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Impact on product recalls and production efficiency

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Abstract

The primary aim of food traceability is to increase food safety, but traceability systems can also bring other benefits to production systems and supply chains. In the literature these benefits are extensively discussed, but studies that quantify them are scarce. In this paper we propose two hypothetical improvements of the traceability system within the chocolate production system and supply chain and we illustrate the resulting benefits by using a case study. Based on the case study, we quantify the influence of these improvements on production efficiency and recall size in case of a safety crisis by developing a simulation tool. These results are aimed to illustrate and quantify the additional benefits of traceability information, and could help food industries in deciding whether and how to improve their traceability systems.

Keywords: traceability, supply chain, recall, simulation, chocolate, food safety.

1. Introduction

Due to recent food scares, much attention has been given to food safety issues (e.g. Trautman et al. 2008). Food safety crises like the bovine spongiform encephalitis (BSE) in the 1990s globally caused economical losses for US$5.6 billion, and approximately seven million people are affected by food borne illness each year in Europe (World Health Organization, 2002; Sarig, 2003; Kimball and Taneda, 2004). The consequences of food safety crises could be reduced with appropriate traceability systems that keep track of food trades and processing information along the food supply chain. With such traceability systems, the identification of causes could be faster, market withdrawals and/or recalls of the involved products could be reduced in size, and total costs of the crises could be decreased.

1.1 Traceability in the food supply chain
In relation to food products, risk is defined by the European Commission as a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard (European Commission, 2002). Most food products contain a certain degree of risk. The magnitude of risk directly affects safety of the foods to public health and possibility of a food crisis that may require a product recall. The costs of a product recall can vary depending on food category, magnitude of the recall and seriousness of the food safety problem. A large share of the costs are often caused by indirect consequences, such as damage to the reputation of the brand and loss of market value, which can even lead to the bankruptcy of the brand (Onyango et al., 2007; Wilcock, Ball & Fajumo, 2011). However, traceability systems themselves do not reduce the probability that food crises occur, they only reduce their consequences. The better and more accurate a traceability system is, the faster a firm can identify a food safety problem, resolve it by withdrawing or
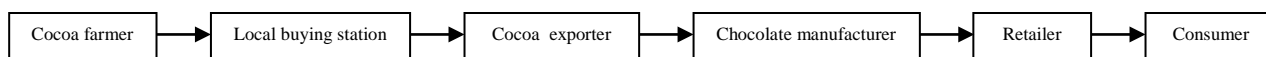
Figure 1. Supply chain of the case study.

recalling the implicated products and effectively investigate what caused the problem (Regattieri et al., 2007; Ruiz-Garcia et al., 2010; Karlsen et al., 2011).

In the food industry, raw material batches from different suppliers may be mixed. If a food safety problem comes from a certain raw material batch, all finished products containing raw materials from that batch have to be identified and recalled. Thus, the magnitude of a recall directly depends on batch dispersion in production and distribution. Recently, researchers found that the best solution to reduce batch dispersion is to reduce processing batch size and batch mixing. However, it was also found that reducing batch size leads to losses in production efficiency, due to increased production setup times, setup costs, cleaning efforts, etc. (Dupuy et al., 2005;Wang et al., 2009b; Rong and Grunow, 2010).

1.2 Value of traceability information

According to Golan et al. (2004) traceability consist of data collection regarding the origin and processes of a product. Thus, having an accurate traceability system also means having an extended amount of data on the products. That is, all actors involved in the supply chain of a food product collect and store data which, theoretically, could be available for all actors involved as well as the consumers. Depending on the nature of the products, data collected by a single actor of a supply chain could be useful for other actors involved in the same supply chain, like food manufacturers or traders. In modern food supply chains a huge amount of data is collected but most of it is not exchanged between or not available for the different actors in the supply chain.

In the literature much material is available regarding the value of traceability information for consumers, but few studies discuss this value for actors of the food supply chain which are not consumers (Canavari et al., 2010). Some recent work did however focus on additional benefits, like lower inventory levels, faster detection of difficulties in manufacturing processes by improved process control, decreased labour cost, improved operational planning, and increased efficiency of logistics and distribution operations (Viaene and Verbeke, 1998; Alfaro and Rábade, 2009; Wang et al., 2009a; Mai et al., 2010). To achieve these benefits of traceability the key issue is to integrate traceability with operations and supply chain management, and to increase the extent of traceability information being collected, which is currently often very myopic and only focused on tracing the origin of products. This lack in communication might be due to the absence of an information system able to handle data in an appropriate way, probably in turn caused by the absence of an interest of the food companies in such data. Thus, the challenge here is to find benefits of having this data available that could justify the investment needed in creating a system which could increase the exchange of data between the actors in the supply chain, from food manufacturers to the final consumers. Furthermore, it is essential to be able to evaluate the expected magnitude of such benefits, and even though these benefits of traceability are extensively discussed in the literature, only few papers actually quantity them (Wang et al., 2009b; Akkerman et al., 2010; Thakur et al., 2010).

2. Objectives

The aim of this paper is to quantify and discuss the benefits of traceability improvements to food manufacturers. As the quantification would not be possible on a completely theoretical level, we chose to focus on the supply chain of chocolate and the production system of a chocolate manufacturer to be able to illustrate the trade-offs and potential benefits of improving traceability. Based on this case study, we are able to illustrate two main aspects. First, we quantify the influence of reducing batch dispersion on production efficiency and recall size. Secondly, we quantify the benefits in terms of reduction of recall size for possible improvements of the traceability system used in the cocoa supply chain. Overall, we aim to demonstrate the additional value of traceability information in the chocolate supply chain, as well as providing an inspirational example case for other industries.

3. Materials and methods

3.1 Case study

The case study was constructed based on available literature and a series of interviews with industry experts (from two different chocolate manufacturers and a cocoa trading company). In order to protect the confidentiality of their

Table 1. Overview of simulation model parameters, values or range of value and parameter type.

Simulation model parameter	Value /range of values	Parameter type
Chocolate production process		
Waste from cleaning	12.9%	P
Processing batch size	1600 - 5000 kg	P
Cocoa liquor extracted from nibs	87.1%	P
Cocoa liquor to mixing process	62%	P
Cocoa liquor to pressing process	38%	P
Cocoa butter extracted	49%	P
Cocoa liquor (fraction)	0.40	P
Cocoa butter (fraction)	0.12	P
Sugar (fraction)	0.47	P
Lecithin and others (fraction)	0.01	P
Packaging size	0.1 kg	P
Supply chain		
Cocoa beans produced per cocoa farmer	1000 kg	C
Number of cocoa farmers	630	P
Number of local buying stations	12	P
Number of cocoa farmers per local buying stations	52 - 53	P
Cocoa beans per local buying station	52000 - 53000 kg	P
Number of cocoa exporters	5	C
Number of local buying stations per cocoa exporters	2 – 3	C
Cocoa beans per cocoa exporter	104000 - 159000 kg	P
Batch size of the cocoa exporter	10000 - 18000 kg	U
Number of batches per cocoa exporter	5 -16	U
Total cocoa beans received/chocolate manufacturer	630000 kg	P
Number of chocolate manufacturers	1	C
Total chocolate produced	740812.94 kg	P
Number of packages	7408129.37	P

Notes. C: constant parameter; P: predetermined parameter; and U: uncertain parameter.

contributions, data on the involved firms is omitted. The entire supply chain of the case study is shown in Figure 1 and briefly outlined below.

The supply chain of chocolate starts with cocoa farming. Cocoa farmers grow, harvest, ferment and dry the cocoa beans. After packing the dried beans in 15-kg bags the cocoa farmers deliver the cocoa beans to local buying stations, which combine the bags of several cocoa farmers and deliver them to a cocoa exporter (de Muijnck, 2005; Lainé, 2001). Cocoa exporters combine the bags of several local buying stations into batches which size typically varies between 10,000 kg and 18,000 kg. The cocoa exporters organize the shipping to the chocolate manufacturer. It is assumed that the chocolate manufacturer produces monthly 741,000 kg of chocolate, packed in 100 g bars. This quantity was chosen as it represents the average of the monthly production of all Swiss chocolate manufactures in 2008 (ChocoSuisse, 2009). The mass balance of the chocolate production was defined according to de Muijnck (2005). Since it is not relevant for the purpose of our study, no data regarding retailer and consumers are included in the case study. The number of actors and amounts of product handled can be seen in Table 1.
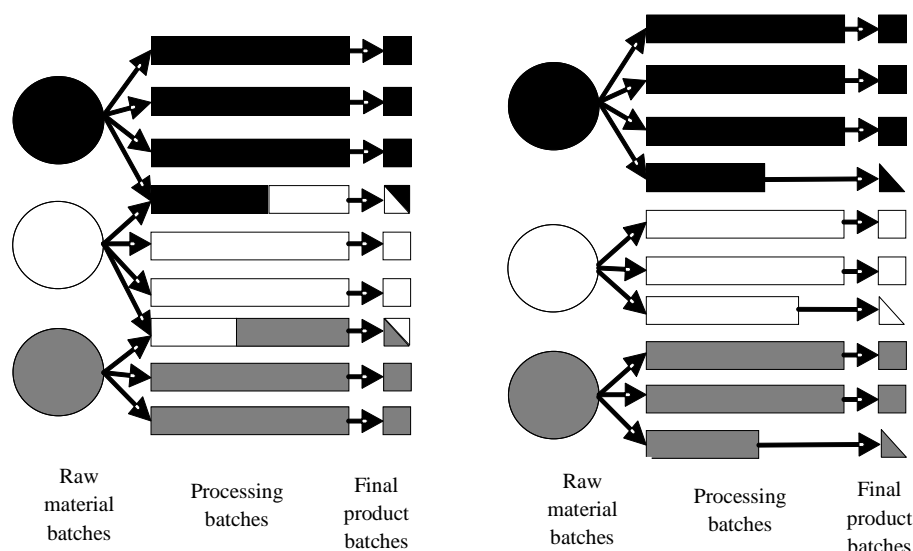
Figure 2. Left: PS1 production strategy. Raw material batches are mixed in order to utilize the maximum processing batch capacity. Right: PS2 production strategy, where raw material batches are never mixed.

3.2 Simulation model

In order to analyze the impact of traceability improvements on the consequences of a safety crisis we simulated recalls in the case study. To do this, we developed a spreadsheet simulation model implemented in Visual Basic for Microsoft Excel. These types of simulation models are often preferable because of the software usability and availability (Akkerman and van Donk, 2008). The simulation model is based on a series of parameters that are classified as constant (C), predetermined (P) or uncertain (U). Constant parameters refer to parameters that remain unchanged, predetermined to those that can actively be changed in the model, and uncertain to unknown parameters (see also Akkerman and van Donk, 2010). For the unknown parameters, a probability distribution is typically defined and the simulation model randomly chooses a value for each simulation run. All data used for developing the simulation model and their classification are shown in Table 1. It should be noted that wherever a range of values is denoted, a uniform distribution is used in the simulation.

In the chocolate production process the roasting process represents a key step for improving the microbiological condition as well as for defining the aroma profile of the final product (de Muijnck, 2005). Safety and quality of the finished chocolate strongly depend on the roasting process. Each batch of cocoa beans received by the chocolate manufacturer is usually split into several processing batches, whose dimension depends on the capacity of the roasting equipment. Thus, each processing batch goes into a specific roasting process. In this way, if a problem occurs to one roasting process, only the finished chocolate produced with that specific roasting process will suffer the consequences of the problem. The processing batch size is therefore a key (predetermined) parameter in the simulation model, and an essential planning decision in practice.

3.3 Experimental design

3.3.1 Different production strategies

The simulation model was designed to simulate the chocolate production system for two different production strategies, one based on production efficiency (PS1) and one based on reduced batch dispersion (PS2). In PS1 the maximum processing batch size is always used so that the equipment in the production stage is always used at full capacity. Since the size of the cocoa bean batches delivered to the chocolate manufacturer is not necessarily a multiple of the processing batch size, some cocoa beans are mixed with the next batch of cocoa beans. This results in having some batches of finished product produced from two different batches of raw materials. Instead, PS2 focuses on reducing batch dispersion, where the chocolate manufacturer avoids mixing the different batches of cocoa beans. Here, some processing batches might be smaller in size. As batch processes are involved, this results in some partially unutilized processes in the chocolate production line, with a corresponding reduction in production efficiency. On the other hand, if a safety crisis occurs to a batch of raw materials, a PS2 production strategy would lead to smaller recall sizes compared to PS1. A graphical illustration of both PS1 and PS2 can be seen in Figure 2.
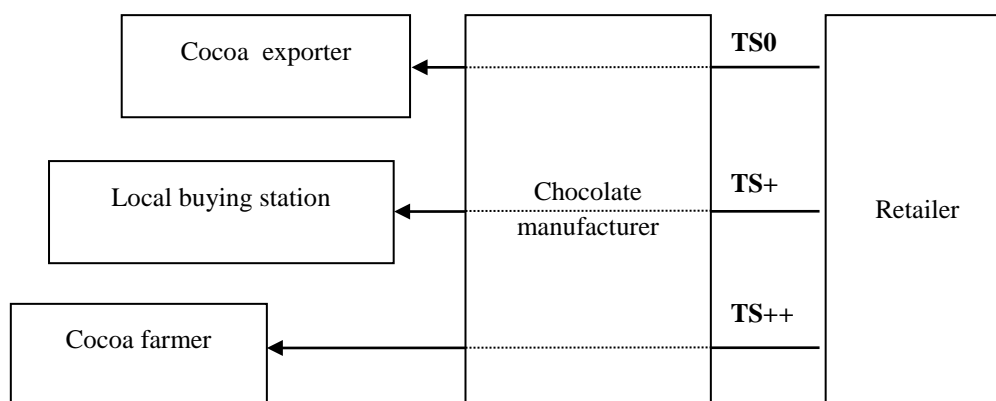
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Figure 3. The figure shows up to where a chocolate bar is traceable when using TS0, TS+ and TS++.

In the remainder of this paper, production efficiency is measured by the number of processing batches because:

- The number of processing batches equals the number of times a roasting process is performed and the duration of the roasting process depends on the roasting grade desired, not on the amount of nibs processed into the equipment (Jinap et al., 1998; de Muijnck, 2005). Therefore less processing batches mean less time needed for roasting, with a constant number of equipments; or less equipments needed, with a constant processing time required. Thus, less processing batches lead to a higher efficiency.
- Smaller batch sizes (also meaning more batches when processing a constant raw material amount) were found by other authors to lead to an increase in production setup times and costs, resulting in losses of production efficiency (Dupuy et al., 2005; Wang et al., 2009b; Rong and Grunow, 2010; Dabbene and Gay, 2011).

3.3.2 Different traceability systems

The simulation model includes a basic traceability system (TS0), and two improved traceability systems (TS+ and TS++). TS0 fulfils the European law regarding traceability, thus the actors involved in the supply chain and located within the European borders follow the "one step back-one step forward approach" required by law (European Commission, 2002). That is, the finished chocolate product is traceable from the supermarket, to the chocolate manufacturer, to the cocoa exporter. As the cocoa exporter is assumed to be located outside Europe it is not possible to trace the cocoa beans further in the supply chain.

TS+ is an extension of TS0, where the local buying stations, when buying the cocoa beans from the cocoa farmers, mark all cocoa bags with a unique code and the buying date. Also, when the cocoa exporter buys the cocoa and mixes bags from different local buying stations, the original bags remain. This means the cocoa is delivered to the chocolate manufacturer in the original bags with the code of the local buying station. These codes are then registered so that the finished chocolate can be traced up to the local buying station.

TS++ extends TS+ with the addition that the cocoa farmers, when packing the cocoa beans, already mark all bags with unique codes and date. In this case the finished chocolate is traceable up to the individual cocoa farmer. Alternatively, the local buying station could mark the bags at arrival, with the information of the farmer delivering the beans.

In Figure 3 the different traceability systems can be seen.

3.3.3 Different product recalls

The simulation model is able to simulate two possible food crises and corresponding recalls (R1 and R2) that could occur in the case study supply chain. R1 simulates the product recall in case of a contamination of the cocoa beans, which could be a chemical contamination while farming, fermenting or drying. In this case all chocolate bars produced with cocoa beans from a certain cocoa farmer need to be recalled. R2 simulates the product recall in case of a contamination of a processing batch, which could be caused by a problem in a roasting process. In this case all chocolate bars produced in a certain roasting process need to be recalled. The simulation models allow to run single and multiple simulations. Due to the importance of the roasting process it is also possible to run single or multiple simulations automatically for different processing batch sizes. For this paper, we simulated the food scares for a range of processing batch sizes between 1,600 kg to 5,000 kg (every multiple of 200 kg). Each of the sizes is then run multiple
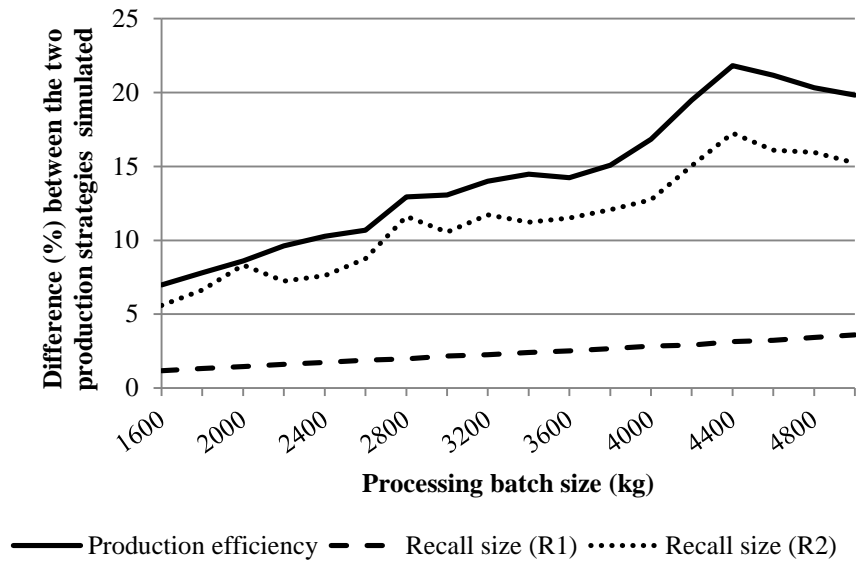
Figure 4. Difference between two production strategies in terms of production efficiency and recall sizes.

times, while information such as number of runs, processing batch size, recall size and number of processing batches (which reflects the production efficiency) is registered, and average results can be determined.

4. Results and discussion

4.1 Comparing different production strategies

In order to compare the production strategy based on production efficiency (PS1) to the production strategy based on reduced batch dispersion (PS2) the simulation model has been run for different processing batch sizes. The average results are shown in Figure 4 as the difference in percentages between the two production strategies (values of PS1 represent the 100%) in (*i*) production efficiency, (*ii*) recall size in case of contamination of the raw materials (R1) and (*iii*) recall size in case of contamination of a processing batch size (R2).

PS2 is a production strategy where the batches of raw materials are not mixed. Thus, the last processing batch from a raw material batch might not fully occupy the batch processing equipment. That is, the production equipment that processes this smaller batch will only be partially utilized. The actual overall utilization therefore depends on the processing batch size b and the raw materials batch size n. Combined, these two factors lead to a required number of processing batches r (with $r = n/b$) and a utilization of

$$u = \frac{r}{\lceil r \rceil} \times 100\% \, , \qquad (1)$$

where $\lceil r \rceil$ denotes the smallest integer larger than or equal to r. For situations in which the processing batch size is fixed (as can be expected in industry), but raw material batch size varies, this leads to different expected utilizations for each possible processing batch size b:

$$u_b = \frac{1}{|N|} \sum_{i \in N} \frac{r_i}{\lceil r_i \rceil} \, , \qquad (2)$$

where r_i is the required number of batches for raw material batch size n_i, $i \in N$ an index representing the different possible raw material batch sizes used in the simulation (based on the uniform distribution discussed in Section 2.2), and $|N|$ the number of elements in set N. The expected process utilization value u_b for the processing batch sizes simulated in our case study when using PS2 can be seen in Figure 5.

Figure 5 shows that, by simulating a large number of possible raw material batch sizes, and thus a large set N, the expected utilization u_b varies significantly. When producing with PS1, the raw material batches are mixed, always processing with fully occupied batch processing equipment, thus reaching high utilization in the production processes.
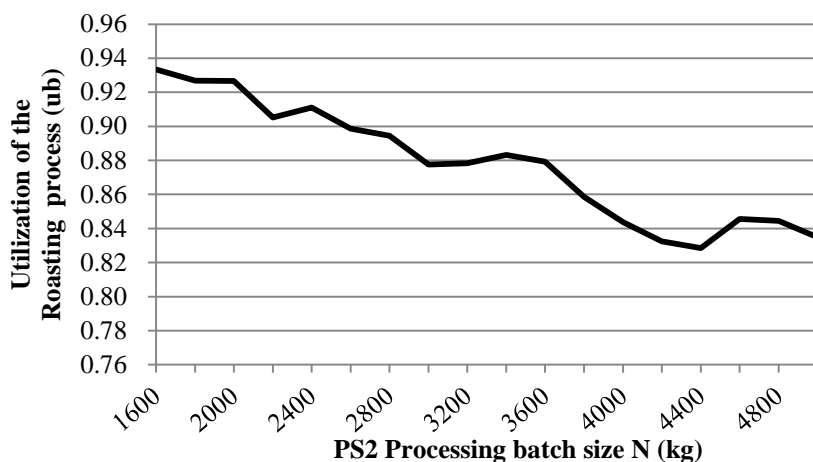
6

Figure 5. Utilization of the roasting process (u_b) at the different processing batch sizes (N) simulated for PS2.

Therefore, the number of processing batches for PS1, representing production efficiency, has a decreasing trend for an increasing processing batch size. As the decrease in the number of processing batches for PS2 is not constant, the percentage difference between the two production strategies is not increasing at a constant rate in Figure 4. This is most visible at processing batch sizes around 4,400 kg, but smaller incontinuities can be noticed around 2,800 kg and 3,600 kg. A chocolate manufacturer that produces with a PS2 production strategy should therefore take the expected utilization value u_b as calculated in (2) and illustrated in Figure 5 into account when deciding on the size of the processing batches. Obviously, the recall size in case of contamination of a processing batch (R2) strongly depends on the processing batch size. Thus, this variable unutilized fraction of the process results in a variable difference in recall size between PS1 and PS2, which is reflected in the peaks present in the R2 results curve in Figure 4. The recall size in case of contamination of the raw material (R1) is also affected by this variable difference, but since this type of recall consists of multiple batches of finished product, this has a relatively small influence on the results, and cannot be seen in Figure 4.

Overall, Figure 4 shows that for all processing batch sizes the relative difference in production efficiency ranges between 7 and 22%, the relative difference in recall size for R1 between 0.5 and 4%, and for R2 between 6 and 16%. In general, when comparing PS1 to PS2, the difference of both production efficiency and recall sizes between PS1 and PS2 increases when increasing processing batch sizes, due to the decreasing utilization and the increased size of mixed batches.

When comparing the benefits in increased production efficiency of PS1 to the benefits in reduced recall sizes of PS2, we did not include the probability that a product recall occurs. A product recall obviously does not occur for every batch produced, while benefits in production efficiency influence all produced batches. Therefore, when deciding whether adopting a new production strategy would be beneficial, the probability that a product recall occurs must be assessed and included in the decision-making process. However, even without this probability, the results obtained in this paper show that the effects in terms of production efficiency in PS1 are significant. This suggests that adopting a production strategy focused on reduced batch dispersion (such as our PS2 strategy) might often not be economically feasible. However, it should also be taken into account that the efficiency losses and the amount of lost product are only part of the economical effects. It is well known that in case a product recall occurs, food companies also incur costs related to organizing the recall, bad publicity and damage to the reputation of the brand (Onyango et al. 2007). If these aspects were quantified and taken into account, reducing recall sizes would have a bigger impact and PS2 might also become economically feasible. Quantifying the losses caused by bad publicity and damage to the reputation of a brand in case of product recall is outside the scope of our paper.

4.2 Influence of different traceability systems on product recall size

When constructing the case study it was seen that currently no full traceability is in use in the supply chain of chocolate. This is probably due to the fact that cocoa is farmed in non-European countries, where there is no legislation obliging the actors involved in a food supply chain to have traceability systems. The European legislation states that within Europe, food companies must be able to identify immediate suppliers and customers of a specific product (European Commission, 2002). This legislation guarantees full traceability within the European borders, but traceability is lost
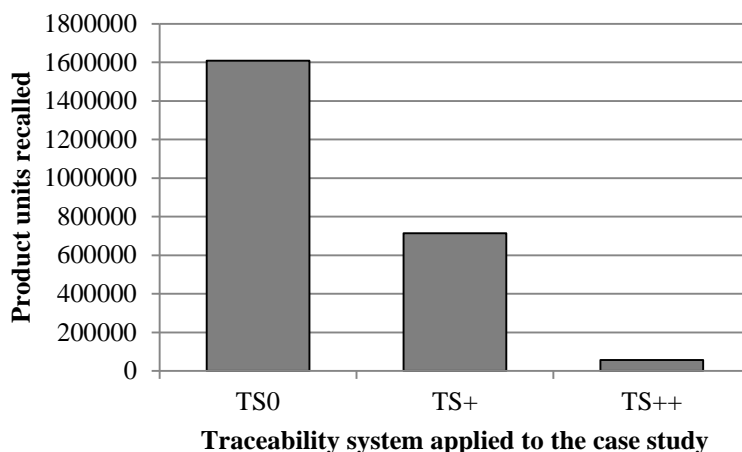
Figure 6. Recall size when simulating a food scare caused by contamination of the raw material with different traceability systems.

when part of the supply chain goes outside these borders. In the example case study constructed in this paper it was seen that cocoa could be traced up to the local exporter, which, since located outside Europe, is not obligated to comply with the European law on traceability and therefore does not record any further traceability information.

In our study the benefits of having a traceability system that is more accurate than what the law requires are quantified in terms of reduction of product recalls. In order to propose realistic improvements of the traceability system of the case study supply chain, TS+ and TS++ were designed taking into consideration that most of the cocoa farmers would not have the resources to invest in technologies, therefore these improvements imply very low investments. In order to analyze the influence of these different traceability systems (TS0, TS+ and TS++) on the recall size of the finished product in case of contamination of the raw materials, we again used the simulation tool. In order to have an accurate result the simulation model has been run 100 times for each processing batch size and data are shown in Figure 6 as the average of the averages of the results of all roasting equipment sizes (kg).

The results show an average recall size of 1,608,719 units of product for TS0, an average recall size of 714,584 units of product for TS+ and an average recall size of 55,789 units of product for TS++. No standard deviation is shown in the Figure 6 because it would show a variation which is mainly caused by the different roasting equipment sizes, thus giving a false sense of variability. However, acceptable standard deviations were seen when analyzing the underlying simulation results for each of the equipment sizes. These results show that in the case study supply chain, in case of contamination of the raw materials the adoption of TS+ would reduce the recall size of approximately 55% and the adoption a TS++ would reduce the recall size of approximately 96%. Again, the probability that a recall occurs would need to be considered to justify the investment needed to set up such traceability systems.

5. Conclusions

This paper outlines and quantifies the benefits of traceability improvements in the production system as well as in the entire supply chain of chocolate. In the literature, the benefits of traceability are largely discussed, but authors rarely quantify them. We believe that quantitative results on real or hypothetical improvements present a significant help to food industries in the decision to improve their traceability systems and how to do this.

We found that adopting a production strategy based on a low batch dispersion strategy would lead to a reduction of potential product recall sizes between 0.5 and 4% in case of contamination of the raw materials and between 6 and 16% in case of contamination of a processing batch size. On the other hand, it would also lead to a reduction of the overall production efficiency between 7 and 22%. We also found that improving traceability in the entire supply chain of chocolate could result in reduction of the magnitude of a recall in case of contamination of the raw material of 55% or 96%, depending on the type of improvement.

It is crucial for the industry to take these results into account when planning production improvements. These results show that the biggest benefit might be achieved when improving traceability through the entire supply chain, more than when improving it on a single production system. Our results also show that adopting a production strategy focused only on the reduction of batch dispersion would result in reduced losses in case of product recall, but it might not always be economically feasible when taking production efficiency into consideration. In this paper we also use an

expected process utilization value u_b that can be used for assessing the optimal processing batch size. Especially for larger batch sizes, this has a significant effect on the realized production efficiency, but also on the size of potential recalls. Taking this value into consideration is therefore crucial for reducing batch dispersion and minimizing losses in production efficiency.

In the future, a specific legislation for contaminants in cocoa beans will be enacted (Codex Alimentarius commission, 2007). Thus, increasing the control on the supply chain and improve cocoa traceability will even be a requirement. Therefore, identifying and quantifying the additional benefits of a system that in the future will anyway need to be improved might be of high interest for the chocolate as well as for other food industries. Here, we focus on the benefits of traceability implementations in terms of safety crises and production efficiency. According to Golan et al. (2004), traceability systems can handle an extended amount of information, which could represent a significant added value of traceability improvements. The characteristics of the final chocolate product strongly depend on the processes done at the very beginning of the supply chain. Studies show that each cocoa farmer differs in the way he handles and processes the cocoa beans (Lainé, 2001), For instance, flavour precursors, such as free amino acids and reducing sugars, are formed during fermentation done by the farmers, and are transformed into flavour compounds during the roasting of the cocoa beans. These flavour compounds are subsequently responsible for the flavour profile of the finished chocolate (e,g, de Brito et al. 2001; Jinap et al. 1998; Ramli et al. 2006). Detailed information on product conditions and the way it was farmed could be used to optimize processing parameters, such as roasting temperature and cocoa bean selection. Further research must however be done to analyse these possibilities.

In conclusion, this paper shows that traceability systems are highly valuable tools from which, if well designed and well integrated with the production operations, food producers can benefit in terms of safety issues as well as in the daily operational activities.

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