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Contamination of free-range ducks by chlordecone in Martinique (French West Indies): A field study

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HIGHLIGHTS

- Ducks were raised in an area contaminated with chlordecone (410 μg/kg dry matter).
- Liver, egg, abdominal fat and leg muscle were contaminated with chlordecone.
- Up to 13 weeks would be required to decontaminate these products.

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ABSTRACT

The former use of chlordecone (CLD) in the French West Indies has resulted in long-term pollution of soils and subsequently of food chains. In contaminated areas, free-range ducks used to control weeds in orchards may be exposed to CLD through polluted soil ingestion. The question arises whether they may be consumed.
Muscovy ducks were raised on a guava orchard planted on a soil moderately contaminated (410 μg CLD/kg dry matter). Ducks were raised indoor up to 6 weeks of age and allowed to range freely outdoors thereafter. Twenty-nine females were sequentially slaughtered by groups of 2 to 5 ducks, after 4, 16, 19, 22 or 26 weeks spent in the orchard or after 16–17 weeks in the orchard followed by 3, 6 or 9 weeks in a closed shelter for depuration.
CLD concentration increased from 258 to 1051, 96 to 278, 60 to 169 and 48 to 145 μg/kg fresh matter (FM) as the exposure through grazing increased from 4 to 22 weeks, in liver, abdominal fat and leg with and without skin, respectively. Eggs collected in the orchard contained up to 1001 μg CLD/kg FM. All these values exceeded the Maximum Residue Limit (MRL) of 20 μg/kg FM. CLD concentration in all tissues was divided by around 10 within the 9-week confinement period. Despite this quite rapid decontamination, it is estimated that 12–13 weeks would be required to achieve the MRL in liver and in eggs, and 5–6 weeks in leg muscle. Such durations would be too long in practice. Thus, the consumption of products from free-range ducks should be avoided, even in areas mildly contaminated with CLD.

1. Introduction

In the French West Indies soils have been polluted by an organochlorine pesticide, chlordecone (CLD), formerly used in banana plantations to control black weevil populations (*Cosmopolites sordidus*). This contaminant is highly persistent in soil as it strongly binds to organic matter and is recalcitrant to degradation under environmental conditions (Jablonski et al., 1996; Cabidoche et al., 2009). Thus CLD is still found in soils, with subsequent contamination of water, crops, animals (Dubuisson et al., 2007; Coat et al., 2011) and human impregnation through food (Guldner et al., 2010). Contamination of foodstuffs by CLD is of great health concern in the French West Indies as it is suspected to increase the risk of prostate cancer (Multigner et al., 2010) and to impair the cognitive and motor development of Guadeloupean infants exposed during pregnancy or through breast feeding (Dallaire et al., 2012; Boucher et al., 2013).

Abbreviations: BW, body weight; CLD, chlordecone; FM, fresh matter; MRL, maximum residue limit.

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Grazing poultry have been shown to be efficient alternatives to the use of pesticides to control weeds and pests in crops and in orchards (e.g. Tajuddin, 1986; Clark and Gage, 1996; Lavigne et al., 2012). Especially ducks have been successfully used (Zhang et al., 2009; Li et al., 2012). However, products from free-range poultry are likely to display high contamination levels of organic environmental pollutants due to the ingestion of quite high amounts of soil (e.g. Schoeters and Hoogenboom, 2006; Waegeneers et al., 2009). In addition, several studies indicate that soil-bound persistent organic pollutants such as dioxins, furans or polychlorobiphenyls are readily released in the digestive tract of farm animals (Hoogenboom et al., 2006; Fournier et al., 2012; Feidt et al., 2013). Especially, it was shown that CLD present in polluted soils collected in Martinique was as available to chicken hens and to pigs as CLD ingested through oil (Bouveret et al., 2013; Jondreville et al., 2013). In an experiment conducted with laying chicken hens exposed daily to the environmental level of 53 μg CLD through feed, Jondreville et al. (2014) reported that CLD was significantly transferred to liver, egg and meat so that the CLD concentration largely exceeded the Maximum Residue Limit (MRL) of 20 μg CLD/kg product (Regulation no. 396/2005/EC). This study also demonstrated a quite rapid decontamination of the laying hens.

As farmers may be interested in self-consuming or selling the products from the ducks used for pests and weeds control in their orchards, the current field study was conducted in order to assess the level of contamination of ducks grazing on a soil contaminated with CLD and its distribution among tissues. Moreover this study was also aimed to test whether a confinement period prior slaughter may be an efficient way of tissues CLD decontamination.

2. Materials and methods

2.1. Study design

The study was conducted in an 1100 m^2-orchard located in Ducos (Martinique) and planted on a CLD-contaminated soil with guava *(Psidium guajava)*, star apple *(Chrysophyllum cainito)* and longan *(Dimocarpus longan)*. The grass cover was made of natural grass and sown legumes (*Desmodium heterophyllum*). The soil was a volcanic nitisol (Cabidoche et al., 2009).

Fifty one-day old Muscovy ducks (*Cairina moschata*) imported from metropolitan France were purchased from Soproda (Rebais, France). They weighed 97 ± 6 g at three days of age. They were raised indoor up to 6 weeks of age (1320 ± 230 g body weight, BW) and were allowed to graze in the orchard thereafter. At 10 weeks of age, 35 ducks identified as females based on sexual dimorphism, were individually weighed, marked with a numbered ring placed on the wing, and assigned to one of eight experimental treatments (4 or 5 birds per treatment) based on BW. The eight treatments differed for the durations of exposure (grazing) and of depuration (confinement) phases, after which ducks were slaughtered (Table 1). Thus, exposure started when the ducks were aged 6 weeks and lasted 4, 16, 19, 22 or 26 weeks without depuration (treatments 1, 2, 3, 4 and 5, respectively), or 16–17 weeks of grazing followed by 3, 6 or 9 weeks of depuration (treatments 6, 7 and 8, respectively). Depuration was achieved by raising birds in an enclosed 10 m^2-shelter allowing their complete isolation from the contaminated environment.

During confinement, from hatch to 6 weeks and for depuration prior slaughter, ducks were exclusively given commercial feed. When free ranging, ducks were given a mixture of maize and of commercial feed through three feeders placed in the orchard. All these feeds, mostly made from cereals imported from metropolitan France, were purchased from Martinique Nutrition Animale (Lamentin, Martinique). Throughout the experiment waterers filled with drinkable water were available. Because feeds and ducklings were imported from metropolitan France, they were considered as devoid of CLD. In addition, drinkable water provided to ducks was free of CLD (below the detection limit of 0.01 μg/L), according the monitoring programs of Regional Health Agency. Thus, in the current study, soil ingestion is regarded as the main source of exposure of the grazing ducks to CLD.

2.2. Sampling and chemical analysis

In order to characterize the level of soil contamination by CLD, the 1100 m^2-orchard was divided into 3 equal subplots. Within each subplot, 15 samples of soil (0–10 cm depth) were collected and pooled. The three soil samples were air dried, manually crushed, sieved to 2 mm and crushed in a rotor beater mill (model SR200 by Retsch, Haan, Germany) before analysis.

Table 1
Body weight of female ducks and concentrations of chlordecone in liver, in abdominal fat and in leg with or without skin.

Treatment	1	2	3	4	5	6	7	8	*P*-value	RMSE
Exposure (week)	4	16	19	22	26	16	16	17		
Depuration (week)	0	0	0	0	0	3	6	9		
Age at slaughter (week)	10	22	25	28	32	25	28	32		
n	2	4	4	4	2	5	5	3		
Body weight (g)										
10 weeks	1283	1300	1275	1263	1375	1330	1365	1358		
Slaughter	1283 a	2371 b	2555 bc	2537 bc	2281 b	2698 c	2362 b	2770 c	*<0.001*	172
Fat concentration (g/kg fresh matter)										
Liver	44	75	50	92	81	97	82	116	*0.21*	34
Leg without skin	44	49	62	53	44	60	73	77	*0.41*	21
Chlordecone concentration (μg/kg fresh matter)										
Liver	258 ab	615 c	517 bc	1051 d	1215 d	223 a	141 a	47 a	*<0.001*	191
Abdominal fat	96 bcd	133 cde	166 de	278 f	212 ef	82 bc	32 ab	9 a	*<0.001*	45
Leg with skin	60 abc	78 bc	87 c	169 d	153 d	42 ab	18 a	7 a	*<0.001*	28
Leg without skin	48 ab	66 b	77 bc	145 d	122 cd	36 ab	15 a	6 a	*<0.001*	31
Chlordecone concentration (μg/kg fat)										
Liver[a]	6628 ab	8160 b	10,453 bc	13,351 c	15,145 c	2761 a	1881 a	405 a	*<0.001*	3503
Abdominal fat[b]	105 bcd	144 cde	180 de	302 f	231 ef	89 bc	35 ab	10 a	*<0.001*	48
Leg without skin[a]	1288 ab	1500 b	1514 b	2762 c	2846 c	740 ab	274 a	77 a	*<0.001*	760

Values in the same row not followed by the same letter (a, b, c, e, f) differ ($P < 0.05$).
RMSE is the root mean square error of the model.
[a] Calculated as the ratio of assayed chlordecone concentration (μg/kg fresh matter) to assayed fat concentration (g/kg fresh matter), multiplied by 1000.
[b] Calculated as the ratio of assayed chlordecone concentration (μg/kg fresh matter) to a fat concentration of 918 g/kg fresh matter (Chartrin et al., 2006), multiplied by 1000.

Slaughter was achieved by injection of sodium pentobarbital into the occipital venous sinus. This operation was performed by a trained public officer in the laboratory of the Direction de l'Alimentation, de l'Agriculture et de la Forêt (DAAF) in Martinique. At slaughter, ducks were weighed and the two legs, liver and abdominal fat were collected. The bone was removed from the two legs and one of them was cleared of its skin. When aged 27 weeks, some females started to lay. The one to four eggs collected weekly in the orchard and in the closed shelter were pooled. In addition, egg yolks and egg whites collected in the orchard when ducks were aged 28 weeks (after 22 weeks of grazing) were separately analyzed, in order to assess the fraction of egg to which CLD is transferred. All samples were stored under vacuum at −18 °C before analysis.

Soil CLD analyses were performed by the Laboratoire Départemental d'Analyses de la Martinique (LDA972, Fort-de-France, France) as described by Woignier et al. (2012). Briefly, extraction was carried out with dichloromethane and acetone (50:50 *v*/*v*). The purified samples were then analyzed on a Varian (Palo Alto, CA, USA) and Agilent (Santa Clara, CA, USA) gas chromatograph-electron capture detector (GC-ECD). The calibration used hexabromobenzene and triphenylphosphate as internal standards. The resulting average extraction coefficient was 0.91.

CLD in animal samples was analyzed by the Laboratoire Départemental d'Analyses du Morbihan (LDA56, Saint-Ave, France) according to the POP 09 method for pesticide analysis developed by the French Agency for Food, Environmental and Occupational Health and Safety (Anses, Maisons-Alfort Laboratory for food safety, Chemical Food Contaminants Department, Pesticides and Marine Biotoxins Unit). After homogenization (Ultra Turrax), a first extraction was carried out with hexane and acetone (85:15 *v*/*v*). For abdominal fat, it was preceded by two extractions with acetonitrile and dichloromethane (75:25 *v*/*v*). Chlordecone hydrate was then obtained by alkalinisation with a sodium hydroxide solution, and the aqueous phase was washed with hexane to eliminate fat. Then, CLD was reformed through acidification of the solution by means of sulfuric acid (60%) and a second extraction phase was carried out with hexane:acetone (85:15 *v*/*v*). CLD was analyzed by liquid chromatography-tandem mass spectrometry (LC-MS/MS) with an Ab Sciex (Massachusetts, USA) API 4000 system. Quantification by isotope-dilution was carried out with CLD-C_{13} as internal standard. The resulting average extraction coefficient was 1.04 for all animal tissues.

Limits of quantification were 10 μg/kg dry soil, 2.0 μg/kg abdominal fat, 1.0 μg/kg in whole egg, egg yolk and white, and 0.05 μg/kg in leg muscles. Limits of detection were a third of limits of quantification. Both laboratories (LDA972 and LDA56) work under the international standard ISO/IEC 17025:2005 (General requirements for the competence of testing and calibration laboratories) and are accredited by COFRAC, the French Accreditation Committee.

Total lipids were extracted quantitatively from liver and from leg without skin by homogenizing samples of minced tissues in chloroform and ethanol (2:1 *v*/*v*) and collecting gravimetrically (Folch et al., 1957).

Table 2
Chlordecone concentration (μg/kg fresh matter) in pooled eggs collected one day a week.

Exposure (week)	Depuration (week)	Age (week)	n^a	CLD (μg/kg FM)
22	0	28	2	323
25	0	31	3	1001
26	0	32	2	774
16	5	27	4	132
16	6	28	1	148
17	6	29	2	99
17	7	30	2	107
17	8	31	3	63
17	9	32	1	29

[a] Number of eggs pooled to form a single analyzed sample.

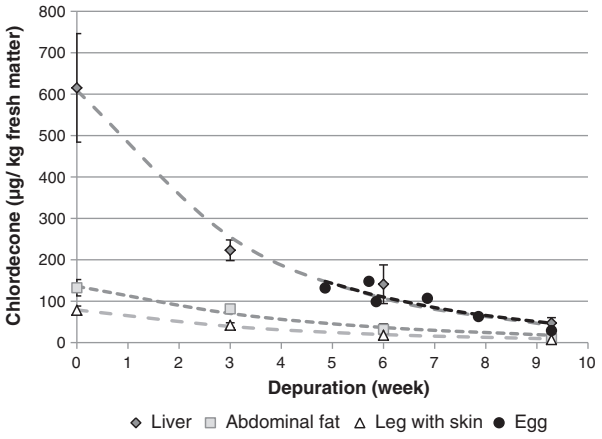

Fig. 1. Time-dependent concentrations of chlordecone (μg/kg fresh matter) in liver, in egg, in abdominal fat and in leg with skin in ducks kept indoor after a 16-week grazing period. The data points are adjusted means ± standard error presented in Table 1 for all tissues, except for eggs (Table 2). Within each tissue, the dashed line represents the first order kinetic model presented in Table 3.

2.4. Calculations and statistical analyses

The assayed concentrations of CLD in animal tissues are expressed on a fresh matter (FM) basis. They are also presented on a fat basis by dividing by the total lipid concentration of the tissue. Lipid concentration was measured in leg without skin and in liver and set at 918 g/kg FM in abdominal fat, because this latter is rather stable between animals (Chartrin et al., 2006).

Statistical analyses were performed by means of the Statistical Analysis Systems software package (SAS, version 9.1, SAS Institute, Cary, NC). Body weight at slaughter and CLD concentration in the tissues were analysed using the GLM procedure. The duck was considered as the experimental unit and the model included the experimental treatment (combination of exposure and depuration durations, $n = 8$). This analysis was followed by a comparison of means using Student's *t*-test. Differences were considered significant for *P*-values < 0.05. Such analysis could not be implemented for eggs because of lack of replicates within each treatment.

Within each tissue, the mean CLD concentrations during the depuration period (i.e. treatments 2, 6, 7 and 8) were used to estimate the half-life of CLD by iterative non linear regression using the NLIN procedure of SAS. For eggs the single available data per week was used. Parameters k and A were adjusted using a first order kinetic model of the following form:

$C(t) = A \times \exp(-k \times t)$, where C (t) is the CLD concentration (μg/kg FM) in the considered tissue or egg, after a t-day depuration period, k (d^{-1}) is the depuration rate constant of CLD from the tissue and A (μg/kg FM) is an estimate of the concentration of CLD after 16 weeks of exposure (treatment 2). Half-life (d) was calculated as ln (2) / k.

3. Results and discussion

The CLD concentration in the three subsamples of soil collected in the orchard was 360, 360 and 510 μg/kg soil dry matter (DM). This level of pollution is considered as mild with respect to the global contamination of soils in the French West Indies (Levillain et al., 2012; Clostre et al., 2014). Indeed, soils are considered as mildly and moderately contaminating for crops when their CLD concentration range between 100 and 500 μg/kg soil DM and 500 and 1000 μg/kg soil DM, respectively, while they are considered as strongly contaminating when their CLD concentration exceeds 1000 μg/kg soil DM (Lesueur-Jannoyer et al., 2012).

3.1. Animals' body weight

At slaughter, 6 of the 35 ducks initially identified as females revealed to be males. As a consequence, the number of replicates for each treatment ranges between 2 and 5 (Table 1). The ducks slaughtered at the age of ten weeks (treatment 1) displayed the lowest body weight (1283 g, $P < 0.05$). From 22 weeks of age, animals had completed their growth and the body weight of the ducks remained stable, ranging between 2362 g (treatment 7) and 2770 g (treatment 8). Besides, no systematic difference in body weight could be detected between animals grazing up to slaughter and those allowed a depuration period before slaughter.

3.2. Concentration of chlordecone in tissues and eggs

CLD was quantified in all analyzed samples. In the pooled sample of three egg whites corresponding to the eggs collected in the orchard after 22 weeks of grazing, CLD concentration was 2 μg/kg FM while the corresponding concentration in egg yolk was 1172 μg/kg FM (results not shown). Similarly, Jondreville et al. (2014) did not detect any CLD in the white from hens' eggs (*Gallus domesticus*), while egg yolk contained 1685 μg/kg FM. This strongly suggests that CLD is almost exclusively transferred to egg yolk in birds, as observed for most other organochlorine compounds (e.g. Kan and Meijer, 2007).

The concentration of CLD in liver, in abdominal fat and in leg with and without skin is presented in Table 1. Whatever the tissue, CLD concentration increased as the exposure duration through grazing increased (treatments 1 to 5) and decreased during depuration (treatments 6 to 8) (treatment, $P < 0.001$). After 4 weeks of exposure (treatment 1), CLD concentration was already 258, 96, 60 and 48 μg/kg FM in liver, in abdominal fat and in leg with and without skin, respectively. The maximum concentration was reached after 22 to 26 weeks of exposure (treatments 4 and 5), with concentrations of 1051 to 1215, 212 to 278, 153 to 169 and 122 to 145 μg/ kg FM, respectively. As these animals had completed their growth, it suggests that uptake of CLD and its elimination were balanced. CLD concentration in all tissues rapidly decreased and was divided by around 10 within the 9-week depuration period (treatment 2 to treatment 8) from 615 to 47, 133 to 9, 78 to 7 and 66 to 6 μg/kg FM, respectively. This decrease in body tissue CLD concentration during confinement strongly suggests that feed and water they were given did not contain significant amounts of the contaminant. In eggs, CLD concentration was in the order of the values recorded in liver. The maximum 1001 μg CLD/kg FM was recorded in the pool of 3 eggs collected in the orchard after the ducks had been grazing for 25 weeks with no depuration (Table 2). In ducks kept indoor after 16 or 17 week grazing, CLD concentration in eggs ranged between 100 and 150 μg/kg FM after 5 to 6 weeks of depuration and was progressively reduced down to 29 μg/kg FM after 9 weeks of depuration.

In the seventies, the production of CLD resulted in the contamination of the James River in the USA. Even higher concentrations than observed in this study were recorded in the livers (200 to 130,000 μg/kg FM) and carcasses (100 to 40,000 μg/kg FM) from bald eagles, which subsisted mainly on fishing (Stafford et al., 1978). The current concentrations at the end of the 22–26-week exposure comply with the 1640, 460, 331 and 123 μg CLD/kg FM reported in liver, egg, abdominal fat and muscle, respectively, reported in laying hens (*G. domesticus*) exposed during 6 weeks to 53 μg CLD daily (Jondreville et al., 2014).

Overall, on a fresh matter basis, liver was 3.9 times more concentrated in CLD than abdominal fat, while muscles with and without skin were 1.7 and 2.0 times less concentrated than fat, respectively. However, when expressed on a fat basis, CLD was 53 and 10 times more concentrated in liver and in leg muscle than in abdominal fat, respectively (Table 1). Similarly, liver and leg muscle of laying hens (*G. domesticus*) orally exposed to 53 μg CLD daily during 6 weeks were reported to be 36 and 16 times more concentrated on a fat basis than abdominal fat (Jondreville et al., 2014). Compared to other organochlorine pesticides such as DDT, dieldrin or mirex, which equally distribute towards body fat and hepatic tissues on a fat basis, CLD is known to preferentially accumulate in the liver in human (Cohn et al., 1978), in mouse (Hewitt et al., 1986), and in rat (Egle et al., 1978; Belfiore et al., 2007). This preferential accumulation is believed to be due to the binding of CLD to gluthathione-S-transferase in liver of pigs and of rats through its ketone group (Soine et al., 1984; Belfiore et al., 2007). Beside, the peculiar distribution of CLD between tissues may result from its preferential transport through high density lipoproteins, while other chlorinated pesticides are preferentially linked to very low and low density lipoproteins in rats and in humans (Soine et al., 1982). The current study, as well as the studies conducted with laying hens by Jondreville et al. (2014) and with bald eagles by Stafford et al. (1978), confirms this preferential accumulation of CLD in liver of birds, its quite high concentration in eggs and its peculiar distribution into body fat, especially its low accumulation in peripheral fat.

3.3. Depuration of ducks

The depuration curves of liver, egg, abdominal fat and leg muscle are presented in Fig. 1. First order kinetics models were adjusted with coefficients of determination of 0.99, 0.98, 0.99, 0.99 and 0.79 in liver, abdominal fat, leg with skin, leg without skin and egg, respectively (Table 3). Estimates of the half-lives were 17, 19, 22 and 21 days in liver, egg, abdominal fat and muscles, respectively. Thus, as previously reported by Naber and Ware (1965) and Jondreville et al. (2014) in laying chicken hens, CLD is readily transferred to animal products but is quite rapidly eliminated in contrast to other compounds such as DDT which display half-lives of 7–10 weeks (e.g. Kan and Meijer, 2007). Because the ducks had almost completed their growth before being

Table 3
Parameters of the first order kinetics of chlordecone in liver, in abdominal fat, in leg and in egg and duration of confinement required to recover concentrations compliant with the regulatory MRL[a].

	Model[b]				$t_{1/2}$ (d)	Time required for decontamination (d)[c]
	A	k	R^2	RMSE		
Liver	609	0.0414	0.99	24	17	83
Abdominal fat	136	0.0313	0.98	7.5	22	–
Leg with skin	79	0.0333	0.99	1.9	21	41
Leg without skin	66	0.0327	0.99	2.0	21	37
Egg	521	0.0371	0.79	23	19	88

R^2 is the coefficient of determination between predicted and observed values; RMSE is the root mean square error of the model.

[a] MRL, maximum residue limit (20 μg/kg fresh matter in all edible products except in abdominal fat for which it is 200 μg/kg fresh matter) (Regulation no. 396/2005/EC).

[b] The model is $C(t) = A \times \exp(-k \times t)$, where $C(t)$ is the concentration of CLD (μg/kg FM) in the considered tissue or egg, after a t-day depuration period and k (d^{-1}) is the depuration rate constant of CLD from the tissue. Half-life (d) is calculated as ln (2) / k, while A (μg/kg FM) is an estimate of the concentration of CLD after 16–17 weeks of exposure.

[c] Duration of the depuration period to recover a CLD concentration in edible products in accordance with the regulation; calculated as (ln(A) − ln(MRL)) / k.

confined, dilution of the contaminant through growth probably only marginally contributed to the decrease in tissue CLD concentration. In some species, CLD undergoes hepatic metabolism allowing its hydroxylation into chlordecone-alcohol and its subsequent elimination through bile. This biotransformation, which fosters the rapid elimination of CLD, was observed in humans and in pigs but not in most rodents (Soine et al., 1983). Whether this metabolic pathway exists in birds, and especially in ducks, is not known. However, the rather rapid depuration observed in the current study, as well as in the studies conducted by Naber and Ware (1965) and Jondreville et al. (2014) on laying chicken hens, would suggest that such a way of CLD elimination would occur in these avian species. In addition, the collected eggs were concentrated in CLD so that they also contributed to body depuration of the female ducks. However, the quite low laying rate in the current experiment probably limited the contribution of this way of CLD elimination. In this respect, the low laying rate observed in the current study may partly explain the long depuration half-life compared to the values of around 5 days reported by Jondreville et al. (2014) in highly productive hens, regularly laying one egg daily.

Nevertheless, expressed on a FM basis, the maximum concentration of CLD in liver, egg, abdominal fat and leg without skin, reached after 22 to 26 weeks grazing (treatments 4 and 5) was 2.8, 2.2, 0.6 and 0.3 times the concentration of 410 μg/kg DM in soil, respectively. At environmental levels of exposure to CLD of piglets and of laying hens through soil ingestion Bouveret et al. (2013) and Jondreville et al. (2013) reported that CLD concentration in tissues was proportional to CLD ingested. Particularly, Jondreville et al. (2013) reported that in laying hens, CLD concentrations in liver, egg and abdominal fat responded linearly to a daily ingestion of 2 to 12 μg CLD through contaminated soil. With a soil containing 410 μg CLD/kg DM, this would correspond to a daily ingestion of 5 to 30 g of soil DM, which is in the order of the level of soil ingestion reported in free-range laying hens (Waegeneers et al., 2009; Jondreville et al., 2010). Thus, it can be assumed that, at environmental levels of CLD exposure, the ratio of CLD concentration in tissues to its concentration in soil is independent of the level of exposure. This would mean that, in case ducks would be allowed to graze until slaughter, soil CLD concentration should be below 10 μg/kg DM for liver and eggs being compliant with the MRL of 20 μg/kg FM (Regulation no. 396/2005/EC) and below 60 μg/kg DM for compliant meat. Given the limit of quantification of CLD in soil of 10 μg/kg DM, it means that products from free-range ducks raised under the current conditions should not be consumed unless the soil is free of CLD. Owing to the quite short half-life of CLD, animals kept indoor were efficiently decontaminated. Nevertheless, it is estimated that 12–13 weeks of confinement would have been required to achieve the MRL in liver and in eggs, and 5–6 weeks in leg muscle (Table 3). With regards to the objective of farmers to maintain the animals grazing as long as possible to control weeds, these durations seem long. However, they hold true for the current experiment and may be shortened if the tissue concentration at the end of the exposure period is reduced, through the limitation of soil ingestion during the grazing period. This may be achieved by providing a nutritionally well balanced feed through feeders avoiding its contamination with soil particles (Waegeneers et al., 2009; Jondreville et al., 2010). However, before the consumption of these grazing ducks is possible, rearing practices must be improved.

4. Conclusion

The current study shows that products from ducks grazing on a soil moderately contaminated with CLD are rapidly contaminated at levels exceeding the MRL. It confirms the peculiar distribution of CLD, with a preferential accumulation in liver and a moderate contamination of abdominal fat. It shows that decontamination of products through confinement is possible, but, despite the quite short half-life of CLD, the time required to obtain edible products would be too long in practice. Thus, the consumption of products from free-range ducks should be avoided, as soon as the soil contains CLD, unless rearing practices are improved.

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