Food Safety Blockchain Technology for Monitoring the CCPs in UHT Milk Production

Wannakarn Lawilo[1], Ekkarat Boonchieng[2],
Pravate Tuitemwong[3], Saengrawee Jongvanich[4]
Thanyaporn Siriwoharn[5], Wachira Jirarattanarangsri[5],and Sukhuntha Osiriphun[5*]

[1]Graduated school of Faculty of Agro-Industry,
Chiang Mai University, Chiang Mai 50100, Thailand
[2]Department of Computer Science, Faculty of Science,
Chiang Mai University, Chiang Mai 50100, Thailand
[3]Department of Microbiology, Bioscience Program,
Risk and Decision Assessment Lad., Faculty of science,
King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[4]NEOGEN ASIA (THAILAND) Co., LTD., Bangkok 10120, Thailand
[5]Division of Food Science and Technology,
Agro-Industry, Chiang Mai University, Chiang Mai 50100, Thailand

Abstract

Food safety management systems increasingly utilize blockchain technology for verification and archival purposes. In the domain of milk production, the application of this technology offers an efficient approach to mitigate risk threats. This study aimed to develop a food safety blockchain for UHT milk production by incorporating HACCP-compatible risk assessments to identify risk parameters and mitigate microbial hazards. Over a year, it was found that 86.25% of a population of 1,000,000 consumed UHT milk. The Exponential and Modified Beta Poisson Models predicted potential illnesses caused by *E. coli* and *S. aureus* to be 1.02E+01 and 2.99E-01, and 3.59E-03 and 5.47E-04 persons per year, per 1,000,000 people, respectively. Using the recorded data, a functional blockchain technology system was created for the UHT milk supply chain. This novel blockchain system, the latest in Thailand, offers an alternative for enhancing food safety in various production sectors.

*Corresponding author : sukhuntha.o@cmu.ac.th
Received : 28/06/2023 Revised : 08/09/2023 Accepted : 25/09/2023

Keywords : Food Safety, Risk Assessment, Blockchain Technology, Milk Production

Introduction

Milk is a good source of nutrition for people at all ages [1]. Maintaining milk at high temperatures for a short amount of time is the main goal of dairy preservation. This results in the least harmful chemical, physical, and sensory alterations by killing microorganisms and inhibiting enzyme activity while also time [2]. This procedure increases the milk's shelf life without affecting its nutritional value. UHT processing uses a continuous flow of milk, which results in less chemical change [3]. Food risk management attempts to safeguard public health by minimizing food risks through the selection and implementation of appropriate controls. Food safety management systems, such as HACCP, which are frequently created on the basis of qualitative data, aim to protect people's health by limiting food risks as effectively as possible through the selection and implementation of appropriate procedures. Quantitative risk assessment can be used to provide more quantitative insight into food safety issues. A better knowledge of the elements affecting food safety is provided by quantitative risk assessment. There are four steps in it: identification of hazards, evaluation of exposure to hazards, characterization of hazards, and characterization of risks [4]. Food supply chain management has become more significant as a result of the rapid population growth and concomitant rise in food consumption. However, food supply chains around the world lose close to one third of their annual production. Food supply chain operations can now benefit from food safety, transparency, and traceability thanks to the growing usage of digital technology like blockchain [5, 6]. Therefore, it is essential to analyze each step of the food supply chain in order to increase its effectiveness and sustainability [7]. To verify the quality of raw milk, storage conditions, technology, animal welfare, and the environment, milk supply chains based on blockchain technology must be traced [8]. The milk industry uses blockchain technology to reduce the likelihood of milk spoilage and other hazards throughout the supply chain. Reduce risks by using blockchain technology to gather quality and hygiene data along the whole supply chain. Each piece of information, including the time, location, and distribution, were recorded. Each product group's milk transactions are all kept track on [9]. Throughout the supply chain, records of food-related data, milk quality, milk temperature, and moisture were maintained. For instance, a number of norms and laws have been established regarding temperature, humidity, expiration date, hygienic conditions, and other factors [10, 11]. It can use risk assessment concepts to gather data and do analysis food hazard related factors affecting food safety in order to create mathematical models and apply it in conjunction with blockchain technology to food safety.

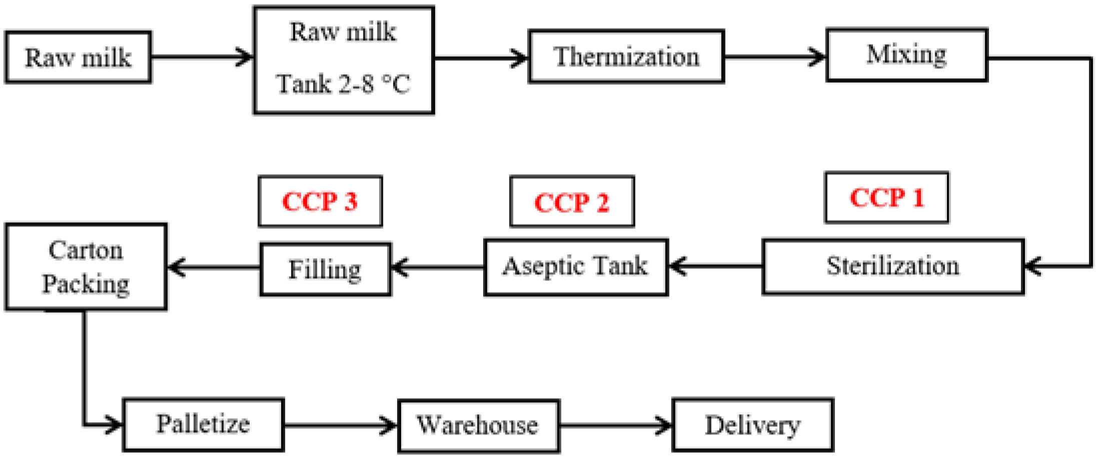

Figure 1: Process flow diagram of UHT milk

Research Objectives

To apply the food safety risk assessment concept for identifying the parameters for enhancing the CCPs of UHT milk production

To develop the food safety blockchain as a new tool for complying the HACCP system in UHT milk production

Research Methodology

1 Materials

Chiangmai Fresh Milk Co., Ltd., located in Chiang Mai Province, Thailand, kindly supplied the raw milk and UHT milk for this study. The samples of both raw milk and UHT milk were stored at temperatures of 0-8 °C and room temperature respectively, inside covered containers before transportation to the Faculty of Agro-Industry at Chiangmai University.

2. Identification of Parameters for Hazard Control of UHT Milk Production

The factory utilized in this research is Chiangmai Fresh Milk Co., Ltd. The UHT milk production process is controlled according to the HACCP standard, with critical control points (CCP) defined at three stages: 1. Sterilization, 2. Aseptic Tank, and 3. Filling. Figure 1 illustrates the chart of the production process and quality control for UHT milk.

3. Physico-chemical and Microbiological Analysis for Hazard Control and Quality Con-

trol

3.1 Physical Analysis

Color analysis for all samples was performed using a Minolta colorimeter (Konica Minolta, CR-400 Series), measuring L*, a*, and b* values on the Hunter scale.

3.2 Chemical Analysis

The determination of pH, total soluble solids (TSS), fat content, and protein content followed the AOAC 2000 guidelines.

3.3 Microbiological Analysis

The total plate count was performed following the FDA BAM analysis standards using 3M Petrifilm TM Aerobic Count Plates. The samples were applied to the plates with a micropipette and incubated for 48 hours at 35±1 °C. The colonies were counted twice upon completion of the process. Similarly, raw milk and UHT milk samples were tested for pathogenic bacteria according to the FDA BAM analysis standards. The criteria for sample selection included critical control points (CCPs) and food safety risk assessment. Pathogen counts for *Escherichia coli* and *Staphylococcus aureus* were carried out using 3M Petrifilm TM count plates following similar procedures.

3.4 Statistical Analysis

All measurements were performed in triplicate. The mean and standard deviation (SD) were computed for the data. Analysis of variance (ANOVA) and Duncan's multiple range tests were used to identify significant differences, with analysis conducted using SPSS software version 17.0.

4. Microbial Risk Assessment

Data on *E. coli* and *S. aureus* exposure to UHT milk were collected. This information, combined with data from literature, internet sources, and experimental data, was used to establish the dose-response model. Laboratory research data from the Faculty of Agro-Industry, Chiang Mai University, were also calculated in this study.

The probabilistic models of *E. coli* and *S. aureus* contamination in processed UHT milk samples were adequately explained by statistical models. The outcomes showed a statistical distribution of the amount and prevalence of *E. coli* and *S. aureus* in the final product. Microsoft Excel TM was used to sample 10,000 times to ensure that the output distributions' tails would eventually converge (Microsoft Corp., Redmond, WA, USA). To compute the intake dosage distributions, the data were employed.

4.1 Dose Response relationships

The measured relationship between the quantity of exposure (dose) and the frequency of occurrence of this effect in the exposed population of hosts (response) for a given concentration is represented by the dose-response correlation. In the dose-response relationship, the disease end-point used in this study was illness. The probability of ingesting number j is Pexp(j). The number of organisms may cause infection with a probability of infection (Pinf), and the infection may result in symptoms and develop into an illness with a probability of illness (Pill). Assuming that pathogenic organisms are distributed randomly within the food, the probability of exposure (Pexp) can be explained by Equation 1 [12].

$$P_{\text{exp}}(j) = \frac{\mu^j}{j!} e^{-\mu} \tag{1}$$

where μ is the average number of organisms ingested per piece, j is the total number of ingested organisms, duration > 0 indicates infection, and the length of the infection event is regarded as the most important factor in determining the disease. The length of the infection reflects the balance between host defenses and pathogen growth, which may vary depending on dose [13].

4.2 Exponential dose response model

The exponential dose-response model assumes a Poisson distribution with a mean of dose (λ) [14].

$$P(inf/\lambda) = 1 - exp(-\lambda_P) \tag{2}$$

where λ_P is the predicted number of infections caused by this dosage and the equation for $P(inf/\lambda)$ denotes the Poisson probability of at least one infection. Equation 2 can be rewritten as follows:

$$P(inf/\lambda) = 1 - exp(-r_D) \tag{3}$$

where r is equal to the previous probability p, but the Poisson mean λ is substituted by the actual dosage D received, which contradicts the underlying principle. Experimental data for the Thai dosage-response model were not available in our study. Alternatively, [15] used epidemiological and dietary survey data to construct a mathematical model to derive the R value for the exponential and dose-response models. The dose-response relationship of the pathogen may be characterized by the exponential model in Equation 4, based on the notion of a purposely cautious dose-response relationship:

$$P_{inf} = 1 - e^{-RN} \tag{4}$$

where P is the likelihood of a negative health consequence and N (or D) denotes the quantity of biological agents ingested (CFU). Equation 4 can be inferred and translated into Equation 5 using the following formula:

$$P_{inf} = 1 - e^{-RN} \tag{5}$$

where R is a constant specific to each pathogen, which aids in defining the dose-response curve. R is defined as follows:

$$ID_{50} = \frac{ln0.5}{-r} \tag{6}$$

where ID_{50} denotes the ingested dosage required to infect half of the exposed population or the median infectious dose.

4.3 Modified Beta Poisson model

Furumoto & Mickey, 1967 originally explained the modified beta poisson model [16], Haas, 1983 [17] used it for microbial dose-response calculations and applied further by Teunis et al., 1999 [18]. Pathogen-host interactions can be used to characterize the pathogen-host survival probability using a fixed value based on the results of the exponential model. The modified beta poisson model accounts for variability in pathogen-host interactions. If the pathogen-host survival probability is represented by the beta probability distribution, the probability of infection $(Pinf)$ may be expressed as follows:

$$P_{inf} = 1 - [1 + \frac{d}{ID50}(2^{1/\alpha} - 1)]^{-\alpha} \tag{7}$$

where d denotes the dose, α is a measure of the model's proximity to the Poisson distribution (exponential) or pathogen infectivity (slope parameter), and $ID50$ is the dose that infects half of the exposed population or the median infective dose. Given a dosage response function, the $ID50$ was calculated as follows:

$$ID_{50} = \frac{\beta}{(2^{1/\alpha} - 1)} \tag{8}$$

Where $\alpha$is shape parameter and β is scale parameter when $\beta \geq 1$and $\beta > \alpha$.

5. Application of Blockchain Technology in UHT Milk Production

Blockchain technology, a form of Distributed Ledger Technology (DLT), ensures data integrity by prohibiting alteration or modification of recorded data. It utilizes encryption principles and distributed computing capabilities to establish trust [19].

Blockchain technology allows for secure data storage in a distributed computing environment, reducing the risk of hacker attacks and identity theft. It provides access to the same data group for each user, simplifying verification and identity confirmation processes. The implementation of "self-sovereign identity" theory with blockchain technology enables organizations to compile personnel data without intermediaries. This not only reduces paperwork but also increases efficiency in verification processes. The integration of IoT and blockchain technology advances food safety traceability, permitting real-time audits and ensuring HACCP compliance from production inception to consumption.

Figure 2 illustrates the transition from a centralized database to a blockchain system for UHT milk production. Risk management data, including physical, chemical, and microbiological analysis data, are recorded at various stages of production such as homogenization/sterilization, aseptic tank filling, and carton packing/finished product.

The results of the microbiological risk assessment, encompassing information on pathogenic microorganisms in food and the likelihood of *E. coli* causing human illness, were included in the risk assessment data and made accessible to all departments involved in the production of UHT milk.

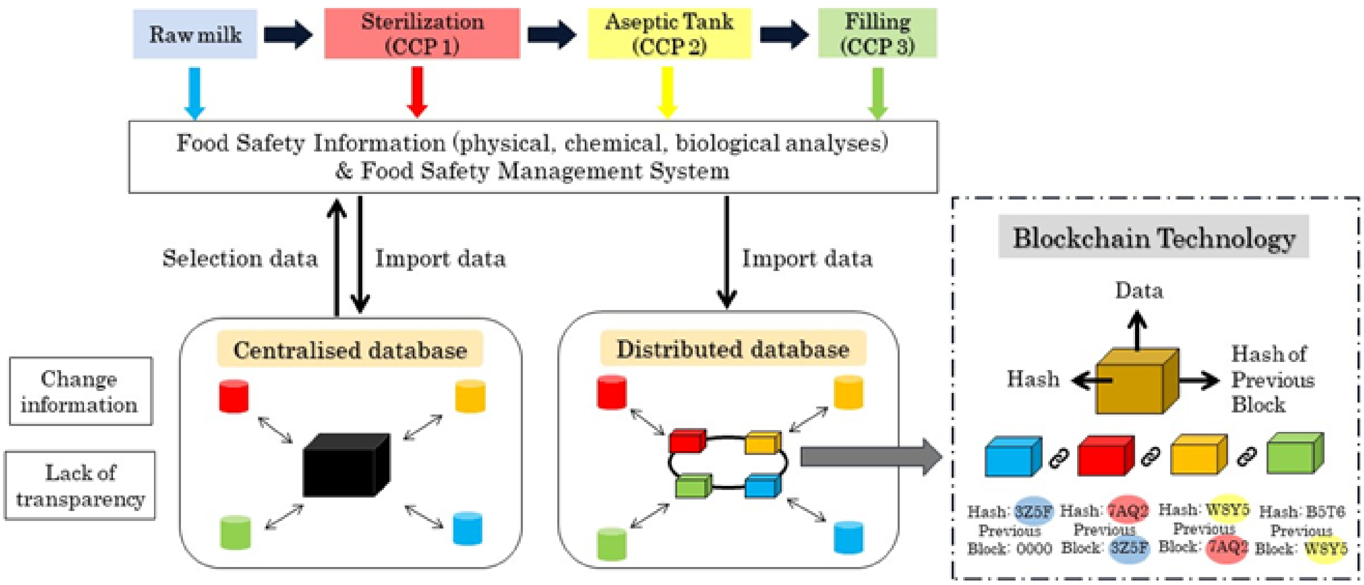

Figure 2: Application of Blockchain Technology to UHT milk production

Results

This research paper's Results section mainly focuses on the quality control methods of milk processing, specifically UHT (Ultra-high temperature processing) milk, and the monitoring of *E. coli* and *S. aureus* in UHT milk.

1. Hazard Control Analysis

Discusses the methods employed to control food-related illnesses in the processing of milk, implementing critical checks at various stages. These checks include sterilization, aseptic tank, and package integrity. The checks are measured against control limits to ensure they remain within safe parameters.

Food-related illnesses are becoming more prevalent. However, continuous conflicts over standards in food quality and safety inhibit international trade were to achieve acceptable quality standards. To ensure that the approved standards are maintained, milk quality must be monitored and managed using tests that have received international approval. There are rules and regulations for milk and milk products [20].

Quality assurance is required before the consumption of processed food can be achieved through the implementation of planned and systematic activities at each stage of the quality system. HACCP systems for food processing use critical checks at each stage of food processing to assess the risk of physical, chemical, or microbiological hazards. There was a critical control point, control measures and monitoring system as follows:

CCP 1: Sterilization

This was found that harmful germs survived. This was as a result that the Ultra-high-temperature processing temperature and time was dependent of the specified value. Control measures, such as temperature control and sterilization time, were created. UHT milk that has heated for one to eight seconds, typically at 135-154 °C, is the critical limit. The sterilization operator reads the data from the monitor at the pasteurized, tetra therm aseptic, and storage area every 30 minutes for sterilization batches as part of the monitoring system (Figure 3).

CCP 2: Aseptic Tank

This was found that harmful germs survived. This was as a result that the pasteurization's temperature and time was dependent of the specified value. Control measures, such as temperature control and pasteurization time, were created. End cluster valve at 110–120 °C and agitator at 95–105 °C for 30–40 minutes are the critical limits. A pasteurizer operator reads data from a monitor at the end cluster valve (110–120 °C) and an agitator on top (95–105 °C) for every sterilized batch every 30 minutes as a part of the monitoring system (Figures 4 and 5).

CCP 3: Filling (Package Integrity)

Within the constraints of the filler's sterile zone, aseptic packaging systems fill sterile product into sterile packages. From the point where sterilized packaging enters the sterile zone to the point where the sealed package was evacuated, there is an aseptic zone/sterile zone. Tetra Pak, Inc. was employed as a carton packing device and hydrogen peroxide sterilant for dairy goods.

Microorganisms, dust, and other pollutants contaminate products as a result of brazing and fields between packaging and incomplete products. In order to examine the coordination and welding between the package and the product at the top of the box, bottom of the box, pull test, and ink injection, control procedures were devised. the links to the packages below. It has a monitoring system, and every 30 minutes, the controller takes a sample of the product to verify.

The TS (left and right jaw) at the top and bottom of the box did not exhibit any leaks, and the connections were sound, according to Table 1's examination of the box for leaks. Erythrosin red ink was injected directly down the air channel without deviating, and after that, the box seam connection was finished without leaks or fractures.

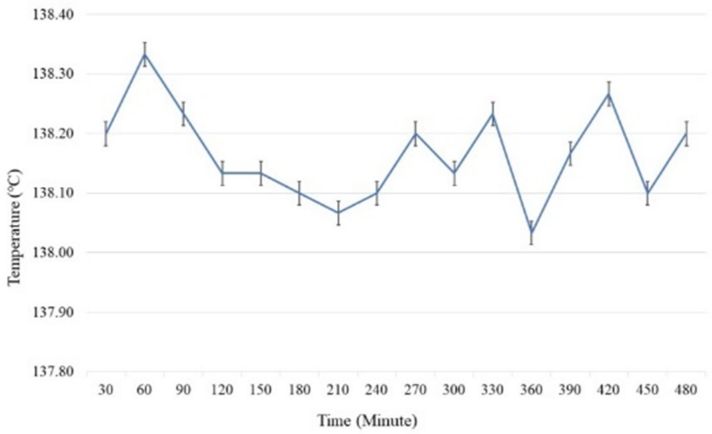

Figure 3: Monitoring of the sterilization temperature at 135 ^{o}C every 30 minutes.

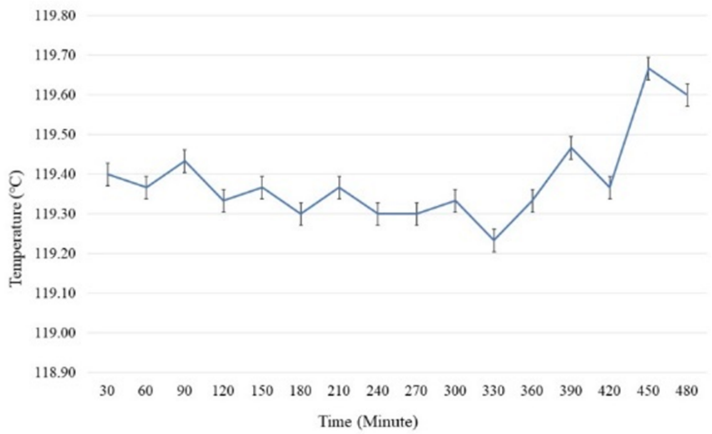

Figure 4: Temperature monitoring at the end of cluster valve at 110-120 ^{o}C every 30 min.

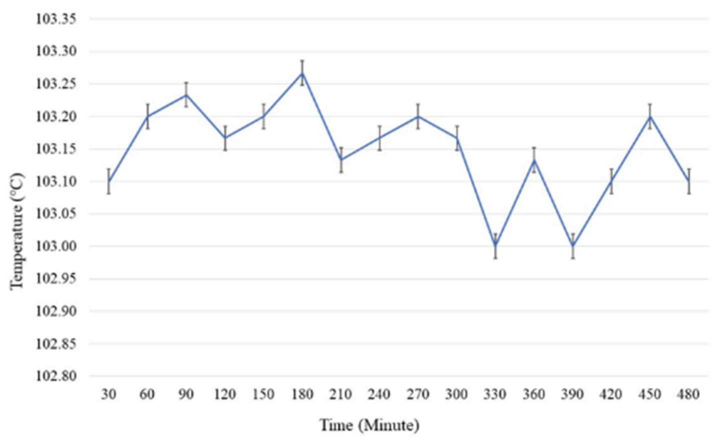

Figure 5: Temperature monitoring at the agitator's top at 95-105 ^{o}C every 30 minutes.

Table 1: Statistical analytical results of physical-chemical analyses of raw milk and UHT milk

Parameter	Color (Hunter scale)			pH	TSS	Fat	Protein
	L*	a*	b*		(°Brix)	(%)	(%)
Raw Milk	85.29 ± 0.96^{c}	-3.38 ± 0.21^{b}	5.51 ± 0.63^{b}	6.74 ± 0.03^{a}	9.88 ± 0.96^{d}	3.79 ± 0.05^{a}	3.05 ± 0.01^{b}
UHT Milk (CCP1)	91.64 ± 1.43^{b}	-2.81 ± 0.48^{a}	6.93 ± 0.96^{a}	6.53 ± 0.02^{b}	12.70 ± 0.09^{c}	3.57 ± 0.03^{bc}	3.04 ± 0.06^{a}
UHT Milk (CCP2)	92.30 ± 0.70^{ab}	-2.99 ± 0.32^{a}	7.27 ± 0.72^{a}	6.53 ± 0.01^{b}	12.90 ± 0.15^{a}	3.56 ± 0.01^{c}	3.05 ± 0.03^{b}
UHT Milk (CCP3)	92.47 ± 0.86^{ab}	-3.05 ± 0.39^{ab}	7.48 ± 0.42^{a}	6.54 ± 0.05^{b}	12.73 ± 0.13^{bc}	3.57 ± 0.02^{bc}	3.06 ± 0.05^{b}

Values in a column followed by different letters indicate significant differences. ($P<0.05$)

2. UHT Milk Quality

The research delves into the physical, chemical, and microbiological aspects of UHT milk quality. This includes comparing raw milk and UHT milk samples in terms of their components, such as fat, protein, and pH levels. The comparison also extends to their color using the Hunter scale. It concludes that there's no significant difference between raw milk and UHT milk in these aspects. The section also demonstrates the effectiveness of sterilization in eliminating bacteria.

The data in Table 1 show that the average values for color (a*, b*, and L* on the Hunter scale), pH, TSS, fat, protein, and color in samples of raw milk were 85.29±0.96, -3.38±0.21, 5.51±0.63, 6.74±0.03, 9.88±0.23, 3.79±0.05, and 3.05±0.01, respectively. For raw cow milk, the TAS 6003-2010 Thai Agricultural Standard was set for the quality and safety of products. It indicates that the protein content should be at least 3 percent by weight, the pH should be between 6.6 and 6.8, and the fat content should be at least 3.35 percent by weight.

Thermoresistant spores in milk are not totally inactivated by pasteurization procedures, despite the fact that possible pathogenic germs are successfully eradicated. The elimination of all bacteria is accomplished through sterilization. Physical and chemical testing were done to make sure the end product (UHT milk) complied with the requirements for quality and safety. The data provided in Table 1 demonstrates that there was no significant difference in the mean values of color (a*, b*, and L* on the Hunter scale), pH, TSS, fat, and protein in UHT milk samples (CCP 1-3). The 2013 Notification (No. 352) from the Ministry of Public Health guided the conduct of this study.

Table 2: Statistical analytical results of microbiological analysis of raw milk and UHT milk

Parameter	Raw Milk				UHT Milk (CCP1)				UHT Milk (CCP2)				UHT Milk (CCP3)			
	Count (CFU/ml)															
Dilution	10^1	10^2	10^3	10^4	10^1	10^2	10^3	10^4	10^1	10^2	10^3	10^4	10^1	10^2	10^3	10^4
Total Plate Count	TNTC	TNTC	8.3×10^4	ND	ND				ND				ND			
E. coli	1.12×10^2	ND	ND	ND	ND				ND				ND			
S. aureus	TNTC	TNTC	ND	ND	ND				ND				ND			

TNTC = too numerous to count and ND = not detected

As a result, Table 1's physical-chemical analysis of raw milk and UHT milk demonstrates that sterilized raw milk provides UHT milk that completed all necessary processing. Comparing BE 2013 to the Thai Agricultural Standard (TAS 6003-2010) and the Ministry of Public Health's Notification (No. 352) for raw cow milk.

The data shown in Table 2 illustrates that the mean values of total plate counts, total coliform counts, *Escherichia coli* counts, and *Staphylococcus aureus* counts (cfu/ml) in raw milk samples were total plate counts at dilutions 10^1 and 10^2 were too numerous to count, at dilutions 10^3 and 10^4 were 8.3×10^3 cfu/ml and not detected, respectively. Total coliform counts at dilutions 10^1, 10^2, 10^3, and 10^4 were not detected, *E. coli* found at dilution 10^1 was 1.12×10^2 cfu/ml and at other dilutions was not detected, and *S. aureus* found at dilutions 10^1 and 10^2 was too numerous to count and at other dilutions was not detected. For raw cow milk, all results meet the Thai Agricultural Standard (TAS 6003-2010).

Accordingly, the results of the microbiological investigation of raw milk and UHT milk (Table 2) demonstrated that the production of UHT milk was prevented by microorganisms, as evidenced by the lack of total plate count, total coliform count, *E. coli* count, and *S. aureus* count in UHT milk. UHT milk effectively destroys bacteria during production, but it also signifies the creation of crucial control points in a successful HACCP system. It may effectively remove the main microorganisms that are harmful to milk.

3. Probabilistic Distribution of Exposure to *E. coli* and *S. aureus* in UHT Milk

Describes the probabilistic distribution of exposure to *E. coli* and *S. aureus* in UHT milk. The research makes an assumption that these bacteria are randomly distributed in all processes, and transfer rates were calculated using a given formula. The study then uses dose-response models to predict the risk of illness based on the presence of these bacteria.

To simplify the probabilistic model, we assumed that *E. coli* and *S. aureus* were randomly distributed in all the processes, including raw milk, processing, and consumption. *E. coli* and *S. aureus* were not found in UHT milk products collected during processing. To establish the concentrations of *E. coli* and *S. aureus* in the UHT milk samples, the transfer rates of *E. coli* and *S. aureus* to UHT milk were determined. The transfer rates were calculated based on the number of microorganisms present on surfaces that were recovered by a single contact plate, using the following formula: % transfer rate = (Ns/Nf) × 100%, where Nf = CFU recovered from food and Ns = CFU on surfaces recovered by contact plate [21].

From the dose-response relationships, the imputed daily dose can be computed based on the daily and annual risks. It was assumed that *E. coli* and *S. aureus* infections were restricted to the Thai population (66,159,679 individuals).

The total amount of UHT milk consumed by the sub population of concern was approximately 49 g/day, and the levels of *E. coli* and *S. aureus* in UHT milk were assumed to be 50 and 100 mean CFU/g, respectively (from our laboratory). Thus, the levels of *E. coli* and *S. aureus* ingested when these products are consumed were calculated by multiplying the level of *E. coli* and *S. aureus* in the UHT milk by the serving size, N *E. coli* = 50 × 49 g = 2,450 CFU/serving/day, N *S. aureus* = 100 × 49 g = 4,900 CFU/serving/day. The total number of servings per day of UHT milk products consumed by the Thai population with a high level of *E. coli* was 49 × 50 ≈ 2,450 serving/day and *S. aureus* was 49 × 100 ≈ 4,900 serving/day.

An exponential dose-response curve was constructed from the concept of a purposefully conservative dose-response relationship for the Thai population. The Beta-Poisson curve assumes that the R value is not a coefficient constant, but is a beta probability distribution [22]. The parameter values used to predict the dose-response curves are listed in Table 3.

Table 3: Summary of parameters used in Exponential and Beta Poisson dose response models

Data set	1	2	3	4
Agent	*E. coli* O157:H7	*E. coli* O157:H7	*Staphylococcus aureus*	*Staphylococcus aureus*
Best fit model	Exponential	Beta-Poisson	Exponential	Beta-Poisson
Optimized parameter(s)	R = 2.18E-04	α = 1.55E-01 β= 2.11E+06	R = 7.64E-08	α=1.30E-01 β=2.3E+09
LD50/ID50	3.18E+03	-	9.08E+06	-
Host type	pig	human outbreaks	human	-
Agent strain	EHEC O157:H7,	*E. coli* O157:H7	-	-
Route	Oral (in food)	Oral (in milk)	subcutaneous	-
# Of doses	3	3	6	-
Dose units	CFU	-	CFU/cm^2	-
shedding in feces	shedding in feces	-	infection	-
Reference	[23]	[24]	[25]	Predicted

3.1 Dose Response Models

The dose-response models used in this study were the Exponential and Beta-Poisson models. The R values were 2.18E-04 and 7.64E-08 of datasets 1 and 3 were used to calculate the dose-response curves of the Exponential model for *E. coli* and *S. aureus*, respectively. The alpha (α) values of dataset 2 (*E. coli*) and dataset 4 (*S. aureus*) for the Beta-Poisson models are 1.55E-01 and 1.30E-01, respectively, and the beta (β) values for datasets 2 and 3 are 2.11E+06 and 2.3E+09, respectively.

The R, α and β values in datasets 1, 2, and 3 were obtained from [23, 24, 25] and predicted from dataset 3, respectively. The results for these formulas are presented in Table 3.

Figures 6 (a, b) to 7 (a, b) illustrate the predicted models' probability of illness from infection based on datasets 1, 2, 3, and 4. The risk estimate was obtained using the dose-response parameters. It was calculated how several *E. coli* and *S. aureus* disease cases there seem to be each year in Thailand.

The section continues to explain the dose-response models - Exponential and Beta Poisson models - used to calculate the risk of illness from *E. coli* and *S. aureus*. The paper also predicts

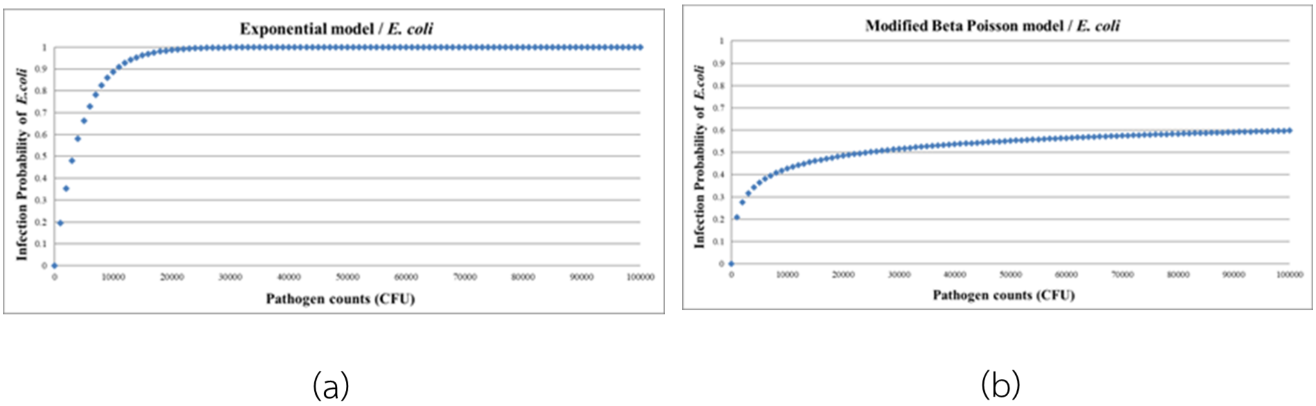

Figure 6: Probability of *E. coli* infection predicted by Exponential model (a) and Modified Beta Poisson model (b)

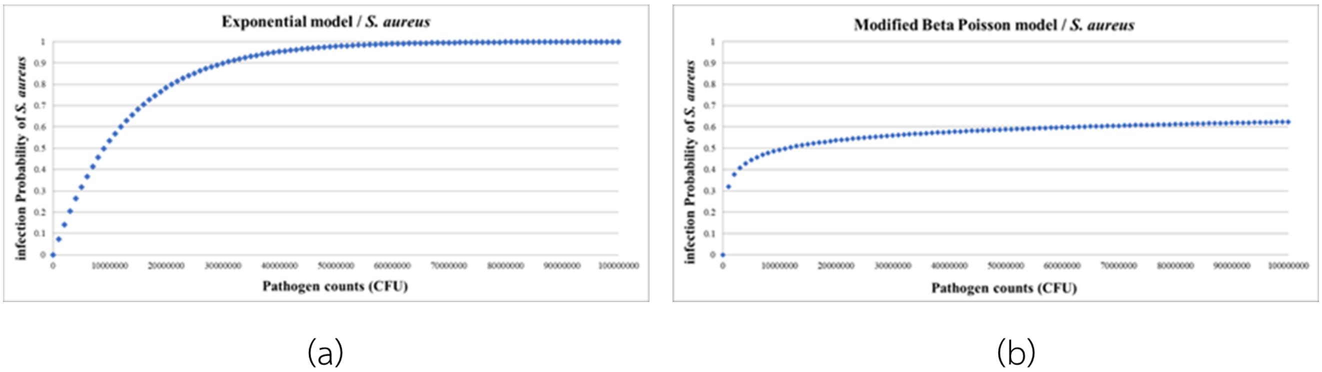

Figure 7: Probability of *S. aureus* infection predicted by Exponential model (a) and Modified Beta Poisson model (b)

how many disease cases from these bacteria could occur in Thailand per year. The research finally discusses the use of blockchain technology in the production of UHT milk. The technology is touted as a solution to challenges in data traceability and transparency in milk production. The use of smart contracts, automation through the Internet of Things, and consumer access via mobile applications are presented as potential advancements.

4. Model of Blockchain Technology System for UHT Milk Production

Figure 8 illustrates that blockchain technology has been applied to the production of UHT milk. Information can really be edited or modified using the distributed database system for use by blockchain. Data gathering helps manage and store important products and supply chains. Through this, it is possible to overcome the challenges to data traceability and transparency in the production of UHT milk. All participants in the UHT milk process, including employees, supply chain representatives, and stakeholders, have required to follow by the guidelines of the hazard analysis and critical

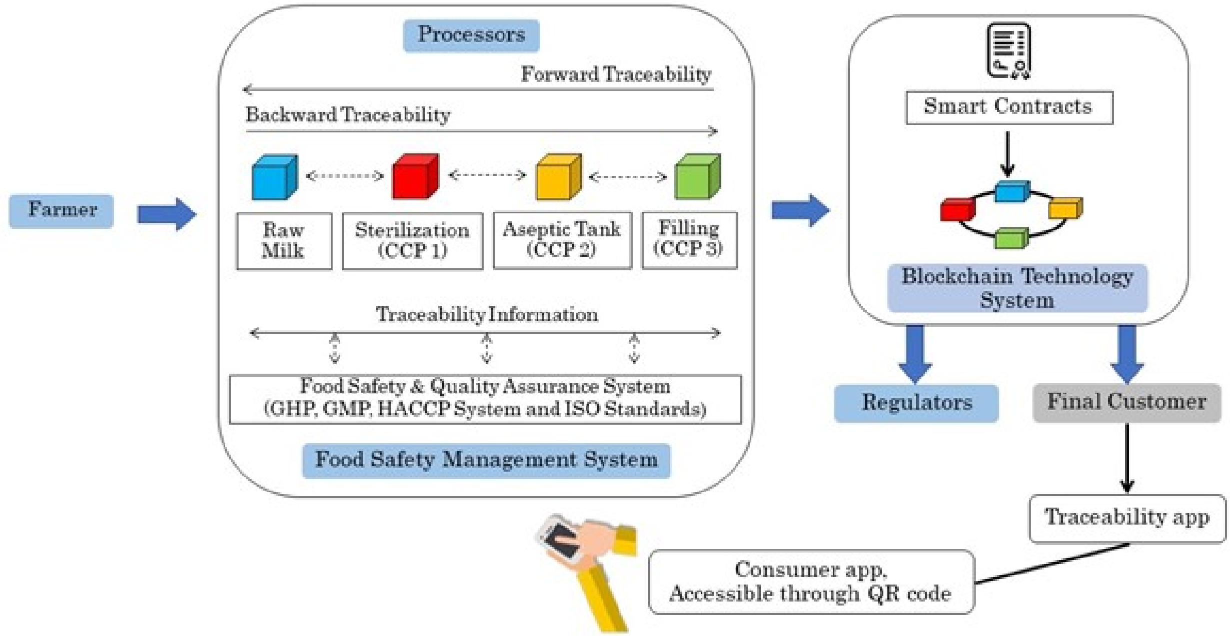

Figure 8: Model of Blockchain Technology System for UHT Milk Production

control point (HACCP) system. The Internet of Things can automate it. RFID tags, sensors, and other devices can be used for automation to update data based on the system.

It is important to use blockchain technology in smart contracts to conduct thorough, recorded administrative audits that could hinder the overall performance of the UHT milk process. Smart contracts should also be encrypted to prevent fraud, theft, and other management concerns. Blockchain networks are deploying smart contracts. Each linked node receives these contracts. Recent modifications to the local database could lead the computer code's conditions to behave in accordance with the relevant stream or notification.

The UHT milk process is completed by consumers, who can access the consumer app using an Android or iOS device. According to the information given, this can be accessed by scanning a QR code located on the UHT milk product. to improve trust and transparency, as well as to help consumers choose products.

In summary, this research provides significant information on the safety measures, quality assurance techniques, and risk assessment of bacterial contamination in the production of UHT milk. Moreover, it explores the potential of technological advancements in maintaining food safety standards.

Discussion

1. Hazard Control Analysis

Based on the determination of the critical control point, control measures, and monitoring system, it was discovered that the control measures at CCP1-3 (CCP 1: Sterilization, CCP 2: Aseptic Tank, and CCP 3: Filling (Package Integrity) were within the required criteria during the UHT milk production process every 30 minutes, indicating that the critical control point was defined in the HACCP system can truly control the hazards that may occur in the production process. UHT processing uses continuous flow, which renders less chemical change to the product in comparison to retort processing. Minimum processing times and temperatures are determined by the inactivation of thermophilic bacterial spores [3]. Ideal time-temperature profiles inactivate bacterial endospores and limit chemical changes with minimal decrease in nutritional and sensory quality [26]. The major challenge in UHT milk production is sufficient heat treatment with minimal flavor change. Direct heating imparts less flavor change but requires more energy in comparison to indirect heating. Total microbial lethality at constant time and temperature varies between direct and indirect heating systems [27].

2. UHT Milk Quality

The Ministry of Public Health's notification (No. 352) B.E. 2013 Re: Other Milk Products, stating that there was no contamination with pathogenic bacteria, is consistent with the average values of total plate count, total coliform count, *E. coli* count, and *S. aureus* count (cfu/ml) not being found in UHT milk. The total plate counts, total coliform counts, *E. coli* counts, or *S. aureus* counts (cfu/ml) should not be included in a 0.1 ml sample, though. All findings were within control limits as per the HACCP plan and the Ministry of Public Health (No. 352) B.E. 2013 Re: Other Milk Products. Product characteristics such as pH, water activity, viscosity, composition, and dissolved oxygen dictate the processing conditions necessary to achieve commercial sterility [28].

And as shown in Table 2, the results of the analysis of microbial contamination show that the microorganisms analyzed are all bacteria. Coliform bacteria, *E. coli* and *S. aureus*. The results of the analysis can be discussed as follows: Analysis of raw milk found *E. coli* and *S. aureus* which are consistent with Bryan, 1983 [29]. Raw milk was often implicated in outbreaks of staphylococcal intoxication before rapid cooling of milk and pasteurization became accepted practices. Several workers isolated *E. coli* from milk and stated that it might cause a potential risk, particularly for children [30], comparable to what was reported by Salman and Hamad, 2011 [31] reported that about 32% of the raw bulk milk was *E. coli* positive in Khartoum State. After UHT milk, there was no growth of *E. coli* in the samples obtained from factory (Table 2). This result was in agreement with that reported by SSMO, 2007 [32] for pasteurized milk of *E. coli* which was zero, and this stated that UHT milk should be free from pathogenic microorganisms, with a total bacterial count of not more than 10 cfu/ml and free from *E. coli*. Higher results were obtained by El-Asuoty, 2006 [33].

The results of this study showed that, no growth of *S. aureus* in samples (Table 2). The results are in disagreement with Laszlo, 2003 [34] reported count of more than 10^3 cfu/ml. While Lílian, et al. (2011) found that 30% of the samples were contaminated with *Staphylococcus aureus*. This study revealed that the Total Plate Count, Total Coliforms, *S. aureus* and *E. coli*, are absent (Table 2). This result agrees with [35] after the application of HACCP. The lower bacterial counts might be due to quality of raw milk, good manufacturing practices, and efficient storage conditions. The present study revealed proper pasteurization due to the reduction of microorganisms, which agreed with Dumalisile et al., 2005 [36].

3. Probabilistic Distribution of Exposure to *E. coli* and *S. aureus* in UHT Milk

An exponential dose-response curve was constructed from the concept of a purposefully conservative dose-response relationship for the Thai population. The ID50 or ND50 and alpha values for the Beta-Poisson model were calculated from the value of R using Equation 8. The Beta-Poisson curve assumes that the R value is not a constant, but is a beta probability distribution [37]. The ID50 and alpha values of this study were lower than the study of Crockett et al., 1996, where the ID50 was 2.54E+13 and the alpha values were 9.47E+2 [38].

4. Model of Blockchain Technology System for UHT Milk Production

Figure 8 shows the application of blockchain technology in UHT milk demonstrates the storage process that enables short-time and reliable traceability of food safety-related data. In those study of Steiner et al., 2016; Tian, 2016; Kamath, 2018; Lin et al., 2018 [39, 40], it was determined that: Blockchain Technology is a rapidly evolving technology and with wide use, it appears to be changing many areas in the public and private areas of the food and agricultural industry. Traceability of block chain technology to improve safety / Quality of the global food supply chain and international distribution, blockchain technology. It has the ability to keep records unchanged and a traceable transaction history, which has great potential for increased efficiency, transparency and traceability [41].

Security management is the creation of an information database. That is beneficial to the management of the factory and will be information for factory executives to make decisions in various fields. It is a reflection of the overall risks. Risk management will give management a better understanding and realize the importance of information system management and manage the resources efficiently and appropriately. This makes the management confident in the management and making decisions in areas such as strategy formulation future event planning, etc.

There are extremely few persons that use computer technology in the food industry. And we can demonstrate that computer technology can manage security data. This is advantageous to both manufacturers and consumers Farmers and producers can properly explain raw ingredients and manufacturing processes. Meanwhile, consumers or buyers may correctly verify the product's origin as well as the supply chain. Scan a QR code on the package to obtain information. You can also learn about the certification of international quality and food safety standards. Blockchain Technology that has been generally acknowledged for data accuracy in various organizations such as finance, procurement, and supply chain, etc., to boost customer and consumer confidence in accessing information.

Conclusion

Hazard Characterization, it was found that the risk was low. The probability of illness per person per year from the consumption of UHT milk. The Exponential Model and the Modified Beta Poisson Model caused by *E. coli* were 1.02E+01 and 2.99E-01 and *S. aureus* was 3.59E-03 and 5.47E-04 person per year, per 1,000,000 people, respectively, based on this study, that also examines the perceived hazard of *E. coli* and *S. aureus* illness related to the consumption of UHT milk products. The CCPs and risk parameters at each steps of UHT milk production had been approached.

Using blockchain technology, it's also able to rapidly and securely validate every piece of information related with a food item. Similar to the above, in the instance of an outbreak of a foodborne illness, the history of a particular food item can be examined to identify the heart of the problem, allowing it to be rapidly recalled. Food products with blockchain-based information dissemination can enhance consumer confidence in a food product with blockchain-based information attached to it, ultimately preventing consumers from falling for counterfeit food products. This is because the information stored in the blockchain platform cannot be altered.

Finally, despite the fact that utilizing blockchain-based dairy supply chain systems seems to provide a variety of advantages, there are also a number of difficulties in their implementation. Blockchain is a recent technology, and business owners now face higher administrative costs. The noncommercial and fragmented dairy farming industry in developing nations is another significant limitation. The participation of these farmers in a blockchain-based dairy supply chain system does not come without difficulties. Therefore, in-depth research is required in order to apply blockchain technology to the dairy industry. Furthermore, these techniques can be applied to other related food industries in the future.

Acknowledgments

The authors gratefully acknowledge scientists at the Faculty of Agro-Industry, Chiang Mai University, for their assistance with laboratory work.

This research and innovation activity is funded by National Research Council of Thailand (NRCT) (Grant ID N41B650178 GSCMU(NRCT)/13/2565), and the work was kindly supported by Faculty of Agro-Industry, Chiang Mai University

This work was supported by NEOGEN ASIA (Thailand) for 3M Petrifilm: aerobic count plate, *E. coli*/coliform count plate, and staph express count plate.

References

[1] En, A., Donia, M., Abd-Rabou, N., Abou-Arab, A., & El-Senait, M. (2009). Chemical Composition of Raw Milk and Heavy Metals Behavior During Processing of Milk Products. Global Veterinaria, 3.

[2] Raljić, J., Lakić, N., Lalicic, J., Barac, M., & Sikimic, M. (2008). Color Changes of UHT Milk During Storage. Sensors, 8, 5961-5974. https://doi.org/10.3390/s8095961

[3] Datta, N., & Deeth, H. (2007). UHT and Aseptic Processing of Milk and Milk Products. Advances in Thermal and Non-Thermal Food Preservation. https://doi.org/10.1002/9780470277898.ch4

[4] Food & Agriculture Organization. (1997). Codex alimentarius. Food hygiene basic texts. Hazard analysis and critical control point (HACCP) system and guidelines for its application, 38-44.

[5] Demestichas, K., Peppes, N., Alexakis, T., & Adamopoulou, E. (2020). Blockchain in Agriculture Traceability Systems: A Review. Applied Sciences, 10, 4113. https://doi.org/10.3390/app10124113

[6] Kamble, S., Gunasekaran, A., & Gawankar, S. (2019). Achieving Sustainable Performance in a Data-driven Agriculture Supply Chain: A Review for Research and Applications. International Journal of Production Economics, 219, 179-194. https://doi.org/10.1016/j.ijpe.2019.05.022

[7] Pohlmann, C., Scavarda, A., Alves, M., & Korzenowski, A. (2019). The role of the focal company in sustainable development goals: A Brazilian food poultry supply chain case study. Journal of Cleaner Production, 245, 118798. https://doi.org/10.1016/j.jclepro.2019.118798

[8] Charlebois, S., & Haratifar, S. (2015). The perceived value of dairy product traceability in modern society: An exploratory study. Journal of Dairy Science, 98, 3514–3525. https://doi.org/10.3168/jds.2014-9247

[9] Kayikci, Y., Subramanian, N., Dora, M., & Bhatia, M. (2020). Food supply chain in the era of Industry 4.0: Blockchain technology implementation opportunities and impediments from the perspective of people, process, performance and technology. Production Planning and Control, 1-21. https://doi.org/10.1080/09537287.2020.1810757

[10] Tan, A., & Phạm Thi, N. (2020). A Proposed Framework model for dairy supply chain traceability. Sustainable Futures, 2, 100034. https://doi.org/10.1016/j.sftr.2020.100034

[11] Casino, F., Kanakaris, V., Dasaklis, T., Moschuris, S., Stachtiaris, S., Pagoni, M., & Rachaniotis, N. (2020). Blockchain-based food supply chain traceability: a case study in the dairy sector. International Journal of Production Research, 59, 1-13. https://doi.org/10.1080/00207543.2020.1789238

[12] Pfm, T., der, H., der, G., & Havelaar, A. (1996). The dose-response relation in human volunteers for gastro-intestinal pathogens.

[13] Teunis, P. F. M., Nagelkerke, N. J. D., & Haas, C. N. (1999). Dose Response Models For Infectious Gastroenteritis [https://doi.org/10.1111/j.1539-6924.1999.tb01143.x]. Risk Analysis, 19(6), 1251-1260. https://doi.org/https://doi.org/10.1111/j.1539-6924.1999.tb01143.x

[14] Vose, D. (2008). Risk Analysis – A Quantitative Guide.

[15] Buchanan, D., Claydon, T., & Doyle, M. (1999). Organisation development and change: the legacy of the nineties. Human Resource Management Journal, 9(2), 20-37. https://doi.org/https://doi.org/10.1111/j.1748-8583.1999.tb00194.x

[16] Furumoto, W. A., & Mickey, R. (1967). A mathematical model for the infectivity-dilution curve of tobacco mosaic virus: Theoretical considerations. Virology, 32(2), 216-223. https://doi.org/https://doi.org/10.1016/0042-6822(67)90271-1

[17] Haas, C. N. (1983). Estimation of risk due to low doses of microorganisms: a comparison of alternative methodologies. Am J Epidemiol, 118(4), 573-582. https://doi.org/10.1093/oxfordjournals.aje.a113662

[18] Haas, C. (2003). Dose-Response Modeling for Microbial Risk. In Food Safety Handbook (pp. 47-57). https://doi.org/https://doi.org/10.1002/047172159X.ch4

[19] Yermack, D. (2017). Corporate Governance and Blockchains*. Review of Finance, 21(1), 7-31. https://doi.org/10.1093/rof/rfw074

[20] FAO/WHO, (2010). FAO/WHO expert meeting on the application of nanotechnologies in the food and agricultural sectors: Potential food safety implications-meeting report Rome (2010), pp. 24-42

[21] Kusumaningrum, H., Riboldi, G., Hazeleger, W. C., & Beumer, R. (2003). Survival of pathogens on stainless steel surfaces and cross-contamination to foods. International journal of food microbiology, 85, 227-236. https://doi.org/10.1016/S0168-1605(02)00540-8

[22] Gale, P. (2001). Developments in microbiological risk assessment for drinking water. Journal of Applied Microbiology, 91(2), 191-205. https://doi.org/https://doi.org/10.1046/j.1365-2672.2001.01421.x

[23] Cornick, N. A., & Helgerson, A. (2004). Transmission and Infectious Dose of Escherichia coli O157:H7 in Swine. Applied and environmental microbiology, 70, 5331-5335. https://doi.org/10.1128/AEM.70.9.5331-5335.2004

[24] DuPont, H. L., Formal, S. B., Hornick, R. B., Snyder, M. J., Libonati, J. P., Sheahan, D. G., LaBrec, E. H., & Kalas, J. P. (1971). Pathogenesis of Escherichia coli Diarrhea. New England Journal of Medicine, 285(1), 1-9. https://doi.org/10.1056/nejm197107012850101

[25] Haas, C. N., Rose, J. B. & Gerba, C. P. (1999). Quantitative Microbial Risk Assessment. John Wiley& Sons, New York.

[26] Datta, N., Elliott, A. J., Perkins, M. L., & Deeth, H. C. (2002). Ultra-High-Temperature (UHT) Treatment of Milk: Comparison of Direct and Indirect Modes of Heating. The Australian Journal of Dairy Technology. 57 (3): 211-227.

[27] Westhoff, D. C. (1981). Microbiology of Ultrahigh Temperature Milk. J. Dairy Sci. 64 (1): 167-173.

[28] Overman, E. M. (1998). Aseptic Packaging and Shelf Stability of Foods. M.S. Report. Kansas State University.

[29] Bryan, F. L. (1983). Epidemiology of milk borne diseases J. Food Prot. 46.637-649.

[30] Padhye, N, V. & Doyle, M . P. (1991). Escherichia coli epidemiology pathogenesis and methods for detection in food .J. prot., 55(7):555- 556.

[31] Salman , A. & Hamad, I. M. (2011). Enumeration and identification of coliform bacteria from raw milk in Khartoum State, Sudan. Journal of Cell and Animal Biology Vol. 5(7), 121-128.

[32] SSMO (2007). Sudanese Standards and Metrology Organization. Sudanese standards for pasteurized milk No(189).

[33] Elmagli, A. A. O. & Elzubeir, I. E. M. (2006). Astudy on the compositional quality of pasteurized milk in Khartoum State (Sudan). International journal of dairy science, 1 (1):12-20.

[34] László,V. (2003). Microbiological quality of commercial dairy products. In: A. Mendez-Vilas (Ed). Communicating Current Research and Educational Topics and Trends in Applied Microbiology.

[35] Kassem, M., Salem, E., Ahwal, A., Saddik, M., & Gomaa, N. (2002). Application of hazard analysis and critical control point system in the dairy industry. Eastern Mediterranean health journal = La revue de santé de la Méditerranée orientale = al-Majallah al-sihhiyah li-sharq al-mutawassit, 8, 114-128. https://doi.org/10.26719/2002.8.1.114

[36] Dumalisile, P.; Withuhn, R. & Jbritz, T.(2005). Impact of different pasteurization temperatures on the survival of microbial contamination isolated from pasteurized milk. International Journal of Dairy Technology, 58(2):74-82.

[37] Gale, P., Developments in microbiological risk assessment for drinking water. Journal of Applied Microbiology, 2001. 91(2): p. 191-205.

[38] Awosile, B. B. & B. A. Smith (2017). "Risk assessment modelling of fecal shedding caused by extended-spectrum cephalosporin-resistant Escherichia coli transmitted through waste milk fed to dairy pre-weaned calves." Journal of Dairy Science 100(12): 9667-9673.

[39] Kamath, R. (2018). Food traceability on blockchain: Walmart's pork and mango pilots with IBM. The Journal of the British Blockchain Association 1 (1), 3712.

[40] Lin, J., et al., (2018). Blockchain and IoT based food traceability for smart agriculture. Proceedings of the 3rd International Conference on Crowd Science and Engineering.

[41] Tripoli, M. & Schmidhuber, J. (2018). Emerging Opportunities for the Application of Blockchain in the Agri-food Industry.