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Computer Assisted Rapid Non-destructive Method for Evaluation of Meat Freshness

In this study a technique was developed to predict the meat freshness decay by employing a nondestructive visible imaging method and a computer assisted analysis. The technique uses Opto-magnetic imaging spectroscopy and machine learning algorithms for detecting of freshness during storage. The opto-magnetic spectra of meat samples were acquired at 0, 12 and 24 hours of refrigerated storage using specially developed imaging system and computer image processing algorithm. The obtained spectra were related to the storage time of the samples, and several machine learning classification algorithms were tested. The best prediction results of freshness for chicken and beef was achieved using lazy IB1 classifier with the accuracy of 97.47% for chicken, and 98.23% for beef. Since the method is concerned with detecting changes in the state of water in tissues, the freshness decay period was estimated based on changes in meat hydration properties.

Keywords: *meat, freshness, nondestructive method, opto-magnetic imaging spectroscopy, computer-assisted data analysis*

1. INTRODUCTION

Meat is a high-value item in the human diet and greatly prized by consumers. In most developed countries meat is very high on the list of food market demands. Considering that the present economic trends lead to an increasing distance between consumption and productions zones, and consequently to an extension of the delivery chain [1], it is necessary to set on methods for an objective and reliable control of quality and freshness of a product at all the stages of the commodity chain. [2]

In order to test the quality standards of meat and meat products, different techniques such as chemical procedures, instrumental methods, sensory analysis and screening methods have been used [3].

Freshness, as one of the most important quality attributes, has attracted attention from producers and consumers and has a strong relationship with product sales and consumption [4]. It can be affected by many factors, such as handling and storage conditions, and variations of biochemical components [5].

In the last few decades, the meat processing industry has shown an increasing demand for fast and reliable methods to determine product quality characteristics. Some analytic control procedures, such as chemical and microbiological analysis, sensory analysis and screening methods, must be carried out on meat in order to keep the quality standards as close as possible to the preference of the target consumer. Traditional quality analyses have several drawbacks, the most significant of which are low speed, use of chemical reagents, high manual dexterity, destruction of the sample and the physical distance between the process and the analytical instrument. [6] Consequently, conventional methods for the determination of meat quality parameters are still not suitable for on-line application [7].

The development of rapid, low-cost, non-destructive methods for freshness monitoring has been one of the most interesting research fields of food industry in the last few years [8]. Spectroscopy based methods, coupled with computer assisted data analysis techniques, represent an alternative approach for the estimation of quality attributes in meat and meat products. Various literature reports have covered extensively the application of spectroscopy based methods and techniques for meat quality assessment and evaluation of freshness [3, 6, 9, 10]. Imaging methods such as hyperspectral imaging [11] in combination with powerful techniques of data analysis can make significant improvement in meat science and quality control.

The purpose of present research is to explore possibilities of using Opto-magnetic imaging spectro–scopy [12] with computer assisted data analysis as a non-destructive method for rapid evaluation of meat freshness. Similar methods have been used to analyse human tissues which lead us to believe that they also have potential for use in muscle type tissue characteristic for meat used in human diet. [9] The method of Opto-magnetic imaging spectroscopy is based on light-matter interactions and was first introduced as a skin characterization method [12], but later found numerous other applications for chara–

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cterization of different materials [13-15]. It has a distinctive advantage of using digital RGB images which makes it more rapid and cost-effective compared to the hyperspectral imaging methods. Opto-magnetic imaging spectroscopy has been so far successfully applied in detection of viruses in human plasma [16] characterization of epidermal layers [17], skin oxyge–nation [18] and for discrimination of cancerous and healthy human tissues and cytological smears [19, 20]. This paper presents results of application of this method in the characterization of meat and estimation of freshness using classification algorithms based on machine learning.

2. EXPERIMENTAL

2.1 Meat samples

Samples of chicken breast (20) and beef chops (20) were acquired at a local butcher shop just after the unloading – that was the starting time of the experiment.

Any remaining pieces of skin and bones were removed manually and excess surface moisture removed by patting with a paper tissue. Meat samples were stored in refrigerator throughout duration of the experiment at the temperature of +4-6°C, and taken out only for digital image collections. This temperature range was chosen because it often represents the recommended one for the storage of meat in shops.

2.2 Opto-magnetic imaging spectroscopy

The setup for Opto-Magnetic Imaging Spectroscopy (OMIS) used in this research had a customized housing with a Canon digital camera (model IXUS 105, 12.1 MP) and two illumination systems of 6 light emission diodes (Nichia, STS-DA7-3195) arranged in a circle and placed at appropriate angles above the sample holder (Figure 1).

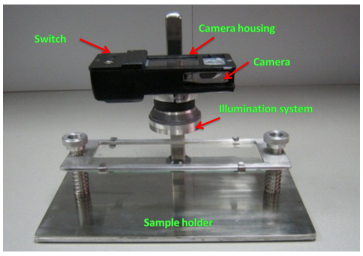

Figure 1. Opto-magnetic imaging spectroscopy setup for meat freshness evaluation (Nanolab, University of Belgrade)

The first illumination system is set to provide white diffuse light normal to the sample surface, while the second one is under angle of incidence of 53° in respect to the sample - Brewster's angle (polarization angle) for water-air interface which provides polarized reflection from the sample [12, 21]. The experimental procedure includes making two images of the region of interest using two different illuminations for generating one opto-magnetic spectra for that region. A meat sample is flattened against the sample holder and digital images of randomly chosen regions of interest were captured because meat structural properties vary across a sample (Figure 2), and the decay process is not necessarily uniformly distributed.

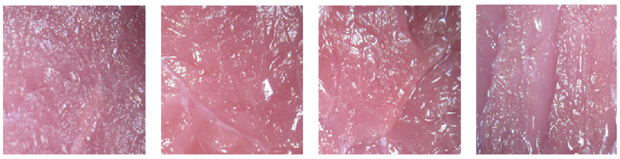

Figure 2. Examples of digital images of same beef sample captured at different locations to cover different variations in meat structure, color, texture and decay process

Digital images of the samples were captured immediately after purchasing and then after 12h and after 24h of refrigeration. Acquisition of images takes no longer than 10 seconds per each sample. The saved images had following parameters: 395 x 350 pixels resolution, 180dpi, 24-bit depth, .jpg format.

More in-depth explanations of the method are given in previous reports [12-21].

After the acquisition of images, they were processed using the code developed in MATLAB which provides conversion of the digital image to Opto-magnetic spectra through several operations, starting with the creation of histograms for red and blue colour channel of the RGB image and subsequent conversion of the histograms to opto-magnetic spectra [12]. Every colour channel should contribute additional information, but for the purposes of this research only red and blue colour channel were used to limit the amount of data.

Developed opto-magnetic spectra of chicken and beef samples before and after storage were divided in two datasets. Chicken meat dataset had 37 spectra of fresh samples, 61spectra of samples after 12h storage and 60 spectra for 24h storage; in total 158 spectra were used further in classification analysis.

Beef meat dataset had 60 spectra of fresh samples, 125spectra of samples after 12h storage and 97 spectra for 24h storage; in total 282 spectra were used in classification analysis.

2.3 Data analysis

Spectral datasets were exported from MATLAB and processed using WEKA 3.7.6 software (Machine Learning Group at the University of Waikato).

Before the discrimination analysis the opto-magnetic spectra were first visualized in order to select a number of attributes. An ordered set of attributes constitutes a vector that provides multidimensional description of analysed image area of meat sample.

All spectroscopic and imagery methods deal with large amount of data and data analysis is necessary to extract features of interest. Generally, multivariable classification analysis is a data mining function with a goal to accurately predict class of instances with known attribute values while class values are unknown. In this study, the goal of the classifier is to correctly predict the class – according to freshness, based on the opto-magnetic spectra of meat samples. The opto-magnetic spectra is a vector defined by attributes – relative intensity at different wavelength difference numbers. These attributes vary depending on the state of sample and were used for estimation of freshness.

The number of attributes which constitute opto-magnetic spectra can be up to 300, but by visual inspection of all spectra together it was concluded that only in the region of 100-140nm significant variations occur, thus only 40 attributes were selected as variables to perform discrimination process. The following methods were used in discriminant analysis: Naïve Bayes, Rotation Forest, Random forest, Lazy.IB1 and Lazy.KStar. The applied discrimination analysis methods have been described in detail by Witten and Frank [22] and the individual advantages of methods can be found in a comprehensive review by Vijayarani and Muthulakshmi [23].

Cross validation was used in both datasets for internal validation. Cross validation estimates the prediction error by splitting the spectra into groups. One group is reserved for validation and the remaining groups were used for calibration [24, 25]. The process is repeated until all groups have been used for validation once. In this study the cross-validation with leaving 5 spectra out was used.

The performance of different classifiers was evaluated using additional measure of classifier accuracy - Cohen's kappa [26]. Cohen's kappa measures classifier accuracy, while compensating for successes due to chance. Cohen's Kappa statistics ranges from -1 (total disagreement) through 0 (random classification) to 1 (total agreement) [27].

3. RESULTS AND DISCUSSION

Spectroscopic methods are widely used for muscle food quality assessment and control, in both laboratory and meat industry settings [28]. Optical spectroscopy offers a variety of techniques for meat characterization because of its non-contacting characteristics and easy to use portable devices. It has been widely investigated in the field of meat science as a means of gaining structural information. In addition, polarized light gives organizational data and are therefore often used for these application [9]. Opto-magnetic spectroscopy is a novel method which utilizes diffuse and polarized light to extract information on tissues by converting digital images – as a medium of captured reflectance properties to opto-magnetic spectra. Advancements in the field of digital image processing have made it possible to do various operations with digital images. Theoretically, if a digital image of a sample is acquired using illumination under Brewster's angle, and subtracted from the image of the same sample acquired using illumination with diffuse white light, then the resultant image would represent a sort of composite image or a map of the magnetic properties of that sample [19].

In cancer research, the application of the Opto-magnetic imaging spectroscopy method was used to discover the differences between the paramagnetic /diamagnetic state of water in healthy and cancerous tissues because in tumour cells and tissues, the state of water is altered [29-32]. This altered state of water detected through changes in the paramagnetic /diamagnetic properties of water was used as classification criterion between healthy and cancerous states. The same rationale was used in this research – during the decay process of meat the state of water changes [34-36], and therefore the same method could be applied for assessment of meat freshness.

The Figures 3 and 4 present averaged opto-magnetic spectra for three different classes according to the state of freshness for beef and chicken samples in the region (100-140nm) where most variations were observed between classes. It can be seen from the figures that averaged opto-magnetic spectra for both types of meat differ depending on the state of freshness. Based on visual inspection of the plots, the number of attributes used in the classification analysis was further reduced to only 20 attributes - in the region from 110-130nm.

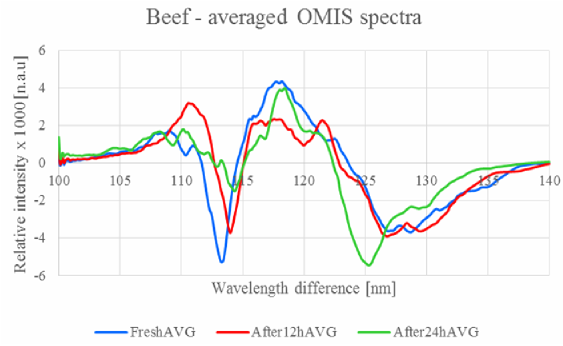

Figure 3. Comparison of the average opto-magnetic spectra of beef chops for the fresh samples, samples after 12h and 24h of refrigerated storage

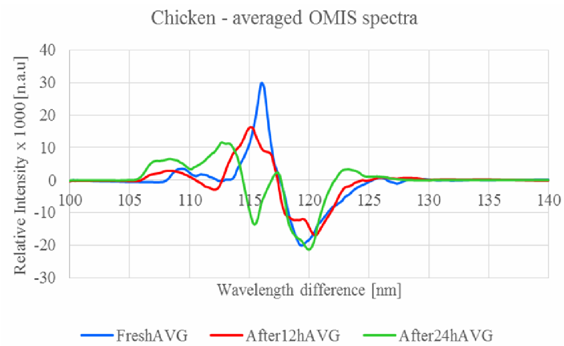

Figure 4. Comparison of the average opto-magnetic spectra of chicken breasts for the fresh samples, samples after 12h and 24h of refrigerated storage

More than 50 classification methods were verified to assign a given sample to the respective class. The best results yielded by 5 different methods are presented in Tables 1 and 2.

Before classification, the datasets were divided into sub-sets by cross-validation. One group was the learning dataset, and the remaining groups were test datasets.

Table 1. Accuracies of different classification algorithms for beef chops classification according to freshness

Algorithm	Correctly Classified Instances	Incorrectly Classified Instances	Kappa statistic
Naïve Bayes	71.9858	28.0142 %	0.5532
Rotation Forest	88.6525 %	11.3475 %	0.8206
Random forest	92.9078 %	7.0922 %	0.8877
Lazy.IB1	**98.227 %**	**1.773 %**	**0.9722**
Lazy.KStar	97.8723 %	2.1277 %	0.9669

Table 2. Accuracies of different classification algorithms for chicken breasts classification according to freshness

Algorithm	Correctly Classified Instances	Incorrectly Classified Instances	Kappa statistic
Naïve Bayes	70.8861 %	29.1139 %	0.5573
Rotation Forest	89.8734 %	10.1266 %	0.8439
Random forest	94.9367 %	5.0633 %	0.9222
Lazy.IB1	**98.1013 %**	**1.8987 %**	**0.971**
Lazy.KStar	97.4684 %	2.5316 %	0.9612

Kappa statistics for all classifiers is high, close to 1, which excludes the possibility that this classification results are due to chance. The best accuracy was achieved by using Lazy.IB1 classifier. IB1 is a basic instance based learner which finds the training instance closest in Euclidean distance to the given test instance and predicts the same class as this training instance [37]. IB1 classifier correctly classified 98.1% opto-magnetic spectra of chicken, and 98.23 %correctly classified spectra of beef according to defined class of freshness. Detailed prediction results are presented in the form of confusion matrices (Tables 3 and 4).

Table 3. Confusion matrix – summary of classification results by IB1 classifier for beef chops according to freshness

Confusion matrix		Predicted class		
		Fresh	After 12h of storage	After 24h of storage
Actual class	Fresh	58	2	0
	After 12h of storage	1	124	0
	After 24h of storage	0	2	95

Water holding capacity or hydration of fresh meat is closely related to microbial quality.

Table 4. Confusion matrix – summary of classification results by IB1 classifier for chicken breasts according to freshness

Confusion matrix		Predicted class		
		Fresh	After 12h of storage	After 24h of storage
Actual class	Fresh	37	0	0
	After 12h of storage	1	60	0
	After 24h of storage	1	1	58

Most of the methods used for measuring this property are based on determination of the water liberated under applied pressure, swelling or extract-release volume – ERV [34-36]. With the extent of spoilage meat shows an increase in water holding capacity, and as a result changes in hydration can be used as index of spoilage of meat [34-36]. The results of prediction of freshness in this research, based on the opto-magnetic spectra confirm the potential of the Opto-magnetic imaging spectroscopy method to discriminate between different state of freshness for chicken and beef. Since the method is concerned with detecting changes in water state in the tissues, this means that the differences in freshness are found based on changes in the state of hydration.

4. CONCLUSION

The results show the feasibility of Opto-magnetic spectroscopy for estimating quality decay of fresh beef and chicken meat during refrigerated storage. The spectra obtained from sliced chicken breast and beef chops images using this method have been related to storage time of the samples with the accuracy of 97.47% for chicken, and 98.23% for beef. Overall, these results show that this novel method could support conventional techniques in determining the shelf life of meat. Moreover, due to their non-invasive nature, these techniques could be applied in on-line monitoring system. Similar image-based methods are already widely used in the food industry for quality control, but opto-magnetic spectroscopy is far more cost-effective due to the use of digital images. The proposed method and data analysis we report herein is fast, low-cost and non-destructive and we consider it suitable for monitoring the freshness of meat. Further repeatability, reliability and accuracy studies will be carried out in due course.

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КОМПЈУТЕРСКИ ПОТПОМОГНУТА, БРЗА, НЕДЕСТРУКТИВНА МЕТОДА ЗА ЕВАЛУАЦИЈУ СВЕЖИНЕ МЕСА

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У овом истраживању је за процену свежине меса развијена техника која користи недеструктивну методу на бази оптичке слике и компјутерски потпомогнуту анализу. Техника подразумева комбиновање Опто-магнетне имицинг спектро–скопије и алгоритама машинског учења како би се утврдила свежина меса, односно време складиштења. Аквизиција Опто-магнетних спектара узорака меса, чуваних у фрижидеру за време трајања експеримента, рађена је након 0h, 12h и 24h складиштења и то специјално развијеним имицинг системом, подржаним одговарајућим компјутерским алгоритмом за обраду слике. Добијени спектри корелисани су са временом складиштења узорака и на таквом сету података тестирано је неколико класификационих алгоритама машинског учења. Најбољи резултати предикције, за пилеће и јунеће месо, добијени су коришћењем "лењог" (енг. *lazzy*) ИБ1 класификатора са тачношћу 97.47% за пилетину и 98,23% за јунетину. Како је метод базиран на детекцији промена стања воде у ткивима, период свежине меса одређен је на основу промена у хидратацији и активности воде у месу.