IMPROVING FOOD PRODUCT QUALITY AND SAFETY BY APPLICATION OF THE FAILURE MODES AND EFFECTS ANALYSIS METHODOLOGY (FOR CHEESE MANUFACTURING)

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Abstract

Failure Modes and Effects Analysis (FMEA) it is a predictive and preventive methodology specific to non-compliance and risk management. The aim of this study was the application of the FMEA to improve scalding cheese quality. Among the steps and activities required to apply the FMEA methodology is distinguished as specificity the calculation Action Priority (AP) depending on the severity (S) of consequences of manifestation of nonconformities to the consumer, on the probability of occurrence (O) of a potential hazard for food safety and on the probability of its detection (D). The AP was determined for each category of identified potential hazards: physical (P), chemical (C) and biological (B) for all ingredients and for all stages of the technological flow for cheese manufacturing. The highest value of AP (360) was observed for non-compliant pasteurization of milk, for B hazards. Through AP, a quantitative assessment can be made of the potential food safety problems in a system, and respectively a prioritization of implementation of preventive actions; the results are clearly the improving of quality and safety of cheese, based on lowering of potential nonconformities.

Key words: food technology, failure modes and effects analysis, cheese quality

The Failure Modes and Effects Analysis (FMEA) is a modern tool used in the purpose of identifying potential failure modes, the causes and effects of each nonconformity for keeping under control the technological processes and to improve the quality of finished products. The aim of this study was the application of the FMEA methodology to improve scalding cheese quality.

For a correct application of the FMEA methodology, the technological process must be very well known, being described in the documentation of the food quality and safety management system. Normalized and pasteurized milk is coagulated with selected cultures (*Streptococcus lactis*, *Streptococcus thermophilus* and *Lactobacillus casei*) for 30-45 minutes at a temperature of 32-35°C. Processing the coagulum involves cutting and mixing it for 10-15 minutes until pea-sized grains are obtained, followed by vigorous mixing for 5-10 minutes with the mixer. In this way, a good dehydration of the coagulum mass is obtained, a process that is continued by the second heating to 38-40 °C, during which the mass is subjected to continuous mixing. After the second heating, the curd grains are collected and pressed on the bottom of the valve, after which they are placed in a draining seat, with shredding to favor the elimination of the whey. The curd is pressed until a humidity of 46-48% is achieved, then left in rooms at a temperature of 22-24°C for fermentation, until a pH of 4.8-5.0 is obtained, considered the optimal value for scalding. The operation specific to the manufacture of cheese is scalding, and it provides the cheese with those plastic properties such as consistency and elasticity, with minimal loss of dry matter or fat. For this, the curd is cut into slices or small pieces and mixed with hot water at a temperature of 70-75°C (it can even reach 85°C), for 1-2 minutes with continuous mixing of the curd mass with spatulas, thus that the curd becomes a soft and elastic paste and has a final temperature of around 55°C. To remove the water, the scalded curd is kneaded by hand, stretched several times and overlapped in layers, with the dry salting of the scalded curd strips. Salting can also be done during scalding of the curd, adding a brine with a concentration of 8-12%. The warm paste is placed in cylindrical or parallelepiped forms of different sizes, it is left for 24 hours with periodic turning of the forms, after which they are removed from the forms and placed on shelves in airy rooms. The ripening process (three months) takes place in spaces with a temperature of 16-20°C and a

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humidity of 85%. After the end of ripening, the cheese forms are washed, ventilated and packaged, being stored in cold spaces at temperatures of 4-8°C and humidity of 85-90%.

MATERIAL AND METHOD

The activities required to apply the FMEA method (AIAG & VDA Handbook, 2019) in cheese manufacturing have been phased, realizing the setting of the technological flow stage, identification, for each step in the flow, of potential nonconformities/hazards (physical, chemical and biological), identifying the causes that led to the emergence of dangers, determining the probability of occurrence of each hazard category (O), determining the severity (seriousness) of the occurrence of the hazard to the consumer (S), establishing the probability of detection of hazards (D), calculating the RPN, evaluating AP, setting critical control points (CCPs) and establishing the HACCP plan.

RPN=A x S x O (*value from 1 to 10*)

AP= S to A to O (*fom standard table with value from 1 to 10)*

At the same time, after establishing the AP, CA were identified for each category of hazards specific to the different stages of the flowchart of cheese.

RESULTS AND DISCUSSIONS

Technological steps specific to scalding cheese are schematically presented (*figure 1)*, through a flowchart diagram, which uses standardized international symbols. The application of FMEA specific for flowchart of scalding cheese lead to improvement of quality, especially after corrective action (*table 1*).

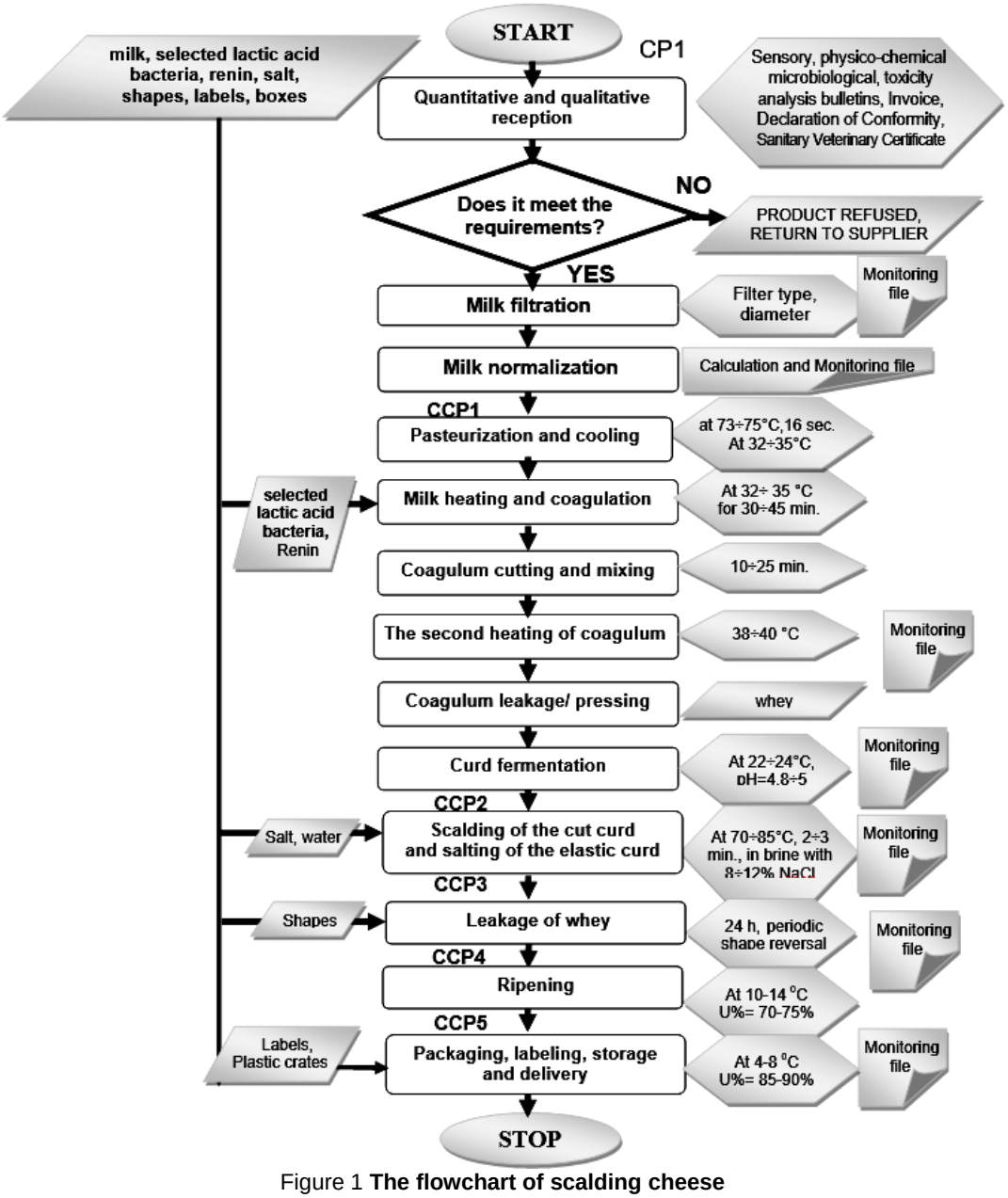

Figure 1 **The flowchart of scalding cheese**

Table 1.

Failure modes and effects analysis (FMEA) specific for flowchart of scalding cheese

Flow stages		Noncompliance/Hazard		Causes	S	O	D	RPN	AP	Corrective Actions (CA)	S	O	D	*RPN	AP
1.	Quantitative and qualitative raw material reception	P	Foreign bodies: hair, insects	Untrained personal, bad handling. Unselected supplier	4	6	5	120	M	Provider evaluation Batch rejection. Personal training	4	2	1	8	L
		C	Antibiotics, mycotoxins, pesticide residues, heavy metals (Pb, Cu, Hg, Zn), detergents.	Unselected supplier. Personal negligence	8	5	3	120	M	Provider evaluation. Documents control from supplier. Batch rejection.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella sp., Staphylococcus aureus, Listeria monocitogenes*	Unsanitary manipulation. Unselected supplier. Inadequate temperature and transport conditions.	9	7	4	252	H	Provider evaluation. Batch rejection Personal training. Checking analysis bulletins, sanitary veterinary certificates. Checking transport conditions and thermograms. The temperature of raw materials control and recording.	9	2	1	18	L
2	Milk filtration	P	Foreign bodies: hair, insects, personal objects, etc.	Improper handling. Unselected supplier. Untrained personal	5	5	5	125	L	Personal training. Respecting hygiene procedures / preliminary programs (PRP)	5	2	1	10	L
		C	Traces of detergents, disinfectants	Improper rinsing of machinery/equipment	8	5	4	160	M	Personal training. Respecting hygiene procedures.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unhygienic handling. Inappropriate temperature and conditions of filtration	9	5	4	180	H	Personal training. Enhance raw material temperature control, monitoring, recording Pest Control, Disinsection, Disinfection (DDD)	9	3	2	54	L
3.	Milk normalization	P	Hair, insects, personal objects, etc.	Improper handling. Personal negligence	5	5	5	125	L	Personal training. Compliance with procedures, PRP, metrological verification plan	5	2	1	10	L
		C	Traces of detergents, disinfectants	Improper rinsing of machinery and equipment.	8	4	3	96	M	Personal training. Respecting hygiene procedures	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unhygienic handling. Inappropriate temperature and conditions of processing	9	6	3	162	H	Checking staff hygiene, machinery, utensils, equipment, work environment by performing sanitation tests	9	2	2	36	L
4.	Pasteurization and cooling	P	Hair, insects, stale coagulum etc.	Improper cleaning. Untrained staff	5	5	2	50	L	Personal training. Hygiene procedures implementation	5	2	1	10	L
		C	Traces of detergents, disinfectants	Unselected supplier. Personal negligence - faulty rinsing (machines, utensils, equipment)	8	4	3	96	M	Personal training. Hygiene procedures implementation	8	2	2	32	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Contaminated pasteurizer Unsanitary pasteurization Inadequate temperature and environmental conditions	9	8	5	360	H	Checking the staff, machinery, utensils, equipment, work environment hygiene performing sanitation tests. Ventilation control. Keeping maintenance plan.	9	2	1	18	L
5.	Milk heating and coagulation	P	Hair , insects, personal objects, etc.	Improper handling. Untrained staff	5	4	2	40	L	Personal training	5	2	1	10	L
		C	Inadequate dosage of selected lactic acid bacteria and Renin. Traces of detergents, disinfectants	Non-compliance of the equipment used. Faulty rinsing (machines, utensils, equipment). Untrained and neglectful personal	8	3	2	48	L	Personal training. Respecting hygiene procedures and maintenance plan.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Neglectful personal Inadequate temperature and environmental conditions	9	5	3	135	H	Personal training. Checking the staff, machinery, utensils, equipment, work environment state of hygiene by performing sanitation tests.	9	2	1	18	L
6.	Coagulum cutting and mixing	P	Metallic fragments, hair, insects, personal objects etc.	Lack of maintenance plan Noncompliance manipulation. Untrained and neglectful personal.	5	3	2	30	L	Checking and application of maintenance plan. Personal training. Respecting hygiene procedures. Use of PRP.	5	2	1	10	L
		C	Traces of detergents, disinfectants	Untrained personal. Improper rinsing of equipment	8	3	2	48	L	Personal training. Use of PRP. Use of product standard and recipes.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Defective hygiene conditions. Untrained and neglectful personal	9	7	3	189	H	Performing periodic sanitation tests. Personal training	9	2	1	18	L
7.	The second	P	Hair, insects, personal objects.	Noncompliance manipulation Untrained	5	2	2	20	L	Personal training. Use of PRP	5	2	1	10	L

Flow stages		Noncompliance/Hazard		Causes	S	O	D	RPN	AP	Corrective Actions (CA)	S	O	D	*RPN	AP
	heating of coagulum			personal. Personal negligence.											
		C	Traces of detergents, disinfectants	Improper rinsing of machinery and equipment.	8	2	1	16	L	Personal training. Use of PRP	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Inadequate temperature and environmental conditions	9	4	3	108	H	Checking the staff, machinery, utensils, equipment, work environment state of hygiene by performing sanitation tests. Personal training	9	2	1	18	L
8.	Coagulum leakage/ pressing	P	Foreign bodies, hair, insects.	Improper handling. Uninstructed staff. Personal negligence	5	5	4	100	L	Personal training. Use of PRP	5	2	1	10	L
		C	Traces of detergents, disinfectants.	Personal negligence. Improper rinsing of equipment	8	4	3	96	M	Personal training. Use of PRP	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Inadequate temperature and environmental conditions	9	8	4	288	H	Monitoring of leakage specific parameters. Performing sanitation tests. Personal training	9	2	1	18	L
9.	Curd fermentation	P	Foreign bodies, pests.	Improper handling. Uninstructed staff. Personal negligence. Noncompliance of DDD plan	5	2	1	10	L	Personal training. Maintaining and compliance of the DDD plan	5	1	1	5	L
		C	Traces of detergents, disinfectants.	Faulty rinsing machines, equipment.	8	3	1	24	L	Personal training. Use of PRP	8	1	1	8	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Inappropriate hygiene of storage areas. Personal negligence	9	5	2	90	H	Personal training. Performing sanitation tests.	9	1	1	9	L
10.	Scalding of the cut curd and salting of the elastic curd	P	Foreign bodies, hair, insects, personal objects, etc.	Noncompliance manipulation. Untrained personal. Personal negligence	5	3	2	30	L	Personal training. Respecting hygiene procedures/ PRP.	5	2	1	10	L
		C	Inadequate dosage of salt. Traces of detergents, disinfectants	Untrained personal. Improper rinsing of machinery and equipment	8	3	2	48	L	Personal training. Use of PRP. Use of product standard.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Inadequate temperature and environmental conditions	9	7	3	189	H	Performing periodic sanitation tests. Personal training	9	2	1	18	L
11.	Leakage of whey	P	Foreign bodies, hair, insects, personal objects, metallic fragments etc.	Noncompliance manipulation Untrained personal. Personal negligence. Lack of maintenance plan	5	2	2	20	L	Personal training. Checking and application of maintenance plan	5	2	1	10	L
		C	Traces of detergents, disinfectants	Improper rinsing of machinery and equipment.	8	2	1	16	L	Personal training. Use of PRP	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Unsanitary manipulation. Inadequate temperature/ environmental conditions	9	5	5	225	H	Checking staff, machinery, utensils, equipment, work environment state of hygiene by performing sanitation tests. Personal training	9	2	1	18	L
12	Ripening	P	Foreign bodies: hair, insects.	Improper handling. Uninstructed staff. Personal negligence	5	5	6	150	L	Personal training. Use of sanitation PRP. Maintaining and compliance of the DDD plan	5	2	1	10	L
		C	Traces of detergents, disinfectants, mycotoxins	Personal negligence. Nonconformity of ripening cells	9	3	3	81	L	Personal training. Use of sanitation PRP.	8	2	1	16	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*, development of moulds	Unsanitary manipulation. Inadequate temperature and environmental conditions for ripening	9	8	4	288	H	Monitoring of ripening specific parameters. Sanitation of ripening cells. Performing sanitation tests. Personal training	9	2	1	18	L
13	Packaging, labelling, storage and delivery	P	Foreign bodies, pests.	Improper handling. Personal negligence. Noncompliance of DDD plan	5	2	1	10	L	Personal training. Maintaining and compliance of the DDD plan	5	1	1	5	L
		C	Traces of detergents, disinfectants Contamination with chemicals substances from packages.	Faulty rinsing machines, equipment. Use of unauthorized food packages. Migration of chemicals from the packaging in products	8	3	1	24	L	Personal training. Use of PRP	8	1	1	8	L
		B	Pathogenic microorganisms: *Escherichia coli, Salmonella, Staphylococcus aureus*	Inappropriate hygiene of packaging and storage areas. Personal negligence	9	2	2	36	L	Personal training. Performing sanitation tests.	9	1	1	9	L

* RPN after corrective action; L – low priority action; M –medium priority action; H – highest priority action.

For the technological flowchart of scalding cheese was identified the three categories of potential hazards (physical/P, chemical/C and biological/ B), as well as the causes of their occurrence. The new process FMEA uses specific colors for warning the team depending on the AP ranking: „must/ red", „should/ yellow", „could/ green".

There are high differences compared to the old FMEA methodology which based on the RPN value automatically applies corrective actions (at values higher than 100 resulting in serious quality problems). At present, after the application of the new methodology based on AP, the identified potential nonconformities can be classified in L category even if the RPN value is higher than 100 (for examples for *Ripening* step, at P hazards /foreign bodies, the RPN value is 150).

On the other hand, the AP can be in H category (at lower value than previously 100 of the RPN, for step of *Curd fermentation*, for *Pathogenic microorganisms*/ B hazard, RPN is 90).

However, the value of S is the decisive element for classification of potential hazards and nonconformities.

The highest value of AP/ RPN (360) was observed for B hazards, for non-compliant *Pasteurization of milk* (the established CCP1) and respectively 288 for the *Coagulum pressing* and the *Leakage of whey* steps(CCP3).

In this study, for the technological flowchart of scalding cheese, after applying the FMEA methodology was observed at the level of B hazard that the majority of AP was from H category. The FMEA team "Needs" to identify the appropriate action to improve the prevention or detection controls. The CA application led, in all cases, to considerable diminution of AP (from H and M prioritize to L).

The results obtained have led to the formulation of some recommendations for improving and expanding the FMEA application within food safety management systems.

The possibility of diminishing the risks signalled by the FMEA methodology, through preventive and corrective interventions, was reported in other similar studies conducted for food safety specific to the different categories of food products (for a food safety management system for dry meat product, for ultra-filtrated milk cheese, for malting process, for chocolate production, strudel and potato chips, salmon and octopus, ready to eat vegetables, red pepper, Turkish delight, diary production, bread, meat products) further demonstrates the utility application of FMEA (Pop C., *et al*, 2019; Aleksic B., *et al*, 2021; Shahidy, S. A., *et al* 2021; Arvanitoyannis S.I. and Savelides S.C., 2007; Arvanitoyannis S.I. and Varzakas T.H., 2007a/b; Arvanitoyannis S.I. and Varzakas T.H., 2008a/b; Varzakas T.H. and Arvanitoyannis S.I., 2008; Ozilgen S. *et al*; 2013, Ozilgen S., 2012; Shirani M. and Demichela M., 2015; Wang X. and Lu Q., 2015).

FMEA has been widely used in high-risk industries to evaluate and mitigate process weaknesses. FMEA has been effectively applied to examine and mitigate risks and failure modes in many healthcare processes (for healthcare risk analysis (Liu H. C., 2019; Vazquez-Valencia A., *et al*, 2018; Sharma K.D. and Srivastava S., 2018; Niv Y., *et al*, 2018; Huang J., *et al*, 2020; Moradi L., *et al*, 2020; Ullah E., *et al*, 2022).

CONCLUSIONS

In general, the highest AP /potential hazards gravity and RPN value was observed for B hazards. Through AP, a quantitative assessment can be made of the potential food safety problems in a system, and respectively a prioritization of implementation of preventive actions; the results are clearly the improving of quality and safety of scalding cheese, based on lowering of potential nonconformities frequency.

After CA, AP was visible lowered for all stages of flowchart. The personal training, the most frequent CA (the active factor that influence the quality of food products being the human resources/ the workers who are directly involved in each stage of the technological process), health status control, strict personal hygiene, strict hygiene of personal equipment's, machine, work equipment's, work surfaces, periodically sanitation tests are the principal CA that lower the potential hazards occurrence, and respectively the AP value.

This instruments are effective and very closed for the top management of any organization, being in accordance with international law and standards; if they are applied correct, the quality of the products will be sure improved.

This research provides a useful insight for dairy sector managers, veterinarians and food technologists; also can serve as a guide in the scalding cheese production chain to increasing competitive advantage. The results can be applied worldwide taking into account the common characteristics of the scalding cheese (one of the most consumed types of cheese), which would contribute to public health and food safety improvement.

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