Salmonella Contamination in Chocolate Products: Simulation Model and Scenario Analysis

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Abstract: - Safety in the food industry is gaining more and more importance every passing day. In recent years, several outbreaks of Salmonella have occurred in chocolate products. Traceability and HACCP system are important instruments for the food safety management. Traceability is useful to properly and efficiently handle a recall, but by itself it has no effects on the safety of the production. The HACCP system is useful to identify both the production stages that can assure the final product safety and the ones that might increase the hazard of contamination. The aim of this paper is to study the flow of cocoa beans along the supply chain, until they are transformed in dark chocolate bars in order to study three different scenarios of traceability systems and recontamination. A simulation model in Plant Simulation has been developed; it includes models of survival and thermal inactivation of Salmonella over time and a simple traceability system.

Key-Words: - Discrete event simulation, cocoa-chocolate supply chain, safety, traceability, Plant Simulation, Salmonella

1 Introduction

Recent food crises have increased consumer awareness of the impact on public health of food production, processing, and distribution in Europe and beyond. Nowadays, consumers include factors like quality, safety and environmental conformity in their buying decision, while much research is performed to determine if they are willing to pay more for sustainable products [19]. It is possible to outline three main aspects in today's food industry: product quality, product safety and traceability, and process sustainability [1].

Food quality is highly dependent on the raw materials but also on the conditions of distribution and storage operations. During these operations the product is subject to chemical and physical transformations. Keeping control of changes is of vital importance for the supply chain and will dominate the technical and structural evolutions of it, for example there are technological developments such as time-temperature integrators or indicators that can be used to improve the temperature monitoring throughout the distribution system [9]. Food safety is related to quality and is one of the main characteristics that a product of this sector must have, and various systems and standards have been developed to support this; one of these being the Hazard Analysis Critical Control Point (HACCP) [1]. This approach is aimed at identifying potential food safety hazards, in order to apply key actions that can reduce or eliminate the risk of the hazards being realized. Since food safety hazards can occur at any stage of the food chain, an effort from all the parties of the network is required. To guarantee the supply of safe food "from farm to fork", the design and implementation of a traceability system is an important step, it increases safety by limiting the impact of a safety problem, also minimizing its economic fallout [10]. Next to safety reasons, sharing information can also lead to increased efficiency, innovation, and customer service [2, 7, 16]. In previous literature, several modelling and simulation approaches have studied the link between traceability systems and operational efficiency. An important contribution is the discussion of batch dispersion [6], which relates to how production batches are spread out through production and distribution systems. Several authors used this concept subsequently in mathematical modelling approaches to minimize the impact of product recalls [e.g. 4, 14]. Simulation approaches have also been used in this context, providing a more dynamic setting in which to analyse traceability aspects and logistical issues [e.g. 13, 15]. In this paper, we add to this body of work by studying a specific supply chain setting, namely

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cocoa products being used to make chocolate, and combine traceability aspects with commonly used HACCP methodology to analyze food safety risks.

2 Cocoa-chocolate process supply chain description

The production of dark chocolate can be divided in two main stages. In the first stage, cocoa beans are grown, harvested, fermented, dried, and shipped. In the second stage, cocoa beans are received by the chocolate manufacturer (usually located in a country far from the one of the farmer), and processed in order to create end products such as dark chocolate, the object of this study. Upon arrival at the chocolate manufacturer, the beans are subjected to a thorough inspection. Since imported cocoa beans can be very heterogeneous, it may happen that manufacturers, as previously cocoa exporters did, blend them to have a uniform level of quality of the raw material. After the inspection the cocoa beans are cleaned and, once the beans are clean, the processor has the option of roasting them before or after the shell is removed. Once the beans have been shelled and roasted (or roasted and shelled, as the case may be), the nibs are sorted according to their size in a process called winnowing thereafter to be the grounded into a paste with the grinding process. The heat generated by this process causes the cocoa butter in the nib to melt, earning it the name cocoa liquor. Then part of this (about 38%) is pressed to obtain cocoa cake (51%) and cocoa butter (49%).

To produce dark chocolate, cocoa butter (12%), cocoa liquor (40%), sugar (47%) and others (vanilla, lecithin 1%) are blended together. The resulting mixture is rolled and ‘conched’. Conching is a treatment whereby chocolate is kept in continuous movement to allow the cocoa mass to thicken and to develop into a homogenous substance. The paste is cooled at controlled temperature and time (tempering) to obtain the desired crystallization of the cocoa butter, then moulded in several shapes and finally packaged. Salmonella is the main hazard of chocolate products. The chocolate industry faces a difficult task in controlling *Salmonella* for several reasons, such as:

- Raw materials and ingredients may carry *Salmonella;* furthermore these contaminated elements often enter the process after the heating treatment, responsible of the inactivation of the bacteria.
- Low water activity and high fat content increase the thermal resistance of the pathogen so that even considerable heating is required to eliminate *Salmonella.*
- Small numbers of *Salmonella* may cause illness, both for the protective effect of chocolate against gastric acid in the stomach and because the main consumers of chocolate products often are children, that are more vulnerable than adults consumers.
- *Salmonella* can survive for a long period in chocolate products, up to 9 months.

Several investigations of past outbreaks suggested that one of the major causes was cross-contamination; this result is understandable because of the impossibility of Salmonella to grow in the cocoa-chocolate products. Constant efforts must therefore be made to eliminate or minimize the risks of contamination with Salmonella during chocolate production by introducing preventive measures based on the HACCP (Hazard Analysis and Critical Control Points) system and by adherence to good manufacturing practices [3]. HACCP is a system used to assure product microbiological safety. The word “Hazard” stands for an unacceptable contamination, growth or survival of organism of concern to safety, in this case Salmonella. The HACCP system consists of:

1. Analysis of hazard and assessments of their severity;
2. Identification of Critical Control Point (CCP);
3. Monitoring CCPs and corrective actions.

The CCPs are divided in CCP1 and CCP2, the first is a location, practice, procedure or process that will assure the control of a hazard, the latter is a location, practice, procedure or process that can minimize the hazard, but cannot assure the control of it. Hazards may occur at one or more operation of a food chain. Once these have been identified they should be eliminated or reduced.

Cocoa beans, which are the main raw material, are frequently contaminated with Salmonella and the roasting step is the only one that, if properly done, has a lethal effect on it. Therefore this operation is considered as CCP1. The environment of the roasted bean processing area is a CCP2 because it may avoid possible risk but never totally eliminate it; this area has to be constantly monitored by visual observation. The environment in which raw beans are handled is likely to be contaminated (unclean area); therefore it has to be physically separated from the area in which the roasted beans are further processed (clean area). Raw materials that are added at the mixing step and rework must be carefully handled, they are considered as CCP2.

Figure 1 represents a flow diagram of the production of chocolate in which CCP are displayed.

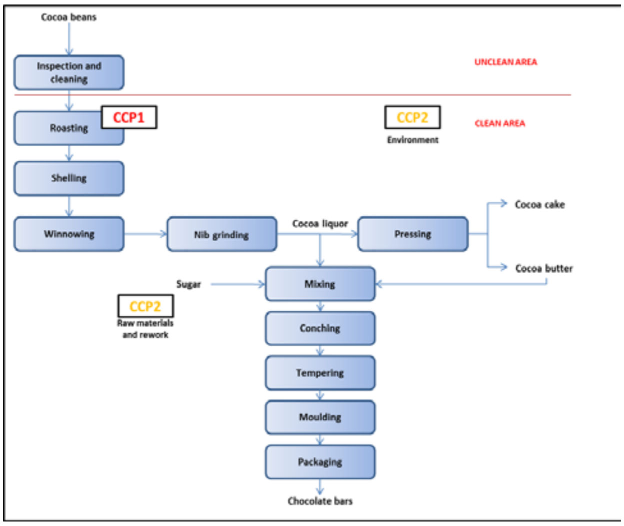

Figure 1: CCPs in chocolate production

3 Model construction

The simulation model used is based on discrete-event simulation logic, and implemented in Tecnomatix Plant Simulation 9 software developed by Siemens Industry Software ltd. A wide variety of sources were used to determine model parameters related to product details and supply chain characteristics. Even though simulation has been used before in quantitative risk assessment, only limited work has used discrete event simulation [13, 20]. Nevertheless, when modeling logistical systems where a variety of events happen in different places and different times, discrete-event modeling is common practice [13].

The model associates attributes to each unit related to its safety, e.g. if the unit is contaminated or not with Salmonella and the level of contamination; but also related to traceability such as farmers ID, cocoa exporter ID and roasting ID. Moreover within the simulation, in order to represent the dynamic of the concentration of bacteria in the product, models of inactivation and survival of Salmonella in cocoa beans and chocolate are implemented. The model considers only key aspects of production and processing that would affect the safety of the final product.

Figure 2 displays the main stages of the supply chain: farmers, LBS (Local Buyer Station), CE (Cocoa Exporter) and manufacturer. The last one is divided in more detailed stages, since these play a key role in the safety of the product and have to be investigated more in depth.

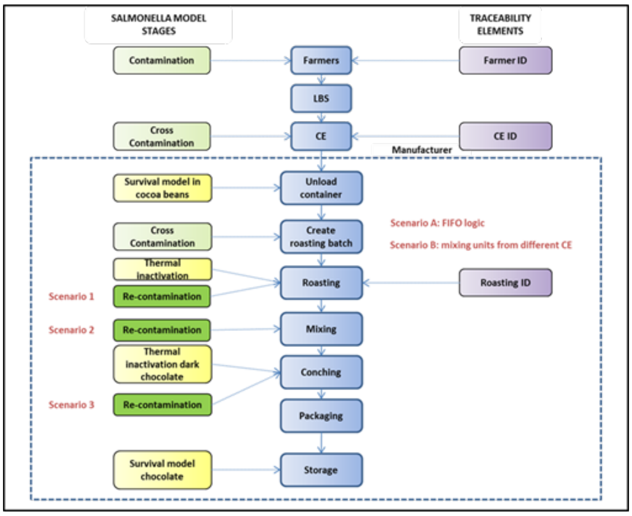

Figure 2: Logic scheme of the simulation model

One or more of the following biological events related to Salmonella, may take place in certain stages of the process:

- Contamination,
- Cross-contamination,
- Re-contamination,
- Survival,
- Thermal inactivation.

The handling processes have influence on the final concentration of bacteria of the end product. The main handling processes considered are:

- Mixing either different units of cocoa beans (CE, Create roasting batch stages) or different ingredients (Mixing stage). It may start cross-contamination
- Transport time has influence on the bacteria survival model.
- Storage, as well as transport, is assumed to be done in the proper way, and its length influences the survival model.
- Partitioning (Packaging stage) does not influence the contamination or safety of the end product, but after the packaging stage the number of cells per bar is defined.

For the simulation model, survival models of the bacteria have been defined, both in cocoa beans and chocolate, and the thermal inactivation models. An empirical survival model of Salmonella in cocoa beans is built

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upon the study of Komitolpoulou and Peñaloza [11]. By using recorded levels of Salmonella at 21°C and 7.2% moisture a model is deduced. It describes the decrease in bacterial population over time during storage or transportation at a fixed temperature and water activity.

$$C = \begin{cases} C_0 - 0.977 \cdot d \cdot C_0 & if\ d < 7 \\ 0.317 \cdot C_0 - 0.012 \cdot C_0(d-7) & if\ d \geq 7 \end{cases} \quad (1)$$

Where C is the concentration level (cell/g), d are the days elapsed from the first time the model is applied and C_0 is the initial concentration level (cell/g). If the value of C is below 0, it is assumed to be 0, it means that the inactivation is such to make the unit safe. This model is used to consider the inactivation of Salmonella during the shipment from CEs to the processing plant, and during the storage at the manufacturing level before the roasting batches are created. To study the inactivation that occurs after chocolate bars are packaged before being consumed, data from the study of Tamminga *et al.* [17] are used to create a model similar to the one of cocoa beans. Data of concentration levels of Salmonella Eastbourne in bitter chocolate at 20°C and water activity of about 0.5 is used, leading to:

$$C = \begin{cases} C_0 - 0.1667 \cdot d \cdot C_0 & if\ d < 6 \\ 2 \cdot 10^{-4} \cdot C_0 - 7.6 \cdot 10^{-8} \cdot C_0(d-6) & if\ d \geq 6 \end{cases} \quad (2)$$

During roasting and conching processes Salmonella is inactivated because of the high temperature reached. The concentration after inactivation is calculated according to equation (3), where t is time length of the process (min) and D is the D-value (the time necessary to have a decrease in concentration of 90% at a fixed temperature).

$$C = C_0 - (0.9 \cdot \tfrac{t}{D}) C_0 \quad (3)$$

The roasting process D-value is estimated from a study of Van Asselt and Zwietering [18], the D-value for the conching process is based on the studies of Krapf and Gantenbein-Demarchi [12] and Goepfert and Biggie [8].

The simulation model is designed to simulate two different batch creation strategies of the manufacturer and three different sub-scenarios about re-contamination. In scenario A the manufacturer creates roasting batches with a FIFO logic, as soon as cocoa beans are available. In scenario B the manufacturer waits for different batches of cocoa beans and mixes them to create roasting batches of a constant quality level. In both scenarios re-contamination may happen at the roasting step (scenarios A1/B1), at the mixing step (scenarios A2/B2), or after conching (scenarios A3/B3). Moreover farmer ID and cocoa exporter ID are used to simulate a recall (R1) caused by a chemical contamination during farming. The quantity to recall is calculated in two traceability systems:

- T1 is the current traceability system in which it is just possible to trace back the CE that the product belonged to,
- T2 is an improvement of T1 in which cocoa farmers, when packaging the cocoa beans, mark each bag with a code and date so that it is possible for the manufacturer to trace back each farmer through the cocoa bean bag.

The roasting ID is used to calculate a recall due to a problem at the roasting stage (R2).

4 Results and sensitivity analysis

It is important to underline that, in a real application, a model should be validated with data gathered from the physical system. The validity of main assumptions should be tested, but in this work it cannot be done. The only tool used to evaluate inputs and assumptions is the sensitivity analysis.

The simulation has been run for 226 days. In the simulation the flow of more than 10200 units (500kg/unit) from the farmer to the manufacturer has been studied.

Both in scenario A and B the T2 system allows an accurate recall just of products manufactured with the raw materials coming from the farm with problems. The traceability system T1, instead, entails a bigger recall because of the lack of farmer information. In scenario A the manufacturer applies a FIFO logic to the making of roasting batches, this does not increase the batch dispersion and prevent the mixing of cocoa beans coming from different cocoa exporters. With traceability system T1 13,78% of the production has to be recalled, while with the T2 just 11,88%. Scenario B represents a logic that is often actually used because of the need of using raw materials with the same quality level. Units from different cocoa exporters are mixed to create roasting batches. This increases batch dispersion and with the actual traceability system T1, all products should be recalled in case of contamination of a farm (100% of the total production). With T2 the recall quantity decreases (25,50% of the total production) but it is bigger than in scenario A. If, after analysis of samples, there are doubts about the safety of the roasting process (as it is simulated in scenario A1 and B1), some chocolate bars may be hazardous and need to be recalled from the market. Thanks to the use of the roasting ID only the units produced in the time frame the roasting process was deemed unsafe, are recalled.

Figure 3 shows how the three different scenarios of re-contamination (A1, A2 and A3) affect the concentration of Salmonella in infected end products and how many of them are safe. Scenario A1 is the one that has the highest rate of safe product (about 46,6%), while in scenario A2 about 44% of production is safe. In these two scenarios, the remaining contaminated products have lower values of concentration than in scenario A3.

In scenario A3 contaminated products are 55% of the total production, and most of them (more than 53%) have a final concentration that is more than 100 cells/bar.

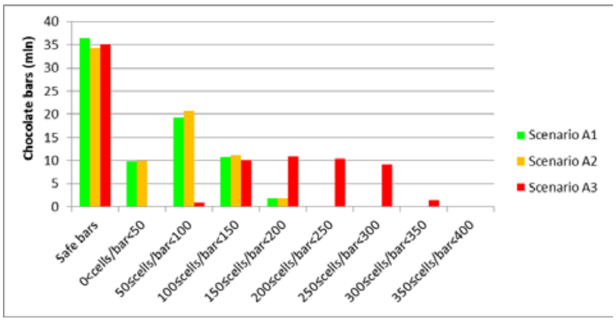

Figure 3: Contamination in three scenarios measured after packaging process

As expected, the way batches are formed does not influence significantly the final concentration of Salmonella in chocolate bars and the number of contaminated units. Figure 4 displays the contamination after packaging and the number of chocolate bars that are safe for each of the scenarios.

The sensitivity analysis is done to have a deeper knowledge of the relationships between inputs and outputs; it is useful to assess the impact that changes in a certain parameter have on the model's conclusions. Moreover it is an effective tool for the model development because errors can been found through it. Each input listed in Table 1 was introduced in each scenario of the model with *n* different values x_i. In each simulation the effects on the average concentration y_i are then evaluated [5].

The analysis revealed that, in each scenario of re-contamination, the primary factor influencing the output is the severity of the re-contamination. The second most influencing input is the percentage of re-contamination. When re-contamination happens after roasting (scenario A1 and B1), an important input is the *D*-value of the conching process. Also the *D*-value of the roasting process has a strong influence on the final result. If re-contamination happens after mixing (scenario A2 and B2), the values are almost similar to the previous case. If re-contamination happens after conching process (scenario A3 and B3), *D*-value of the roasting process has still influence, but less than in previous scenarios. Moreover, the *D*-value of the conching process is completely non-influential.

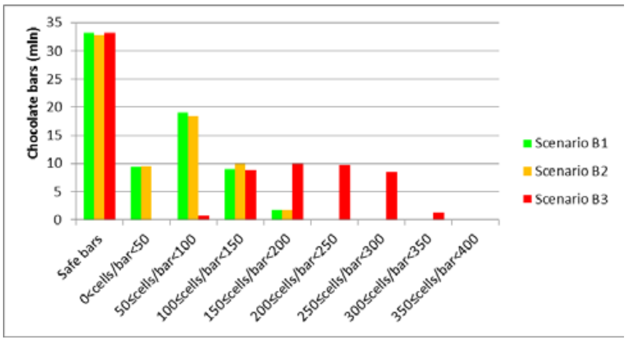

Figure 4: Contamination in three scenarios measured after packaging process

	A1		B1	
Rank	Input	r	Input	r
1	Increase of concentration after roasting	1	Increase of concentration after roasting	1
2	Re-contamination after roasting	0,999	Re-contamination after roasting	0,998
3	D-value conching	0,975	D-value conching	0,977
4	D-value roasting	0,972	D-value roasting	0,96
	A2		**B2**	
Rank	Input	r	Input	r
1	Increase of concentration after mixing	1	Increase of concentration after mixing	1
2	Re-contamination after mixing	0,997	Re-contamination after mixing	0,996
3	D-value roasting	0,981	D-value roasting	0,98
4	D-value conching	0,977	D-value conching	0,977
	A3		**B3**	
Rank	Input	r	Input	r
1	Increase of concentration after conching	1	Increase of concentration after conching	1
2	Re-contamination after conching	0,999	Re-contamination after conching	0,999
3	D-value roasting	0,945	D-value roasting	0,948
4	D-value conching	0	D-value conching	0

Table 1: Sensitivity analysis

5 Conclusion and future developments

In the previous paragraph it has been shown that scenario A and B do not have substantial differences in terms of final contamination of Salmonella. But scenario B enormously increases batch dispersion. This means that two scenarios are indifferent only in case of a Salmonella contamination, or any other contamination that can be overcome through the roasting process. If a chemical contamination happens at a farmer (recall R1), the two scenarios give results that are enormously different. If a traceability system as T1 could be implemented, there would be no need of mixing cocoa beans to form roasting batches. Therefore this improved traceability system would help not only in case of recall but also to use cocoa beans with more awareness. The analysis of scenarios revealed that the roasting process (scenario A1 and B1 show a mistake at this level), as CCP1, is the key of the production safety. Other elements of the plant, as CCP2, are equally crucial and, even if they cannot control the hazard, they can minimize it. In fact the safety of ingredients (scenario A2 and B2 illustrates the lack of it), the hygiene of the environment and the process layout (scenario A3 and B3 simulate them), if managed properly can reduce the hazard. Sensitivity analysis revealed that some assumptions made for the simulation (*D*-values, percentage of re-contamination and level of re-contamination) have big effects on the final result, and should therefore be more precisely defined. Additional research is needed on the biological aspect of the model. In future developments the model could be applied to a specific manufacturing system and its supply chain; so that, after being validated, it could lead to significant results for a plant manager. Moreover the results of the simulation could be further elaborated to have a complete risk assessment that considers also elements such as the consumption of the product and dose-response models, in order to calculate the number of predicted illnesses due to the consumption to contaminated chocolate bars.

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