How to monitor dioxin in the dairy chain?

Final report

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Abstract

Dioxin and dioxin-like chemicals in food pose a serious threat to human health. The biggest risks of dioxins are het poor degradability and the accumulation over time in fat cells of the human body. Products that contribute the most to human dioxin exposure are products containing animal fat, including dairy products. A dioxin contamination incident within the food supply chain requires a sequence of actions; testing, recalling and destroying the suspected food products, which will add up in costs, both directly and indirectly. Routine monitoring is a way to detect dioxin contamination as early as possible to prevent an incident. A financial impact model is used to calculate the financial consequences of a set of contamination incident scenarios. Based on the average settings of the Dutch consumption milk chain (= baseline), the financial impact equals 8,9 mln Euro a year under the assumption of 1 incident in 5 years. The financial impact is most sensitive to changes in the HRP; with an increase from 7 to 14 days until detection the financial impact increased more than 3 times. This financial impact is used as a budget constraint for an optimalization model for monitoring systems. In most scenarios the optimal monitoring defined by a budget constraint equalling the financial impact forgone resulted in high levels of monitoring effectiveness (> 95%). This should be an incentive for actors in the Dutch dairy chain to implement a monitoring scheme which makes government interference not necessary. Moreover results indicate that the implementation of a risk based monitoring system would lead to a significant cost decrease due to the larger pools and the smaller amount of tests needed to obtain the same level of effectiveness in detecting a contamination.

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1. Introduction

Dioxin and dioxin-like chemicals in food pose a serious threat to human health (WHO 2010). The biggest risks of dioxins are het poor degradability and the accumulation over time in fat cells of the human body (EC 2001). Products that contribute the most to human dioxin exposure are products containing animal fat, namely dairy products, fish, meat and meat products (Lascano-Alcoser et al. 2011). Dioxins and dioxin like products can be produced by natural and industrial processes (Lascano-Alcoser et al. 2011). Due to earth's natural presence of dioxin a contamination of human food with dioxins can easily happen even in cases where neither occupational nor accidental exposure was reported.

The most recent cases of dioxin incidents in food occurred when using contaminated animal feed for food producing animals as was the case in the incidence of 1998 in The Netherlands and Germany (Lascano-Alcoser et al. 2011), of 1999 in Belgium (Fedichem 1999), of 2008 in Ireland (Marnane 2012) and of 2010/2011 in Germany (Adolphs et al. 2013; Hoogenboom et al. 2004). In particular the 1999 Belgium incident resulted in an increased effort of the EU to control the various sources of dioxin contamination and to limit the introduction of dioxins into the food chain by setting strict limits for feed and food (Hoogenboom et al. 2004).

A dioxin incident within the food supply chain requires a sequence of actions; testing, recalling and destroying the suspected food products, which will add up in costs, both directly and indirectly (Velthuis et al. 2009). Routine monitoring is a way to detect dioxin contamination as early as possible to prevent an incident. However, as dioxins can already be toxic at low levels of exposure, monitoring needs to be very sensitive therefore requiring costly equipment and sampling procedures (Hoogenboom and Traag 2013).

This research focuses on the effectiveness i.e. the sensitivity of dioxin monitoring schemes within the dairy chain, specifically in consumption milk. The aim of this research is to evaluate the cost effectiveness of monitoring schemes varying in the sensitivity to detect and therefore the losses that can be prevented, using the estimated financial impact of a dioxin incident as a maximum budget. This evaluation is done by using an existing financial impact model and an optimalization model for monitoring systems as developed by Lascano-Alcoser (2011, 2013).

To accomplish the defined aim, the following research questions will be answered:

- What monitoring actions are currently undertaken in the Dutch dairy chain?
- Which possible contamination scenarios in the dairy chain, differing in moment of detection, frequency per time unit, contamination quantity and concentration can be constructed to reflect the large variability in type of incidents?
- What is the financial impact of these outlined scenarios?
- Given the financial impact of the scenarios, what would be the most cost effective monitoring system?
- What are the advantages of a risk based monitoring system?

This report starts with a chapter to describe the background of the dioxin problem in human food, the costs of excluding dioxin from the human food chain, the policies and regulation regarding dioxin and food and the current monitoring system in The Netherlands. Then, in subsequent Chapter 3, the research methods and the scenario development are provided. In Chapter 4 the scenario results from both the financial impact model and the optimalization model are presented. Finally the discussion and recommendations for further research as well as the discussion are presented in Chapter 5.

2. Literature review

2.1. Dioxin contamination of food

While the amount of dioxins and dioxin-like compounds in the environment has declined since the late 1970s, there is a continuous concern about the safety of the food supply and the potential health risk of exposure to this group of substances (EC 2001; EFSA 2010; WHO 2010) as they are supposed to be among the most toxic of organic compounds (EFSA 2010). The biggest risk of dioxins are het poor degradability and the accumulation in fat cells of the human body. Prolonged exposure trough food can result in dioxin levels which exceed the critical value which could lead to a broad series of toxic and biochemical effects of which some are classified as known human carcinogen (EC 2001). Other effects that already occur at lower levels of exposure than carcinogenic effects levels are damage in the immune system (immunotoxic effects) and reproduction (endometriosis, sperm count, genital malformations) and developmental and neurobehavioral disorders (EC 2001; EFSA 2010; Hoogenboom and Traag 2013). Although the individual effects of dioxin compounds on human health are identified, the effects on humans of exposure to a mixture of dioxins an dioxin-like chemicals are unknown, which makes the actual toxic effects of these mixtures difficult to determine (Hoogenboom 2009).

Dioxins and dioxin like products can be produced by natural and industrial processes (Lascano-Alcoser et al. 2011) as a by-product of a chemical reaction as for example in the production of herbicides or wood protectors. Besides that, they occur in combustion processes as natural fires, smoking and industrial processes (Fedichem 1999). Dioxins and dioxin-like compounds most often refer to 29 congeners of polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and dioxin-like polychlorinated biphenyls (PCB)(EFSA 2010). PCBs are synthesised by direct chlorination of biphenyl and can be divided into different groups according to their biochemical and toxicological properties. Non-*ortho* and mono-*ortho* substituted PCBs show toxicological properties that are similar to dioxins. They are therefore often termed „dioxin-like PCBs‟ (EFSA 2010). The toxic level of dioxin and dioxin like chemicals can be compared using toxic equivalents (TEF's). The toxic equivalence (TEQ) indicates the total toxicity of the mixture of PCB's.

Products that contribute the most to human dioxin exposure are products containing animal fat, namely dairy products, fish, meat and meat products (Lascano-Alcoser et al. 2011). In general, food of animal origin contributes to about 90% of the overall human exposure (EC 2001; Shen et al. 2012). Dioxins are not soluble in water but highly soluble in fat. This means that they bind to sediment and organic material in the environment and are absorbed in animal and human fatty tissue. In addition they are not biodegradable so they are persistent and bio-accumulate in the food chain. Which means that once released into the environment, via air or via water, they pile up in the fat tissue of animals and humans (EC 2001). They are generally not taken up or absorbed by plants, with the exception of some members of the cucurbit family (pumpkins, melons and cucumbers), but may settle on the surfaces of the leaves. They can then enter the food chain when animals eat the contaminated leaves. In aquatic environments, fish and other marine animals can absorb dioxins and dioxin-like PCBs (EFSA 2010).

History provides us with numerous dioxin contamination incidents, both environmental and food chain related incidents. The source of the contamination in most recent food chain related incidents differed per case. For example in the 1998 case within The Netherlands and Germany contaminated citrus pulp was used as ruminant feed ingredient (Lascano-Alcoser et al. 2011) and in the 2010/2011 case in Germany the contamination occurred due to the usage of contaminated bakery waste which was used as animal feed (Hoogenboom et al. 2004). In the 2008 case in Ireland the source was the usage of a liquid fuel contaminated with highly persistent PCBs in feed production (Marnane 2012). The spread of a contamination through animal feed can happen quickly since compound feed consists of many animal feed ingredients. A single contaminated batch can be divided into multiple compound feed batches, resulting in a possible spread among many compound feed producers (Meuwissen et al. 2009). These incidents and the difference in contamination origin show that dioxin and dioxin like PCB's form a complex problem which cannot easily be solved by focussing on one specific source (Hoogenboom and Traag 2013).

Prevention or reduction of human exposure to dioxin is best done via strict monitoring and control of industrial processes (WHO 2010). Unfortunately a total prevention of dioxin formation is not possible due to the earlier described natural processes. Routine monitoring can help to determine background levels and trends of dioxins in food and feed products and therefore to indicate dioxin contaminations (Lascano-Alcoser et al. 2013). In the European Union (EU) the food processor is responsible for the quality and safety of its products, and must monitor and test whether its products meet the legal standards and its own or its clients' quality standards (Velthuis et al. 2009). To diminish the spread of the contamination through a food chain in case of an incident there is a need for a rapid detection process. Nevertheless tests to detect dioxin in human food are costly. At the moment, the most optimal and rapid way of testing is combining the CALUX-bioassay for screening with the HRGC/HRMS for confirmation, which costs approximately €350,- per combined test (Hoogenboom et al. 2004; Lascano-Alcoser et al. 2013).

Besides a proper monitoring system, a tractability system contributes to the food safety of products. In case of an incident were unsafe products are put on the market, these products must be withdrawn from downstream businesses or recalled from the consumer as quickly as possible (Velthuis et al. 2009). The time lag can be decreased by an effective traceability system which can minimize the damage done by the unsafe products (Dorp 2004; Meuwissen et al. 2003; Teratanavat and Hooker 2004). In Europe the markets of food products are highly interrelated. This requires communication with other national agencies in the investigation and follow up of incidents with a potential cross-border component (Marnane 2012).

2.2. Policy and regulations

At the beginning of the 1990s, many countries have put programs in place to identify and control sources and to reduce emissions of PCDD/PCDF/PCB into the environment (Büchert et al. 2001). Dioxin regulations were indicated later on. Partly because of the toxicity at a low level of exposure which can only be detected with very sensitive and costly equipment (Hoogenboom and Traag 2013).

The European Commission prescribed a list of actions to reduce the presence of dioxins and dioxin-like PCBs in 2002. It later introduced regular monitoring by Member States of food and feed, including, if possible, also non-dioxin-like PCBs (EFSA 2010). The Dioxin Strategy describes an integrated approach to legislation on food and feed to reduce the presence of dioxins, furans and PCBs throughout the food chain. This integrated approach consists of three pillars:

1. The establishment of strict but feasible maximum levels in food and feed using a "strict but feasible" policy. This means that based on a database including dioxin levels per product group, feasible norms are determined. Subsequently the norm is altered in such a way that the highest 5-10 percent of the contaminated products would exceed the norm. This is done to prevent having a substantial part of food and feed products rejected without these products being a standalone risk (Hoogenboom and Traag 2013).
2. The establishment of action levels to trigger action when levels in food or feed are found clearly above background levels. These action levels have an early warning function.
3. The establishment of target levels to be achieved over time so as to bring the exposure of the majority of the European population within the limits recommended by the Scientific Committee on Food (EFSA 2010).

The tolerable daily intake (TDI) of dioxins is given in pictograms (pg) per kilogram (kg) of bodyweight. These regulated TDI's vary per country. For example in Japan it is 100 pg/kg/day and in the US it is only 0,006 pg/kg/day which is a very low limit given the fact that the average human ingests about a hundred times the American standard (Fedichem 1999). European governments have developed a range of TDI, most of them according to the World Health Organisation (WHO) TDI criteria between 1–4 pg/kg/day (McKay 2002; WHO 2010). However the toxicity of dioxins is related to the amount accumulated in the body during lifetime, the so-called body burden (EC 2001).

2.3. Current dioxin monitoring in the Netherlands

Due to EU general food law all food product groups operate under the same policies regarding food safety and food quality. Before methods for food regulation were defined and drafted, now only the requirements for the product groups are set. Under current law and policies the quantity of testing for contaminants is not (yet) determined. As earlier stated, the chain actor who places the product on the consumers market is responsible for the food safety and quality (de Nijs 2013).

In the dairy chain private organisations play an important part in guaranteeing food safety. Because the Netherlands is a big dairy exporting country, image damage from contaminated products would be catastrophic. The NZO (Nederlandse zuivel organisatie/ Dutch dairy organisation) is an interest organisation created to safeguard the quality and safety of all Dutch dairy products, among the members large companies as Friesland Campina as well as small private owned cheese producers. The NZO collects hundreds of raw milk samples every year to test for contaminants including dioxins. They perform their test at the raw milk stage.

The government, in this case the NVWA (Nederlandse voedsel en warenautoriteit/ Dutch food and safety authority) has a controlling part in monitoring for contaminants like dioxins. In the Netherlands there is also an intermediar organisation, the COKZ (Het Centraal Orgaan voor Kwaliteitsaangelegenheden in de Zuivel). This organisation operates as a supervisor for quality and safety programs from actors in the dairy chain. Further, the COKZ supervises the monitoring and testing programme of the NZO. The NVWA tests end products which come from the shelf's of retailers but they test the end product animal feed as well. Due to the monitoring programme of the NZO and the supervision of the COKZ, it is very unlikely that the NVWA finds a contamination, the intention of these tests, therefore is to find nothing what could harm food safety or food quality. If the NVWA however finds something, there is something very wrong, this because both the COKZ and the NZO didn't detect this contamination which makes their programmes insufficient. It is even more exceptional for the NVWA to find something due to the low quantity and frequency (?) of their tests. One might say that the most important reason for NVWA tests are to reassure consumers. Hence there need to be said that the Netherlands is by far the country which performs the most tests ensuring food safety on a yearly basis. The NVWA however keeps records of all their findings and looks at periodic trends and changes so that they are able to alarm producers in case of shifting values (de Nijs 2013).

2.4. Financial impact of a dioxin incident in the livestock production chain

A dioxin incident within the food supply chain requires a sequence of actions; testing, recalling and destroying the suspected food products which add up in costs. During the 2008 Ireland incident approximately 30 000 tonnes of recalled products were destroyed, 170,000 pigs and 5,700 cattle from the farms that received contaminated product were slaughtered and destroyed on a precautionary basis (IARG 2009). The estimated costs of the recall were 120 million euro. However, these calculations did not include any reputational damage to the Irish agriculture and food industries (Marnane 2012).

A dioxin crisis in a livestock production chain has financial consequences, both direct and indirect. Direct costs generally refer to cost involved in risk mitigation and to the value of destructed livestock and contaminated products. In case of a contamination a recall is unavoidable and the losses of a recall can be significant (Velthuis et al. 2009). A recall gives direct financial consequences, which include the costs for media announcements, transportation, warehousing costs, extra labour, and destruction (Meuwissen et al. 2009; Velthuis et al. 2009). Refunding consumers are direct costs as well. However these represent a small part of the total costs since many consumers will not ask for a refund simply because they missed the recall announcement (Velthuis et al. 2009). A later recall moment will influence the direct costs positively as there will be already more contaminated products consumed already means there is simply less left to recall.

Indirect costs refer to consequential losses including the loss of customer confidence resulting in reduced sales and revenues and/or a lower stock price in the capital market, crisis response expenses and costs incurred for brand rehabilitation. Crisis response expenses include fees and expenses of outside consultants engaged exclusively for the function of responding to the product contamination and recall (Kramer et al. 2005; Meuwissen et al. 2009; Teratanavat et al. 2005). Unfortunately indirect costs are often difficult to quantify and the factors that determine the indirect costs are unknown and information on these costs is lacking (Kramer et al. 2005; Velthuis et al. 2009). A way to reduce the indirect costs of a recall is an early initiation of a recall (Teratanavat et al. 2005). Since a later recall moment increases the risk of damaging consumer confidence, the company's name, or the whole sector (Velthuis et al. 2010).

In 2001 a group of experts from the European Science Foundation concluded that European food and feed monitoring programs were generally inadequate (Büchert et al. 2001). Though, an efficient monitoring system can shorten the period between the detection of the problem and the execution of a recall, which therefore lowers the financial impact of an incident (Teratanavat and Hooker 2004). However a monitoring system for compliance with any legal limits set for dioxin an dioxin like chemicals in food could be complex and costly (Büchert et al. 2001), and when these costs exceed the costs of an incident, monitoring is financially unattractive. This however excites a moral issue; consumers want to consume and expect to consume safe food. At the moment there are norms and regulations for food processing companies stating the maximum amount of dioxin allowed in a product. Nevertheless the government positioned “dioxin-safe food” as a common private good, which means it is the responsibility of the private sector that requirements are met, and not that of the government. Some actors in the chain and the government sample randomly, however there is no information available whether this frequency is high enough to prevent a dioxin contamination incident from happening. From the 1999, 2003, 2004 and 2006 dioxin incidents in the Netherlands, two were noticed during governmental sampling, one by regular milk sampling and one because of a decreased egg production and hatching (Meuwissen et al. 2009). In the well known Belgian dioxin contamination in 1999 the contamination was detected by the direct biological health effects observed in poultry, not through a monitoring program. Four other cases of dioxin contamination (citrus pulp, kaolinitic clay, artificially dried grass meal and choline chloride) have been detected in Europe since 1997 within the framework of local monitoring programs (EC 2001).

3. Material and Methods

The aim of this research is to evaluate the cost effectiveness of monitoring schemes varying in the sensitivity to detect and therefore the losses that can be prevented, using the financial impact of a dioxin incident as a maximum budget. This research focuses on the dairy chain, specifically on consumption milk. Consumption milk is a simple product in terms of having one ingredient and only a few steps in the production process (Velthuis et al. 2009). Due to the level of fat in milk (0.5-4%), this product is sensitive for dioxin contaminations.

First a literature study and expert interview was conducted to provide insight in available background material on dioxin and the risks it causes to humans health, the policies and regulations on dioxin and the current dioxin monitoring programme of the Netherlands. This information was used to construct chapter 2. Than information was gathered on the costs involving a dioxin contaminated food crisis and the costs of a dioxin monitoring system. This to understand the two papers on dioxin incidents in the dairy chain which Lascano-Alcoser et al. published and which will be used in this research. The first paper offers a practical tool which can be used to calculate the financial impact of a milk dioxin contamination (Lascano-Alcoser et al. 2011) and the second paper describes a model which can be used to determine the minimum amount of monitoring resources required to accomplish a certain level of monitoring sensitivity effectiveness or to calculate the achieved level of effectiveness at a certain monitoring budget (Lascano-Alcoser et al. 2013). This research is first in linking these models by using the financial impact resulting from the first model as an budget constraint for the second model. These models will be further explained in the following paragraphs.

3.1 Evaluation financial impact of dioxin incidents in the dairy chain.

The milk dioxin contamination impact model (MiDCIM) is a deterministic model developed in Microsoft Office Excel 2003 (Microsoft, Redmond, WA) which only accounts for direct costs. These costs include the costs of different control measure like tracking and tracing of the contamination, sampling and testing of suspected and contaminated products, blocking of farms and firms containing suspected and contaminated products and livestock, recalling contaminated products, replacing recalled products and the destruction of contaminated products.

In the MiDCIM model, the financial impact of a dioxin incident can be calculated for scenarios that differ in the time between the start of the contamination and the moment of detection (the high risk period; HRP). The MiDCIM includes four chain stages: feed supplier, dairy farm, milk processor, and retailer. Network information from the Dutch dairy chain about all stages in the dairy chain is used as model input. In the performed model calculations of Lascano-Alcoser et al. (2011) as well as in thie study it is assumed that a single feed supplier production factory is the starting point of the contamination by producing and supplying dioxin-contaminated compound feed for dairy cows. From this stage, the contamination is spread through the dairy farms, where contaminated feed is offered to dairy cows and contaminated milk is collected. Following, the milk processors, where contaminated milk is processed into milk for consumption, and the retailers, where milk for consumption is sold to the consumption. In the calculation of the financial impact the “worst-case scenario” is assumed, meaning that all milk produced will be converted into milk for consumption, the contamination is continuous over time and the entire daily production of each business unit form feed supplier to milk processor stage is contaminated.

Given the lack of information regarding the path that milk followed from each farm to each specific milk processing site, it is assumed that each group of 51 farms delivers milk to two milk processing plants from one milk company beginning on the first day of having received new feed, with a maximum of 26 out of 52 milk processing plants in The Netherlands (Lascano-Alcoser et al. 2011). Under the assumption that every farm gets supplied every 14 days, that there are 26 feed suppliers and 18,470 dairy farms; one single feed mill has a customer base of 714 farms and supplies 51 farms a day. In this calculation Lascano-Alcoser (2011) assumes that every feed mill in the Netherlands is from the same size and they have an equal customer base.

Lascano-Alcoser used a deterministic set up of the dairy chain. By evaluating various scenarios which differ in time of detection, contamination concentration and quantity, and in frequency of an incident we hope to get insight in the contribution of these variables on the financial impact. The calculated financial impacts, the costs for the entire chain in case of an contamination incident, are subsequently used as a budget constraint for the optimalization model to calculate the most cost effective monitoring schemes for these different scenarios.

The following scenarios have been evaluated:

Baseline scenario

Based on history, the number of incidents per ten year is set at two. The number of farms from which the milk is collected in one truck is assumed to be 4, accounting for the truck capacity and the average milk production per farm. In combination with the general settings of Lascano-Alcoser et al. (2011) this results in the following baseline setting which can be used to compare the constructed scenarios:

- # of farms supplied by feed mill = 51
- # of processors = 2
- # incidents per 10 year = 2
- # of farms per milk truck = 4

High Risk Period scenarios

The financial impact of a contamination depends on the day of detection. The period between the contamination and the day of detection is called the HRP. The HRP can range from 1 to 14-days. The maximum of 14 was chosen by Lascano-Alcoser based on the assumption that each farm receives new compound feed every 14 days. If detected on day 14, the maximum number of dairy farms, milk processing plants and retailer contaminated from a single feed production site is reached. Therefore, although the contamination could continue after day 14, given a new delivery of contaminated compounded feed, the level of damage would not increase further after two weeks.

In this model the milk is sampled at the trucks which collect the milk at the farm and deliver it to the milk processor. Milk is not collected daily but is stored on the farm with a maximum of three days before collected. Therefore the first HRP is set at 3 days, the second after a week (HRP=7) and the last scenario has a HRP of 14 days. The scenarios are presented in Table 1 (scenario 1 and 2). For all other scenarios and the baseline scenario the HRP is set at 7 days.

Dairy chain network scenarios

The Dutch dairy chain network data which is used as input for the MiDCIM (Lascano-Alcoser et al. 2011) is based on both real time data and assumptions. First, the changes in financial impact in case the contaminated feed mill supplies to less than and to more than the basic 51 farms every day have been evaluated. Table 1 shows the relating constructed scenarios 3 and 4.

Also 2 scenarios (scenario 5 and 6) have been constructed to evaluate the impact of the number of milk processors that are supplied by the milk trucks, which is either 1 or 3.

Incident frequency

To see what would happen if the number increases to three or halves which means that there is one incident every ten years two scenarios (7 and 8) are assembled.

Table 1 Scenarios defined to evaluate the financial impact of a dioxin incident in the dairy milk chain.

Scenario number	Variable				
	HRP	# of farms supplied by feed mill	# of milk processors	# incidents per 10 year	# of farms per truck
Baseline	7	51	2	2	4
1	3	51	2	2	4
2	14	51	2	2	4
3	7	49	2	2	4
4	7	53	2	2	4
5	7	51	1	2	4
6	7	51	3	2	4
7	7	51	2	1	4
8	7	51	2	3	4
9	7	51	2	2	3
10	7	51	2	2	5

3.2 Evaluation cost effectiveness of monitoring schemes

The developed linear programming optimization model in a subsequent publication of Lascano-Alcoser et al. (2013) is used to determine the minimum amount of monitoring resources required to accomplish a certain level of monitoring sensitivity (effectiveness) or to calculate the achieved level of effectiveness (probability of detecting at least one contamination) at a certain monitoring budget (Lascano-Alcoser et al. 2013). In this model sampling happens in the trucks which go from the farm to the processor. Monitoring costs includes all activities performed to measure the concentration of dioxins in pooled samples which is a sum of sampling and testing costs. The financial impact in cases of an incident of the evaluated contamination scenarios will be used as budget constraint to determine the most cost effective monitoring strategy for these scenarios. The model is created in Microsoft Office Excel 2003 (Microsoft, Redmond, WA) using the Solver command from Frontline Systems Inc. (Frontline Systems Inc., 2011) for optimalization.

The aim of the optimization model is to detect at least one of the contaminated farms present. When one farm is detected within the monitoring system alarm bells will go off and with the use of track and tracing the source and other contaminated farms will be detected. The number of contaminations present is a setting of the optimalization model. If you define the number of contaminations to 10, this means that you aim to find at least 1 out of 10 contamination by monitoring. This is given the underlying assumption that the contamination is present due to a contaminated feed ingredient, and therefore there are more farms (10 in this case) contaminated.

Sensitivity analyses will be applied to evaluate the impact of the number of contaminated farms present on the definition of the most cost effective monitoring system. Sensitivity analysis will be applied on model settings related to the amount of farms supplied by one feed mill, the numbers of farms per truck, and the number of processors. An at last the impact of a risk based monitoring system will be evaluated where the milk from farms which are supplied by the same feed mill pooled in samples to be tested.

All scenario's will be tested for different goal concentrations; respectively 2, 3, 10 and 20 pg of TEQ per kilo gram fat. They will be tested for different settings regarding the amount of expected contaminated farms. First calculations will be made in cases where it is expected that only one farm is contaminated and therefore this one farm needs to be detected. In the other starting situation it is expected that ten farms are contaminated and the goal is to find at least one of these contaminated farms.

A small frame of reference regarding the sampling frame based on the results of Lascano-Alcoser et al. 2013: using the baseline scenario when testing for 2 pg of TEQ per kg of fat and searching for 1 out of 1 contaminated farm there are 15,283 truck samples collected each month, there is one truck sample mixed into a pooled sample so there will be 15,283 pooled samples tested every month. When testing for 20 pg of TEQ per kg of fat and searching for at least 1 out of 10 contaminated farm there are 1,527 truck samples collected each month, there are 19 truck samples mixed into a pooled sample so there will be 80 pooled samples tested every month (Lascano-Alcoser et al. 2013).

Risk based monitoring system scenario

Finally a scenario has been analysed where a risk based monitoring system is assumed. This has not been analysed by Lascano-Alcoser. In this scenario trucks which contain milk from farms which are supplied by the same feed mill are pooled together in a sample. If assumed that the dioxin contamination is originated at the feed mill, all farms supplied by the feed mill are contaminated. Therefore the concentration dioxin in the sample would be higher than in the case of one contaminated farm. Therefore, more trucks can be pooled in the sample without a dilution effect, which could results in lower monitoring costs.

The number of trucks per pooled sampled is determined as followed:

$$\#\, trucks\ per\ pooled\ sample\ = \frac{\left(\frac{(Action\ level -\ Background\ level)}{(Decision\ limit -\ Background\ level)}\right)}{\#\, farms\ per\ truck}$$

If the whole truck is contaminated and not only one farm collected in the truck, the action level can be multiplied with the number of farms per truck. This raises the # of trucks per pooled sample with the # of farms per truck, in the original case this means times 4. The equation in case of risk based monitoring is:

$$\# \, trucks \, per \, pooled \, sample \; = \left(\frac{(Action \, level - \, Background \, level)}{(Decision \, limit - \, Background \, level)}\right)$$

For the risk based monitoring system we assume that it is a fair statement that farms which are geographically close to one another are supplied by the same feed producer and will produce for the same milk processing plant (and company). Which makes it fair to say that the milk from these farms could be collected by the same milk truck.

4. Results

The financial impact from the scenarios explained in chapter 3 are calculated and presented in this chapter. Besides the financial impact, the maximum effectiveness (indicated as the probability of detecting at least one contaminated farm present) which could be obtained when using the financial impact as the indicator for the budget constrain are presented.

4.1. Financial impact

The different HRP's used in scenario 1, 2 and the baseline result in large changes of the financial impact. When detecting on day 3 the ten year impact is much lower (€ 22 million) than when detecting on day 7 (€ 89 million). When detecting at day 14 the financial impact raises 316 percent compared to a HRP of 7 to € 282 million (Table 2).

The number of farms supplied by a single feed mill, with other words the scale of the feed mill is positively correlated with the financial impact in case of a contamination incident. This means a lower number of farms supplied by one feed mill, a smaller scaled feed mill, results in a lower financial impact. The other way around, an increase in the number of farms per feed mill gives a higher financial impact. A decrease of 2 farms supplied by one feed mill gives a financial impact decrease of 1.28% to € 88 million. An increase of 2 farms gives an 1.28% increase in financial impact resulting in a impact of € 90 million (Table 2).

The number of milk processors is positively correlated with the financial impact. Assuming that the group of 51 farms supply to 1 food processor (one big site) or to 3 food processors (relatively smaller sites) result in a respectively lower (-32.69%) and higher financial impact (+32.69.%) than in the case of 2 food processing sites (table 2).

If more dioxin incidents take place in a 10 year period the financial impact per 10 years increases linear (table 2).

Table 2 Maximum monthly monitoring budget based on the expected financial impact of the various dioxin contamination scenarios.

Scenario number	Variables					Financial impact /10 year	Max. monthly monitoring budget
	HRP	# of farms supplied by feed mill	# of milk processors	# incidents per 10 year	# of farm per truck		
Baseline	7	51	2	2	4	€ 89.317.560	€ 744.313
1	3					€ 21.933.360	€ 182.778
2	14					€ 282.460.838	€ 2.353.840
3		49				€ 88.173.840	€ 734.782
4		53				€ 90.461.160	€ 753.843
5			1			€ 60.116.040	€ 500.967
6			3			€ 118.519.080	€ 987.659
7				1		€ 44.658.720	€ 372.156
8				3		€ 133.976.280	€ 1.116.469
9					3	€ 89.317.560	€ 744.313
10					5	€ 89.317.560	€ 744.313

The number of farms from which the milk is collected in the same truck cannot be altered in the MiDCIM model and therefore does not influence the financial impact in case of an incident. It can be altered in the optimalization model which results in a change of the optimal monitoring system and will be discussed later in this chapter.

4.2. Optimalization of monitoring system

4.2.1. Scenarios relating High Risk Period

The difference in the day of detection (HRP) demonstrates large differences in financial impact. Table 2 presents the corresponding monthly monitoring budgets. In the case of detecting one contamination out of one (baseline), and looking for a low concentration of TEQ per kg of fat (2 pg and 3 pg per kilogram fat), the available budget of the baseline scenario could only provide a 56.7% and 78.8% effectiveness. When searching for higher concentrations (10 pg and 20 pg) the baseline budget is enough to provide a 99.0% and 99.8% effectiveness.

When the sector is able to detect the contamination in an early stage, HRP=3 (scenario 1), the budget is not sufficient to provide high effectiveness of monitoring (resulting in respectively 18.6%, 31.6%, 67.7% and 79.9% effectiveness in case of a contamination of respectively 2,3,10 and 20 pg/kilogram fat).

When detecting late, at day 14 of the contamination the financial impact is high. This makes the budget for monitoring high and this results in high levels of effectiveness (resulting in respectively 92,89%, 99.25%, 100.0% and 100.0% effectiveness in case of a contamination of respectively 2,3,10 and 20 pg/kilogram fat).

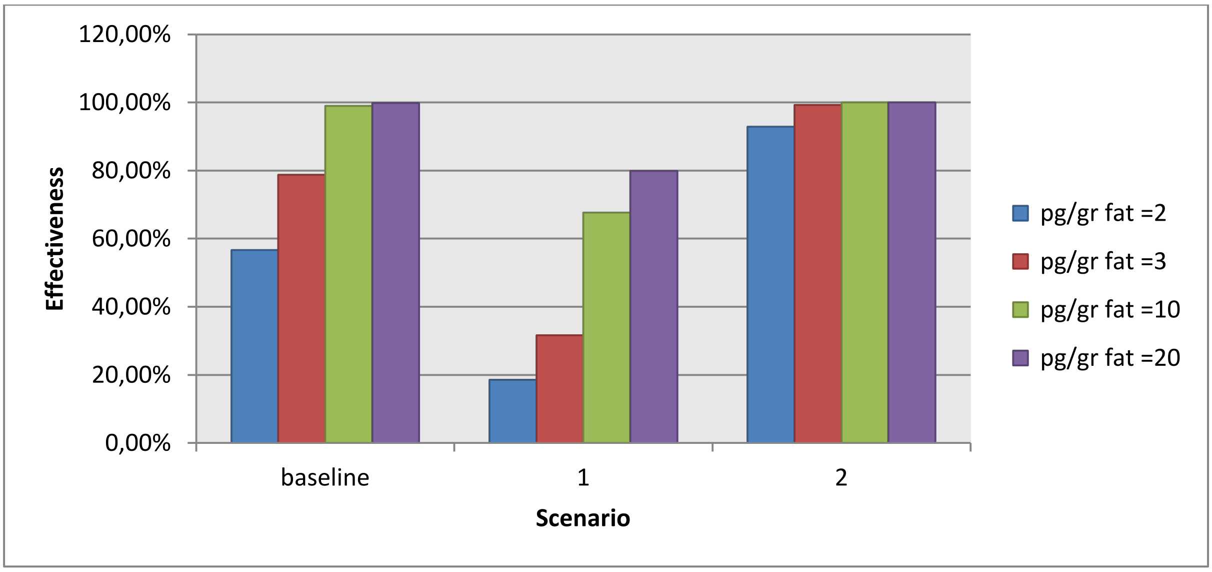

Figure 1 Distribution of monitoring effectiveness per concentration given the available budgets as defined for baseline (HRP=7), scenario 1 (HRP=3) and scenario 2 (HRP=14).

When searching for at least one contamination out of ten contaminations, for all concentrations the effectiveness of the optimized monitoring schemes based on the budget constraints of the baseline, scenario 1 and 2 is above 98.0% except for scenario 1 with a concentration of 2 pg TEQ per kg of fat, here the effectiveness is 87.2%.

4.2.2. Scenarios related to the dairy chain network input

Table 3 Effectiveness per contamination concentration for scenarios related to the dairy chain network input

	Detect 1 contaminated farm				Detect at least 1 out of 10 contaminated farms			
	2 pg	**3 pg**	**10 pg**	**20 pg**	**2 pg**	**3 pg**	**10 pg**	**20 pg**
baseline	56.7%	78.8%	99.0%	100.0%	99.9%	100.0%	100.0%	100.0%
3	56.2%	78.3%	98.9%	100.0%	99.9%	100.0%	100.0%	100.0%
4	57.1%	79.2%	99.1%	99.9%	100.0%	100.0%	100.0%	100.0%
5	43.3%	64.7%	95.5%	98.8%	99.6%	100.0%	100.0%	100.0%
6	67.0%	97.2%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%
7	34.2%	53.9%	90.0%	96.2%	98.5%	100.0%	100.0%	100.0%
8	71.5%	90.2%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%

All scenario’s are tested for different goal concentrations; respectively 2, 3, 10 and 20 pg of TEQ per kilo gram fat. And are tested for different baselines regarding the amount of expected contaminated farms. First the level of effectiveness/sensitivity of monitoring are presented in case it is expected that only one farm is contaminated and therefore you need to find this one farm. Second is the corresponding effectiveness in the case of ten contaminated farms with the goal to find at least one out of these contaminated farms. Table 2 shows a small change in monthly monitoring budget for scenario 3 and 4. The number of farms supplied by a single feed mill, with other words the scale of the feed mill has little impact on the effectiveness of monitoring systems.

The number of milk processors to where the milk is delivered has a rather large influence on the financial impact. Table 3 shows the maximum effectiveness reached when transforming these financial impacts into monthly monitoring budget constraints. The optimized monitoring schemes in scenario 5 and 6 reach for all concentrations an effectiveness above 95% when aiming to detect at least 1 out of 10 contaminations. When aiming to detect 1 out of 1, the scheme in scenario 5 provides an sufficient budget with an effectiveness above 95% with a concentration of 10 pg or more. In case of scenario 6, the available budget is enough to reach a 95% effectiveness for concentrations of 3 pg or more.

In case there is only one incident every 10 years (scenario 7) searching for one out of one contamination with a low concentration (2 pg and 3 pg) based on the impact related monitoring budget constraints results in a low effectiveness; 34.2% and 53.9%. Even when looking for a higher concentration of 10 pg TEQ per kg of fat the effectiveness is only 90.0%. When the Netherlands suffer three incidents every 10 year (scenario 8) the effectiveness levels raise subsequently due to the increased impact and therefore available budget, which is shown in table 3.

4.2.3. Scenarios relating Risk based monitoring

When implementing a risk based monitoring system the monitoring costs will decrease. The monthly monitoring costs of monitoring for a detection of 1 out of 1 with a concentration of 2 pg TEQ per kg of fat will decrease with 76.7% compared to the baseline, a non-risk based monitoring scheme. As table 4 shows, risk based monitoring with a 95% effectiveness costs only 0.6 million euro a month instead of 2,6 million euro per month. When looking at the difference in monitoring costs for a detection of 1 out of 1 with a concentration of respectively 3 pg, 10 pg and 20 pg TEQ per kg of fat the cost reduction is 68.2%, 43.0 and 28.7%.

In case of detecting at least 1 out of 10 contamination the percentage cost reduction is the same as for detecting one out of one.

Table 4 Monthly monitoring costs for risk based versus non risk based monitoring (95% effectiveness)

	detect 1 contaminated farm				detect at least 1 out of 10 contaminated farms			
	2 pg	**3 pg**	**10 pg**	**20 pg**	**2 pg**	**3 pg**	**10 pg**	**20 pg**
Baseline	€ 2,667,463	€ 1,439,567	€ 484.536	€ 340.922	€ 266,519	€ 143,834	€ 48,412	€ 34,063
Risk based	€ 620,969	€ 457,249	€ 276,296	€ 243,154	€ 62,044	€ 45,686	€ 27,606	€ 24,295

5. Discussion and Conclusion

5.1. Discussion

During this research I was able to answer all research questions. The answers can be found in either previous chapters or they are discussed further on in this chapter.

In most scenarios the optimal monitoring schemes defined by a budget constraint equalling the financial impact forgone resulted in high levels of monitoring effectiveness (> 95%). This indicates that the monthly budget is sufficient and in many cases even more than sufficient. Hence, monitoring for dioxin requires less funds than needed covering the financial impact in case of an incident, indicating a positive incentive for implementing a monitoring scheme in the Dutch dairy chain without government interference. However the optimalization model only considers part of the costs involved, namely the costs for sampling and testing. The maximum budget for monitoring only covers these structural monitoring costs. In case of a contamination, a process of recalling the product is set in place and the costs of doing so are not included in the total costs of monitoring. This needs to be taken into account when performing an economic trade-off between monitoring or not monitoring. In a more recent optimalization study Lascano-Alcoser performs on the pig chain the costs of tracing the contamination to its initial source are included are included in the costs function of the optimalization model.

This research has looked at the advantages of performing a risk based monitoring system. The results show that the costs of monitoring with an effectiveness of 95% decrease tremendously (a reduction between 76.7 and 28.7%) in case of risk based monitoring. There has not been paid any attention to the possible differences in costs for collecting the milk and sample, however since it is a reasonable assumption that farms supplied by the same feed mill are geographically close to one another, it is predicted that there is not a big difference. This makes further research on implementing a risk bases monitoring scheme worth wile for actors in the Dutch dairy chain.

When setting up a sufficient chain monitoring system actors have to come up with the required funds. The MiDCIM model gives insight in the financial impact of four different stages/actors in the chain, providing insight in which actor experiences the biggest loss. In case of an early detection (HRP ≤ 4) the farmers have the largest contribution to the financial loss (between 47% and 85% of the total financial impact of an incident). From HRP ≥ 5 the milk processors contribute the most to the total chain impact in case of an dioxin incident (between 54% and 77%). If the NZO (an interest organisation created to safeguard the quality and safety of all Dutch dairy products) or a different organisation would implement some monitoring system described in this report they could look at a finance scheme where all actors contribute according to their loss in case of an incident.

Due to dilution there is a limit to the amount of samples which can be pooled for testing. When testing for dioxin, slightly lower mean levels were found when moving from farm and bulk to retail milk. This could be related to the dilution effect at retail level in the mixing of milk from different origins or to a targeting of possible suspect samples at farm level (EFSA 2010). Because of this dilution effect it could be argued that the level of dioxin for which is tested could be higher. A higher test level, for instance from 10 pg TEQ per kg of fat to 11 pg increases the maximum number of truck samples per pool from 9 to 10 which therefore decreases the costs of testing. Understandable, research is needed on the exact dilution effect in the dairy chain.

The route of a dioxin contamination within the chain is simulated in a deterministic way since fixed values for inputs variables and fixed relation between variables are considered. For example, for each feed mill involved in the contaminations, 51 farms are expected to be delivered by this feed mill and, subsequently, a fixed number milk processor assumed to become contaminated. More real would be if such inputs variables and their interactions are simulated randomly. A stochastic approach should be more suitable to simulate the flow of the dioxin contamination along the dairy chain. In fact, by using a stochastic approach the full distribution including all possible contamination scenarios can be revealed. However, there is limited information available which describes the probability distributions of such inputs. In addition, when using a stochastic approach, it will not be possible to get clear insights into main factors affecting the spread of a contamination, given the simultaneous variation of the inputs and their interactions. Moreover, it allows for building contamination scenarios that can show the spread and the possible extent of a dioxin contamination throughout the chain.

Literature (Büchert et al. 2001; Hoogenboom et al. 2004; Kan and Meijer 2007; Lascano-Alcoser et al. 2013) states that testing for dioxin in food and therefore monitoring is rather expensive, however these quotes are not placed in any context. According to Lascano-Alcoser et al. (2013) the monthly monitoring costs for the Netherlands to detect 1 contaminated farm out of 1 contaminated farms with a concentration of 2 pg of TEQ/g of fat are € 2.7 million given a 95% effectiveness of monitoring. Dutch yearly production of milk is 11.851 million kg (Productschap-Zuivel 2012). Consumers in the Netherlands pay between €0,70 en €1,00 for a litre of fresh milk. Safeguarding dioxin free milk by producers entirely charged to consumers would mean a consumers price increase of 0.0027 percent. And when implementing a monitoring scheme where the goal is to detect at least 1 contaminated farm out of 10 contaminated farms with a concentration of 10 pg of TEQ/g of fat are € 48,000 given a 95% effectiveness which would lead to a price increase of only 0.000048 percent.

Finally, this research only looks at monitoring within the dairy milk chain by testing milk collecting trucks. In the Dutch dairy chain there are currently two testing places where the products are tested for safety and quality, to say at raw milk stage (by NZO) and the shelf product (by NVWA). In this research it is assumed that the source of the contamination is animal feed. In this case there is another testing point which needs to be considered is the search for a costs effective monitoring system with a high effectiveness for detection, namely that within the feed production chain.

5.2. Conclusion

- Higher levels of effectiveness can be reached when testing for at least one out of ten contaminated farms instead of looking for one out of one contaminated farm. When searching for at least one out of ten contaminated farms the effectiveness of all scenarios except scenario 1 (HRP=3 days) is higher than 99.4 percent. Even when looking for a concentration of 2 pg of TEQ per kg of fat these high effectiveness levels are reached. This gives that the monthly budget is sufficient and in many cases even more than sufficient. Hence, monitoring for dioxin outweighs the financial impact in case of an incident indicating a positive incentive for implementing a monitoring scheme in the Dutch dairy chain without government interference.
- In most scenarios the optimal monitoring schemes defined by a budget constraint equalling the financial impact forgone resulted in high levels of monitoring effectiveness (> 95%)..

This indicates a positive incentive for actors in the Dutch dairy chain to implement a monitoring scheme which makes government interference not necessary.

- When the dairy chain is able to detect an incident at an early stage, i.e. HRP=3 , the financial impact is relatively low. In this case the budget is too low to provide a cost effective monitoring system (given the requirement of a 95% effectiveness).
- When searching for contamination with high concentrations (≥10 pg TEQ per kg of fat) more samples can be pooled which reduces the costs significantly. Less tests needs to performed which makes the monitoring system cheaper.
- Implementing a risk based monitoring system would lead to a significant cost decrease due to the bigger pools and the smaller amount of tests.

6. References

Adolphs, J., Kleinjung, F., Numata, J., Mielke, H., Abraham, K., Schafft, H., Müller-Graf, C., and Greiner, M. (2013). "A probabilistic model for the carry-over of PCDD/Fs from feed to growing pigs." *Chemosphere*, 93(3), 474-479.

Büchert, A., Cederberg, T., Dyke, P., Fiedler, H., Fürst, P., Hanberg, A., Hosseinpour, J., Hutzinger, O., Kuenen, J. G., Malisch, R., Needham, L. L., Olie, K., Päpke, O., Rivera Aranda, J., Thanner, G., Umlauf, G., Vartiainen, T., and Van Holst, C. (2001). "Dioxin contamination in food." *Environmental Science and Pollution Research*, 8(2), 84-88.

de Nijs, M. (2013). "Interview on the food safety monitoring systems in the Netherlands". City: RIKILT Wageningen.

Dorp, C. A. v. (2004). *Reference-data modelling for tracking and tracing*, Wageningen University., Wageningen.

EC. (2001). "Fact Sheet on dioxin in feed and food", E. Commission, (ed.). City: Brussels

EFSA. (2010). *Results of the monitoring of dioxin levels in food and feed*. European Food Safety Authority, Parma, Italy

Fedichem. (1999). *Dioxine en leefmilieu: feiten, fabels en vragen*. Fedichem, Brussel

Hoogenboom, L. A. P. (2009). "Dioxins, polychlorinated biphenyls and brominated flame retardants. ", in I. Shaw, (ed.), *Endocrine-disrupting chemicals in food* Oxford: Woodhead Publishing in Food Science, Technology and Nutrition pp. pp. 383-405

Hoogenboom, L. A. P., and Traag, W. A. (2013). *Grond gerelateerde voedselincidenten met dioxines en PCB's*. RIKILT, Wageningen.

Hoogenboom, R., Bovee, T., Portier, L., Bor, G., van der Weg, G., Onstenk, C., and Traag, W. (2004). "The German bakery waste incident; use of a combined approach of screening and confirmation for dioxins in feed and food." *Talanta*, 63(5), 1249-1253.

IARG. (2009). *Report of the Inter-Agency Review Group on the Dioxin Contamination Incident in Ireland*. www.agriculture.gov.ie., Dublin.

Kan, C. A., and Meijer, G. A. L. (2007). "The risk of contamination of food with toxic substances present in animal feed." *Animal Feed Science and Technology*, 133(1–2), 84-108.

Kramer, M. N., Coto, D., and Weidner, J. D. (2005). "The science of recalls." *Meat Science*, 71(1), 158-163.

Lascano-Alcoser, V. H., Velthuis, A. G. J., Hoogenboom, L. A. P., and van der Fels-Klerx, H. J. (2011). "Financial Impact of a Dioxin Incident in the Dutch Dairy Chain." *Journal of Food Protection*, 74(6), 967-979.

Lascano-Alcoser, V. H., Velthuis, A. G. J., van der Fels-Klerx, H. J., Hoogenboom, L. A. P., and Oude Lansink, A. G. J. M. (2013). "Optimizing bulk milk dioxin monitoring based on costs and effectiveness." *Journal of dairy science*, 96(7), 4125-4141.

Marnane, I. (2012). "Comprehensive environmental review following the pork PCB/dioxin contamination incident in Ireland." *Journal of Environmental Monitoring*, 14(10), 2551-2556.

McKay, G. (2002). "Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review." *Chemical Engineering Journal*, 86(3), 343-368.

Meuwissen, M. P. M., van Andel, A. L. A., van Asseldonk, M. A. P. M., and Huirne, R. B. M. (2009). "Eliciting processing industry damage from feed crises." *British Food Journal*, 111(8), 878-892.

Meuwissen, M. P. M., Velthuis, A. G. J., Hogeveen, H., and Huirne, R. B. M. (2003). "Traceability and certification in meat supply chains." *Journal of Agribusiness*, 21, 167–181.

Productschap-Zuivel. (2012). *Zuivel in cijfers* Productschap Zuivel, Zoetermeer.

Shen, H., Henkelmann, B., Rambeck, W. A., Mayer, R., Wehr, U., and Schramm, K.-W. (2012). "The predictive power of the elimination of dioxin-like pollutants from pigs: An in vivo study." *Environment International*, 38(1), 73-78.

Teratanavat, R., and Hooker, N. H. (2004). "Understanding the characteristics of US meat and poultry recalls: 1994–2002." *Food Control*, 15(5), 359-367.
Teratanavat, R., Salin, V., and Hooker, N. H. (2005). "Recall event timing: Measures of managerial performance in U.S. meat and poultry plants." *Agribusiness*, 21(3), 351-373.
Velthuis, A. G. J., Meuwissen, M. P. M., and Huirne, R. B. M. (2009). "Distribution of direct recall costs along the milk chain." *Agribusiness*, 25(4), 466-479.
Velthuis, A. G. J., Reij, M. W., Baritakis, K., Dang, M., and van Wagenberg, C. P. A. (2010). "Recall costs balanced against spoilage control in Dutch custard." *Journal of dairy science*, 93(6), 2779-2791.
WHO. (2010). "Dioxins and their effects on human health"*Fact Sheet 225*. City: WHO.