CONTACTLESS METHODS FOR QUALITY EVALUATION OF DAIRY PRODUCTS

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Abstract: The aim of the report is to present a comparative analysis of the methods and technical means for assessment of the quality and safety of dairy products, particularly yellow cheese by spectral characteristics. As a result of the analysis are established appropriate methods for representation of the spectral characteristics and classification of the researched product. In the development are shown and evaluated the accuracy and performance of the results of studies conducted in the laboratory of the Trakia University, faculty of Technics and technologies with the discussed methods for evaluation the quality of the food product.

Keywords: Dairy products, Noncontact methods, Yellow cheese, Spectral analysis, Classification.

1. INTRODUCTION

Milk and dairy products are one of the main foods that presents on our table. Due to their structure and chemical composition they are favorable environment for microorganisms. Secondary contamination can occur in the extraction of raw materials and at different stages of production of dairy products. Today, most consumers monitor a wider range of criteria in choosing of dairy products. They consider dairy products not only in terms of their taste and their direct nutritional value, but also in terms of their potential beneficial and health effects. This makes the traditional and well-established dairy products in an appropriate basis for the search and development of new functional foods and directs its efforts towards characterization of lactic acid microflora [27,32].

Figure 1. Number of publications for dairy products in Google Scholar and ScienceDirect

Therefore, before, now and in the future dairy products have been, are and will be a constant subject of research by many scientists. This is evidenced the recent upward trend in the number of scientific papers published in refereed databases [9,24] „ScienceDirect“ and “Google Scholar“ (Figure 1) on the innovations in assessing the quality of dairy products.

With the country's accession to the European Union (EU) dairy industry has become an integrated part of the European Common Market, as well as to policy and regulations existing in the market and on market competition. The milk sector in Bulgaria, unlike that of other member states, has its specificity – it is based mainly on cattle, although Bulgaria has traditionally been a manufacturer and sheep, goat and buffalo milk – in the limited quantities. While in other EU countries the share of cow's milk is over 98%, in Bulgaria it is between 85-90% with an expected upward trend due to the continued contraction of the sheep and goat farming in the new marginalization [4].

a) Production of dairy products

b) Consumption of dairy products

Figure 2. Production and consumption of dairy products by year

The results of in-depth analysis testify to a distinct tendency to maintain high levels of production and consumption (Figure 2) dairy products from cow's milk in Bulgaria and the European Union, White and Yellow Cheese remains one of the most consumed products [8]. The production and control of this product should be harmonized with European requirements and tailored to the nature and specifics of consumer needs. Safety, quality and wholesomeness of dairy products can only be guaranteed through the integration of law and control the entire food chain. The achieving of these indicators on food also is a goal that requires joint efforts and competence of experts from various professional fields - technologists, engineers. Standards related to the quality and safety of dairy products are subject to improvement by amendments – adopted procedures for standardization in practice, if some of their clauses and details do not withstand the test of time.

International Standard BDS EN ISO 22000 integrates the principles of the system of hazard analysis and critical control points (HACCP - Hazard Analysis and Critical Control Points) with: ISO 22004 for steps for its implementation, developed by the Commission of Codex Alimentarius; BDS EN ISO 22005 - Traceability in the food and food chain ISO/TS 22003 management systems of food safety. The national standard for Bulgarian yellow cheese BDS 14: 2010 is valid from 16.11.2010 and applies to Bulgarian yellow cheese made from cow, sheep or mixed milk, whole or in standardized ratio casein / fat using starter culture produced in Bulgaria selected strains of lactic acid bacteria isolated in Bulgaria by coagulation with rennet, given the necessary treatment, undergo a process of ripening and intended for consumption.

2. NONDESTRUCTIVE METHODS FOR OBJECTIVE ASSESSMENT OF THE QUALITY OF DAIRY PRODUCTS

In recent years are carried research for dairy products to determine the brand (manufacturer) of white and yellow cheese, identification of the content of hydrogen peroxide, the geographical origin of the product. In modern stage are seek methods for coadministration of multi-sensor systems with or without fusing the data from them for quality evaluation of dairy products [14]. In Table 1 are presented from the literature known types of sensors and measurement methods used in assessing the quality of dairy products. Some of the methods are contact, while others are used without a direct physical impact on the product.

Table 1. Sensors used for analysis and evaluation of the quality of dairy products

Type of the sensor	Method of measurement	Description	Reference
Conductive electrode	Conductance	The method is contact	[15,20]
Gas	Resistance, frequency	Electronic nose - contactless method used are polymer or resistive sensing elements	[21,31]
Biosensors	Resistance, frequency	Electronic tongue - contact method used are selective sensors	
pH	Acidity	pH meter – contact method	[27,30,31]
Viscosity	Current of the motor, time to expiration	Viscometer – contact method	[27]
Penetration	Penetrometer	Contact method - measuring the force required for penetrating of the sensitive element in the product	[22]
Optical	NIR, VIS, UV, IR, laser	Spectrometers, colorimeters with transition and reflection, video camera	[7,12,21]
Ultrasound	Impedance, amplitude, frequency	Non-contact method – reflection or transition	[1]

Table 2. Comparative analysis of optical methods for non-destructive evaluation of the quality of dairy products

Method	Advantages	Disadvantages	Reference
Computed tomography	Non-destructive	High cost of the equipment	[16]
	Detailed images are obtained	Long time for data processing	
		Limitation of application areas	
Computer vision	Can be obtained spatial information about the object	Restriction for objects with varied composition	[33]
	Higher precision than the human judgment	Not suitable for detection of the internal defects	
	The ability to detect external defects		
Spectral analysis	Easy to use	Limited sensitivity to small changes in the properties of the object	[6]
	Obtaining of spectral information		
	Suitable for internal defects		
Hyperspectral analysis	Obtaining of spectral and spatial information	Висока цена на оборудването	[11]
	High sensitivity to small changes in object	Problems processing the data	
	Construction of images on the chemical composition of the object		

Contact methods have significant disadvantage that measured on immersion of the measuring probe in the product, in which can be inserted micro-organisms from the environment. For example, some types of electronic tongues use sensors that measure the extent of the chemical reaction between the chemical substance and product to detect the presence of harmful toxic element for humans [13]. These disadvantages of the contact methods of measurement are prerequisites for seeking suitable contactless methods for assessing key quality indicators of dairy products. Such techniques are optical, gas, ultrasound. Gas sensors are suitable for assessment of raw milk as a feedstock for the production of dairy products. For example, in lactic acid fermentation of Bulgarian yoghurt does not emit odoriferous substances and this type of sensors are not appropriate. They could be applied in the preparation of functional foods from milk as yogurt, cheese, cottage cheese, because it is possible products used as additives to emit aromatic substances in fermenting. Video sensors are suitable mainly for assessment of milk and again in the preparation of functional foods and microbiological analysis in microscopic research and evaluation of surface characteristics of dairy products.

Table 3. Examples of application of spectral analysis for quality assessment of dairy products

Spectral range, nm	Parameters of the product	Number of the samples	Method of representing of the data	Method for processing	Reported results	Ref.
270÷550, 310÷590	Riboflavin	42	Parallel factor analysis (PARAFAC)	Partial least squares regression (PLSR)	$R^2=0,94\div0,97$	[36]
400÷1000, 325÷1075	Determination the type of product	160	Principal component analysis (PCA)	Back propagation Neural network (BPN)	100% recognition	[37]
No data	Determination of arsenic, plumbum, mercury and selenium	No data	Comparative analysis of five measuring apparatus	Relationship with reference parameters	Common error of the devices 0÷23%	[19]
325÷1075	Sugar and pH	35	Combination of PCA and artificial neuron network (ANN)	PLSR	$R^2=0,91\div0,92$	[26]
200÷1000	Amendment during storage of the humidity, protein, fat, ash content	No data	Conversion of spectrum to L, S, H color components	Analysis of variance (ANOVA)	Non-parametric comparative analysis	[28]
500÷2500	Determination the type of product	No data	Possibilities for predicting parameters by spectral characteristics		Non-parametric comparative analysis	[18]
1100÷2300	Fat content	141	Coefficients of PLSR	PLSR	$R^2=0,93\div0,98$	[10]
200÷1000	Changes during storage: pH, viscosity	75	Coefficients of PLSR and relationship with reference parameters	PLSR	$R^2=0,02\div0,85$ depending on the observed parameters	[2]
400÷1200	Protein	257	Coefficients of PLSR	OC-PLS (one class)	10% outliers	[35]
1000÷4000	Melamine	No data	No data	Correlation analysis	2% precision of determination	[23]
900÷1700	Fat content	No data	Coefficients of PLSR	PLSR	$R^2=0,97$	[25]
420, 520, 700	Changing of the pigments during storage	No data	Conversion of spectrum to color components	No data	Non-parametric comparative analysis	[34]

More universal application than other methods are found optical and ultrasonic sensors that are applied to assess the quality of dairy products at all stages of production and that acceptance of raw milk pasteurization, starter culture, tracking of the fermentation process, control of final product and storage. Known from the literature for non-destructive analysis of dairy products occupy considerable space the optical methods. Such methods are computer vision, spectral and hyperspectral analysis. Table 2 presents comparative analysis of the presented methods for non-destructive evaluation of the quality of meat and meat products and are listed their advantages and disadvantages.

The spectral analysis is a set of physical methods for quantitatively and qualitatively determining the composition of substances by studying their spectra. It is widely used in the research of the quality of various food products, including milk and dairy products. Compared with computer vision, spectral analysis has found wider application in assessing the quality of dairy products. The possibilities for application of spectral analysis in the near infrared and mid-infrared range are well studied in the evaluation of dairy products. This includes monitoring the production process, determining the geographical origin, quality assessment, monitoring the ripening process of some dairy products. The relationship between the composition of a substance is the electromagnetic spectrum emitted or absorbed by it, allows spectral analysis be used as sensitive, relatively simple and quick method in research and industry. One of its advantages is that it can be applied to a large number of samples without this having a significant impact on the price and timing of the study [13,32].

3. METHODS OF EXTRACTING THE INTRINSIC PROPERTIES OF SPECTRAL CHARACTERISTICS

Principal component analysis (PCA) [26]. Extracting characteristic features is a transformation of the original data with all their variables in a sample of reduced benefits. Use all measurements or variables that are designed in small size area. The reasons for the extraction of characteristic properties are as follows:

- Reducing the bandwidth of the input data;
- Providing a smaller number of features to speed up the classification;
- To reduce the surplus of information;
- To obtain a smaller dimension of the data in the ideal case - two dimensions with a minimum loss of information and in this way data are displayed better.

Discrete parametric models [3]. Discrete parametric models reflect discrete behavior of the object only in moments of time that are multiples of the so-called "time sampling" – time measurement clock cycle T_0 . For processing of the spectral characteristics of the surface areas of dairy products are selected discrete parametric models as they are discrete in nature.

4. METHODS FOR PROCESSING OF SPECTRAL DATA AND CLASSIFICATION

In the study are used methods for classification: discriminant analysis DA; K-nearest neighbors KNN; Method of support vector machines SVM (Figure 3). Referred are the main characteristics of these methods.

Figure 3. Methods for classification used in the investigation

Discriminant analysis [5,13]. The discriminant analysis is multidimensional data analysis, which is used when there is need for "predicting" the values of the grouping variable. This is also called classification or pattern recognition. In non-linear discriminant analysis to build non-linear discriminant functions of the predictors. The aim is to obtain a rule for assignment of a new observation of the given class. Assignment or „distribution“ to a certain class of features is necessary on this development.

K-Nearest Neighbors (KNN) [13]. The method of k-nearest neighbor (k-nearest neighbors method- KNN) is a method of classification of images, which is based on the closest training examples in the space of features. Unknown image refers to a class to which they belong at least S from k nearest neighbors by providing a sample of images. S is the threshold for credibility.

Support vector machines (SVM) [17,29]. In this method is performed non-linear transformation of the original data in another space with a higher dimension where the objects are linearly separable (Figure 6c). In SVM – the method on the support points that represent breakpoints for a class data in multidimensional space of the features can be calculated hyper planes separating classes for which the distance limits between the two classes is maximum.

The original algorithm of the SVM method is linear, but are developed and nonlinear ones. In nonlinear algorithm data are separated by a non-linear kernel function. This allows the algorithm to match the hyper plane with the greatest separation between the two classes in the transformed feature space. The kernel non-linear function can be homogeneous polynomial, non-homogeneous polynomial, Gaussian radial basic and hyperbolic. The significance of the parameter Capacity - C, which is common to all types of SVM, account during the phase of training of the classifier and is expressed in prioritizing one of the two factors - minimizing the number of wrongly classified objects of the training sample or complexity factors of the synthesized hyper plane.

Errors in determining the parameters of the models are calculated by equations, described in table 4.

Two-factor analysis of variance [28]. The main objective of the analysis of variance is as in regression analysis - to investigate the significance of a particular group of factors (independent variables) on a dependent variable, but here factors are nominal variables. Two-way analysis of variance allows simultaneously to study the influence of two factors on the outcome of the research object.

Partial least squares regression and principal component regression [25,26]. Quantitative analysis of the data was realized by partial least squares regression (PLSR) and principal component regression (PCR). The effectiveness of certain methods in the processing of predictive values with high dimension, such as the spectral characteristics of meat and sausages. Both methods generate new predictive variables known as components as a linear combination of the original predictive values. Methods used to analyze data

create these components differently. PCR creates components describing the variation in the prediction variables without considering basic components. In the partial least squares regression these output variables are taken into consideration and results obtained with lower accuracy at a small number of components. The choice of method of analysis of the data depends upon the particular application in which they are used.

Table 4. Errors in determining the parameters of the models

R^2	$R^2 = \frac{r_{ss}}{t_{ss}}$	$t_{ss} = \sum_{i=1}^n (y_i - y_{mean})^2$ $r_{ss} = \sum_{i=1}^n (y_i - y_{i\ fit})^2$	R^2 – Regression coefficient y_i – Measured values y_{mean} – Mean of measured values y_{fit} – Values of the model n – Number of measurements
MSE	$MSE = \frac{1}{n} \sum_{i=1}^n (y_{i\ pred} - y_i)^2$		MSE – Mean squared error $y_{i\ pred}$ – Predicted values y_i – Measured values n – Number of measurements
RMSE	$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_{i\ pred} - y_i)^2}$		RMSE – Root mean squared error $y_{i\ pred}$ – Predicted values y_i – Measured values n – Number of measurements
Common error	$\varepsilon_0 = \frac{\sum_{i=1}^n (\sum_{k=1}^n y_{ik} - y_{ii})}{\sum_{i=1}^n \sum_{k=1}^n y_{ik}} \cdot 100, \%$		y_{ik} is number of samples from class i , classified in class k y_{ii} – Number of correctly recognized samples $k = 1...n$ – number of incorrectly classified as a class i in the total number of samples n – Number of classes

5. ANALYSIS AND ASSESSMENT OF THE CHANGE OF SURFACE CHARACTERISTICS OF DAIRY PRODUCTS BY SPECTRAL DATA

Objects of the study is yellow cheese purchased from a licensed manufacturer and manufactured of BDS and the adjacent regulations. Characteristics to be assessed are surface changes of the product in storage in conditions not complying with the requirements specified by the manufacturer. The spectral characteristics were obtained with laboratory staging for measuring spectral characteristics of reflection in the visible spectral region, developed at the Department of „Electronics, Electrical Engineering and Automation” of the faculty „Technics and Technology” – Yambol. Laboratory measurements of titratable acidity were made at the Department of „Food Technologies” at the same faculty. Figure 4 shows the spectral characteristics of object areas with yellow cheese and mold during every day of measurement. There is overlap of these characteristics in different spectral ranges are also visible differences in these characteristics, for example in the range 550÷600nm.

Figure 4. Spectral characteristics of object areas with yellow cheese and mold in different days of measurement

➤ Presentation of the spectral characteristics as features

Figure 5 shows auto regression coefficients and major components of the measured spectral characteristics of the yellow cheese and mold on day 3. There is a partial overlap of the autoregression coefficients, while the principal components is available clearly distinguish of the surface characteristics of product under study, divided into two classes „yellow cheese” and „mold”.

Figure 5. Representation of the spectral characteristics as features for day 3

➤ Designation of the necessary number of principal components for a description of spectral characteristics

Figure 5c presents the results in determining the required number of major components for a description of spectral characteristics of the object areas with yellow cheese and mold. It can be seen that the two main components describing 99,9% of the variance in the data.

➤ Evaluation of the separability of object areas of spectral characteristics in different days of storage by classifiers

The evaluation of the separability of object areas was realized with three classifiers that are most commonly used for analysis of dairy products. These are discriminant analysis (DA), method of support vector machines (SVM) method and K-Nearest Neighbors (KNN). DA and SVM are used with nonlinear separating functions.

Discriminant analysis. Figure 7 shows the results when using a non-linear discriminant analysis of separability of the object areas with yellow cheese and mold on day 3.

For all days of storage were used spectral characteristics (raw), Autoregression coefficients (AR) and principal components (PC). For all methods of data representation is observed overlapping of classes.

Figure 7. Classification with DA for day 3

Table 5. Separability of object areas on a particular day of the storage with discriminant analysis

Day of the storage	Raw	AR	PC
	$\varepsilon_0, \%$	$\varepsilon_0, \%$	$\varepsilon_0, \%$
day 1	49	11	1
day 3	47	11	9
day 4	46	12	5
day 6	46	12	4

Raw - spectral characteristics; AR - auto regression coefficients; PC - principal components

This overlap is also reflected by the common error of the classification. The values of this error for all days of storage are presented in Table 5. Small amounts of the common error is obtained using major components $\varepsilon_0=1\div9\%$. Using a nonlinear discriminant analysis and two other classifiers for the presentation of object areas – spectral characteristics and autoregression coefficients the common error greatly exceeding 10%.

KNN analysis. The results of Severability of object areas for day 3 are shown in Figure 8. Overlap between the two classes is observed using direct spectral characteristics and Autoregression coefficients while using the principal components will overlap of classes on this day.

Figure 8. Classification with KNN for day 3

Table 6. Separability of object areas on a particular day of the storage with KNN analysis

Day of the storage	Raw	AR	PC
	$\varepsilon_0, \%$	$\varepsilon_0, \%$	$\varepsilon_0, \%$
day 1	30	25	5
day 3	26	31	13
day 4	28	32	12
day 6	34	19	3

Raw - spectral characteristics; AR - auto regression coefficients; PC - principal components

This trend is observed for the remaining days of storage. Table 6 indicates the values of the common error in classification by three methods for presenting data of object areas with yellow cheese and mold. Using principal components was observed common error within $3\div13\%$ depending on the day of measurement. In other methods of representing the spectral characteristics the common error is over 10%.

SVM analysis. Figure 9 shows the results in the classification of yellow cheese for day 3 of storage. The processing of data by the three methods for their submission with the method of the support vectors indicates that the direct use of spectral characteristic overlapping was observed of the two classes while using the autoregressive coefficients, and the main components that overlap is with minimal error.

Figure 9. Classification with SVM for day 3

Table 7. Separability of object areas on a particular day of the storage with SVM analysis

Day of the storage	Raw	AR	PC
	ε_0 , %	ε_0 , %	ε_0 , %
day 1	35	2	2
day 3	31	2	4
day 4	36	2	4
day 6	31	2	2

Raw - spectral characteristics; AR - auto regression coefficients; PC - principal components

Evidence of this is the common error of the overlap of classes for individual days of measurements, which values are presented in Table 7. Using auto regression coefficients and principal components error values are between 2÷4%, while in the direct use of spectral characteristics the common error is over 10%.

Results from analysis of the processing time. The values for the time of data processing in classification are coefficient of variation $3 \div 12\% \ll 30\%$, so it can be presented as mean values (Figure 10). Data on time for the processing at classification are analyzed with two-way analysis of variance by the means of Data Analysis Toolpack of MS Excel. At accuracy level $\alpha=0,05$ the results obtained are presented in Table 8. The table shows that it is derived significance level $p < 0,05$, which indicates that there are differences in the results using the various classifiers and other methods of representing data. The results of the analysis indicate that at least processing time is obtained with direct using of the spectral characteristics and classification method of K-Nearest Neighbors (KNN).

a) depending on the classifier

b) depending on the features

Figure 10. Time for processing the results of classification

Table 8. Analysis of the results of time for data classification

Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Average	Variance		
KNN	3	16,42	5,47	13,65		
DA	3	20,95	6,98	24,36		
SVM	3	24,34	8,11	37,98		
raw	3	11,26	3,75	0,15		
AR	3	37,62	12,54	7,49		
PC	3	12,83	4,28	0,73		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	10,53	2,00	5,26	3,38	0,14	6,94
Columns	145,76	2,00	72,88	46,81	0,00	6,94
Error	6,23	4,00	1,56			
Total	162,52	8,00				

Errors in the classification. Errors in the classification are coefficient of variation $3 \div 12\% < 30\%$ so it can be presented as mean values (Figure 11). Data on time for the processing at classification are analyzed with two-way analysis of variance by the means of Data Analysis Toolpack of MS Excel. At accuracy level $\alpha=0,05$ the results obtained are presented in Table 9. The table shows that it is derived significance level $p < 0,05$, which indicates that there are differences in the results using the various classifiers and other methods of representing data. The results of the analysis indicate that the smallest value of common error is obtained with using of principal components and classification method of support vector machines (SVM).

a) depending on the classifier

b) depending on the features

Figure 11. Common error of classification

Predicting the titratable acidity by partial least squares regression. Figure 12a presents the results of prediction of titratable acidity by spectral characteristics. The regression coefficient R^2 is 0,98; the sum of squared errors is 183,6; root mean square error is 3,194. Can be concluded that the titratable acidity can be predicted by spectral characteristics at 98% accuracy, but high levels of errors.

Table 9. Analysis of the results for a common error in data classification

Anova: Two-Factor Without Replication						
SUMMARY	Count	Sum	Average	Variance		
DA	3	63,25	21,08	515,15		
KNN	3	64,50	21,50	133,56		
SVM	3	38,25	12,75	315,44		
Raw	3	109,75	36,58	84,90		
AR	3	40,25	13,42	155,90		
PC	3	16,00	5,33	7,15		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Rows	146,18	2,00	73,09	0,84	0,50	6,94
Columns	1578,60	2,00	789,30	9,03	0,03	6,94
Error	349,69	4,00	87,42			
Total	2074,47	8,00

a) by PLSR

b) by PCR

Figure 12. Predicting the titratable acidity by spectral characteristics

Predicting the titratable acidity by principal components regression. Figure 12b presents the results of prediction of titratable acidity from spectral characteristics by principal components regression. The regression coefficient R^2 is 0,85; the sum of squared errors is 1145; root mean square error is 7,974. Can be concluded that the titratable acidity can be predicted by spectral characteristics at 85% accuracy, but high levels of errors.

6. CONCLUSION

This report provides an overview of current research related to the quality and safety of dairy products. From the analysis of publishing activity in this field is found that the yellow cheese is the main subject of study because it is one of the commonly consumed dairy product along with cheese curd and yogurt. Moreover, this product is a favorable environment for the development of hostile microorganisms.

A review was made of the methods and technical equipment for assessing the quality and safety of yellow cheese in which it is established that are suitable for the purpose contactless methods because the measurement with contactless sensors does not affect the composition and structure of the product.

From contactless methods with small error values up to 2%, in determining the content of substances harmful to health in dairy products and the ability to predict the physicochemical parameters with accuracy more than 97% have proven optical methods.

In recent years, optical methods of research have proved the spectral and hyperspectral analysis. From these methods is selected spectral analysis because it is easy to use method and does not require special preparation of measuring equipment.

An assessment is made of the possibilities for separating objects areas on the surface of yellow cheese during storage in conditions not regulated from specified by the manufacturer using the three most commonly used in the analysis of food products classifiers – SVM, KNN and DA. The work of these classifiers was evaluated by the common error of classification. From this analysis it is found that the direct use of spectral characteristics the classification common error is over 10%. Suitable to use are principal components for the representation of spectral characteristics and classification because the common error of classification is up to 5%.

For classification are suitable the discriminant analysis (DA) using nonlinear discriminant function and support vector machines (SVM) with the use of principal components, because the processing time is up to 5s.

The use of KNN classification method is impractical because the total error of the classification in it, irrespective of the method for representing the spectral data is greater than 10%, while in comparison with the other two classifier processing time in this classifier is shortest.

7. LITERATURE

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