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Brief paper

Application of FMEA analysis in the short cheese supply chain

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A b s t r a c t: The aim of this study was to apply Failure Mode and Effect Analysis (FMEA) methodology to determine the biological, chemical and physical failures that could occur during the farmhouse production of white brined cheese (short cheese supply chain) in Serbia. For that purpose, the values for occurrence (O), severity (S) and detection (D) of failures were determined. These estimated values were used to calculate risk priority number (RPN), for each potential failure. Very high RPNs were determined for biological failures in this short cheese supply chain. The highest RPNs were determined for the milking step, followed by the cheese ripening step and the transport of cheese by personal vehicle. The main chemical risks associated with raw milk were the presence of aflatoxins and antibiotic residues. Our results indicate the greatest risks in the short cheese supply chain can be attributed to biological and chemical failures, due to any failures being unlikely to be detected by cheese producers and having severe consequences. The proposed corrective measures include different pre-requisite programs. Even the application of these measures will not result in great risk reduction, as the severity and detection will remain the same. The lowest RPNs were obtained for physical failures, as they are visible and, therefore, easier to detect.

Keywords: *short cheese supply chain, farmhouse cheese production, FMEA analysis, risk.*

Introduction

Cheese is a fresh product or a product of different stages of maturity, which is obtained by separating whey after coagulation of milk (cow, sheep, goat, buffalo and/or their mixtures), cream, whey, or a combination of these raw materials or by using other technological solutions to achieve milk coagulation. Cheese can also be seen as a way to conserve raw milk, because the technological process of cheese production usually results in a reduction of pathogenic microorganisms **(***Serbia*, 2010a; *Zhao*, 2013**).**

According to the data published by the Serbian Bureau of Statistics, a total of 1,475,000,000 L of cow and sheep milk were produced in Serbia in 2018 (*Serbia*, 2019). Data published by authors from the Faculty of Agriculture in Novi Sad (*Vlahović et al.*, 2018) revealed that 54% of the total amount of raw milk produced was delivered to dairies, while about 18.6% was processed into cheese. Cheese production can be performed in households, i.e., small artisan processing, or in industrial conditions in which large quantities of milk are processed daily. In this paper, we use the term farmhouse cheese to denote a product produced according to traditional methods by cheese producers in households from milk derived from their own cows. This type of production, which implies a direct link between producers and consumers, is known as a short food supply chain (*Malak-Rawlikowska et al.*, 2019) and was considered in our study. In our case, this chain is further referred to as the "short cheese supply chain", since in Serbia, almost 15% of total cheese produced is made in households and is sold at green markets. Contrary to this, long food supply chains are very complex, with observed changes of food quality and safety throughout the entire supply chain, until food is finally consumed (*Yu et al.*, *2013*).

Each year, according to the World Health Organization (*WHO*, 2019), about 600 million people become ill with food-borne and water-borne

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diseases, resulting in about 420,000 deaths. More than 320,000 food-borne illnesses are registered in the EU each year. According to data from 2018, a total of 5,146 food- and water-borne outbreaks were registered caused by zoonotic agents, among which campylobacteriosis was the most common food-borne disease in the EU, followed by salmonellosis, from which most of the cases were caused by eggs and egg products, 2.2% cases were caused by cheeses, Shiga-toxin producing *E. coli*-induced diseases and yersiniosis (*EFSA*, 2019). It was also determined that 2,549 cases of listeriosis were detected in in the EU, of which 15.6% ended fatally, which is why listeriosis is considered to be one of the most severe food-borne diseases (*EFSA*, 2019). According to data reported by the Public Health Institute of Serbia, the most commonly diagnosed food-borne diseases in Serbia were salmonellosis, campylobacteriosis, stomach flu (norovirus) and staphylococcal poisoning (*Serbia*, 2018). There are no published and available data of food-borne diseases caused by farmhouse cheeses sold at the green markets in the Serbia.

The term "hazard" means a biological, chemical or physical agent or a food condition that has a potential to cause an adverse health effect, while the term "risk" is the likelihood the hazard will occur, as well as the seriousness of any possible health consequences. Food-related hazards can be divided into three main groups, microbiological, chemical and physical (*Shirani et al.*, 2015). In the food supply chain, different hazards can be identified at each stage from primary production to the consumer (*Shirani et al.*, 2015; *Motarjemi and Lelieveld*, 2013). Risk can be assessed using different methods and tools, including Hazard Analysis and Critical Control Points (HACCP), Failure Mode and Effect Analysis (FMEA), Preliminary Hazard Analysis (PHA), Risk Ranking, etc. (*ICH*, *2005*).

FMEA is a systematic approach that improves production lines and is used to define, identify, eliminate or reduce potential failures in each step of the process, before they enter the next stage (*Scipioni et al.*, 2002; *Kurt and Özilgen*, 2013). It is an engineering tool (*Djekic at al.*, 2018), which consists of several successive steps, organised by dividing the manufacturing process into phases and calculating the risk priority number (RPN) for each potential failure at all stages of production (*Scipioni et al.*, 2002; *Özilgen at al.*, 2013). This methodology was developed in 1949 by the United States Army, and nowadays, it has been implemented in different areas including the food industry (*Scipioni et al.*, 2002). FMEA is a "bottom up" quantitative evaluation of the risks, by which the risk is assessed as the product of multiplication of values determined for severity (S), detection (D) and frequency of occurrence (O) of possible failures. Establishing a critical value for the RPN determines the need for appropriate corrective action. After corrective measures have been applied, the values for O and D have to be re-evaluated, while the value of S remains unchanged (*Djekic at al.*, 2018; *Arvanitoyanis et al.*, 2007).The assessment of the severity (S) of a failure is a measure of the impact that a failure can have on the health of the consumer, the required quality of the product and/or legislation. Assessment of occurrence (O) determines the frequency of occurrence of a given failure, while detection (D) is a measure of the possibility of easier or more difficult detection of a given failure (*Kurt and Özilgen*, 2013). In this paper, FMEA methodology was used to determine the biological, chemical and physical failures that may occur during the farmhouse production of white brined cheese (short cheese supply chain) in Serbia.

Materials and methods

Cheese supply chain

To apply FMEA methodology, a flow diagram was made for the production of white brined cheese production in farmhouse conditions and green market sale (short cheese supply chain, Figure 1). This was done according to *Popovic-Vranjes* (*2015*) and the authors' personal experience.

FMEA analysis

After the flow diagram was prepared, the potential failure modes were identified for each step, and the possible effects and causes of each failure mode were also identified. Afterwards, the risk level of each failure mode was assessed, and corrective actions to reduce and eliminate the potential failures were suggested. Finally, the risk level of the corrected design was recalculated.

To assess biological, chemical and physical failures, the values for occurrence (O), severity (S) and detection (D) in the manner shown in Table 1 were determined, according to *Djekic et al*. (2018). For each potential failure, the RPN was calculated using estimated values for O, S and D. A numerical ranking for values of O, S and D was established taking into consideration available literature data, epidemiological studies and our own expertise and knowledge. All co-authors of this study, as experts in the field, participated in ranking the risks, using the Delphi method to stimulate and synthesize the opinions of experts and achieve consensus (*Heiko*, 2012). There were no holdouts and consensus for each type of risk analysed was achieved. Also, all participants confirmed that all important food safety hazards had been included in each activity within cheese supply chains. Depending on the likelihood of occurrence, each failure was assigned with an O value in the range from 1 to 5. The highest O value represented the greatest probability the failure would occur. The possibility to detect the failure before it occurs and the seriousness of the failure were also ranked from 1 to 5, where the values increase as it becomes more difficult to detect the failure before occurring, or as the potential damage caused by the failure increases.

Table 1. Severity (S), occurrence (O) and detection (D) rating scale used for FEMA analysis (according to *Djekic et al.*, 2019)

SEVERITY (S)	
Estimation	**Consequence**
1	no consequences
2	minimal consequences
3	Low
4	High
5	Severe
OCCURRENCE (O)	
Estimation	**Probability**
1	very unlikely
2	Unlikely
3	Possible
4	great probability
5	Certainly
DETECTION (D)	
Estimation	**Control potential**
1	easy to detect
2	a great opportunity for detecting
3	little chance of detecting
4	difficult to detect
5	very difficult to detect

The calculation of RPN was based on the work of *Kurt et al.* (*2013*), and it included multiplication of the values of O, S and D. The maximum value for RPN that could be obtained was set at 125. A RNP value of 6 has been accepted as the critical limit, above which corrective measures need to be taken (5% of the maximum value with a statistical significance of 95%). The RPNs after the corrective actions were also recalculated.

Results and Discussion

White brined cheese refers to a large group of cheeses characterised by the name of the geographic area where they are produced. Although this group accounts for a large number of cheeses and, hence, great variety in their specific properties, their common characteristic is that they are matured in brine under anaerobic conditions. The most popular cheeses that belong to this group in Serbia include Sjenica Cheese, Zlatarski Cheese, Svrljiški Cheese, Serbian white cheese etc., while Greek Feta Cheese, Cypriot Haloumi, Egyptian Domiati, etc. are white cheeses known worldwide. Traditionally, these cheeses are made from cow, sheep or goat milk, or their mixtures. In the farmhouse production of white cheeses, raw milk is often used, giving the product specific sensory characteristics, due to the presence of indigenous microbiota (*Popovic-Vranjes*, 2015; *Radulovic et al.*, 2011; *Terzic-Vidojevic et al.*, 2006).

In this paper, Serbian white brined cheese, traditionally produced in Pomoravlje, is described as an example of farmhouse cheese and a general flow diagram showing its production steps is presented in Figure 1. This cheese is usually made from raw cow milk, which is heated to the required temperature (in summer 18–20°C, in winter 25–30°C), and at this temperature, rennet is added to the milk. After coagulation, which lasts for 4–6 h, the cheese curd is left in a strainer and hung to drain; this is followed by pressing the cheese curd with a board and a stone (the pressure should be 1–2 kg/1 kg of cheese curd). Drainage and pressing usually takes up to 24 hours. The drained cheese curd is cut into slices, sprinkled with dry salt and arranged in wooden buckets or plastic cans. Ripening is done under load and usually lasts for 2–3 weeks (*Popovic-Vranjes*, 2015). The characteristics of farmhouse white brined cheeses depend on the microbiological composition of raw milk, as the types of indigenous non-starter lactic acid bacteria (LAB) present in milk depend on the ecological characteristics of the climate in which the cheese is produced (*Terzic-Vidojevic et al.*, 2007; *Radulovic et al.*, 2011; *Popovic-Vranjes*, 2015).

FMEA analysis in the short cheese supply chain

The identified failures in cheese production and distribution chains, the calculated RPN values, corrective measures that can be applied, as well as the recalculated values for RPNs are presented in Table 2.

Assessment of biological failures in the short cheese supply chain

Very high values for RPN were determined for biological failures in the short cheese supply chain (Table 2). The highest values were determined for the milking step (total RPN for different biological failures=175), followed by cheese ripening step (RPN=132) and transportation of cheese by personal vehicle (RPN=110). The presence of pathogenic microorganisms in raw milk might indicate the animals' impaired health condition, but also inadequate hygienic milking conditions. Dairy products play a significant role in the occurrence of food-borne disease outbreaks, because raw milk can contain pathogens that might remain in the dairy products and consequently lead to food-borne diseases. Due to its composition (water content, neutral pH, nutrient content), milk is a suitable medium for microbial multiplication. The most commonly isolated pathogens from raw milk include *Staphylococcus aureus, Streptococcus* spp*., Listeria monocytogenes, Campylobacter jejuni, Escherichia coli,* etc. Special attention towards the legislation was given to the infectious diseases, brucellosis and tuberculosis (*Oliver et al.*, 2005*, Kurt et al.*, 2013*, Le et al.*, 2014*, Serbia*, 2011). Some of these microbiological hazards can be controlled at the primary production level (e.g. tuberculosis, brucellosis), while *Listeria monocytogenes* is much more widespread in the environment and the introduction of this bacterium into dairies can result in product contamination, biofilm formation, etc. (*Oliver et al.,2005*; *Kurt et al.*, 2013; *Le et al.*, 2014; *Shirani et al.*, 2015). Legislation foresees the conditions that raw milk should meet in terms of total number of microorganisms and somatic cell counts (*Serbia*, 2010a; *Serbia*, 2011; *Serbia*, 2017b; *Serbia*, 2017c; *Serbia*, 2019). Application of good breeding practice and good veterinary practice, utilisation of animal feed from verified suppliers, education of owners and breeders of animals, who are often also the cheese producers in farmhouse production conditions, and application of legally determined norms could be used as corrective actions to control some biological failures in this cheese chain. By applying the proposed corrective measures, the recalculated RPNs values were reduced (Table 2).

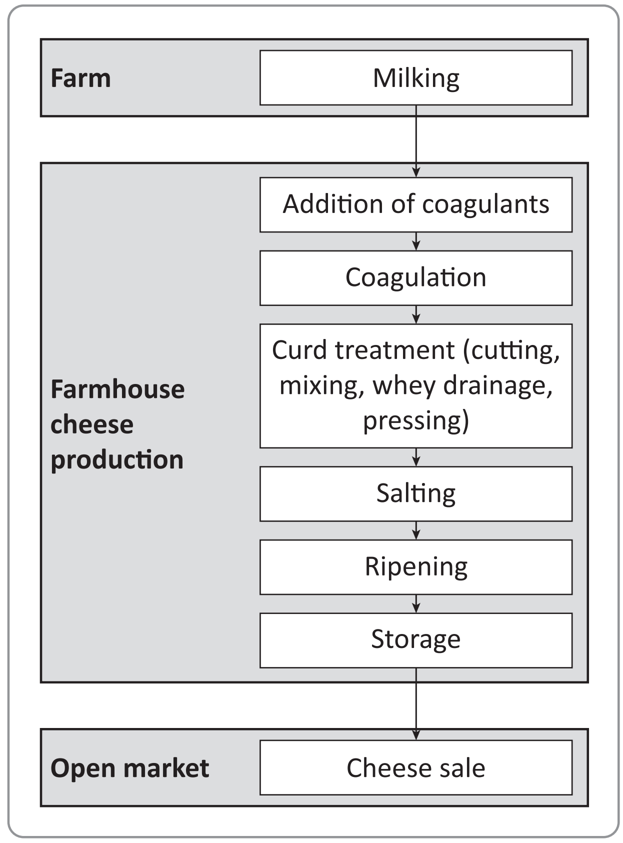

Figure 1. Short supply chain for farmhouse white brined cheese (according to *Dozet et al.*, 2004; *Popovic – Vranjes*, 2015)

Farmhouse cheese production, from the aspect of using raw milk that has not undergone any thermal treatment (Figure 1), carries the risk of causing food-borne diseases (*Mauropoulos et al.*, 1999; *Oliver et al.*, 2005). However, the controlled processes of coagulation and ripening of cheeses, due to the action of naturally occurring LAB, can still result in a product that is recognized as safe. Namely, LAB activity leads to a decrease in pH, and in conjunction with other factors such as storage temperature, salt concentration and water activity (a_w), might be limiting to the survival and multiplication of pathogenic microorganisms. In addition to this, LAB also produce antimicrobial substances such as bacteriocins, hydrogen peroxide, fatty acids, diacetyl, bacteriocin-like molecules, etc. (*Mauropoulos et al.*, 1999; *Bintsis et al.*, 2002; *Terzic-Vidojevic et al.*, 2006; *Veskovic-Moracanin et al.*, 2007; *Bulajic et al.*, 2017).

Table 2. FMEA analysis for farmhouse white brined cheese (short supply chain)

Production, processing and marketing phase	Failure /cause	O[1]	S[2]	D[3]	RPN[4]	Corrective actions	O	S	D	RPN
Register of identification of potential biological failures and proposed corrective actions										
Milking	Contamination with pathogenic microorganisms (*E. coli* O157:H7, *Salmonella* spp., *Mb. tuberculosis*, *Listeria monocytogenes*, *Staphylococcus aureus,* etc.) due to milking	3	5	5	75	Cheese production must be done in registered households Cheese production in the household can only be done from milk produced in that household (*Serbia*, 2017c) Milking animals must be covered by the program of measures and that the conditions for the production of raw milk and milk should meet the legal requirements (*Serbia*, 2011a)	2	5	5	50
	Contamination with pathogenic microorganisms in milk equipment due to: ▪ usage of contaminated water for washing dishes (i.e. buckets) ▪ faulty washing / milk trapping ▪ poor storage conditions of washed equipment	2	5	5	50	Water quality should be periodically controlled Disinfection of containers must be done Washing the equipment must be complete The storage room for milk-contacted equipment must be kept clean and protected from pests	1	5	5	25
	Contamination with pathogenic microorganisms due to impaired health of the person handling raw milk	2	3	5	30	Intermittent sanitary inspections must be done Education of farmers / persons handling raw milk is recommended Maintaining personal hygiene is essential People with signs of illness are not allowed to work with food	1	3	5	15
	Psychrotrophic microorganisms present in raw milk (spoilage microorganisms) and their possible outgrowth during cooling	2	2	5	20	Adequate temperature	1	2	5	10
Addition of coagulants	Contamination with pathogenic microorganisms due to impaired health of the food handler / cheese producer	2	3	5	30	Intermittent sanitary inspections must be done Education of cheese producers is recommended Maintaining personal hygiene is essential People with signs of illness are not allowed to work with food	1	3	5	15
Coagulation	Coagulation vats - inadequate washing / residues of milk and gel from previous productions	2	3	5	30	Utensils have to be washed and rinsed after each usage Using of potable water is recommended	1	3	5	15
Curd treatment	Microbiological contamination of cutting equipment (knife, cutting wires) Microbiological contamination due to manual manipulation	2	3	5	30	Regular cleaning of cutting equipment must be done Intermittent sanitary inspections must be done Education of cheese producers is recommended Maintaining personal hygiene is essential People with signs of illness are not allowed to work with food	1	3	5	15
	Microbiological contamination due to unhygienic utensils used (strainer, spoon and cloths)	2	3	5	30	Adequate cleaning and disinfection of strainer and spoon A new cheese cloth is recommended to be used each time	1	3	5	15
	Mold development due to: ▪ inadequate hygiene of the pressing table ▪ wooden pressing circles ▪ load stone	3	2	4	24	Regular cleaning and disinfection must be done Hygiene of wooden circles and stone using other materials instead of wood must be done	1	2	4	12

Production, processing and marketing phase	Failure /cause	O[1]	S[2]	D[3]	RPN[4]	Corrective actions	O	S	D	RPN
Ripening	Mold development	4	2	4	32	Cheese must be cleaned during ripening Stone and circle must be cleaned with brushes and potable water Mold growth inhibitors may be used	2	2	4	16
	Microbial contamination of water for making brine solution	2	5	5	50	Visual inspection of brine must be done Potable water is recommended to be used	1	5	5	25
	Growth of pathogens and spoilage microorganisms due to inadequate pre-requisite for cheese ripening room (temperature, room hygiene, room humidity, air flow)	2	5	5	50	The ripening of cheese must take place under controlled conditions The ripening room must be tide and clean The temperature in the maturation room should be below 18°C	1	5	5	25
Storage	Growth of pathogens and spoilage microorganisms during ripening (depends on room temperature, ripening time and hygienic conditions)	2	5	3	30	For cheeses with a long ripening period 10–15°C For cheeses with a shorter ripening period 0–4°C	1	5	3	15
Transportation	Microbial contamination due to poor vehicle hygiene	2	2	5	20	Regular maintenance of vehicle hygiene must be done	1	2	5	10
	Microbial contamination due to inappropriate temperature in the vehicle and / or inappropriate transport time	2	4	5	40	Cold chain must be maintained Transport / handheld refrigerator / thermo bag may be used Transport time should be maximal 2 hours (*Serbia*, 2017c)	1	4	5	20
	Microbial contamination due to the simultaneous transportation of different types of food	2	5	5	50	Physical separation of different types of food must be done	1	5	5	25
Direct sale (open market)	Microbial contamination due to the usage of water which is not adequate quality (uncontrolled wells, spring water)	2	5	5	50	Using of potable water is recommended	1	5	5	25
	Microbial contamination due to cheese seller (wounds on the hands, diseases)	2	3	5	30	Intermittent sanitary inspections must be done Education of cheese producers is recommended Maintaining personal hygiene is essential People with signs of illness are not allowed to work with food	1	3	5	15
	Microbial contamination due to: ▪ poor hygiene maintenance of refrigerator units ▪ exposure of the product in open containers ▪ customers touching cheese products to taste ▪ simultaneously exposal of several different types of products (meat, eggs, poultry) ▪ returning unsold cheese from the market ▪ poor hygiene of utensils (knives, spoons, dishes, cloths)	2	4	5	40	The refrigerator units must be regularly cleaned Using of containers with lids, using of foil or cloths is recommended Disposable accessories for food tasting (toothpicks, plastic clip, cardboard coasters) may be used Exposure to different types of food is allowed, but care must be taken to avoid cross-contamination Cold chain must be maintained Using of protective clothes / foils is recommended Washing unclean dishes, replacing of worn-out dishes must be done	1	4	5	20

Production, processing and marketing phase	Failure /cause	O[1]	S[2]	D[3]	RPN[4]	Corrective actions	O	S	D	RPN
Register of identification of potential chemical failures and proposed corrective actions										
Milking	The presence of residues of veterinary medicine drugs (antibiotics, hormones, growth stimulants) due to non-compliance with the prescribed withdrawal period	3	3	5	45	Veterinary medicines should be given only according to the instructions of the veterinarian	1	3	5	15
	The presence of aflatoxins in raw milk due to poor agricultural practices (animal feed)	3	3	5	45	Good agricultural practice must be performed Animal nutrition should be done by commercial feed from verified suppliers (authorized animal feed sales)	2	3	5	30
	The presence of chemical contaminants (pesticides, dioxins, organophosphates, etc.) in raw milk due to poor agricultural practices (animal feed)	2	3	5	30	Good agricultural practice must be performed Animal nutrition should be done by commercial feed from verified suppliers (authorized animal feed sales)	1	3	5	15
	The presence of detergents and disinfectants in raw milk collection equipment due to improper washing and rinsing	2	2	5	20	Using of approved agents for washing and disinfection according to the manufacturer's instructions, good rinsing must be done	1	2	5	10
Coagulation	Chemical contamination due to storage of cleaning and disinfecting agents	2	4	5	40	Regular cleaning and disinfection must be done Hygiene products should be stored separately from food	1	4	5	20
	Residues of cleaning and disinfecting agents on the utensils used for milk coagulation	2	2	5	20	Utensils must be washed and rinsed after each production Detergent must be allowed for the use in the food industry Usage of detergents and disinfectants according to the manufacturer	1	2	5	10
Curd treatment	The presence of mycotoxins (following mold development) due to: ▪ inadequate hygiene of the pressing table ▪ wooden pressing circles ▪ load stone	2	3	5	30	Regular cleaning and disinfection of the room must be done Wood and stone hygiene The usage of other materials instead of wood or stone is recommended	1	3	5	15
Salting	The presence of heavy metals (Hg, Pb, As, Cd) in salt	2	3	5	30	Salt must be obtained from the reliable suppliers	1	3	5	15
Ripening	The presence of mycotoxins due to mold development during ripening	2	3	5	30	Cheese must be cleaned during ripening Stone and circle cleaning must be done Mold growth inhibitors may be used	1	3	5	15
	Chemical contamination of the water used to make brine with heavy metals and / or residues of the chlorine	2	3	5	30	Water quality testing must be done regularly Potable water is recommended to be used	1	3	5	15
Direct sale (open market)	Residues of detergents for dishwashing	2	3	5	30	Approved detergents and disinfectants must be used Good rinsing after washing must be done Disinfectants must be used according to the manufacturer's instruction	1	3	5	15
	Chemical contamination due to utensils (dishes, knives, etc.)	2	2	5	20	Materials that are allowed in the food industry must be used Equipment that can be easily maintained and where necessary disinfected (e.g. stainless steel) must be used	1	2	5	10
	Chemical contamination due to inadequate material used to cover the bowl (wood, rusted lids, newspapers, rags)	2	2	5	20	Plastic lids or / and foil may be used	1	2	5	10

Production, processing and marketing phase	Failure /cause	O[1]	S[2]	D[3]	RPN[4]	Corrective actions	O	S	D	RPN
Register of identification of potential physical failures and proposed corrective actions										
Milking	The presence of foreign bodies originating from damaged equipment (pieces of metal, strand wire, cloth parts, etc.)	2	4	2	16	Equipment made of adequate materials must be used Damaged utensils must be replaced Raw milk filtration must be done	1	4	2	8
	The presence of straw / litter, hairs, mud, insects, rodent faces, etc. due to poor hygiene and breeding practices and / or machine milk due to the fall of suction cups on the ground	2	3	2	12	Good hygiene and breeding practices must be applied Protection of raw milk from pest must be done Filtration of raw milk must be done	1	3	2	6
	The presence of foreign bodies originating from a person handling raw milk (buttons, jewelry, etc.)	2	4	1	8	Good hygiene and manufacturing practice Education of farmers / persons handling raw milk is recommended	1	4	1	4
Coagulation	The presence of foreign bodies such as insects, larvae, glass, metal parts, hair) in utensils	2	3	2	12	Manipulation of glass materials must be avoided Protection of utensil from insects and other pests must be done Personal hygiene is required	1	3	2	6
Curd treatment	The presence of foreign bodies originating from the person who cuts curd into slices (hair, buttons, jewelry)	2	4	1	8	Personal hygiene must be regular	1	4	1	4
Salting	The presence of foreign bodies in salt	2	3	1	6	Salt must be obtained from registered stores	1	3	1	3
Transport	The presence of foreign bodies (glass, metal parts, hair, dust, insects, insect larvae, etc.) due to poor vehicle hygiene	2	3	2	12	Regular maintenance of vehicle hygiene must be done Transport in closed containers is recommended Regular cleaning and disinfection must be done	1	3	2	6
Direct sale (open market)	Physical contamination due to cheese exposure in open dishes	2	3	1	6	It is recommended that the cheese is sold at open markets in sealed containers, as well as during the sale remains covered with plastic foil	1	3	1	3
	Contamination due to the presence of metal particles originating from damaged dishes or other equipment (e.g. knives)	2	5	2	20	Cheese in which the presence of metallic particles has been determined must be removed and destroyed Damaged and broken equipment must be replaced	1	5	2	10
	Physical contamination due to touching the product by the customers or sellers (hair)	2	2	2	8	Disposable accessories should be used (toothpicks, plastic clip, cardboard coasters)	1	2	2	4
	Physical contamination due to accidental breakage of glass bottles or glasses	2	4	1	8	Cheese in which the presence of glass has been established should be destroyed and removed Handling with glass near food should be avoided	1	4	1	4

[1]O – occurrence, [2]S – severity, [3]D – detection, [4]RPN – risk priority number

During coagulation and whey drainage, pH should decrease to a value of 4.6 or lower. Syneresis and salt addition decreases the a_w, which slows the growth of pathogenic microorganisms, and affects the cheese structure, enzymatic activity, etc. (*Pacheco et al.*, 2010; *Bulajic et al.*, 2017). In household production, the key moment is the visual inspection of whey, when the appearance of clear, light green whey with a pleasant taste and smell indicates the milk has coagulated well (*Popovic-Vranjes*, 2015). If changes in whey colour, a sour taste of curd or unpleasant smell occur, the production must be stopped and all obtained curd and whey must be discarded (*Serbia*, 2019; *Olofson*, 2010).

In farmhouse cheese production, most of the steps involve manual manipulations, such as milking, rennet addition, gel cutting, salting and stacking in buckets (Figure 1). In addition, during cheese sale at the green markets, manual manipulation is inevitable. Therefore, it is clear that the cheese producers' personal hygiene is very important. Legislation in Serbia determines the conditions that persons involved in food production must meet in terms of maintaining personal hygiene and wearing of appropriate and clean protective clothing. Food handlers must not suffer from food-borne diseases, must not have infected wounds, skin infections and injuries or diarrhoea, and food handlers are obligated to report illnesses or symptoms. For persons who perform activities involving direct contact with food, the legislator mandates health examinations twice a year. Hand hygiene of persons handling food must be maintained, which is achieved by installing a sufficient number of hand washing stations with hot and cold water, hand washing agents and suitable disinfectants (*Serbia*, 2010a; *Serbia*, 2011; *Kurt et al.*, 2013; *Serbia*, 2017).

In farmhouse cheese production, it is essential the production steps of coagulation, gel cutting, whey drainage, salting and stacking in buckets take place in clean environments. Identical hygienic conditions must be met in both industrial production and distribution in retail chains. In farmhouse cheese production, the washing step is usually performed manually, while in industrial facilities, automatic cleaning in place (CIP) technology is applied. The utensils should be washed as soon as possible after the production of cheese, but the washing step must not be performed during the production process. In order to preserve the desirable microbiota in farmhouse conditions, mechanical cleaning and washing of surfaces is recommended, but not the use of disinfectants. In such conditions, special attention should be paid to the mechanical cleaning of cheese making equipment, the appropriate water temperature and detergent concentration, as well as the washing time (*Olofson*, 2010).

Untimely and inadequate washing of equipment used in household cheese production can result in microbiological contamination, due to retention of milk and gel that remain from previous production. We rated this failure as RPN=30. This failure could also be seen through the possibility of biofilm formation. Namely, the occurrence of biofilms on materials used for the food production (stainless steel, plastic, glass, etc.) and from which kitchen equipment used in households is also made, is described in the literature (*Olofson*, 2010; *Giaouris et al.*, 2012; *Moretro et al.*, 2004; *Katic*, 1995). The possibility of this phenomenon in farmhouse cheese production should not be neglected. Although special attention is paid to pathogenic microorganisms such as *Salmonella* spp., *Listeria monocytogenes* and *Staphylococcus aureus*, the occurrence of LAB biofilms has also been described, in which pathogens have been identified.

According to Serbian legislation (*Serbia*, 2017), the mandatory data the small producer must state on the food label are name and address of the manufacturer, production date, product name, shelf life, storage conditions and household registration number. The shelf life of farmhouse white cheeses, and therefore their quality and safety parameters, is dependent on many different factors, including composition, degree of maturity, storage conditions etc. According to *Popovic-Vranjes* (*2015*), white brined cheeses matured for 2–3 weeks might be stored for months. However, when the maturation period is shorter in order to produce fresh cheeses, the subsequent shelf life is also shorter. The production of these cheeses is based on the tradition and experience that generations of housewives have gained. Passing the experience from generation to generation has contributed to the preservation of this traditional production. According to the Serbian legislation (*Serbia*, 2010b), cheeses can be divided into the following categories: extra hard cheeses with a ripening period that must not be shorter than 6 months, hard cheeses that must ripen for at least 5 weeks, semi-hard cheeses that ripen for at least 2 weeks and soft cheeses that ripen for at least 7 days. Depending on the length of the ripening period, the shelf life of these cheeses also changes, as a longer ripening period is associated with a longer shelf life due to microbiological and biochemical changes that characterise the ripening period and by which the desired sensory and textural characteristics are achieved. Fresh cheeses are characterised by low dry matter content with a consequently high a_w, and low fat and protein contents but a high lactose content, which makes them perishable foods (they can remain unspoiled for only a few days). On the contrary, in ripened cheeses, dry matter, fat and protein contents are higher, but lactose and water contents are lower, which prolong their shelf life (*Pacheco et al.*, 2010). Questions remain as to how long the shelf life is of farmhouse-produced cheeses that are sold at green markets in Serbia, and how should the small producers determine the shelf life of their cheeses.

Assessment of chemical failures in the short cheese supply chain

Chemical failures can be identified at all stages of farmhouse cheese production and distribution. The main chemical risks we associated with raw milk were the presence of aflatoxins and antibiotic residues, as a consequence of poor breeding practices and veterinary malpractice, respectively. The highest RPNs were determined for the presence of antibiotic residues and aflatoxin contamination in raw milk. In farmhouse conditions, RPN values were rated as 45, 45 and 30 for antibiotic residue, aflatoxin and chemical contamination, respectively. The occurrence of pharmacologically active substances in food of animal origin is most often caused by the use of veterinary drugs used in the treatment of dairy animals. Residues of veterinary medicinal products are classified in group B of chemicals that can be found in food (according to Annex I of Council Directive 96/23/EC), where environmental contaminants are also present. Here, the greatest importance is given to antibiotics, which are relatively stable at pasteurisation temperatures, but also at low temperatures. The influence of antibiotics in cheese production can be divided into two areas: 1) influence on consumer health (hypersensitivity reactions, development of antibiotic resistance in pathogenic microorganisms, changes in digestive tract microbiota) and; 2) influence on cheese production (inhibition of LAB, delay in achievement of the appropriate pH, as well as altered sensory characteristics and possible growth of pathogenic microorganisms due to inadequate LAB activity) (*Marth et al.*, 1959; *Albright et al.*, 1961; *Kurt et al.*, 2013*, Katic & Bulajic*, 2018). Farmhouse cheeses are made of milk that is produced in that household (*Serbia*, 2017). The presence of antibiotics in milk can be prevented by applying good breeding practices, regular health checks of dairy animals according to legislation (*Serbia*, 2005) and by educating the breeder, who is also the cheese producer, to respect the prescribed withdrawal period.

Mycotoxins are secondary metabolites of fungi that reach the milk via contaminated animal feed. In dairy farming, the highest importance is attached to aflatoxin M1. Aflatoxin M1 is excreted by cows into raw milk, is resistant to heat treatment and due to its binding to casein micelles in cheese, it occurs in higher concentrations in cheese than in the milk from which the cheese is produced. Usually the concentration increase (from milk to cheese) ranges from 3-fold in soft cheeses to 5-fold in hard cheeses. Cheese is considered to be the most important source of aflatoxin M1 among all dairy products (*Ardic et al.*, 2009; *Skrbic et al.*, 2014; *Kos et al.*, 2014; *Polovinski-Horvatovic et al.*, 2009; *Tomasevic et al.*, 2015; *Miocinovic et al.*, 2016). At this point, the control of aflatoxin M1 in farmhouse cheese production is questionable, because no controls of aflatoxin in raw milk are performed at the household level. Aflatoxin M1 in milk originates from animal feed. Therefore, application of good agricultural practice, with special attention to the conditions of storage of animal feed, and good breeding practices are considered as suitable corrective measures.

Chemical contamination resulting from non--compliance with hygiene standards (presence of residues of detergents and disinfectants, inappropriate materials from which equipment is made, etc.) can be prevented by educating individual producers, by applying good manufacturing practices and using permitted means of hygiene and disinfection at all stages of production and trade (Table 2). Also, water used on food production farms must meet the requirements for potable water, regardless of whether it is used from the public supply system of consumers or from their own wells (*Serbia*, 2010a; *Serbia*, 2017).

Assessment of physical failures in the short cheese supply chain

An artefact is defined as any unwanted object in food that originates from the food itself (intrinsic such as bones in meat products, fruit seeds, etc.) or originates from other sources (extrinsic such as glass, plastic, metal parts). The presence of artefacts in food can cause serious consequences (oral cavity injuries, suffocation, damage to the digestive tract, internal bleeding and even death). The most common injuries recorded as a result of ingestion of artefacts were caused by sharp metal objects (parts of equipment, wires, etc.), but such dangers can be caused by other types of artefacts such as jewellery, artificial nails, pieces of wood, etc. (*Trafialek et al.*, 2016). Metal artefacts can be present in cheese due to contamination of raw milk because of poor milking hygiene or can occur during the different production steps as presented in Table 2.

The RPN value calculated for the identified physical failures (116) was significantly lower than those obtained for chemical and biological failures (390 and 741, respectively). The short cheese supply chain consists of a series of manual processes from production to sale, which can result in the occurrence of artefacts in the product (from hair that can lead to consumers' nausea, to metal parts that can lead to injuries). The application of appropriate hygienic conditions during the production, transport and trade of cheese at the markets as well as the education of individual producers are considered as appropriate corrective measures. The highest value for physical defects was determined for the presence of metal foreign bodies originating from damaged equipment during sale at the green markets (RPN=20). Destroying suspect products and replacing damaged equipment are considered good corrective measures to reduce the RPN to 10.

Conclusion

In this paper, FMEA methodology was used to quantitatively determine the risks that can be observed in different phases of white brined cheese production and trade in a short supply chain (farmhouse-produced cheese which is sold at green markets). Our results indicate the greatest risks in the short cheese supply chain can be attributed to biological and chemical failures, due to any failures being unlikely to be detected by cheese producers and having severe consequences. The proposed corrective measures include different pre-requisite programs. Even the application of these measures will not result in great risk reduction, as the severity and detection will remain the same. Small cheese producers on their own initiative rarely send cheese for the external analysis, as this is most often done by competent authority during regular controls. Therefore, the biological and chemical failures are usually not detected at all in farmhouse cheese production. To increase detection and consequently to decrease the risk, some rapid hygiene monitoring techniques such as ATP (detection of adenosine triphosphate by bioluminescence) and protein kits might be used. They are designed to provide rapid results and to be used by unskilled personnel, such as cheese producers, to assess the effectiveness of their cleaning procedures. This might be supported and organised by government institutions. At the same time, this conclusion cannot be applied to physical defects because they are visible and, therefore, easier to detect, which is indicated by the relatively low RPN values for these faults calculated in this study.

Primena FMEA analize u ocenjivanju kratkog lanca snabdevanja sirom

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A p s t r a k t: Cilj ovog rada bio je da se primeni kvantitativna FMEA metodologija (engl. Failure Mode Effect Analysis) u ocenjivanju potencijalnih bioloških, hemijskih i fizičkih nedostataka koji se javljaju tokom proizvodnje i distribucije belog sira u salamuri proizvedenog na gazdinstvima (kratak lanac snabdevanja) u Republici Srbiji. U tu svrhu utvrđene su vrednosti za učestalost pojavljivanja potencijalnih nedostataka (O), ozbiljnost posledica koje izazivaju (S) i mogućnost detekcije (D). Množenjem utvrđenih vrednosti izračunate su RPN (engl. risk priority numbers) vrednosti za svaki potencijalni nedostatak. U kratkom lancu snabdevanja utvrđene su visoke vrednosti za RPN za biološke nedostatke. Najviše vrednosti izračunate su za fazu muže muznih životinja, dok su nešto niže vrednosti izračunate za fazu zrenja sireva i transport ličnim vozilom do pijaca. Hemijski nedostaci za koje je izračunata najvša RPN vrednost odnose se na kontaminaciju sirovog mleka aflatoksinom i reziduama veterinarskih lekova. Naši rezultati ukazuju da biološke i hemijske opasnosti predstavljaju najznačajnije rizike u kratkom lancu iz razloga što je za njihovu detekciju neophodno izvršiti analize, a posledice koje izazivaju po zdravlje potrošača mogu da budu veoma ozbiljne. Predložene korektivne mere zasnivaju se na primeni odgovarajućih preduslovnih programa. Ipak i primenom predloženih korektivnih mera ne može se postići značajnije smanjenje rizika za pojavljivanje odgovarajućih opasnosti, iz razloga što je za detekciju i dalje neophodno primeniti iste postu pke, ozbiljnost posledica koje predstavljaju po zdravlje potrošača ostaje ista, pa su vrednosti za D i O nepromenjene. Kako su fizičke opasnosti lako vidljive i samim tim lakše za otkrivanje, najniže RPN vrednosti utvrđene su za fizičke nedostatke.

***Ključne reči:** kratak lanac snabdevanja sirom, proizvodnja sira na gazdinstvima, FMEA analiza, rizik*

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References

Albright, J., Tuckey, S. & Woods, G. 1961. Antibiotics in milk — a review. *Journal of Dairy Science*, 44(5)*,* 779−807.

Ardic, M., Karakaya, Y., Atasever, M. & Adiguzel, G. 2009. Aflatoxin M1 levels on Turkish white brined cheese. *Food Control*, 20(3)*,* 196−199.

Arvanitoyanis, I. S. & Varzakas, H. T. 2007. Application of failure mode and effect analysis (FMEA), cause and effect analysis and Pareto diagram in conjunction with HACCP to a potato chips manufacturing plant. *International Journal of Food Science and Technology*, 42*,* 1424−1442.

Bintsis, T. & Papademos, P, 2002, Microbiological quality of white brined cheeses: a review. *International Journal of Dairy Technology* 55(3)*,* 113−120.

Bulajic, S., Ledina, T., Djordjevic, J., Boskovic, M., Matovic, V., Markovic, R. & Baltic, M. (2017). Biopreservation of traditional raw milk cheeses with an emphasis on Serbian artisanal cheeses and their historical production. *Meat Technology* 58(1)*,* 52−61.

Djekic, I., Tomic, N., Smigic, N., Udovicki, B., Hofland, G. & Rajkovic, A. (2018). Hygienic design of a unit for supercritical fluid drying — case study. *British Food Journal*, 120(9)*,* 2155−2165.

EFSA (2019). The European Union One Health 2018, Zoonoses Report. *EFSA Journal* 17(12), 1−276.

Giaouris, E., Chorianopoulos, N., Skandamis, P., Nychas, G. Y. & Mahmoud, B. (2012). Attachment and biofilm formation by *Salmonella* in food processing environment. In: *Salmonella* — a dangerous foodborne pathogen. Eds. Mahmoud, B., IntechOpen, pp. 157−181.

Heiko, A. (2012). Consensus measurement in Delphi studies: review and implications for future quality assurance*. Technological Forecasting and Social Change,* 79(8)*,* 1525−1536.

ICH (International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use). (2005). ICH Harmonised Tripartite Guidelines — Quality risk management Q9, step 4 version.

Katic, V. (1995). The survival of *Listeria monocytogenes* in white brined cheese. *Acta veterinaria,* 45 (1), 31−36.

Katic, V. & Bulajic, S. (2018). Higijena i tehnologija mleka, Univerzitet u Beogradu, Fakultet veterinarske medicine.

Kos, J., Levic, J., Djuragic, O., Kokic, B. & Miladinovic, I. (2014). Occurrence and estimation of aflatoxin M1 exposure in milk in Serbia. *Food Control,* 38 (1)*,* 41–46.

Kurt, L. & Özilgen, S. (2013). Failure mode and effect analysis in dairy product manufacturing: Practical safety improvement action plan with cases from Turkey. *Safety Science,* 55(201), 195−206.

Le, S., Bazger W., Hill, A. & Wilcock, A. (2014). Awareness and perceptions of food safety of artisan cheese makers in Southwestern Ontario: A qualitative study. *Food control* 41*,*158–167.

Malak-Rawlikowska, A., Majewski, E., Wąs, A., Borgen, S.O., Csillag, P., Donati, M., Freeman, R., Hoàng, V., Lecoeur, J.-L. & Mancini, M.C. (2019). Measuring the economic, environmental, and social sustainability of short food supply chains. *Sustainability,* 11(15), 4004.

Marth, E. & Elickson, B. (1959). Problems created by the presence of antibiotics in milk and milk products — a review. *Journal of Milk and Food Technology,* 22 (9)*,* 266−272.

Mauropuolos, A. A., Arvanitoyannis, I. S. (1999). Implementation of hazard analysis and critical control point to Feta and Manouri cheese production lines. *Food Control*, 10*,* 213−219.

Miocinovic, J., Keskic, T, Miloradovic, Z., Kos, A., Tomasevic, I. & Pudja, P. (2016). The aflatoxin M1 crisis in Serbian dairy sector: the year after. *Food Additives and Contaminants: Part B,* 10 (1), 1–4.

Møretrø, T. & Langsrud, S. (2004). *Listeria monocytogenes*: biofilm formation and persistence in food-processing environments. *Biofilms 2004,* 1 (2)*,* 107−121.

Motarjemi, Y. & Lelieveld, H. (2013). Food safety management: A practical guide for the food industry, Academic Press.

Oliver, S. P., Jayarao, B. M. & Almeida, R. A. (2005). Foodborne pathogens, mastitis, milk quality and dairy food safety, NMC Annual Meeting Proceedings.

Olofsson, I. (2010). Guidelines for food safety control of artisan cheese making, TemaNord 2010:596, Nordic Council of Ministers, Copenhagen.

Pacheco, F. & Galindo, B. (2010). Microbial safety of raw milk cheeses traditionally made at a pH below 4.7 and with other hurdles limiting pathogens growth. In: Technology and education topics in applied microbiology and microbial biotechnology, Eds. Mendez-Vilas, A. Formatex, pp: 1205−1212.

Polovinski-Horvatovic, M., Juric, V. & Glamocic, D. (2009). Two year study of incidence of aflatoxin M1 in milk in the region of Serbia. *Biotechnology in Animal Husbandry,* 25 (5−6)*,* 713−718.

Popovic-Vranjes A. (2015). Specijalno sirarstvo, Univerzitet u Novom Sadu, Poljoprivredni fakultet.

Radulovic, Z., Miocinovic J., Pudja, P., Barac, M., Miloradovic, Z., Paunovic, D. & Obradovic, D. (2011). The application of autochthonous lactic acid bacteria in white brined cheese production. *Mljekarstvo,* 61 (1), 15−25.

Scipioni, A., Saccarola, G., Centazzo, A. & Arena, F. (2002). FMEA methodology design, implementation and integration with HACCP system in a food company. *Food Control* 13, 495−501.

Serbia (2005). Law on veterinary matters. *Official Gazette of the Republic of Serbia*, No. 91/2005, 30/2010, 93/2012 (in Serbian).

Serbia (2010a). Rulebook on food hygiene conditions. *Official Gazette of the Republic of Serbia*, No. 73/10 (in Serbian).

Serbia (2010b). Rulebook on the quality of dairy products and starter cultures *Official Gazette of the Republic of Serbia*, No. 33/2010 and 69/2010, 43/2013, 34/2014 (in Serbian).

Serbia (2011). Rulebook on veterinary and sanitary conditions, general and specific conditions for hygiene of food of animal origin, as well as conditions of hygiene of food of animal origin. *Official Gazette of the Republic of Serbia*, No. 25/11 and 27/14 (in Serbian).

Serbia (2017). Rulebook on small quantities of primary products used to supply consumers, the area for performing these activities as well as derogations relating to small entities in the business of food of animal origin. *Official Gazette of the Republic of Serbia*, No. 111/2017 (in Serbian).

Serbia (2018). Report on infectious diseases in the Republic of Serbia for 2017, Institute for public health of Serbia, Dr. Milan Jovanovic Batut (in Serbian).

Serbia (2019). Guidance for the production and processing of milk in small capacity facilities and guidance for the production of traditional milk products. Republic of Serbia, Ministry of Agriculture, Forestry and Water Management, Veterinary Directorate.

Shirani, M. & Demichela, M. (2015). Integration of FMEA and human factor in the food chain risk assessment. *International Journal of Economics and Management Engineering,* 9 (12), 4147−4250.

Skrbic, B., Zivancev, J., Antic, I. & Godula, M. (2014). Levels of aflatoxin M1 in different types of milk collected in Serbia: Assessment of human and animal exposure. *Food Control,* 40 (1)*,* 113−119.

Smigić, N. (2019). Food safety and quality legislation, University of Belgrade — Faculty of Agriculture, Belgrade, Serbia (in Serbian).

Terzic-Vidojevic, A., Vukasinovic, M., Veljovic, K., Ostojic, M., Topisirovic, Lj. & (2006). Characterization of microflora in homemade semi — hard white Zlatar cheese. *International Journal of Food Microbiology,* 114 (1)*,* 36−42.

Tomasevic, I., Petrovic J., Jovetic, M., Raicevic, S., Milojevic, M. & Miocinovic, J. (2015). Two year survey on the occurrence and seasonal variation of aflatoxin M1 in milk and milk products in Serbia. *Food Control,* 56*,* 64−70.

Trafialek, J., Kaczmarek, S. & Kolanowsi, W. (2016). The risk analysis of metallic foreign bodies in food products. *Journal of Food Quality,* 39*,*398−407.

Veskovic-Moracanin, S. (2007). Bacteriocin *Leuconostoc mesenteroides* E131 and Lactobacillus sakei I 153 and MAP on shelf life of sremska sausage. Ph.D. Dissertation, Faculty of Agriculture, Belgrade, Serbia (in Serbian).

Vlahovic, B., Mugosa, I, Puskaric, A. & Uzar, D. (2018). Improving cheese production and marketing - Handbook, Faculty of Agriculture — University of Novi Sad, Novi Sad, Serbia (in Serbian).

WHO. (2019). Estimating the burden of foodborne diseases. Available at: https://www.who.int/activities/estimating-the-burden-of-foodborne-diseases.

Yu, M., Nagurney, A. (2013). Competitive food supply chain networks with application to fresh produce. *European Journal of Operational Research,* 224 (2)*,* 273−282.

Zhao, M. (2013). The design of HACCP plan for a small — scale cheese plant, A research paper, University of Wisconsin — Stout, USA.

Özilgen, **S., Bucak, S. & Özilgen, M. (2013).** Improvement of the safety of the red pepper spice with FMEA and post processing EWMA quality control. *Journal of Food Science and Technology,* 50 (3)*,* 466−476.

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