Support Vector Classifier for Constraints Handling in the Design of Inductors for DC-DC Converters

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Development of an Evaluation and Decision Support Method for Food Safety Management along the Supply Chain

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Food industries need to establish very high quality and safety standards in response to consumer expectations and to face possible critical health consequences. Nowadays, there is a growing demand to extend food safety control to the entire supply chain, with the aim of granting prompt interventions to improve health safety. With this motivation, an evaluation and decision support method for risk management is proposed. Its objective is to extend the control of food safety from the single node of the supply chain of a food product to the entire supply chain, overcoming the concept of mere traceability, obtaining an increase in food safety in the face of more extended and globalized supply chains and more timely and targeted interventions, with consequent less production losses and reduction of waste.
The proposed methodology seeks to include the assessment of entire supply chain (from cradle to gate), through two phases: 1) semi-quantitative risk analysis techniques and 2) efficiency indicators or KPIs related to safety processes. The methodology is validated through the application on a hazelnut-based products industry. The identification of the potential hazards was developed along the entire supply chain, trying to point out the critical factors which favor contamination and to define the KPIs. This process returned the critical points in which prevention and intervention measures will be required, to manage and control contamination risks.
The methodology has demonstrated to be valid for identifying potential hazards and critical points and recognizing the possible factors that constitute a threat along the supply chain. The next step of this work will consist of the installation of sensors in the critical points identified to monitor the KPIs defined; these measurements will make possible further improvements in the methodology and guarantee greater safety for companies and consumers.

Keywords: Food safety management, Food risk, Food supply chain, Decision support method, KPI.

1. Introduction

Food safety is a priority that requires more efforts every day, both for regulatory standards that are becoming much more demanding, and for the imminent growth of situations that pose a threat to people's health. According to EFSA, 2021 in 2019 a total of 5,175 foodborne outbreaks were reported in the European Union, for a total of 329,784 cases of intoxication mainly due to Campylobacteriosis, Salmonellosis, STEC infections, and others; and this without considering that food hazards come not only from microbiological sources but also from physical and chemical sources for which no data or statistics are available. This fact is one of the many reasons why this argument is gaining strength, making necessary to ensure much more reliable and monitored processes, covering the entire supply chain and not just the final product.

Nowadays, the techniques for ensuring food safety mainly concern the ISO 22000 standard, the adoption of prerequisites programs such as GMP, GHP or SSOP and the implementation of HACCP (Hazard Analysis and Critical Control Point). Although the HACCP system is the most adopted in the food industry, it has some weaknesses as explained by Oliveira et al, 2016. In fact, Wallace et al, 2014 describes the difficulties in applying the first principle of HACCP, the risk assessment, which represents one of the fundamental pillars of safety.

In some studies, it has been shown how the application of other risk assessment techniques such as FMEA (Wu & Hsiao, 2021), ETA (Shirani, 2015) and other calculation tools (Tuominen et al, 2003) in addition to HACCP can increase the reliability of processes and consequently, contribute to an improvement in food safety. Indeed, Shirani, 2015 integrates management elements such as KPIs into his methodology and evaluates how the human factor has an impact in safety and management of food risks.

Hence, this work aims to develop a methodology that integrates not only the tools of risk assessment but those related to sustainability and management along the food supply chain, also applying innovative methods for greater speed in decision making process about which corrective and preventive actions to adopt, improving the communication along the different stages of the supply chain of any product.

2. Development of the methodology

The method developed includes the entire supply chain from the first steps of cultivation/breeding of raw materials, the processing industry, distribution and reaching the consumer. Furthermore, it is made up of various phases which are integrated in order to extend the evaluation. Going into the detail of the methodology, there are two main phases that involve the elements that concern the semi-quantitative techniques of risk analysis, the component linked to safety, and the efficiency indicators or KPIs that concern risk management but also sustainability and effectiveness of processes along the entire supply chain. The methodology is illustrated in the diagram of Fig. 1.

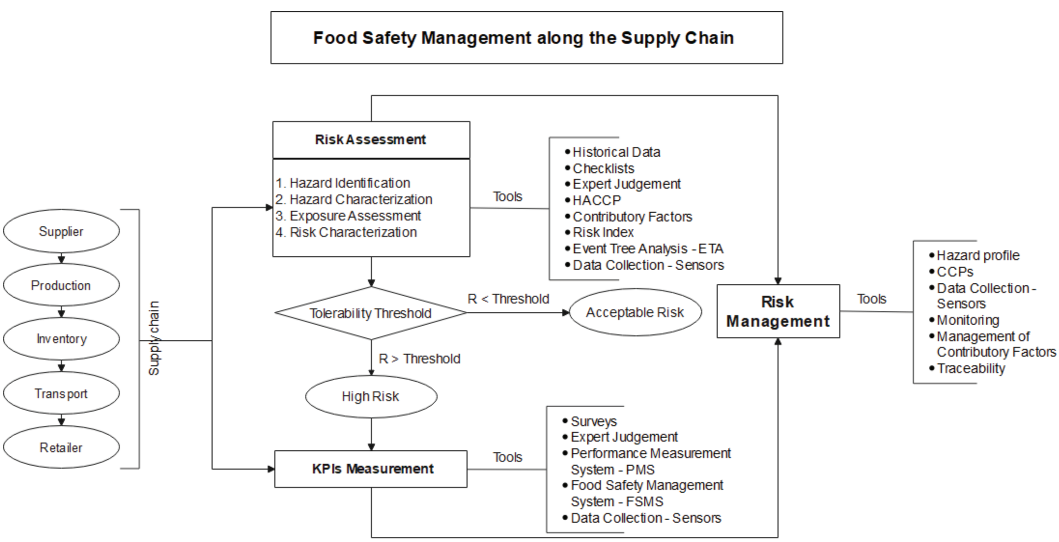

Fig. 1. Evaluation and Decision Support Method for Food Safety Management along the supply chain.

2.1. Supply chain mapping

The starting point of the methodology is represented by the mapping of the entire supply chain of the product. The aim is to identify the different nodes/ subsystems in which the methodology will be implemented. As it is applied there is a series of information that is shared with subsequent nodes maintaining an excellent level of knowledge on what happens in each step, allowing to anticipate possible problems, correcting them quickly and guaranteeing the traceability of the product.

2.2. Risk assessment

In order to have reliable results, various tools are used which, if integrated, allow to obtain a more complete risk assessment. To identify the hazards, a matrix of potential hazards is created where the factors that contribute to product contamination are considered, and which may vary depending on the reference supply chain. To do this, data from the literature (WHO, 2008), historical data on foodborne outbreak published in the EFSA reports (EFSA, 2021), information from the HACCP of the case study and the opinion of experts on safety were considered, validating what is established in the matrix.

The various contributing factors are classified with an index representing the power with which they affect in the potential contamination of hazards, Table 1 (WHO, 2008).

Table 1. Contributing factor classification.

Contributing Factor	Symbol	Index
Principal contributory factor	■	4
Contributory factor	▲	3
Potential	●	2
Likely destroyed in future processes	–	1

The contributing factors are evaluated in each node of the supply chain and by applying the cumulative indexes listed in Table 2 (FAO & WHO, 2009), the probability of contamination for each potential hazard is determined.

Table 2. Cumulative index for probability.

Cumulative Index	Probability
≤ 4	1 x 10^{-4}
5 – 8	5 x 10^{-4}
9 – 12	5 x 10^{-4}
13 – 16	5 x 10^{-2}
≥ 17	1 x10^{-1}

Having the probabilities of the individual hazards for single nodes of the supply chain, the follow step is the construction of the Event trees ETA as in Fig. 2, in order to estimate the probability for the overall supply chain. For quantifying the ETA, the control measures already implemented in the industry are considered. Then, using the range probabilities listed in Table 3, the probability index is obtained.

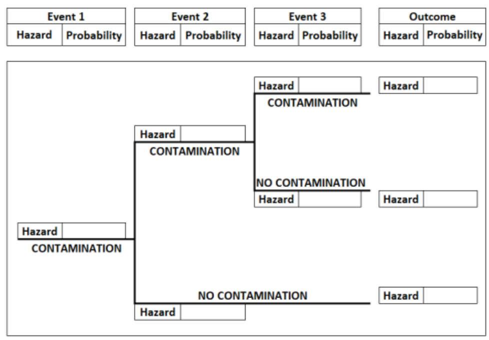

Fig. 2. Event tree sequence.

Table 3. Probability index.

Probability Index	Range Probability
1	< 10^{-4}
2	10^{-3} – 10^{-4}
3	10^{-2} – 10^{-3}
4	10^{-1} – 10^{-2}
5	> 10^{-1}

Afterward, the severity index for the consequence is assigned for each hazard contamination, considering the values listed in Table 4 (FAO & WHO, 2009).

Table 4. Severity index for consequence.

Severity Index	Category	Consequence description
0	None	No effect
1	Very low	Feel ill for few days
2	Low	Diarrhoeal illness
3	Medium	Hospitalization
4	High	Chronic sequelae

Finally, from the combination of probability and severity by using the risk analysis matrix in Fig. 3, the risk assessment is made to determine the tolerability of risk.

Likelihood (Probability Index)	**Severity index of consequences**			
	1 Very low	**2** Low	**3** Medium	**4** High
1 Rare	1 Low	2 Low	3 Low	4 Low
2 Unlikely	2 Low	4 Low	6 Moderate	8 Moderate
3 Possible	3 Low	6 Moderate	9 Moderate	12 High
4 Likely	4 Low	8 Moderate	12 High	16 High
5 Almost certain	5 Moderate	10 High	15 High	20 High

Fig. 3. Risk analysis matrix.

2.3. KPIs identification and measurement

The characterization of the risk allows to identify the nodes that present the greatest criticality and consequently, to define the proper KPIs to monitor and control those factors that directly contribute to the contamination of the product.

First, the most relevant risks and the node in which they have the major probability are identified; then, from the matrix hazard applied in the relative node it is possible to determine the contributing factors and its potentiality, as well as deduce the properties that could be measured through the installation of sensors or innovative systems, as expected in a future work.

3. Results and discussions

The methodology developed was applied to the case study of the hazelnut industry for Hazelnuts praline whose supply chain is described in Fig. 4. Every node in the supply chain, represent a set of industrial processes and not just a single activity, reason why the situations likely to contribute the contamination considered in the risk assessment seems wide but enforceable for each of them.

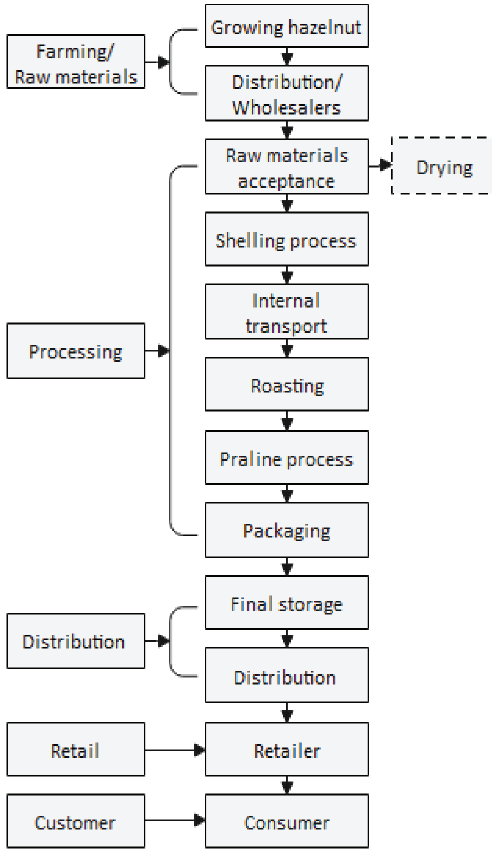

Fig. 4. Supply chain for hazelnuts praline.

Fig. 5 shows the hazard matrix constructed for the method and customized for hazelnut supply chain. The hazard matrix provides the basis for identifying the hazards and probabilities of contamination for a single node.

From the application of hazard matrix in all nodes the probabilities of contamination for single hazards are obtained. The correspondent values for some relevant hazards, are shown in Table 5.

This information gives a first approximation about the potential critical hazards present in each node, which is valuable because could allow to act immediately for reducing individual probabilities in single nodes.

HAZARD MATRIX AND CONTRIBUTING FACTORS ALONG THE SUPPLY CHAIN										
SC	**Situations likely to contribute to product contamination**	**Mycotoxin**	**Salmonella**	**Bacteria/ Molds**	**Insects**	**Pesticides**	**Chemical substances**	**Allergens**	**Acrylamide**	**Foreign bodies**
Raw product Pre-processing	Organic manure		▲	●						
	Soil	●	●	●	▲		●			■
	Irrigation water		●	●			●			
	Rain water	■		●	▲					
	Air			●	●		●			
	Nearby crops				●	●	●	●		
	Treatments					●	●			
Processing/preparation Food processing plant	Impromer moisture adjustment (drying)	■	▲	●						
	Contamination by worker		●	●						●
	Cleaning of equipment		▲	●				●		●
	Heat processes								■	
	Manipulation during process		▲	●						●
	Room-temperature holding	■		●						
	Prolonged storage	▲		●	●					
	Contamination from other ingredients	●						●		●
	Equipment failure						●			●
	Cleaning of environment		●	●	▲					
	Contamination by packaging									●
	Means of transport			●	●					●
Post-processing	Prolonged storage	●	●	●	●		●	●	●	●
	Contamination by worker	●	●	●	●		●	●	●	●
	Contamination by other vectors	●	●	●	●		●	●	●	●
	Cleaning of environment	●	●	●	●		●	●	●	●
	Contamination by packaging	●	●	●	●		●	●	●	●
	Means of transport	●	●	●	●		●	●	●	●

Fig. 5. Hazard Matrix for hazelnut supply chain.

Table 5. Results of probability for single nodes.

Node	Mycotoxin	Salmonella	Bacteria/ Molds	Insects	Chemical substances	Allergens	Foreign bodies
Growing hazelnut	0,0005	0,0005	0,005	0,005	0,005	0,0001	0,0001
Distribution/ Wholesaler	0,0005	0,0005	0,005	0,0005	0	0	0,0005
Raw materials acceptance	0,05	0,005	0,05	0,0005	0,0001	0,0001	0,005
Shelling process	0,0005	0,005	0,005	0,0005	0	0,0001	0,005
Internal transport	0,0001	0,0005	0,0005	0,0005	0	0,0001	0,0005
Roasting	0,0005	0,005	0,005	0,0005	0	0,0001	0,005
Praline process	0,0001	0,0005	0,0001	0	0,0001	0,0001	0,0005
Packaging	0	0,0005	0,0005	0	0	0,0001	0,005
Final storage	0,0001	0	0,0001	0,0001	0	0	0,0001

For the construction of Event tree, the first three stages of the supply chain: 1) Farming/Raw materials, 2) Processing and 3) Distribution are considered. An individual ETA is realized for each stage or phase to make adaptable and replicable the method to other hazelnut products that could involve different processes not considered for hazelnuts praline. The stages 4) retail and 5) Customer are excluded to the analysis of ETA and will be a development of future work.

Considering the stages 1) Farming/Raw materials and 2) Processing, the partial Event tree obtained is shown in Fig. 6. Likewise, the Event tree for stage 3) Distribution, and for the overall processes is made, and by its quantifying the results for overall probability are obtained (see Table 6). These results revealed that there is a high probability to have contamination by mycotoxins in hazelnuts praline; actually, in the literature mycotoxins are the major concern in tree nuts-based products.

Event 1: Farming/Raw materials – CONTAMINATION

	Hazard	Probability
1	Mycotoxin	0,0171
2	Salmonella	0
3	Bacteria/ Molds	0
4	Insects	0,04425
5	Pesticides	0,0032
6	Chemical substances	0,0016
7	Allergens	0,00086
8	Acrylamide	0,0004
9	Foreign bodies	0,028922

Event 2: Processing – CONTAMINATION → Outcome: Contamination

	Event 2 Hazard	Probability	Outcome Hazard	Probability
1	Mycotoxin	0,0171	Mycotoxin	0,0171
2	Salmonella	0,0005	Salmonella	0,0005
3	Bacteria/ Molds	0,0001	Bacteria/ Molds	0,0001
4	Insects	0,022125	Insects	0,022125
5	Pesticides	0,0032	Pesticides	0,0032
6	Chemical substances	0,0016	Chemical substances	0,0016
7	Allergens	0,00086	Allergens	0,00086
8	Acrylamide	0,0004	Acrylamide	0,0004
9	Foreign bodies	0	Foreign bodies	0

Event 2: Processing – NO CONTAMINATION → Outcome: Contamination

	Event 2 Hazard	Probability	Outcome Hazard	Probability
1	Mycotoxin	0,0171	Mycotoxin	0,0171
2	Salmonella	0	Salmonella	0
3	Bacteria/ Molds	0	Bacteria/ Molds	0
4	Insects	0,022125	Insects	0,022125
5	Pesticides	0,0032	Pesticides	0,0032
6	Chemical substances	0,0016	Chemical substances	0,0016
7	Allergens	0,00086	Allergens	0,00086
8	Acrylamide	0,0004	Acrylamide	0,0004
9	Foreign bodies	0	Foreign bodies	0

Event 1: Farming/Raw materials – NO CONTAMINATION

	Hazard	Probability
1	Mycotoxin	0
2	Salmonella	0
3	Bacteria/ Molds	0
4	Insects	0
5	Pesticides	0
6	Chemical substances	0
7	Allergens	0
8	Acrylamide	0
9	Foreign bodies	0

Event 2: Processing – CONTAMINATION → Outcome: Contamination

	Event 2 Hazard	Probability	Outcome Hazard	Probability
1	Mycotoxin	0,0001	Mycotoxin	0,0001
2	Salmonella	0,0005	Salmonella	0,0005
3	Bacteria/ Molds	0,0001	Bacteria/ Molds	0,0001
4	Insects	0	Insects	0
5	Pesticides	0	Pesticides	0
6	Chemical substances	0,0001	Chemical substances	0,0001
7	Allergens	0,0001	Allergens	0,0001
8	Acrylamide	0	Acrylamide	0
9	Foreign bodies	0	Foreign bodies	0

Event 2: Processing – NO CONTAMINATION → Outcome: NO CONTAMINATION

	Event 2 Hazard	Probability	Outcome Hazard
1	Mycotoxin	0	Mycotoxin
2	Salmonella	0	Salmonella
3	Bacteria/ Molds	0	Bacteria/ Molds
4	Insects	0	Insects
5	Pesticides	0	Pesticides
6	Chemical substances	0	Chemical substances
7	Allergens	0	Allergens
8	Acrylamide	0	Acrylamide
9	Foreign bodies	0	Foreign bodies

Fig. 6. Event Tree for stages 1) and 2) of hazelnut praline supply chain.

Table 6. Results of overall probability of hazard contamination.

Hazard	Probability	Probability Index
Mycotoxin	0,1374	5
Salmonella	0,005	3
Bacteria/ Molds	0,0025	3
Insects	0,04435	4
Pesticides	0,0256	4
Chemical substances	0,0132	4
Allergens	0,00748	3
Acrylamide	0,0032	3
Foreign bodies	0,0004	2

In addition, as explained before, the risk assessment is performed, and the results are listed in Table 7. Based on these results is possible to identify the potential hazards for hazelnut praline, being the most critical the contamination with mycotoxins, reiterating the concern about its presence in tree nuts-based products. In addition, risk assessment shows a moderate risk to have a contamination with *Salmonella*, bacteria or molds, and foreign bodies for which it is worth to supervise the actual conditions that lead to have it and implement measures to control and reduce it to improve safety conditions.

Table 7. Results of Risk assessment.

Hazard	Severity Index	Risk Assessment	
Mycotoxin	3	15	High
Salmonella	3	9	Moderate
Bacteria/ Molds	3	9	Moderate
Insects	2	8	Moderate
Pesticides	1	4	Low
Chemical substances	1	4	Low
Allergens	1	3	Low
Acrylamide	1	3	Low
Foreign bodies	4	8	Moderate

In the same way, the risk assessment allow to identify that the critical nodes presenting the major hazards in hazelnut industry are "Raw materials acceptance" and "Shelling process" for which the relevant KPIs are presented in Table 8, and that will be monitored through the measurements of relevant properties as storage condition (temperature, moisture), cleaning conditions and presence of insects using innovative sensors capable to detect environmental disturbances, and certainly, monitoring the proper functioning of equipment in every process.

Table 8. Safety KPI identified.

Hazard	KPIs
Mycotoxin	Moisture adjustment
	Temperature holding
	Prolonged storage
Salmonella	Cleaning of environment/equipment
	Manipulation
Bacteria/ Molds	Moisture adjustment
	Prolonged storage
	Cleaning of environment
Insects	Growing conditions
	Cleaning of environment
Foreign bodies	Equipment failure
	Cleaning of environment

As a future work is expected to proceed with the installation of instrumental devices onsite for real time measures that will make possible, first to monitor and control the hazards, and secondary, to realize improvements in the methodology to increase the reliability, adaptability and guarantee greater safety.

4. Conclusions

The methodology developed in this work for the analysis of food safety risk, integrates the basis of risk assessment with the use of KPIs along the entire food supply chain, bringing an advantage over already existent methods that cover single processes and allowing to support immediate decisions to implement corrective actions that permit to improve the safe conditions promptly.

The results obtained in the application of the method evidence its suitability in the identification of potential hazards for target industry, since the most relevant or critical ones are in line with the common hazards specified in the supply chain evaluated.

In particular, for hazelnut supply chain, the results demonstrate that “Raw materials acceptance” and “Shelling process” are the most critical nodes in which prevention and intervention measures will be required to guarantee safety management. In these nodes, the relevant KPIs identified are mostly related to the conditions of processing and environment.

The next step of the project will consist in the construction of a data collection network capable of transmitting information in real time through the installation of instrumental devices onsite, located where major criticalities were found. The measurements will bring several advantages both for further improvements in the methodology and guarantee greater safety in food products.

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