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Optimizing bulk milk dioxin monitoring based on costs and effectiveness

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ABSTRACT

Dioxins are environmental pollutants, potentially present in milk products, which have negative consequences for human health and for the firms and farms involved in the dairy chain. Dioxin monitoring in feed and food has been implemented to detect their presence and estimate their levels in food chains. However, the costs and effectiveness of such programs have not been evaluated. In this study, the costs and effectiveness of bulk milk dioxin monitoring in milk trucks were estimated to optimize the sampling and pooling monitoring strategies aimed at detecting at least 1 contaminated dairy farm out of 20,000 at a target dioxin concentration level. Incidents of different proportions, in terms of the number of contaminated farms, and concentrations were simulated. A combined testing strategy, consisting of screening and confirmatory methods, was assumed as well as testing of pooled samples. Two optimization models were built using linear programming. The first model aimed to minimize monitoring costs subject to a minimum required effectiveness of finding an incident, whereas the second model aimed to maximize the effectiveness for a given monitoring budget. Our results show that a high level of effectiveness is possible, but at high costs. Given specific assumptions, monitoring with 95% effectiveness to detect an incident of 1 contaminated farm at a dioxin concentration of 2 pg of toxic equivalents/g of fat [European Commission's (EC) action level] costs €2.6 million per month. At the same level of effectiveness, a 73% cost reduction is possible when aiming to detect an incident where 2 farms are contaminated at a dioxin concentration of 3 pg of toxic equivalents/g of fat (EC maximum level). With a fixed budget of €40,000 per month, the probability of detecting an incident with a single contaminated farm at a dioxin concentration equal to the EC action level is 4.4%. This probability almost doubled (8.0%) when aiming to detect the same incident but with a dioxin concentration equal to the EC maximum level. This study shows that the effectiveness of finding an incident depends not only on the ratio at which, for testing, collected truck samples are mixed into a pooled sample (aiming at detecting certain concentration), but also the number of collected truck samples. In conclusion, the optimal cost-effective monitoring depends on the number of contaminated farms and the concentration aimed at detection. The models and study results offer quantitative support to risk managers of food industries and food safety authorities.

Key words: dioxin monitoring, dairy, linear programming, cost-effectiveness analysis

INTRODUCTION

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans are known as dioxins. Polychlorinated biphenyls with dioxin-like properties are known as dioxin-like PCB (**dl-PCB**). Dioxins and dl-PCB are persistent organic pollutants (WHO, 2007) that belong to the 12 more prominent environmental contaminants as classified by the Stockholm Convention on Persistent Organic Pollutants (WHO, 2007; UNEP, 2009). Dioxins and dl-PCB are a potential threat to human health because of their toxicity at very low levels, their stability in the environment (WHO, 2007), and their bioaccumulation and biomagnification along food chains (Huwe, 2002; Schmid et al., 2002). If elevated levels are detected in food, dioxins may lead to extensive financial losses for food and feed businesses due to mitigation strategies and reduced sales (Velthuis et al., 2009; Lascano Alcoser et al., 2011).

In the EU, the intake of dioxins and dl-PCB by the consumers may still exceed the exposure limit of 14 pg of toxic equivalents (**TEQ**)/kg of BW per week (De Mul et al., 2008). Prior studies have shown that foods of animal origin, mainly those containing fat, are the main contributors of dioxins in the human diet (Huwe, 2002). Studies have also shown that the main source of dioxins in food is contaminated feed (Buchert et al., 2001; Huwe, 2002) and feed ingredients (Huwe and Smith, 2005). In this regard, and due to the occurrence of several dioxin-food safety incidents in the

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last part of the 1990s (Malisch, 2000; Bernard et al., 2002), the EU established legislation for dioxins and dl-PCB in food and feed (EC, 2000; SCF, 2001). This legislation includes a strategy to reduce exposure levels over time (EC, 2001a) and defines maximum levels for these contaminants in food and feed products (EC, 2001b, c, 2006c). As part of this strategy, feed and food monitoring is conducted across the EU with the aim of diminishing exposure levels in the population (EC, 2001a, 2006a; EFSA, 2010).

Routine monitoring is a way to determine background levels and trends of dioxins in food and feed products (EC, 2001a) and to detect contaminated food and new sources in agri-food chains (EC, 2002, 2004; Heres et al., 2010; Hoogenboom et al., 2010). In spite of these apparent benefits, it is costly and complex to establish a dioxin monitoring plan (Buchert et al., 2001). One of the major difficulties is the lack of inexpensive and simple tests for real-time detection of dioxins (Kan and Meijer, 2007). This restricts the number of samples that can be analyzed (Huwe, 2002) and thereby reduces the capacity of monitoring to detect possible incidents. An improvement was the introduction of bioassays, such as Calux (Hiyoshi Corp., Shiga, Japan), but even these tests still run at relatively high costs and require several days.

Milk is one of the main contributors of dioxins and dl-PCB to the total exposure in the European population (EFSA, 2010). Consequently, milk dioxin incidents may have a potential salient effect to human health. Additionally, the dairy chains in different countries have been one of the food chains repeatedly involved in dioxin incidents (e.g., Belgian crisis in 1999, Dutch incident in 2004), with salient potential financial effect to the involved farms and firms along the chain (Lascano Alcoser et al., 2011). In this study, the cost and effectiveness of bulk milk dioxin monitoring at milk trucks were estimated with the objective of optimizing the sampling and pooling monitoring strategies aiming at detecting a dioxin incident. This study elicits valuable information to risk managers about the relation between the financial resources spent on monitoring dioxins and the capacity of this system to detect a contamination.

MATERIALS AND METHODS

Two optimization models were built using linear programming (Dijkhuizen and Morris, 1997). The first model (**MC**) aimed to minimize the monitoring costs subject to a minimum required effectiveness, whereas the second model (**ME**) aimed to maximize the effectiveness of monitoring for a given budget for monitoring. The models evaluated a bulk milk dioxin monitoring plan in milk trucks covering 20,000 dairy farms located in an area of 40,000 km^2. Milk trucks, which transport milk from the dairy farms to the milk processing plants, were randomly selected at each sampling time. Within this framework, a dioxin incident is assumed to last for at least 1 mo, which is realistic considering the turnover of feed and the slow elimination of these compounds in dairy cows (Hoogenboom et al., 2010). The models were applied to 8 preselected contamination scenarios representing dioxin incidents of different sizes to be detected (called detectable incidents). The size of a detectable incident was determined by the combination of the number of expected contaminated farms (1 or 10) and the target dioxin concentration (2, 3, 10, or 20 pg of TEQ/g of fat) in the tank milk of contaminated farms (Table 1).

The bulk milk dioxin monitoring aimed to detect at least one of the contaminated farms with a concentration (c_{cf}) equal or higher than the action level for dioxins. The action level (c_{AL}) was defined as the concentration of dioxins at which authorities and food business operators can decide to identify the source of

Table 1. Description of the contamination scenarios

Scenario code	Size of detectable incident: No. of expected contaminated farms (F)	Target concentration (i.e., dioxin concentration at farms)[1] (C)
F1-C2	1	2 pg of TEQ/g of fat[2]
F1-C3	1	3 pg of TEQ/g of fat[3]
F1-C10	1	10 pg of TEQ/g of fat
F1-C20	1	20 pg of TEQ/g of fat
F10-C2	10	2 pg of TEQ/g of fat[2]
F10-C3	10	3 pg of TEQ/g of fat[3]
F10-C10	10	10 pg of TEQ/g of fat
F10-C20	10	20 pg of TEQ/g of fat

[1]TEQ = toxic equivalents.

[2]European Commission action level for dioxins.

[3]European Commission maximum level for dioxins.