SIMULATION AND IMPORTANCE OF A TRACEABILITY SYSTEM IN DAIRY MICROPRODUCTION FOR ENSURING FOOD SAFETY AND QUALITY

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Abstract

Traceability, which provides the ability to track each step of the production chain from raw materials to the finished product, is crucial for guaranteeing the quality and safety of food. In this study, we examine the importance of implementing an effective traceability system in the production of milk and by-products from the Milk Microproduction Workshop of Iasi University of Life Sciences. A system like this makes it possible to quickly identify the causes of non-compliance, reducing the risks involved in removing items from the market and safeguarding consumers' health. In addition, the article offers a realistic simulation of a traceability exercise that involves monitoring raw milk batches, processing them, and identifying each final product, including cheeses and yogurts. The results of the exercise show that a well-designed traceability system increases consumer confidence in the products obtained within the workshop, while guaranteeing compliance with existing laws. The results emphasize how this system must be continuously modified to satisfy market demands and enhance the efficiency of the production and food safety procedures.

Key words: traceability, food safety, food quality, HACCP.

Introduction. The dairy industry was created to keep an eye on and confirm the quality and safety of dairy products from the farm to the customer. By making it easier to track products in the supply chain, these systems encourage accountability and openness among all parties involved, including manufacturers, processors, and retailers (Anastasiadis F. *et al,* 2021).

Implementing traceability methods is essential because they enhance food safety by facilitating quick reactions to contamination and boost consumer confidence by guaranteeing the quality and authenticity of products.

Because it can mimic real-world situations, simulation is important in traceability systems because it helps stakeholders see the supply chain and spot any weaknesses that can jeopardize food safety (Veleșcu I.D. *et al,* 2023).

In order to ensure adherence to safety procedures like Hazard Analysis and Critical Control Points (HACCP), the simulations enable producers to assess different risk management techniques that can be used in the dairy industry. The dairy business may enhance its operational procedures and produce safer and better-quality products by utilizing simulation technologies efficiently (Morrissey M., 2017).

However, there are significant obstacles to the implementation of traceability systems, particularly for small dairy producers. The deployment of these systems may be hampered by the high price of technological expenditures and the requirement for uniform information transmission. Furthermore, a lot of manufacturers continue to use paper records, which reduces the efficiency and quality of data. In order to guarantee product quality and advance food safety procedures in the microdairy industry, these obstacles must be removed (Charlebois S, Sanaz H., 2015).

The necessity for affordable, user-friendly traceability solutions designed for small-scale businesses is emphasized in future research and development areas. The dairy industry may enhance its traceability procedures and eventually satisfy the rising customer demand for safe, premium dairy products by enhancing training programs and creating cooperative projects among stakeholders (Elghannam A. *et al,* 2019).

With particular relevance to a dairy microproduction workshop, the aim of this article is to assess the significance of putting in place an efficient traceability system in the dairy industry. The purpose of the article is to show how

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traceability supports food safety, efficient risk management, and adherence to national and international laws. This study attempts to determine crucial points in the production chain where monitoring techniques can be used to guarantee the quality and safety of dairy products from the point of origin to the end user by simulating a traceability effort (Razak G. M. *et al,* 2021*;* Veleșcu I.D. *et al*, 2022).

MATERIAL AND METHOD

This subchapter provides a detailed framework on the methodology used in the implementation of traceability and the simulation of a traceability exercise in a milk and milk products microproduction. For this study, a Milk and Dairy Products Microproduction Workshop of the Faculty of Agriculture, within the "Ion Ionescu de la Brad" University of Life Sciences from Iasi, with an average processing capacity of approximately 500 liters of milk per day. The main dairy products made in the workshop include pasteurized milk, yogurt, fresh and matured cheeses.

The materials and equipment used in the traceability process and simulation of the traceability exercise included:

- *Batch database* - for recording all relevant batch information: collection date, processing date, supplier details, and the identifier of each processed batch.
- *Batch identification labels* - used to label each dairy product based on the internal coding system.
- *Traceability management software* - for real-time data management, monitoring and verification of the production and distribution process.
- *Parameters monitoring system* - for controlling the processing and storage conditions of milk and dairy products during transport and storage.
- *Employee and supplier questionnaires* - to collect data on food safety practices and traceability.

RESULTS AND DISCUSSIONS

The use and earlier implementation of HACCP concepts (Hazard Analysis and Critical Control Points) in the micro-production workshop was crucial to guaranteeing efficient traceability and a strong food safety system. Any traceability system is built on the foundation of HACCP principles, which guarantee the identification, monitoring, and control of risks at every stage of the production process.

The following are the primary phases of HACCP implementation:

Hazard analysis is the process of identifying and evaluating the biological, chemical, and physical dangers that could arise at various points during the production of milk and dairy products, such as the presence of residual chemicals or bacterial contamination (*table 1*).

Table 1

Hazard identification

Crt. no	Stage	Hazard	Specification
1	Reception Raw Milk	B	- Presence of pathogens such *as Listeria monocytogenes*, *Salmonella*, *E. coli*, *Staphylococcus aureus*, and *Campylobacter* in raw milk. - Cross-contamination from infected animals or poor hygiene during milking. - Bacterial spore formers (e.g., *Bacillus cereus* or *Clostridium*) that can survive pasteurization.
		C	- Residues of antibiotics, hormones, or veterinary drugs in the milk. - Presence of pesticides or herbicides from feed. - Mycotoxins (like aflatoxins) from contaminated animal feed.
		P	- Presence of foreign materials like dirt, hair, or metal particles in milk. - Contaminants from milking equipment, such as plastic or rubber fragments.
2	Milk Pasteurization	B	- Inadequate heat treatment could allow survival of harmful pathogens. - Recontamination after pasteurization due to improper handling or equipment.
		C	- Degradation of milk quality due to improper temperature control. - Cleaning agent residues if the pasteurizer isn’t cleaned thoroughly.
		P	- Potential fragments from faulty equipment.
3	Curdling Process	B	- Growth of spoilage microorganisms if temperature control is inadequate. - Pathogens surviving if unclean rennet or starter cultures are used.
		C	- Improper dosage of rennet or incorrect pH adjustment can lead to defective curds. - Contaminants in rennet or starter cultures.
		P	- Introduction of foreign objects during mixing or curd cutting.
4	Cutting, Draining, and II Heating the Curds	B	- Bacterial growth due to improper temperature control or cross-contamination.
		C	- Contamination from cleaning chemicals if equipment is not rinsed properly.
		P	- Metal fragments from cutting knives or equipment used during the process.
5	Moulding and Pressing the Cheese	B	- Potential for contamination from air, surfaces, or hands during handling. - Growth of mold or spoilage organisms if hygienic practices are poor.
		C	- Residues from processing aids or cleaning products.
		P	- Pieces of cloth, plastic, or metal from equipment used in moulding or pressing.
6	Salting	B	- Pathogen contamination due to improperly stored or contaminated salt. - Microbial growth if salting is not done at the correct concentration or time.

		C	- Excessive salt content can affect safety and product quality. - Potential for iodine or anti-caking agents in salt to cause contamination.
		P	- Foreign particles in salt, like dirt or plastic fragments.
7	Maturation	B	- Growth of harmful bacteria or spoilage microorganisms during ripening due to inadequate temperature or humidity control. - Cross-contamination from the environment, other cheeses, or surfaces.
		C	- Accumulation of undesirable substances (like biogenic amines) if ripening conditions are not monitored.
		P	Foreign objects introduced during storage or handling.
8	Packaging and Labeling	B	- Recontamination of cheese by workers or equipment during packaging.
		C	- Use of non-food-grade packaging materials, leading to chemical migration. - Incorrect labeling regarding allergens (e.g., milk), which can lead to food safety risks for consumers.
		P	- Fragments of packaging material (like plastic or metal) getting into the product.
9	Storage and Distribution	B	- Growth of pathogens if cold chain is broken during storage or transport.
		C	- Absorption of external odors or chemicals during storage, affecting safety and quality.
		P	- Contamination from damaged containers or exposure to foreign objects.

Finding the crucial stages in the production cycle where hazards can be reduced or eliminated is known as *identifying critical control points*, or CCPs. Critical aspects in the dairy business usually include equipment sanitation, storage temperature regulation, and pasteurization procedures (*table 2*).

Identifying the measurable parameters (such as temperature and time) that determine the safety limits in order to establish the critical limits for each CCP. For instance, the crucial limit for pasteurization is the lowest temperature at which harmful microbes are removed from milk.

CCP monitoring: putting in place regular or ongoing monitoring techniques to make sure every CCP stays within crucial bounds. To avoid biological hazards, pasteurization requires constant temperature and time monitoring (*figure 1*).

Table 2

Hazard analysis and assessment

Crt. no.	Operation	Hazards	Hazard S	Hazard P	Hazard HR	What measure(s) can be applied to prevent or eliminate the hazard or reduce in to an acceptable level?
1	Reception Raw Milk	B	3	1	3	Use only milk from certified and regularly inspected farms. Implement testing for pathogens and microbial counts (e.g., *Listeria, E. coli*) upon receipt. Keep strict cold chain control (below 4°C) from farm to processing facility.
		C	2	1	2	Conduct routine screening for antibiotic, hormone, and pesticide residues. Ensure milk suppliers provide certificates of analysis (COA) for each batch.
		P	2	1	2	Use filtration systems at milk reception to remove physical contaminants. Inspect the transportation and milking equipment for wear and tear.
2	Milk Pasteurization	B	**3**	**2**	**6**	Monitor and control time and temperature during pasteurization (CCP). Verify the equipment's calibration regularly. Test post-pasteurization milk for microbial activity.
		C	2	1	2	Implement proper cleaning procedures for pasteurization equipment. Use food-grade cleaning agents and verify rinse cycles to avoid residues.
		P	2	1	2	Regularly inspect equipment for wear, including gaskets, seals, and pipes. Filter milk post-pasteurization to remove potential small particles.
3	Curdling Process	B	2	1	2	Ensure starter cultures and rennet are sourced from approved suppliers and are of food-grade quality. Maintain strict hygiene standards during the handling and preparation of milk.
		C	2	1	2	Monitor the addition of rennet and cultures to ensure accurate dosing. Store rennet and cultures under recommended conditions to prevent contamination.
		P	2	1	2	Conduct regular checks on knives and cutting equipment for potential contaminants.
4	Cutting, Draining, and Cooking the Curds	B	2	1	2	Control temperature during curd processing. Ensure curds are handled with clean, sanitized equipment.
		C	2	1	2	Ensure proper rinsing of equipment to avoid chemical residue contamination. Use validated cleaning procedures for all surfaces and utensils.
		P	2	1	2	Regularly inspect cutting tools and equipment to detect wear or damage.
5	Moulding and Pressing the Cheese	B	2	1	2	Practice good hygiene and wear protective gloves while handling curds. Sanitize pressing and moulding equipment between batches.
		C	2	1	2	Avoid using non-food-grade materials for moulding and ensure equipment is thoroughly rinsed after sanitation.
		P	2	1	2	Inspect pressing machines for loose parts and wear before use.
6	Salting	B	2	1	2	Use only high-quality, food-grade salt and store it in sanitary conditions. Monitor salt concentration and salting time to ensure proper food safety.
		C	2	1	2	Ensure the salt does not contain contaminants such as iodine or anti-caking agents that may affect cheese quality.

		P	2	1	2	Screen salt for foreign particles or use pre-filtered salt.
7	Maturation	B	3	2	6	Control temperature, humidity, and air quality in ripening chambers (CCP). Regularly test for microbial contamination and monitor for spoilage organisms.
		C	3	1	3	Prevent accumulation of undesirable compounds by controlling environmental conditions. Regularly check for off-flavors caused by volatile compounds in ripening rooms.
		P	2	1	2	Keep the maturation environment clean and free from debris.
8	Packaging and Labeling	B	2	1	2	Ensure proper hygiene during packaging. Use sanitized equipment and materials to prevent recontamination.
		C	2	1	2	Ensure packaging materials are food-grade and free from harmful chemicals. Perform allergen checks and validate accurate labeling to avoid consumer risks.
		P	2	1	2	Inspect packaging materials for integrity and foreign objects before use.
9	Storage and Distribution	B	2	1	2	Maintain cold chain during storage and distribution. Regularly monitor storage temperatures and ensure proper handling.
		C	2	1	2	Store cheese away from chemicals or products that could cause contamination. Use proper storage conditions to avoid the absorption of external odors or chemicals.
		P	2	1	2	Use durable, undamaged containers and packaging to prevent contamination during transport.

Corrective actions: setting up the required procedures in the event that monitoring shows a departure from crucial limits. Recalling the impacted batch or making process adjustments are two examples of these measures.

Verification of the HACCP system involves conducting *internal audits and checks* to make sure the system is operating as intended and effectively managing hazards.

Maintaining precise records of risk assessments, CCP monitoring, remedial measures, and recurring checks to support product traceability and compliance inspections is known as documentation and record keeping.

To guarantee an all-encompassing approach to risk management, potential production hazards were categorized according to their risk levels. The three main types of risks—Critical, Significant, and Minor—each call for a different degree of oversight and management. Critical Risks (High) require constant monitoring and strict controls at Critical Control Points (CCPs), such as in maturation and pasteurization procedures (*figures 1, 2*). Significant Risks (Medium) necessitate frequent monitoring and efficient preventive actions, which apply to processes including packaging, salting, and curdling. Good Manufacturing Practices (GMP) and routine inspections are used to handle minor risks (low), which are frequently associated with physical hazards from equipment.

CCP	Hazards		Critical Limits	Monitoring	Corrective Actions	Records	Verification
Milk Pasteurization	B	Pathogens (*Listeria, E. coli, Salmonella*)	Temp: ≥ 65°C; Time: ≥ 30 min	**What:** Temperature & time. **How:** Continuous automatic monitoring. **Who:** Operator. **Frequency:** Continuous, with batch checks.	Re-pasteurize or discard if limits are not met	Temperature & time logs, corrective actions	Calibration logs, microbiological tests
	C	Cleaning agent residues					
	P	Foreign particles from equipment					

Figure 1 **HACCP Plan for Milk Pasteurization (CCP1)**

CCP	Hazard		Critical Limits	Monitoring	Corrective Actions	Records	Verification
Maturation	B	Pathogens, spoilage organisms	**Temp:** 12-14°C. **Humidity:** 75-85%.	**What:** Temperature & humidity. **How:** Continuous data logging. **Who:** Quality control staff. **Frequency:** Daily review of logs.	**If limits are not met:** Adjust ripening conditions. Evaluate and discard affected cheese if necessary.	Temperature & humidity logs, corrective action reports.	Microbiological tests (monthly), sensory evaluations, log reviews (daily).
	C	Biogenic amines					
	P	Foreign materials					

Figure 2 **HACCP Plan for Cheese maturation (CCP2)**

Standardized processes have been created and put into place to follow the entire manufacturing chain, from the acquisition of raw materials to the finished product, in order to guarantee a high degree of traceability. The methodology used the following assumptions:

Milk batch registration: Every batch of raw milk that was gathered was entered into the database along with comprehensive details on the supplier, the collection date, and any quality checks that were performed (*figure 3, 4*).

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cod document: FI-8.3

RECEPTION SHEET

1. RECEPTION IDENTIFICATION DATA

1.1	**Reception record number**	
1.2	**Date of reception**	
1.3	**Time of reception**	

2. SUPPLIER INFORMATION

2.1	**Supplier Name**	
2.2	**Supplier Address**	
2.3	**Supplier Code**	
2.4	**Contact Person**	

3. TRANSPORTATION DETAILS

3.1	**Vehicle number (transport)**	
3.2	**Carrier name**	
3.3	**Delivery temperature**	
3.4	**Transport conditions**	

4. DESCRIPTION OF THE RAW MATERIAL

4.1	**Raw material type**	
4.2	**Raw material code**	
4.3	**Supplier batch**	
4.4	**Quantity received**	
4.5	**Packaging**	

5. ACCOMPANYING DOCUMENTS

5.1	**Invoice/Shipping Note No.**	
5.2	**Certificate of Conformity**	
5.3	**Analysis Bulletin**	

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6. VISUAL INSPECTION UPON RECEIPT

6.1	**Condition of packaging**	*[Intact/Damaged]*
6.2	**Visual appearance of raw material**	
6.3	**Presence of foreign bodies**	*[Yes/No]*
6.4	**Overall quality**	*[Good/Acceptable/Non-compliant]*

7. ADDITIONAL CHECKS

7.1	**Analyses upon receipt (if applicable):** • **Fat content;** • **Protein content;** • **pH;** • **Antibiotic identification.**	

8. STORAGE CONDITIONS

8.1	**Initial storage**	
8.2	**Recommended storage temperature**	

9. FINAL DECISION ON RECEPTION

9.1	**Accepted/Rejected**	
9.2	**Reason for rejection (if applicable)**	

10. SIGNATURES

10.1	**Receptionist**	
10.2	**Supplier representative (if present at reception)**	

Figure 3 **Reception documents**

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PRODUCT MONITORING SHEET

Date:

Product name:

- ***• QUANTITATIVE AND QUALITATIVE RECEPTION:***

No .crt	Quantity of milk (L)	Fat content (%)	Protein content (%)	Non fat dry matter (%)	Total dry matter (%)	pH	NTG (total germ count)	NTS (somatic cell count)
1								
2								

- ***MILK PASTEURIZATION::***

Crt no	Type of pasteurizatoon	Pasteurization temperature (ºC)	Duration of the pasteurization operation
1			

- ***MILK INNOCULATION:***

Crt. no	Name of the culture	Producer	Batch number	Expiry date
1				

- ***COAGULATION:***

Crt. no	Name of the rennet / Producer	Barch no	Expire date	Rennet quantity	Duration of coagulation
1					

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- ***CURD PROCESSING:***

Crt. no	Coagulation time	Second heating (min)	Temperature of second heating (ºC)	Coagulation grain dimension
1				

- ***FORMING / PRESSING::***

Crt. no	Mold type	Self-pressing time	Pressing time	Turning frequency	Draining time	Quantity of curd produced	Quantity of whey produced
1							

- ***MATURATION:***

Crt. no	Maturation period (number of days)	Maturation temperature (T=°C)	Maturation humidity (U%=%)	Frequency of washing with water and salt

- ***STORAGE:***

Crt. no	Date	Temperature	Quantity

- **PACKAGING*:***

Crt. no	Type of packaging	Manufacturer / Packaging batch no	Certificate of conformity

Figure 4 **Production documents**

Final product labeling: Every final product received a distinct label with a batch code that contained details on the equipment utilized, the responsible operator, and the date and time of processing.

Monitoring during distribution: In order to verify ideal storage conditions, temperature data was frequently reviewed and products were monitored along the entire distribution chain.

To assess the system's effectiveness and the precision of the data gathered during the production and distribution process, a traceability exercise simulation was conducted. The following was the format of the exercise:

- *Milk batch selection*: To replicate the traceability procedure, a batch of raw milk was chosen.
- *Identification of a final product*: From the chosen batch of milk, a certain final product was picked.
- *Trail tracing*: To identify each step of the process, the operators involved, and the equipment used, every record in the database—from the raw material collection to the packing stage—was combed through.
- *Results reporting*: To evaluate the level of precision and speed of the traceability process, gathered data was compiled into a report.
- *Data analysis*: The data was analyzed using descriptive and internal process compliance evaluation techniques. Performance metrics for the number of critical spots found during the traceability exercise and batch identification time were computed. The outcomes were contrasted

with the benchmarks set by the current European rules and industry best practices for dairy products.

The following analysis techniques were used to assess how well the traceability system was working and whether internal procedures adhered to food safety regulations:

- The data was analyzed using *descriptive and internal process* compliance evaluation techniques. Performance metrics for the number of critical spots found during the traceability exercise and batch identification time were computed.
- Data was compared to the guidelines and best practices set forth by European laws and regulations pertaining to the dairy sector as part of the compliance evaluation.

Performance metrics: Two primary metrics were computed:

- *Identification of Batches Time*: Indicates the amount of time needed to monitor and identify a particular batch from raw materials to the final product.
- *The quantity of critical points (CCP)* that are accurately tracked: demonstrates both the efficacy of the food safety system in place and adherence to the HACCP plan.

Good practices from other dairy processing facilities were examined in order to evaluate the traceability system's performance level and match internal procedures with global norms. Benchmarking involved comparing identification and monitoring times with information released by other dairy sector micro-productions and businesses. Assessment of traceability protocols: Labeling, monitoring, and recording protocols were examined using industry examples in order to pinpoint areas that could have improvement.

CONCLUSIONS

Adherence to HACCP principles was necessary for the establishment of a trustworthy traceability system in order to guarantee efficient production flow monitoring. Traceability, which provides all pertinent information about each batch of milk and final product, was added as an extra food safety measure following the implementation of HACCP principles.

To sum up, in order to guarantee product safety, improve quality control, and enable prompt reaction to possible contamination incidents, an efficient traceability system is crucial in the dairy industry. By tracking every component and stage of manufacturing, traceability enables manufacturers to maintain an uninterrupted information flow from raw materials to the finished product. This visibility promotes regulatory compliance, keeps pollutants from spreading, and increases consumer confidence in dairy products.

One useful method to evaluate and enhance the traceability system's efficacy is to carry out a traceability simulation exercise. Dairy farmers can test the effectiveness, timeliness, and precision of their response systems by modeling a fictitious contamination event. By identifying possible gaps in the supply chain's data collection and transmission, this exercise makes it possible to put corrective measures in place before a real disaster happens. In the end, a proactive food safety management strategy for the dairy industry inside the Iasi Faculty of Agriculture's Dairy Production Workshop is based on strong traceability and recurring simulation exercises.

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