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1 **Generic methodology to prevent food contamination by soil born POPs**
2 **in free range livestock**

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13 **Abstract**

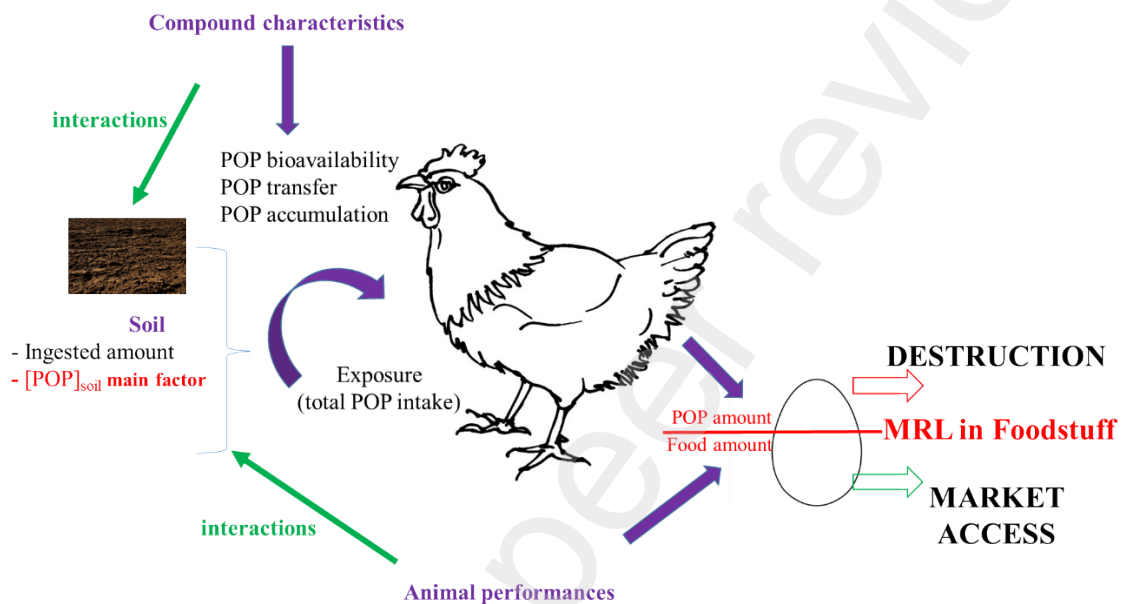
14 Control of POP presence in feed for animals and food of animal origin is usually included
15 in governmental monitoring, and many countries defined maximum residue levels (MRLs),
16 which established a maximum tolerable concentration of POPs, which has shown not to
17 endanger human health. However, such MRLs do not cover the POPs presence in soil, which
18 could have much higher concentrations compared to feed due to its strong affinity and
19 persistence of these contaminants in comparison to other environmental matrices. In addition,
20 daily soil ingestion could lead to high transfer of soil borne POPs to livestock which lets
21 suppose a high bioavailability of these compounds in soil. In this context, the goal of this study
22 was to develop and to test an approach to evaluate the tolerable POP concentration in soil for
23 different livestock animals in different rearing systems, allowing the safety of the produced
24 food of animal origin. Therefore, we summarize existing knowledge about the risk of POP
25 transfer in different livestock breeding systems *via* soil exposure and modelize *via* a backward

26 calculation from the MRLs the corresponding and tolerable amount of POPs, which may be
 27 ingested by the animals in the considered rearing system.

28

29 **Keywords:** POPs transfer, foodstuff, tolerable concentrations, risk

30 **Graphical abstract**



31

32 **Table of content**

1. Introduction.....	3
2. Material and methods.....	6
2.1 General scheme of the approach.....	6
2.2 Parameter settings.....	7
2.3 Choice of scenarios of animal models and their corresponding rearing system.....	9
3. Results.....	9
3.1 Modelizations of POPs transfer risk in different livestock breeding systems.....	9
4. Discussion.....	12
4.1 Methodological approach based on transfer rate and bioconcentration factor.....	12
4.2 A preventive supporting decision tool.....	14
5. Conclusion.....	16

33

34

35 1. Introduction

36 Nowadays, it is admitted that 90% of chronic human exposure to POPs (Hoogenboom et
37 al., 2015) occurs through consumption of contaminated food especially products of animal
38 origin (Çok et al., 2009; Hoogenboom et al., 2015; Polder et al., 2010; Rodríguez-Hernández
39 et al., 2015). These types of products contain generally more fats than food of plant origin and
40 therefore tend to accumulate more easily lipophilic POPs. As consequence, the most frequent
41 cases of POP contaminated food appear among them. Indeed, food of animal origin is a
42 predominant source of human exposure to POPs (Malisch and Kotz, 2014) especially for such
43 compound families as polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans
44 (PCDD/Fs), polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) due to
45 their high bioaccumulation in fatty tissues and high persistency (ATSDR, 2019, 2005, 2000,
46 1998).

47 The contamination of food of animal origin is directly related to daily animal ingestion
48 of different contaminated feed ingredients, water and even contaminated soil, especially in free-
49 ranged animals. Soil could retain POPs in the matrix for several decades due to its strong
50 affinity to soil organic matter (SOM), and the concentrations of these contaminants are higher
51 in several order of magnitude than in water and feed. Moreover, literature reported that free-
52 ranged animals can ingest consequent amounts of soil. According to previous studies (Healy,
53 1968; Jurjanz et al., 2012) dairy cattle may ingest between 1 and 6 % of dry soil depending on
54 the grazing conditions. Extreme conditions may enhance soil intakes up to 10% of the totally
55 ingested dry matter in dairy cows as well as in beef cattle. Free-ranged poultry could also
56 consume 5 to 10% of soil, but up to 23% while fed only with grains. When such high soil intakes
57 would take place on plots with contaminations of the surface soil, the high transfer and
58 bioaccumulation of the main families of POPs (Amutova et al., 2021) would lead to significant
59 contamination of the food produced by these animals. In this context, the intake of soil has to

60 be considered as the main exposure factor for livestock, especially in areas with a historical
61 contamination.

62 Control of POP presence in feed for animals and food of animal origin is usually
63 included in governmental monitoring, and legislation defines maximum tolerable
64 concentrations of the concerned compounds in these matters. Indeed, numerous countries
65 defined maximum residue levels (MRLs), which established a maximum tolerable
66 concentration of POPs, which has shown not to endanger human health. However, such MRLs
67 do not cover the POPs presence in soil, which could have much higher concentrations compared
68 to feed due to its strong affinity and persistence of these contaminants in comparison to other
69 environmental matrices (Bakoglu et al., 2005; Cheng et al., 2003; Danielovič I. et al., 2014;
70 Deng et al., 2011; Domingo et al., 2000). Results of many studies (Amutova et al., 2021a; Collas
71 et al., 2019; Delannoy et al., 2020a; Jondreville et al., 2013) reported also a high transfer of soil
72 borne POPs to livestock which lets suppose a high bioavailability of these compounds in soil.
73 This has been confirmed by some studies on hens, goats and piglets (Fournier et al 2012; Feidt
74 et al., 2013; Jurjanz et al 2014; Delannoy et al 2015). These data show a real need to estimate
75 the potential of a soil surface to produce their safe food with free-ranged livestock.

76 Indeed, a MRL is a threshold over which food regulations forbid any commercialization
77 of such food products in order to protect consumers. In the case of overpassing, investigations
78 are undertaken to identify and eliminate the contamination source on the farm level and to
79 launch expensive remediation programs.

80 The unacceptable concentration of POPs in soil can be assessed by calculating backwards
81 from the MRLs in animal foodstuffs (starting point) to determine the tolerable POP intake by
82 the animal. Some well-known indicators of POPs transfer are used for this purpose, i.e. transfer
83 rates (TRs) and bioconcentration factors (BCFs). Additionally, to soil intake, other sources of

84 oral exposure (e.g. feed) must be taken into account to calculate the tolerable residual POP
85 supply in order not to exceed the safety level in animal food production.

86 In these calculations, the application of additional security ratio may be necessary
87 depending on the uncertainty of the used parameters, as usually done in risk assessments. The
88 knowledge of the exact quantity of totally ingested pollutants (i.e. from all ingested matrices)
89 which would transfer to the final food product allows classifying farm production systems
90 depending on their sensitiveness to a potential contamination situation. Not available or
91 imprecise parameters of such calculations, such as the analytical method of detection (Megson
92 et al., 2016), source and type of contamination (Guo et al., 2019), animal species, grazing
93 conditions, and animal productivity (Chapman et al., 2007; Holechek J., 1979; Lamy et al.,
94 2012), would enhance the application of security factors. The latter would lead by their
95 accumulation to an overestimation of the risks.

96 The resulting massive destruction of foodstuffs and production systems in a situation of
97 a pollution incident enhances heavy economic and social consequences for the concerned area.
98 However, they can and should be limited on the strictly necessary but while ensuring a perfect
99 protection of the consumers. Rehabilitation of conditions allowing food production in
100 contaminated areas is required for commercial farms but also for private holders producing food
101 for their households. The large surfaces of commercial farms, especially with large animals as
102 cattle, in comparison to generally restraint surface sizes of private holders need to adapt
103 management and restoring strategies to each case. Therefore, the precise establishment but also
104 the efficient reduction of transfer of pollutants can be considered as the main way to evaluate
105 and manage the risks in the case of a contaminated area.

106 Based on the foregoing, the **goal of this work is** to develop and to test an approach to
107 evaluate the tolerable POP concentration in soil for different livestock animals in different
108 rearing systems, allowing the safety of the produced food of animal origin. Therefore, we

109 summarize existing knowledge about the risk of POP transfer in different livestock breeding
110 systems *via* soil exposure and modelize via a backward calculation from the MRLs the
111 corresponding and tolerable amount of POPs, which may be ingested by the animals in the
112 considered rearing system.

113 **2. Material and methods**

114 **2.1 General scheme of the approach**

115 Contrarily to food, nearly no regulation exists about the use of soil depending on its
116 concentration of POPs. Therefore, we built an assessment as a backward calculation starting
117 from the maximum residue limit (MRL) generally fixed by regulations, an evaluation of the
118 transfer across the different animals to evaluate the tolerable exposure *via* the supply of different
119 vector matrices to come at the end to the concentration in the soil on which these animals
120 explore or pasture. The figure 1 summarizes this approach.

121 Therefore, the approach started with the maximum tolerable concentration of the
122 different POPs in foodstuffs. Indeed, such concentrations are fixed for PCDD/Fs and PCBs (for
123 example Commission Regulation (EC) No 1881/2006, 2006). The absence of such regulations
124 may reflect that the oral exposure of consumers is a minor pathway, or the existing knowledge
125 does not allow yet fixing such thresholds (for ex. residues of some OCPs). In the second case,
126 toxicological reference values as for example the acceptable daily intake (ADI) could provide
127 approximate concentration to build an approach.

128 The regulatory threshold concentration is indeed a ratio between an amount of the
129 considered compound and the amount of the foodstuff. Therefore, the productivity of the
130 producing animal may influence this ratio by the dilution-concentration effect, especially for
131 excreted foodstuffs like milk and eggs. The transfer rates (TRs) allow to deduce the daily
132 tolerable exposure amount (DTEA), an ADI equivalent for food producing animals, which
133 would not lead to overpass the regulatory threshold. In the case of possibly consumed tissues

134 (muscle, fat, offal) the rhythm of growth and the duration of bioaccumulation of the compound
135 in the tissue has to be calibrated to forecast the regulatory concentration. The DTEA can be
136 calculated for these cases using the corresponding bioconcentration factor (BCF).

137 The DTEA can be sliced by the compound supply of each intake matter (feed, soil, water
138 and sometimes air) and the bioavailability of the compound in the considered matter. The main
139 route of POPs exposure to ruminants and poultry is the oral consumption of contaminated feed
140 and soil (Rychen et al., 2008). Water and air are generally minor vectors of POPs and can
141 therefore be neglect. Feedstuffs are often regulated(Comission Regulation (EU) 2023/915,
142 2023) and can not be sold if their POP concentrations are over the regulatory thresholds. Only
143 pastured grass or self-produced feeds (silage, hay, and cereal grains) could carry a locally
144 deposited contamination, but POPs are poorly transferred in the aqueous plant sap reducing the
145 contamination of such feeds to soiling. By consequence, the main variation factor in the supply
146 is the vector soil, by its intake rate and by its concentration of the compound. The soil intake
147 can be evaluated today in numerous rearing systems. Finally, the maximum tolerable
148 concentration of the considered POP in soil is the target of this approach.

149 The parameter setting of this approach is not necessarily simple, due to the interactions
150 between parameters what will be developed here below.

151

152 **2.2 Parameter settings**

153 Highly productive cows or hens will dilute the bioavailable amount of POPs in a bigger
154 amount of product (milk or eggs) enhancing a higher sensitivity of low productive animals in
155 extensive rearing systems. However, very productive animals have also higher nutritional needs
156 and by consequence will ingest more feed and – if grass on pasture is low – more soil.

157 The transfer rates can be extracted from literature. Nevertheless, it has to be checked
158 that the duration of the study allowed to reach the steady state in order to get valuable TRs. The

159 settings for meat producing animals is more complicated as such animals will accumulate their
160 whole life and tissue concentrations will be fixed only after slaughter. The growth rhythm and
161 by consequence the duration of the rearing period are very important parameters which would
162 disadvantage extensively (and slowly) raised animals. Here too, BCFs are available in the
163 literature but studies should have a duration consistent with the life expectancy of the
164 considered animals.

165 The bioavailability of the ingested POPs is generally (very) high in water and feedstuffs
166 but can be reduced in soil. Although literature give some indications for reduced bioavailability
167 depending on the characteristics of soil and the considered compound, no consensual
168 methodology is available today to test it in a routine manner. Therefore, available data cover a
169 very limited number of cases. Otherwise, bioavailability is generally set at 100%.

170 The intake of feed (and water) is generally well documented in agricultural
171 recommendations. Some difficulties could be appeared when animals would ingest not optimal
172 feeds in very extensive systems as for ex. the grass intake for free-ranged poultry or pigs.
173 Literature offers some rare data whose extrapolations to the studied rearing system need
174 cautions. Intensively reared animals are mainly raised indoor on a concrete floor and by
175 consequence would hardly have a direct access to soil reducing their soil intake only to dust
176 deposited on the feed. Numerous data for the soil intake of outside raised animals have been
177 published in the last decades allowing a determination or a reliable extrapolation for the
178 majority of rearing systems. Here again, extensively reared animals would be more exposed to
179 consequent soil intakes due to the use of generally poorer surfaces or free-range rearing even
180 when vegetation does not offer large grass swards (drought, winter, ...).

181 All these settings seem indicate that extensive systems may be much more exposed to
182 POP accumulation in the produced food than intensively raised animals on which we will focus
183 our investigations.

184 **2.3 Choice of scenarios of animal models and their corresponding rearing system**

185 Firstly, three POP families have been chosen due to their persistency and their clearly
186 established damageable effects on human health and their high persistency, especially in soil:
187 PCDD/Fs, DDT and lindane as representatives of POPs.

188 Two models have been chosen for the dairy production: a high yielding cow (50 L/day)
189 and a low yielding cow (5 L/day). Both types of animals may be on pasture, i.e., raised outdoor
190 enhancing a risk to produce contaminated milk via soil intake. The egg production has been
191 modelized only for extensively raised laying hens, as intensive systems would hardly use
192 outdoor plots. Consistent with previous models, only extensively and slowly reared meat
193 animals have been modeled: beef cattle raised up grass based during 3 years, broiler chicken
194 raised up in alternative systems as for example organic as well as free-ranged pigs. The table 1
195 summarize the chosen animals as well as their zootechnical parameters used for the
196 modelization.

197

198 **3. Results**

199 **3.1 Modelizations of POPs transfer risk in different livestock breeding systems**

200 Simulations of transfer risks of different POPs to different livestock species were
201 performed in respect to European MRLs (Commission Regulation (EC) No 149/2008, 2008)
202 for milk, eggs and several edible animal tissues as presented in tables 2-4. Highly toxic POPs
203 such as 2,3,7,8-TCDD, DDT and lindane (i.e. g-HCH) have been chosen as examples. Main
204 rearing systems that were integrated in the modelizations has 2 groups of livestock animals
205 depending on its raising purposes:

206 Group 1 - excreting animals: high productive dairy cows (50 L/day), low productive dairy
207 cows (5L/day), and laying hens with productivity 45% (tables 2-3).

208 Group 2 – meat producing animals: extensive growing beef cattle, extensive growing pigs
209 and extensive growing chicken (table 4).

210 Different zootechnical parameters of these animals were taken into account for reliable
211 estimations (table 1) such as classical daily feed intake (Dong et al., 2017; Fries G., 1999; Grant
212 and Albright, 2001) and daily soil intake (Jondreville et al., 2010; Jurjanz et al., 2012) . In
213 addition, simulations were based on TR for milk and eggs as well as BCFs for body tissues
214 derived from elsewhere (Amutova et al., 2021; Hoogenboom et al., 2015). Then, DTEA of the
215 pollutants via soil was calculated in correspondence to established MRLs in the foodstuff
216 (tables 2-4).

217 Simulation scenarios of transfer risk for different livestock animals grazing on soil
218 contaminated by TCDD, DDT and lindane (tables 2-4) using TR and BCF-based approaches
219 allowed to:

220 1) Express quantitatively the ingested amount of POPs per kg fresh milk or per 1 whole
221 hen egg. This value has been calculated through the proportion of MRLs in a given foodstuff
222 and corresponding TRs derived from our latest meta-analysis study (Amutova et al., 2021).

223 2) Quantitatively estimate the DTEA of POPs via soil and acceptable concentrations of
224 POPs in dry soil based on soil intake of studied farm animals.

225 3) Calculate a security ratio indicating the multiple between the POP concentration
226 acceptable in soil before overpassing MRLs in the produced food products (i.e. the higher the
227 value of security ratio the lower the risk to reach or overpass MRLs). The security ratio were
228 group in different classes as follows: >100 safe, 10 to 100 possible risk; 0 to 10 high risk.

229 Results of these simulations showed that soil ingestion is a predominant contamination
230 pathway, which is a central factor in the risk assessment of POP exposure on livestock farms,
231 especially in free-ranged systems. Indeed, extrapolation of established EU MRLs of 2,3,7,8-

232 TCDD, DDT and lindane for food and estimated TRs (tables 2-3) or BCFs (table 4) showed
233 several observations.

234 In field conditions of POP exposure, low productive animals may be more susceptible
235 to uptake through the soil than high-yielding animals (Table 2), even if the feed respected
236 MRLs. Indeed, animals in more extensive systems are often ranged on poorer surfaces
237 increasing the risk of soil intake – by weaker vegetation cover of the soil or by a stronger
238 exploring activity of such animals in order to cover their nutritional requirements. Lower values
239 of acceptable concentrations of POPs in soil as well as security ratio indicates the vulnerability
240 of low-producing livestock (dairy cows 5L/day vs dairy cows 50L/day as well as laying hens
241 45%), and, therefore the health risk to consume contaminated milk or eggs (Table 2). This
242 could be explained by higher bioaccumulation of pollutants in their body due to slow depuration
243 processes as consequence of low excretion (Jurjanz et al., 2018). One of the most toxic
244 cancerogenic dioxin congener TCDD revealed the lowest security ratio for low productive dairy
245 cows (5) compared to high productive ones (163). Laying hens with productivity 45% (or 3
246 eggs/week) shown also as a highly sensitive to POPs exposure via soil ingestion. Indeed, their
247 security ratio for TCDD, lindane and DDT and were 16, 2 and 1, respectively (tables 2-3).

248 Risk assessment of meat-producing animals (broilers, pigs, lamb, cattle) showed that
249 the most sensitive edible tissues and organs are liver, followed by muscle and fat (table 4). In
250 case of daily soil ingestion and raising on contaminated territories, security ratio would vary
251 from highly risky to overpass MRL (0.001 for broilers) to possible risky (between 9 and 20 for
252 pigs and beef cattle).

253 Results (tables 2 to 4) demonstrated that even a relatively low concentration of POPs
254 in soil may lead to contamination close to MRLs in food of animal origin. Therefore, livestock
255 animals raised on outdoor plots are under a high risk of POP contamination and therefore may
256 produce contaminated edible tissues, milk or eggs. Soil should be considered as the main POPs

257 carrier in the case of contamination situation in a farm. Indeed, water is a weak vector of POPs
258 and contaminated vegetation could be easily removed from such areas by simple cutting. By
259 consequence, the management of contaminated soil would be the main problem: soil may
260 accumulate a lot of POPs over a long exposure time and is hardly possible to be removed from
261 the areas.

262 4. Discussion

263 4.1 Methodological approach based on transfer rate and bioconcentration factor

264 The considered approach to assess the risks of POPs transfer from contaminated soil to
265 farm animals and food products can be used in the assessment and monitoring of contaminated
266 areas. However, several important nuances must be considered in the practical application of
267 this approach. The correct calculated pollutant transfer coefficients (TR and BCF), the
268 zootechnical parameters of the animal on the farm, the animal's diet, and daily soil consumption
269 should be considered.

270 Equations for calculating the transfer rate and bioconcentration factor can be found in the
271 literature (Amutova et al., 2021; Costera et al., 2006; Lorenzi et al., 2020; Richter and
272 McLachlan, 2001). There is, however, no standardized protocol that includes all the required
273 initial parameters. The transfer coefficient is used to calculate the transfer of a contaminant
274 from the ingested matrix to excreted animal food, such as milk and eggs. The matrix consumed
275 could be contaminated feed, grass, silage, or soil. Equation 1 is used to calculate TR:

$$277 \quad TR_{product} = \frac{[pollutant]_{fat\ of\ product} \times \text{Daily fat excretion of product}}{[pollutant]_{intake\ matter} \times \text{Daily intake}} \times 100\% \text{ (Eq.1)}$$

278
279 The $[pollutant]_{fat\ of\ product}$ corresponds to the concentration of pollutant in the fat of
280 the food product (pg/g fat) and $[pollutant]_{intake\ matter}$ to concentration in the intake matrix

281 feed or in soil (pg/g dry matter). Daily fat excretion of product is amount of fat (kg) of the
282 product (milk or egg) produced by the given farm animal per day. Daily intake is amount of
283 feed or soil (kg) ingested by animal per day.

284 A recent meta-analysis on POPs transfer data showed that the key parameter for the
285 reliable calculation of the transfer rate is concentration of pollutant obtained at the state of
286 equilibrium (or steady state) of animal. The definition of steady state can be found elsewhere
287 (Amutova et al., 2021; Casarett and Doull, 2008). To estimate the steady state of the given
288 animal for a given pollutant, it is necessary to focus on the half-life of the target molecule and
289 the productivity of the animal. For example, Table 5 provides half-lives for TCDD, DDT, and
290 lindane in milk and eggs, the animal production cycle, and demonstrate how to predict exposure
291 time to reach steady state. According to the literature (Holford N., 2012) 3.3 half-lives of the
292 compound ensures that 90% steady state is achieved. Therefore, by multiplying the half-life of
293 the compound by 3.3, it's possible to obtain the exposure time on the animal and estimate the
294 steady state concentration of the pollutant.

295 Exposure time of the animals should correlate and balance to animal production cycle.
296 Indeed, dairy cows (10 years) and meat cows (2 years) or laying hens (1-2 years) and broilers
297 (2 months) have different animal production cycle. Dairy animals and laying birds have a longer
298 lifetime period than meat-producing animals which could impact on achievement of steady
299 state. In contrast meat producing animals could never achieve steady state due to dilution of
300 pollutant during intensive body growth and due to their short lifetime. Therefore, POPs transfer
301 to meat of producing animals estimated by distribution of pollutant in different animal tissues
302 (liver, fat, offal) classically performed using BCF. The equation (2) of BCF is given below:

303
$$BCF = \frac{[\text{pollutant}]_{\text{tissue}}}{[\text{pollutant}]_{\text{intake matter}}} \quad (\text{Eq.2})$$

304

305 Where pollutant in brackets mean concentration of pollutant in tissue or in intake matter
306 (soil or feed).

307

308 **4.2 A preventive supporting decision tool**

309 As a result of anthropogenic chemical activities over the last century and half, animals
310 are exposed to many distinct molecules (Christiansen et al., 2010), for which the environment,
311 particularly the soil, is a sink. Recent awareness of this diversified exposure is addressed by the
312 fairly recent concept of the exposome (Vineis et al., 2020). However, for livestock systems, this
313 global exposure is little considered, unlike human exposure, which is constantly being
314 improved. As this study has shown, TRs and BCFs are two interesting concepts for describing
315 and predicting the transfer of contaminants into food products, as they enable contaminant
316 concentrations in the soil to be directly linked to levels in the foodstuff produced. In this sense,
317 it allows us to rethink the management of chemical safety in food products of animal origin. It
318 adds to the current strategy to control food products of animal origin a necessary lever in
319 chemical safety: prevention.

320 Indeed, current chemical safety controls raise concerns because they make producers
321 responsible for contamination of food production, whereas they are also victims of
322 contamination in their immediate environment. Furthermore, these controls are mainly focused
323 on conventional farming systems and do not consider self-production and self-consumption,
324 which represent a major source of exposure when producing on contaminated soils. In addition,
325 the realization of such controls is known to need a certain delay before the identification of the
326 contaminated food producing systems. Generally, consumers will be in contact with these
327 contaminated food during this time gap what could be avoided by preventing approaches. This
328 led to different crisis as the 1999 "dioxin broiler crisis" ("L'Echo," 2022), in which tons of

329 contaminated animals were consumed before anyone was aware of their non-compliance with
330 dioxin and PCB MRLs, with potential repercussions on the health of the population.

331 To implement this prevention layer, a generic and simple decision tool can be theorized
332 to help food producers to apprehend their own risk of chemical contamination (Figure 2). The
333 starting point should be a chemical analysis of representative soil samples from their land where
334 free-range animals are reared. The chemical analysis of soils assesses the presence of chemical
335 substances. Then, the found chemical substances should be evaluated regarding the ability to
336 be bioaccumulated in target foodstuff based on bibliographical data and chemical
337 characteristics.

338 Indeed, bioaccumulation is a prerequisite for the concentration of contaminants in edible
339 tissues, and therefore in food products of animal origin. In the event that levels of
340 bioaccumulable pollutants are found in soil, soil concentrations should be compared with the
341 tolerable soil concentration as calculated in the present study. If soil levels are greater than 5
342 times these tolerable concentrations, animal production should clearly be avoided. If soil
343 concentrations are below tolerable levels, food production can be carried out on this soil. In
344 other cases, the tool highlights the risk of such production, but calculation uncertainties may
345 lead to overestimations. If maintaining a production is needed according to a particular context,
346 further investigations can refine the risk to accurately assess which cases of production can be
347 allowed. In this case, other models should be developed, involving a toxicokinetic models as a
348 function of farming practices, in order to highlight the most at-risk conditions and avoid food
349 production under these conditions.

350 One of the add values of implementing such a decision-support tool is its genericity and
351 its ability to be updated for emerging pollutants. It requires a relatively simple database
352 including bioaccumulation status, BCF and TR for food products of animal origin, and the
353 calculations as described in the current study. In this context, such a methodology relies on a

354 limited set of animal experiments to obtain the necessary BCFs and TRs (Amutova et al., 2021a;
355 Hoogenboom et al., 2006; Traag et al., 2006). In addition, chemo-monitoring can be
356 implemented thanks to non-targeted approaches (Schymanski et al., 2015) . The data from a
357 soil sample could today be reprocessed to find emerging compounds. Then, food producers can
358 be quickly informed, and may carry out necessary quantification and risk assessments.
359 Moreover, this preventive methodology can also be implemented in non-conventional farming
360 systems such as self-production and self-consumption.

361 **5. Conclusion**

362 This study described a generic methodology to prevent food contamination by different
363 soil born POPs in free range livestock based on integration of transfer coefficients (TR and
364 BCF). This approach will allow to access risk of POPs contamination on different livestock
365 rearing systems (dairy cows, laying hens, meat producing animals).

366 Simulations of the methodology showed that soil ingestion should be considered as a
367 central factor in the risk assessment of POP exposure on livestock farms, especially in free-
368 ranged systems. Results demonstrated that even a relatively low concentration of POPs in soil
369 may lead to contamination close to MRLs in food of animal origin. In perspective, proposed
370 methodology could be useful for food producers to apprehend their own risk of chemical
371 contamination.

372

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376

377 **Author contributions**

378 **Farida Amutova:** Investigation (lead), Conceptualization (equal), Visualization (lead),
379 Methodology (equal), Writing - original draft (lead), Writing-review & editing (equal). Formal
380 analysis. **Matthieu Delannoy:** Conceptualization (lead), Data curation (equal), Writing-review
381 & editing (equal), Validation (equal). **Araylym Akhatzhanova:** Conceptualization (equal),
382 Review (supporting). **Nurlan Akhmetsadykov:** Project administration (equal), Funding
383 acquisition, Review (supporting). **Gaukhar Konuspayeva:** Writing-review & editing (equal),
384 Formal analysis (equal). **Stefan Jurjanz:** Conceptualization (equal), Data curation (equal),
385 Writing-review & editing (equal), Validation (equal) , Supervision (lead).

386 **Declaration of competing interest**

387 The authors declare that they have no known competing financial interests or personal
388 relationships that could have appeared to influence the work reported in this paper.

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