a slight modification (Wilkowska & Biziuk, 2011). Briefly, two Falcon tubes were used for extraction and cleaning. The extraction tube contained 4 g of magnesium sulphate ($MgSO_4$), 1 g of sodium chloride (NaCl), and 1.5 g of sodium citrate. The clean-up tube contained 150 mg of $MgSO_4$ and 25 mg of primary secondary amine (PSA). For extraction, 5 g of each homogenised sample was weighed, placed in a 50 mL centrifuge tube, and extracted with 10 mL acetonitrile. The mixture was then shaken vigorously with the contents of the extraction tube for 1 min and centrifuged at 3500 rpm for 5 min. Six (6) mL of the supernatant was transferred to the second tube for clean-up. The tube was shaken vigorously for 1 min and centrifuged again at 3500 rpm for 5 min. Finally, 1 mL of the supernatant was transferred to an autosampler glass vial with 10 µL of 5% formic acid for the chromatographic analysis.

Instruments and chromatographic condition

Pesticide residues were analysed using gas chromatography (GC, Agilent Technologies 7890A) coupled to mass spectrometry (Agilent Technologies 5975 Cinert). The GC system was equipped with a fused silica capillary column HP-5MS (30 m × 0.25 mm × 0.25 µm; Agilent, Santa Clara, USA). The chromatographic instrumental settings were as follows: the carrier gas was helium, injector set at 250 °C in splitless mode; GC oven temperature program was initiated at 50 °C, raised to 100 °C (at a rate of 25 °C/min), and from 100 to 300 °C (at a rate of 7.5 °C min) before being hold for 3 min; the injection volume was 1 µL, and the flow rates of make-up gas were 20 mL/min. The MS detector was run in SIM mode with the following settings: S Quad 180 °C, MS Source 230 °C, ion source: EI; 70 eV. Three ions were selected for each pesticide. The highest relative abundant ion was used as the quantifier ion, while the other ions were taken for confirmation as qualifier ions.

Quality control

Positive identification of the targeted pesticide was based on detectable signals, matching retention times to authentic standards and high quality matching of sample mass spectra to library spectra. Residual concentrations of pesticides in samples were quantified by external standard calibration curve method and the linear response of the detector for each compound ascertained. Values of the coefficient of determination R^2 for all residues were > 0.99. The limits of quantification (LOQs) were determined by considering a signal-to-noise ratio of 10 with reference to the background noise obtained from the blank sample. LOQs were below or equal to 0.01 mg/kg for all assessed pesticides. Accuracy and precision were evaluated through recovery experiments and good accuracy and precision (RSD below 15%) were obtained with mean recoveries in the range of 83 to 110.3% 1 ppm, 0.1 ppm, and 0.04 ppm.

Estimated daily intake and risk assessment

Based on available data for the daily consumption of each kind of foods, the estimated maximum daily intake (EMDI, mg/kg/day, using the maximal concentration found in food for each pesticide) and the estimated average daily intake (EADI, mg/kg/day, using the average concentration of each pesticide found in food) were calculated as follows (Ferreira de Souza et al., 2021):

$$EMDI = \frac{CM \times \mathrm{FC}}{1000 \times \mathrm{Bw}} \quad (1)$$

$$EADI = \frac{CAV \times \mathrm{FC}}{1000 \times \mathrm{Bw}} \quad (2)$$

where C_M and C_{AV} are, respectively, the maximum and the average residual pesticide concentration (mg/kg), F_c is the food consumption rate (g/person/day), and B_w is the body weight (kg/person).

The food consumption rates for adults were obtained from INSD (2003) and FAO/WHO (2010) and were 213.2 g, 4 g, 168.8 g, and 0.6 g person/day for maize, dried fish, rice, and tomatoes, respectively. Hypothetical body weights of 60 kg for adults, the maximum absorption rate of 100%, and the bioavailability rate of 100% were used to estimate the daily dose resulting from the exposition to these detected pesticides.

Non-cancer risk assessment

The risk of non-carcinogenic effects was expressed as acute and chronic hazard quotient (HQ). The EMDI and EADI as obtained were used to estimate, respectively, the acute and chronic hazard quotient (HQacute and HQChronic) of pesticides detected in samples based on their acute reference dose (ARfD) and acceptable daily intakes (ADI). HQacute and HQChronic were calculated in terms of percentage of ARfD and ADI as follows and HQ exceeding the unity (> 100% of ARfD or ADI) indicates a risk (Parven et al., 2021):

$$HQ\ acute = \frac{\mathrm{EMDI}}{\mathrm{ARf}D} \times 100 \quad (3)$$

$$HQ\ Chronic = \frac{\mathrm{EADI}}{\mathrm{ADI}} \times 100 \quad (4)$$

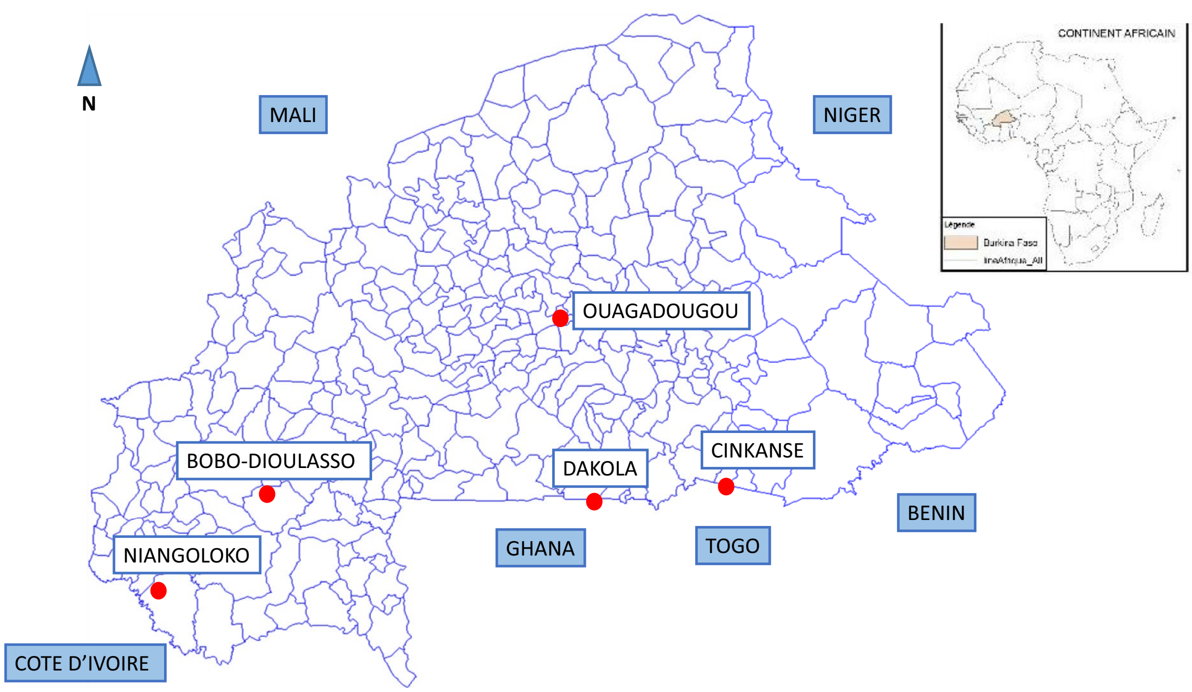

Fig. 1 Map showing sampling sites in the five (5) localities of Burkina Faso

Cancer risk assessment

Based on the USEPA guidelines, the cancer risk (CR) was calculated for chemicals likely to exert a carcinogenic effect as the product of EMDI and the cancer slope factor (CSF) (US EPA, 2005).

$$CR = EMDI \times CSF \tag{5}$$

where CSF is the cancer slope factor for carcinogenic pesticides (mg/kg.day−1), the probability of one substance to increase chances of cancer by oral exposure pathway. The general acceptable health risk value was less than one in one million (10−6).

Results and discussion

Residue levels of pesticides

Commonly consumed foods from 5 localities of Burkina Faso (Fig. 1) were analysed for more than 40 pesticide residues including 16 OCP (2,4′-DDT, lindane, aldrine, Op′DDT, methoxychlor, mirex, PCB 209, dieldrin, heptachlor, alpha-endosulfan, beta-endosulfan, HCB, chlordimeform, chlorothalonil, methazachlor, pretilachlor), 7 OPP (diazinon, dimethoate, mevinphos, heptenophos, monocrotophos, ethoprophos, azinphos ethyl), 12 CP (quintozene, imazalil,

Table 1 Type of samples and incidence of pesticide residues in samples from five (5) localities of Burkina Faso

Type of samples	Locality of collect	Number of samples	No. of samples with one or more residues (%)	No. of samples with at least one result > MRL (%)
Maize	Bobo Dioulasso	6	1 (16.7)	1 (16.7) *
	Cinkanse	3	1 (33.3)	1 (33.3) *
	Dakola	3	1 (33.3)	1 (33.3) *
	Niangoloko	3	1 (33.3)	1 (33.3) *
	Ouagadougou	4	3 (75.0)	3 (75.0) *
	Total	**19**	**7 (36.8)**	**7 (36.8)**
Dried fish	Bobo Dioulasso	9	9 (100.0)	No MRLs
	Dakola	7	7 (100.0)	
	Niangoloko	7	7 (100.0)	
	Ouagadougou	15	2 (13.3)	
	Total	**38**	**25 (65.8)**	
Rice	Bobo Dioulasso	6	5 (83.3)	5 (83.3) *
	Cinkanse	6	5 (83.3)	5 (83.3) *
	Dakola	6	2 (33.3)	2 (33.3) *
	Niangoloko	4	3 (75.0)	3 (75.0) *
	Ouagadougou	14	11 (78.6)	11 (78.6) *
	Total	**36**	**26 (72.2)**	**26 (36.8)**
Tomatoes	Bobo Dioulasso	11	5 (45.5)	5 (45.5) *
	Cinkanse	10	3 (30.0)	2 (20.0) *
	Dakola	9	5 (55.5)	1 (11.1) *
	Niangoloko	9	7 (77.8)	6 (66.7) *
	Ouagadougou	16	8 (50.0)	7 (43.8) *
	Total	**55**	**28 (50.9)**	**21 (38.2)**
Total		**148**	**86 (58.1)**	**54 (36.5)**

Maximum residue level (MRL) mg/kg

*assessment based on EU-MRL legislation when available methomyl, proposcur, carbofuran, diflubenzamide, triadimefon, penconazole, propiconazole, azoxystrobine, simazine, benalaxyl), and 8 PP (cypermethrin, deltamethrin, L-cyhalothrin, cyfluthrin, alpha cypermethrin, tetramethrin, permethrin, bifenthrin). Table 1 shows the types of foods collected in each locality and provides an overview of the occurrence of pesticides in these samples. It appears that 58.1% of all collected samples exhibited at least one or more pesticide residues. This corresponds to more than half

Table 2 Characteristics of residual pesticides detected in sampled food

Family of pesticides detected	Pesticide active ingredients	Authorised by the CSP *	Monitor ions *m*/z (%)**	*b* (slope) ***	R^2	MRL (mg.kg^{-1}) (CAC / EU)			
						Maize	Dried fish	Rice	Tomatoes
OCP	*Chlorothalonil*	**Yes**	109, 124.2, **265.7**	0.438	0.997	NA/0.01	No MRLs	NA/0.01	5/6
	Dieldrin	No	81.2, 121.1, **261.3**	1.280	0.999	NA/0.01		NA/0.01	NA/0.01
	Heptachlor	No	100.2, **237.0**, 160.1	2.510	0.999	NA/0.01		NA/0.01	NA/0.01
	Lindane	**Yes**	**111.2**, 51.20, 143.2	2.550	0.999	NA/0.01		NA/0.01	NA/0.01
	Metazachlor	No	132.3, 159.2, **238.0**	4.740	0.999	NA/0.02		NA/0.02	NA/0.02
	PCB 209	No	355.8, 425.8, **501.5**	0.086	0.993	NA/NA		NA/NA	NA/NA
OPP	*Azinphos ethyl*	No	77.2, **132.2**, 104.1	1.730	0.999	NA/0.05		NA/0.05	NA/0.02
	Dimethoate	**Yes**	87.2, 125.2, **143.2**	1.240	0.999	NA/0.01		NA/0.01	NA/0.01
	Monocrotophos	**Yes**	**127**, 67.1, 109.1	0.264	0.999	NA/0.02		NA/0.02	NA/0.01
CP and others	*Benalaxyl*	No	91.2, 148.4, **205.8**	7.840	0.999	NA/0.05		NA/0.05	0.2/0.5
	Carbofuran	**Yes**	77.1, 103.1, **149.2**	1.850	0.997	0.05/0.01		NA/0.01	NA/0.002
	Imazalil	No	54.3, 173.1, **217.3**	0.926	0.999	NA/0.01		NA/0.01	0.3/0.3
	Propiconazole	No	**69.1**, 173.2, 259.2	1.380	0.999	0.05/0.05		NA/1.5	3/3
	Simazine	No	68.1, 122.1, **201.4**	1.180	0.999	NA/0.01		NA/0.01	NA/0.01
PP	*Cyfluthrin*	**Yes**	91.2, **206.0**, 127.2	0.963	0.996	NA/0.05		NA/0.02	0.2/0.05
	∑ *Cypermethrins*[a]	**Yes**	91.2, **163.2**, 181.0	0.504	0.998	NA/0.3		2/2	0.2/0.5

Organochlorines pesticides (OCP), organophosphorus pesticides (OPP), carbamates pesticides and others (CP), and pyrethroids pesticides (PP) were detected in sampled foods

NA not available

[a]Sum of isomers: alpha-cypermethrin and beta-cypermethrin. MRL values were set by CAC (*codex alimentarius commission*) and EU (European Union) for the corresponding pesticides in each food and were available at http://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/en/ and https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/mrls/?event=search.pr on March 23, 2021

[*]Active ingredient authorised in specified commercial formulations by the Sahelian Pesticides Committee (CSP) for application in gardening checked on http://csp.dev4u.it/search.cfm?title_page=Pesticides on March 24, 2021; **Target and qualifier ions used in SIM mode and quantifier ions are in bold; ***Interception of calibration curves was null in all cases

of the dried fish, rice, and tomatoes (65.8%, 72.2%, and 50.9%, respectively), while only 36.8% of sampled maize were positive for at least one pesticide residue. Seventeen pesticides were found in samples. The verifications performed on the Sahelian Pesticides Committee's (CSP) database (http://csp.dev4u.it/search.cfm?title_page=Pesticides) revealed that 10 of these pesticides are unauthorised in specified commercial formulations (Table 2). Similar results were found by Lehmann's team (Lehmann et al., 2017). Some pesticides listed in the Stockholm convention ratified by Burkina Faso are banned. Although their use has been banned in many countries, they are still used due to their effectiveness for agricultural purposes and relatively cheap price (Ntow et al., 2006).

The MRL fixed by the Codex Alimentarius Commission (CAC) and European Union (EU) are reported in Table 2. They were used to assess the amount of residual pesticides in the collected foods. Fifty-four samples (36.5%) had at least one pesticide above the limit value. This corresponds to all maize and rice (100%) that displayed at least one pesticide, and to 75% of tomatoes (Table 1), which means that most of the pesticides quantified were above the EU-MRL. Similar results were found in the Boucle du Mouhoun (Burkina Faso) region where most of the active substances detected above the MRL were from the organochlorine family (Dakuyo et al., 2020). In addition, pesticide residues were detected in 87% of the samples collected in the main markets of Ouagadougou's, 58.4% of them with concentrations above the MRL (Bakary et al., 2019). Unfortunately, no MRL data were available for dried fish which is a staple food in this part of Africa.

Depending on the food matrices analysed, Appendix A presents for residual pesticides detected, the number of samples in which they were found, the average concentrations, and their concentration range.

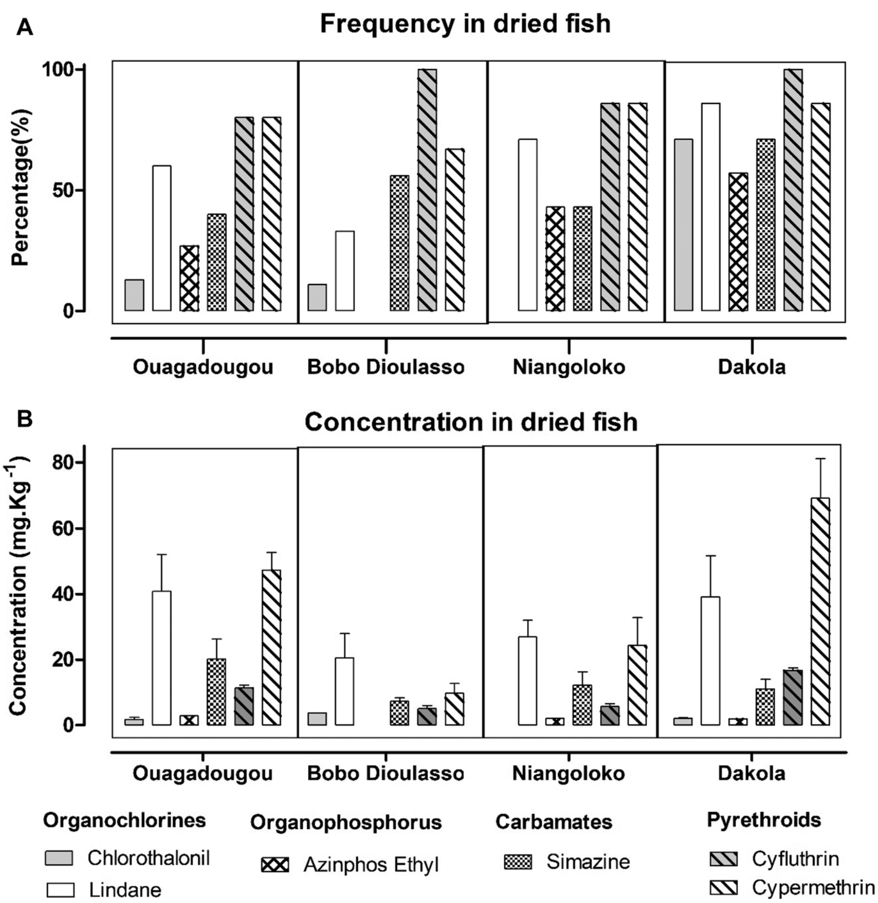

Fig. 2 Frequency (**A**) and concentration (**B**) of major pesticides found in dried fish

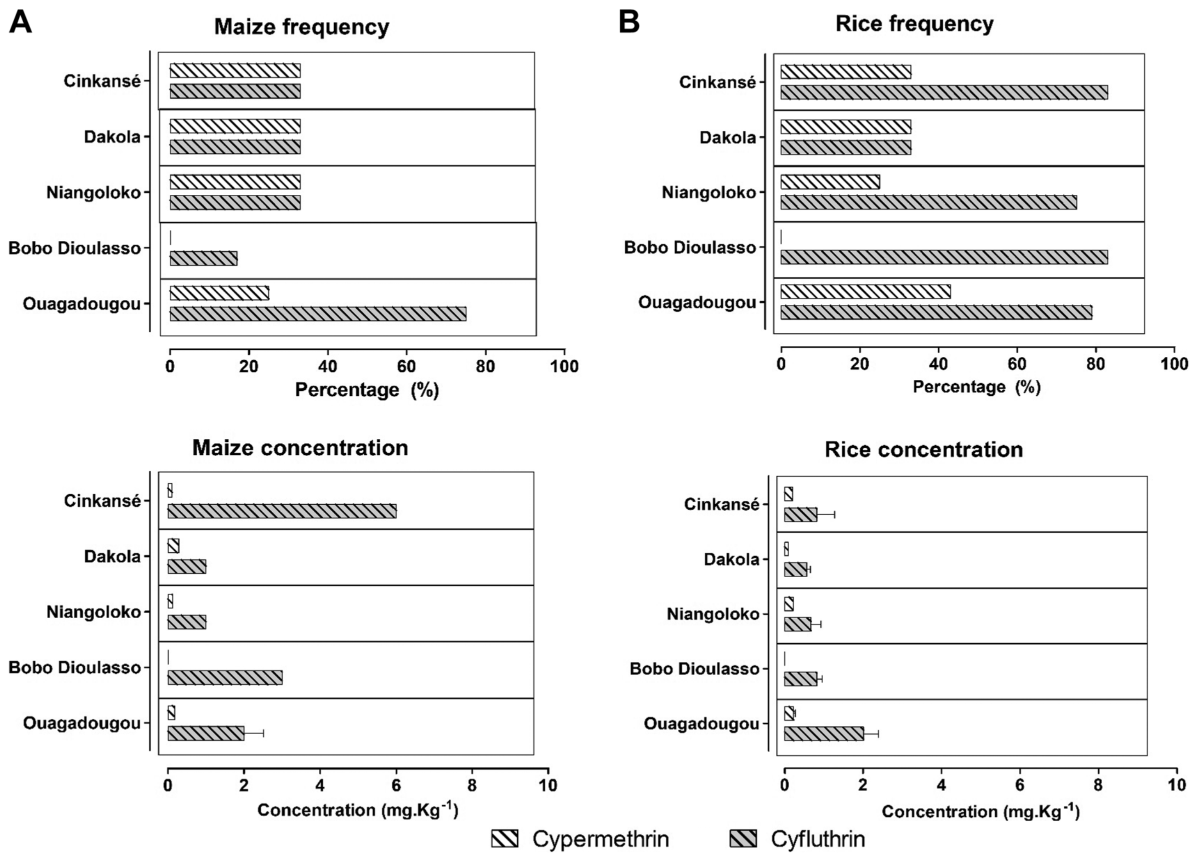

Fig. 3 Frequency and concentration of cypermethrin and cyfluthrin in maize (**A**) and rice (**B**) according to the locality of sample collect

Dried fish contained almost all the pesticides detected in our assessment. Cyfluthrin was detected in 34 samples and cypermethrin in 31 samples. In terms of concentrations, dried fish samples showed the highest content of cyfluthrin (9.77 mg/kg ± 5.22) and cypermethrin (38.34 mg/kg ± 27.37) compared to the other food matrices. This is probably due to the drying process that tends to concentrate pesticide residues. The maximal concentration of cyfluthrin in dried fish reached 21.11 mg/kg and that of cypermethrin 96.68 mg/kg. A closer look at the presence of these pyrethroids according to sampling location (Fig. 2A) reveals that they were detected everywhere. However, for Bobo-Dioulasso and Dakola, all dried fish samples were contaminated by cyfluthrin. Cyper2methrin was found at the highest concentration, especially in the samples collected in Dakola (Fig. 2B). Lindane was detected in 23 samples and was the other most residual pesticide found in dried fish. Its average concentration was 34.7 mg/kg ± 26.9 associated with a concentration range of 2.18 to 91.8 mg/kg. Besides, this OCP was detected in Dakola and Ouagadougou samples and exhibited the highest concentration (Fig. 3). For the most frequently eaten fish collected in Ghana, the dichloro-diphenyl-dichloroethylene (p,p′- DDE) was quantified as the predominant pesticide with a concentration range of 1.022–1.030 mg/kg. In the same study, cyfluthrin was detected with concentrations of 0.032 ± 0.031 mg/kg, 0.027 ± 0.024 mg/kg, and 0.009 ± 0.004 mg/kg in catfish, tilapia, and sardi fish, respectively (Danladi & Akoto, 2021). The high affinity of agrochemicals with soil and the close interconnection of soil with water bodies explain the transfer of pesticides from soil to water and fish (Syafrudin et al., 2021). Therefore, for each locality, the type of pesticides found in fish can

Table 3 Toxicological profile of pesticides detected in samples

Family of pesticides detected	Active ingredients	ADI (mg.kg^{-1}.bw^{-1}) for chronic exposition	ARfD (mg.kg^{-1}.bw^{-1}) for acute exposition	Cancer slope factor (mg/kg/day)*
OCP	*Chlorothalonil*	0.02 (JMPR 2019)	0.6 (JMPR 2019)	NE
	Dieldrin	0.0001 (JMPR 1994)	NE	16
	Heptachlor	0.0001 (JMPR 1994)	NE	4.5
	Lindane	0.005 (JMPR 2002)	0.06JMPR 2002)	NE
	Metazachlor	NE	NE	NE
	PCB 209	NE	NE	2
OPP	*Azinphos ethyl*	NE	NE	NE
	Dimethoate	0.002 (JMPR 2003)	0.02 (JMPR 2003)	NE
	Monocrotophos	0.0006 (JMPR 1995)	0.002 (JMPR 1995)	NE
CP and others	*Benalaxyl*	0.07 (JMPR 2005)	0.1 (JMPR 2005)	NE
	Carbofuran	0.001 (JMPR 2008)	0.001 (JMPR 2008)	NE
	Imazalil	0.03 (JMPR 2018)	0.05 (JMPR 2018)	NE
	Propiconazole	0.07 (JMPR 2004)	0.3 (JMPR 2004)	NE
	Simazine	0.018 (US EPA 2004)	0.3 (US EPA 2004)	NE
PP	*Cyflutrin*	0.04 (JMPR 2006)	0.04 (JMPR 2006)	NE
	∑ *Cypermethrins*	0.02 (JMPR 2006)	0.04 (JMPR 2006)	NE

OCP organochlorines pesticides, *OPP* organophosphorus pesticides, *CP* carbamates pesticides and others, *PP* pyrethroids pesticides, *PCB* polychlorinated biphenyls, *ADI* acceptable daily intake, *ARfD* acute reference dose, *JMPR* Joint FAO/WHO Meeting on Pesticide Residues, *US EPA* US Environmental Protection Agency, *NE* not evaluated

*Values from IRIS (Integrated Risk Information System, https://www.epa.gov/iris)

be directly linked to the management of pesticides used in agricultural practices and could explain the difference of results obtained between collected samples. Because they are able to concentrate pollutants directly from water, fish are used for environmental monitoring. The species-specific bioaccumulation of pesticides in fish have already been reported, especially in the case of OCP (Satyanarayan et al., 1999; Zhang et al., 2013). Many studies have been conducted on fresh fish, while the literature contains very little data on pesticides in dried fish. In many developing communities, drying and smoking is one of the most widely used traditional methods of fish preservation. Our study showed that in this type of foods, residual pesticides can reach 10 to 100 times the levels found in fresh fish as reported in the literature, which could lead to a major public health problem.

Cyfluthrin and cypermethrin were the most predominant residual pesticides in cereals. Cyfluthrin was present in 7 samples of maize and 26 samples of rice, while cypermethrin was found in 4 and 11 samples, respectively. Their mean concentrations were 1.99 mg/kg ± 2.09 for cyfluthrin and 0.17 mg/kg ± 0.08 for cypermethrin in maize, and for rice 1.29 mg/kg ± 1.12 and 0.20 mg/kg ± 0.09, respectively. The frequency of positive samples for these two pyrethroids and their concentration in cereals, according to the locality of collection, were illustrated in Fig. 3. In most of these places, cyfluthrin is much more encountered in rice samples but at lower concentrations compared to maize. Compaore et al. revealed poor practices in the use of pesticides for the cultivation of rice as twelve types of pesticides have been identified, whereas 40% of them were not registered (Compaore et al., 2019). Chouaïbou et al. reported that in Ivory Coast, the utilisation rate of pyrethroids was 11.6 times higher than all other insecticides combined for the cultivation of rice (Chouaïbou et al., 2016). These two pyrethroids were reported to act synergistically as grain protectors for bulk wheat (Bengston et al., 1987) which may explain the occurrence of their residues in the cereal samples tested.

Simazine was found predominantly in the tomatoes (12 of 55 samples) among all other foods. The average concentration of this molecule in tomato samples was 0.09 mg/kg ± 0.13 and reached 0.5 mg/kg at its highest. In gardening areas in Burkina Faso, λ-cyhalothrin has been previously reported in tomatoes at a highest concentration of 0.145 mg/kg (Lehmann et al., 2017). In some gardening sites in the region of Boucle du Mouhoun (Burkina Faso), sixteen active substances of pesticides were detected in tomato samples with a predominance of organophosphorus (Sanou et al., 2020). For tomato samples from Kouka and Toussiana (Burkina Faso), the most commonly used chemical families were pyrethroids (28%) and organophosphates (18%) (Son et al., 2018). These results are in opposition with the predominance of simazine in samples from market places of Ouagadougou and Niangoloko. In Ghana, seven organochlorine residues were detected in tomato sampled from Accra markets (Bempah & Donkor, 2011), while Malathion and Dimethoate were found to be exceeding the MRLs in tomato samples from Kumasi (Akoto et al., 2015).

Health risk assessment of food consumption in Burkina Faso

The amount of pesticides detected in foods and their consumption rate were used to estimate both maximal and average daily intakes (Appendix B). The estimated daily dietary exposures were expressed as

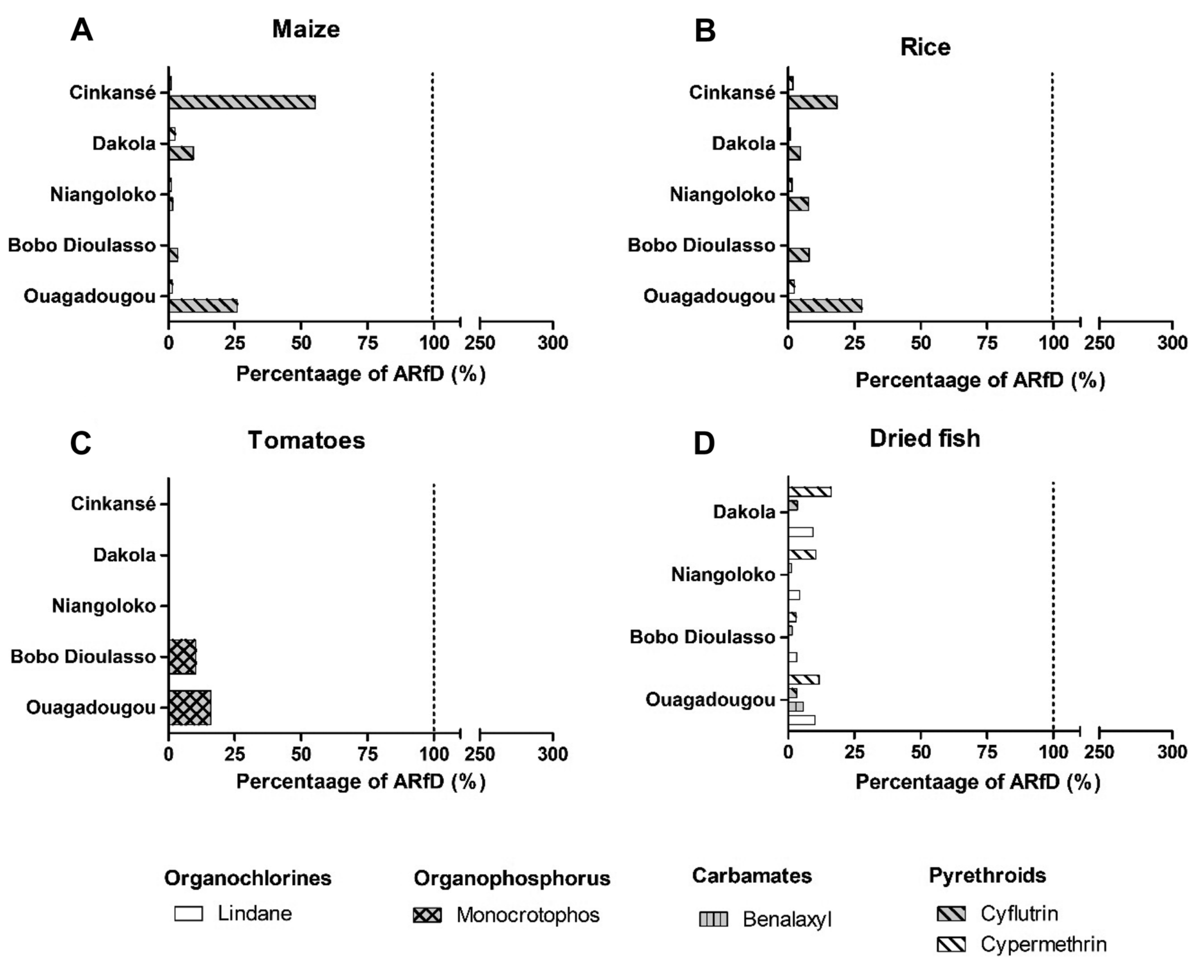

Fig. 4 Short-term (acute) risk assessment of maize (**A**), rice (**B**), tomatoes (**C**), and dried fish (**D**) intake according to their average amounts in localities of study

percentages of health-based toxic reference values such as ARfD and ADI for both short- as well as long-term risk assessment, respectively. These values were provided by Joint FAO/WHO Meeting on Pesticide Residues (JMPR, 2012) and US Environmental Protection Agency (US EPA, 2000) and are reported in Table 3. All quantified pesticides were evaluated for their acute and chronic risk to human health and are shown in Figs. 4 and 5, respectively. The hazard quotients, well below 100% of the ARfD, suggest a low health risk from the short-term consumption of maize, rice, tomatoes, and dried fish from these localities. However, the long-term health risk assessment for consumers revealed more critical results. For example, dieldrin quantified in dried fish from Bobo Dioulasso had a hazard index corresponding to more than 250% of its ADI. Banned in most areas of the world, dieldrin was highlighted as a major potential risk to human health in our assessment. It has been associated with health problems such as Parkinson's (Kanthasamy et al., 2005), breast cancer (Snedeker, 2001), reproductive disorders (Soto et al., 1994), and nervous system disorders (Kitazawa et al., 2001). The assessment of health risks due to oral exposure to chemicals such as pesticides was mainly based on the availability of ADI and ARfD. Unfortunately, these reference values were not available for all pesticides, which limited the comprehensive health risk

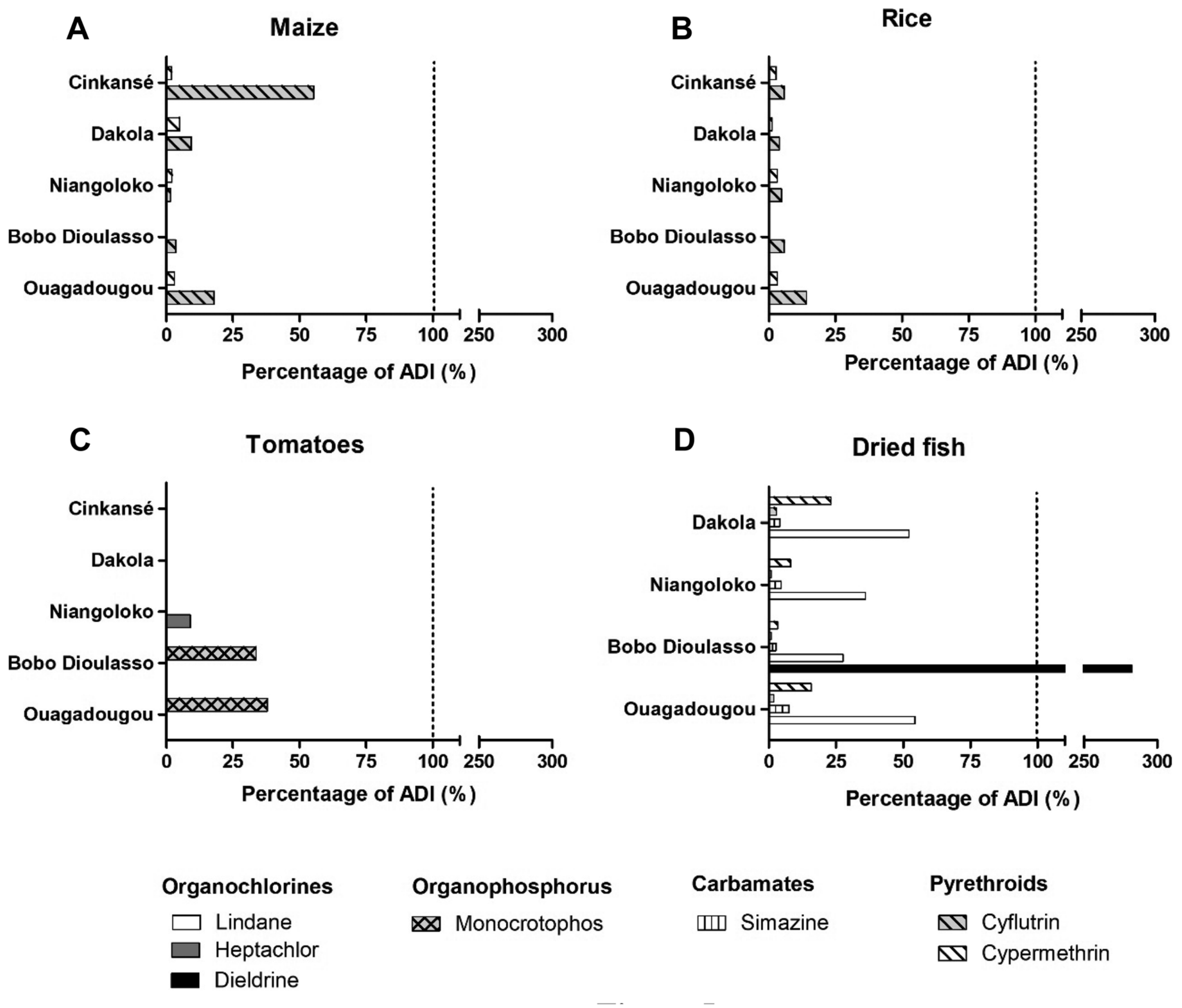

Fig. 5 Long-term (chronic) risk assessment of maize (**A**), rice (**B**), tomatoes (**C**), and dried fish (**D**) intake according to their average amounts in localities of study

Table 4 Cancer risk assessment of pesticides detected in sampled foods

Food Matrices	Localities	Active ingredients	EMDI (mg/kg/day)	CSF (mg/kg/day)	Cancer risk	Risk level	Tumour type(s)
Dried fish	Bobo Dioulasso	*Dieldrine*	*0.0003*	16	4.5×10^{-03}	*Unacceptable high risk*	Liver carcinoma
Tomatoes	Niangoloko	*Heptachlor*	*0.00001*	4.5	4.05×10^{-05}	*Potential risk*	*Hepatocellular carcinomas*
	Dakola	*PCB209*	*0.00001*	2	2.60×10^{-05}	*Potential risk*	*Liver hepatocellular adenomas or carcinomas,*
	Cinkanse		*0.00002*	2	3.00×10^{-05}	*Potential risk*	
	Niangoloko		*0.00001*	2	2.40×10^{-05}	*Potential risk*	
Rice	Ouagadougou	*PCB209*	*0.0005*	2	1.07×10^{-03}	*Potential risk*	
	Niangoloko		*0.0001*	2	1.69×10^{-04}	*Unacceptable high risk*	

EAMI estimated maximum daily intake, *CSF* cancer slope factor

Risk level below one in a million (10^{-6}) is considered acceptable or negligible, between one in ten thousand and one in a million (10^{-4} and 10^{-6}, respectively) implies a potential risk, and greater than one in ten thousand (10^{-4}) is considered an unacceptable high cancer risk

assessment. Therefore, although some pesticides detected in our study may be harmful to human health, they could not be assessed due to the lack of sufficient toxicological data.

The CR is defined as the increased likelihood of developing cancer over a lifetime due to continued exposure to a carcinogen. Some of the pesticides detected in our study have been classified by WHO/IARC (International Agency for Research on Cancer, 2021) as carcinogenic to humans in group 1 (lindane and PCB), probably carcinogenic in group 2A (dieldrin), or possibly carcinogenic to humans in group 2B (chlorothalonil, heptachlor). For pesticides with CSF like dieldrin, heptachlor, and PCB 209, the CR was calculated and the results are presented in Table 4. Comparing the calculated CR with the generally acceptable health risk value of 1 in one million (10−6) (Wiltse & Dellarco, 1996), no negligible risks were found for the assessed pesticides. On the contrary, an unacceptable high risk was found for dieldrin detected in dried fish from Bobo Dioulasso as for PCB 209 found in rice from Niangoloko. With CR between 10−6 and 10−4, the assessment of other chemicals showed potential cancer risks. Based on the above, it can be assumed that consumption of these foods could cause a potential health hazard to consumers. The US Environmental Protection Agency (US EPA) restricted the use of dieldrin due to its possible carcinogenic actions and its bioaccumulation (Tsiantas et al., 2021). Lindane, assigned to group 1 of carcinogenic, was not evaluated due to the lack of data on slope cancer. However, this compound was found in dried fish and quantified in high amounts that could potentially be carcinogenic.

Conclusion

We investigated the presence of residual pesticides in maize, rice, tomatoes, and dried fish from 5 localities of Burkina Faso. More than half of the food collected was positive for at least one residual pesticide. Alarmingly, most of the pesticides found in samples were not authorised for use in the CILSS countries. In addition, 100% of the maize and rice samples, as well as 75% of the tomatoes samples that contained at least one pesticide, had amounts of pesticides above the maximum residual level defined by the European Union. Cyfluthrin and cypermethrin were the main residual pesticides in rice and maize. Simazine was characteristic of tomatoes, while dried fish contained most of the pesticides detected in our assessment. The long-term consumer health risk assessment revealed that dieldrin quantified in dried fish from Bobo Dioulasso had a high hazard index. For all foods sampled, short-term consumption showed very low health risks. However, the cancer risk assessment showed a high to unacceptable potential risk for the pesticides assessed. For hazardous foods such as dried fish or tomatoes, more sampling in Ouagadougou or Dakola should be done for a better assessment of the health risks incurred.

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Declarations

Conflict of interest The authors declare no competing interests.

Appendix

Appendix A: Amount of OCP, OPP, CP and PP detected in sampled foods (mg.kg^{-1})

Family of pesticides detected	Pesticide active ingredient	Maize	Dried fish		Rice		Tomatoes	
OCP	*Chlorothalonil*	-	Nber of samples	8	-		Nber of samples	4
			Means ± SD	2.21 ± 0.77			Means ± SD	0.04
			Range	[0.18 -3.74]			Range	-
	Dieldrin	-	Nber of samples	1	-		-	
			Means ± SD	4.24				
			Range	-				
	Heptachlor	-	-		-		Nber of samples	1
							Means ± SD	0,09
							Range	-
	Lindane	-	Nber of samples	23	-		Nber of samples	4
			Means ± SD	34.7 ± 26.9			Means ± SD	0.13 ± 0.14
			Range	[2.18 -91.8]			Range	[0.03 - 0.33]
	Metazachlor	-	Nber of samples	1	-		Nber of samples	1
			Means ± SD	1.37			Means ± SD	0.03
			Range	-			Range	-
	PCB 209	-	-		Nber of samples	2	Nber of samples	5
					Means ± SD	0.11 ± 0.11	Means ± SD	0.13 ± 0.05
					Range	[0.03 - 0.19]	Range	[0.05 -0.19]

Family of pesticides detected	Pesticide active ingredient	Maize	Dried fish		Rice		Tomatoes	
OPP	*Azinphos Ethyl*	-	Nber of samples	11	-		-	
			Means ± SD	2.29 ± 1.05				
			Range	[1.06 -4.09]				
	Dimethoate	-	Nber of samples	2	-		Nber of samples	1
			Means ± SD	1.51± 0.64			Means ± SD	0.03
			Range	[1.06 -1.96]			Range	-
	Monocrotophos	-	-		-		Nber of samples	4
							Means ± SD	2.22± 0.92
							Range	[1.04 - 3.20]
CP & others	*Benalaxyl*	-	Nber of samples	8	-		-	
			Means ± SD	12.7 ± 29.6				
			Range	[1.01- 85.8]				
	Carbofuran	-	-		-		Nber of samples	2
							Means ± SD	0,06 ± 0.01
							Range	[0.05 - 0.07]
	Imazalil	-	Nber of samples	3	-		Nber of samples	3
			Means ± SD	6.11 ± 1.32			Means ± SD	0,22 ± 0.20
			Range	[4.67- 7.26]			Range	[0.06 - 0.44]
	Propiconazole	-	-		Nber of samples	1	Nber of samples	1
					Means ± SD	0.25	Means ± SD	0.06
					Range	-	Range	-
	Simazine	-	Nber of samples	19	-		Nber of samples	12
			Means ± SD	13.1 ± 10.3			Means ± SD	0.09 ± 0.13
			Range	[2.62- 38.4]			Range	[0.03 - 0.5]

Family of pesticides detected	Pesticide active ingredient	Maize		Dried fish		Rice		Tomatoes	
PP	*Cyflutrin*	Nber of samples	7	Nber of samples	34	Nber of samples	26	Nber of samples	1
		Means ± SD	1.99 ± 2.09	Means ± SD	9.77 ± 5.22	Means ± SD	1.29 ± 1.12	Means ± SD	0.34
		Range	[0.39 -6.23]	Range	[1.05 – 21.11]	Range	[0.1 - 3.95]	Range	-
	∑ *Cypermethrins*	Nber of samples	4	Nber of samples	31	Nber of samples	11	Nber of samples	1
		Means ± SD	0.17 ± 0.08	Means ± SD	38.34 ± 27.37	Means ± SD	0.20 ± 0.09	Means ± SD	0.17
		Range	[0.11-0.28]	Range	[1.6–96.68]	Range	[0.11-0.34]	Range	-

Organochlorines pesticides (**OCP**), Organophosphorus pesticides (**OPP**) Carbamates pesticides & others (**CP**) and Pyrethroids pesticides (**PP**)

Appendix B: Acute health risk assessment as per maximum daily intakes of pesticide residues

Pesticide active ingredient	Estimated Maximum Daily Intakes (EMDI) (mg.kg^{-1}.day^{-1})				Estimated Average Daily Intakes (EADI) (mg.kg^{-1}.day^{-1})			
	Maize	**Dried Fish**	**Rice**	**Tomatoes**	**Maize**	**Dried Fish**	**Rice**	**Tomatoes**
Chlorothalonil	-	*0.00025*	-	-	-	*0.0001*	-	-
Dieldrine	-	-	-	-	-	*0.0003*	-	-
Heptachlor	-	-	-	-	-	-	-	*0.00001*
Lindane	-	*0.0061*	-	*0.00003*	-	*0.0023*	-	*0.00001*
Dimethoate	-	*0.0001*	-	-	-	*0.0001*	-	-
Monocrotophos	-	-	-	*0.00032*	-	-	-	*0.00022*
Benalaxyl	-	*0.0057*	-	-	-	*0.0008*	-	-
Carbofuran	-	-	-	*0.00001*	-	-	-	*0.00001*
Imazalil	-	*0.0005*	-	*0.00004*	-	*0.0004*	-	*0.00002*
Propiconazole	-	-	*0.0007*	*0.00001*	-	-	*0.0007*	*0.00001*
Simazine	-	*0.0026*	-	*0.00005*	-	*0.0009*	-	*0.00001*
Cyflutrin	*0.0221*	*0.0014*	*0.0111*	*0.00003*	*0.0071*	*0.0007*	*0.0036*	*0.00003*
Cyperméthrine	*0.0010*	*0.0065*	*0.0010*	*0.00002*	*0.0006*	*0.0026*	*0.0006*	*0.00002*

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