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Distinguishing Pickled and Fresh Cucumber Slices Using Digital Image Processing and Machine Learning †

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Abstract: In the case of cucumber, postharvest challenges may focus on preserving the high quality and extending the shelf-life. Digital image analysis provides objective information about the quality of food products and the changes in the properties as a result of postharvest processing. This study was aimed at developing discriminative models for distinguishing the pickled and fresh cucumbers based on texture parameters of slice images. The textures were extracted from slice images converted to individual color channels *L*, *a*, *b*, *R*, *G*, *B*, *X*, *Y*, *Z*. The obtained results proved the effect of the preservation on image features of cucumber flesh. Including selected textures in the discriminative models allowed for the complete differentiation of preserved and fresh samples. The application of digital image processing enabled the evaluation of changes in the flesh of cucumber subjected to postharvest preservation.

Keywords: cucumber preservation; quality; image textures; discriminant analysis

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1. Introduction

Cucumber (*Cucumis sativus* L.) belongs to the Cucurbitaceae family. It is a warm-season crop with the geographical distribution and growing season restricted by the ambient temperature [1]. Cucumber is an important fresh consumption crop worldwide often grown in greenhouses and open fields. It is characterized by rapid growth and early maturity. Cucumber is a rich source of protein, carbohydrates, riboflavin, thiamin, niacin, vitamins, and minerals. Cucumber is high in water (90-95%) and low in calories (12–15 kcal per 100 g fresh weight). It has favorable flavor and texture as well as medicinal value including antioxidant ability, antimicrobial activity and ability to lower glycemic. Eating cucumber may be beneficial for improving immunity, boosting metabolism and reducing the risks of cancers [2–4]. Therefore, it is often eaten both fresh, e.g., in salads and processed and preserved, among others, as pickles. Cucumber may be also consumed cooked [2,4]. The purpose of cucumber processing is to preserve the fruit with minimal damage. In the case of pickled cucumbers, the sensory acceptability depends on firmness and crunchiness which is important to consumer preferences [5]. The cucumber processing can depend on the type of vinegar, salt content, pH value, stabilizing additives, heat treatment optimization during pasteurization, or storage temperature [5]. Pickled cucumbers may be produced by direct acidification involving the brining fresh cucumbers in water with acetic acid and salt and then their pasteurization. Whereas the use of a mildly acidic salt solution for brining fresh cucumbers results in fermentation by naturally occurring lactic acid bacteria [6]. Pickling can improve the quality, affect the organoleptic properties and generally enhance the palatability [7]. It also preserves against microbial spoilage and

prolongs the shelf life of the preserved food [7]. The pickled products can be considered as dietary sources of health-promoting components that are characterized by the potential for improving both physical and mental wellness [8].

Image processing may be very useful for the evaluation of the quality of fruit and vegetables. Machine learning algorithms can be helpful for grading and sorting fruit and vegetables based on quality features such as texture, color, shape, size, or the presence of defects and diseases. These characteristics can have an impact on the market value and consumer choice. Image processing can ensure objective, cost-effective, fast and authentic examination. Whereas such research performed by a human may be subjective, time-consuming, influenced by surrounding [9,10]. It was found that the image analysis can be used for monitoring of processing and preservation of food samples including fermentation [11–14].

The objective of this study was to distinguish the pickled and fresh cucumbers based on texture parameters of slice images. The discriminative models were built using different algorithms. Thus, the effect of the preservation on the properties of cucumber flesh was evaluated using image processing and machine learning.

2. Materials and Methods

The research material consists of cucumbers collected from a garden in central Poland. The fruit samples were cleaned and washed. Fresh cucumbers were subjected to imaging immediately after harvest. The second part of the material was pickled with the use of boiling potable water, white vinegar, sugar, salt, mustard seeds, allspice, bay leaves, dill and garlic and stored in one-liter glass jars for six months at a temperature of 11±1 °C.

Before the image acquisition, the fresh cucumbers after harvest and the pickled cucumbers after storage were sliced. The images of 100 slices of pickled and 100 slices of fresh cucumbers were obtained using a digital camera. The sample images are presented in Figure 1. The MaZda software (Łódź University of Technology, Institute of Electronics, Poland) was used for image processing [15]. The slice images were processed in order to convert to individual color channels *L*, *a*, *b*, *R*, *G*, *B*, *X*, *Y*, *Z* and compute image textures.

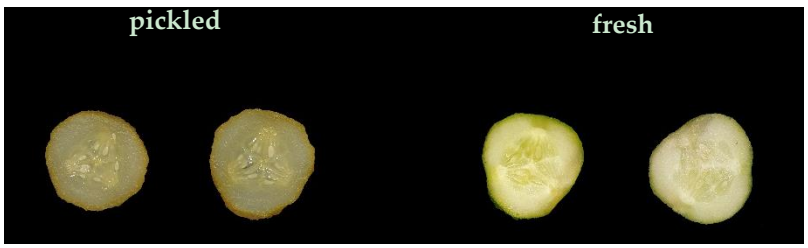

Figure 1. The slice images of pickled and fresh cucumbers.

The discriminant analysis was carried out with the use of the WEKA application (Machine Learning Group, University of Waikato) [16–18]. For distinguishing the pickled and fresh cucumbers based on texture parameters, the models developed using the selected algorithms from the groups of Bayes, Functions, Lazy, Trees, Meta and Rules were used. The textures with the highest discriminative power were selected using the Best First algorithm. The discrimination was performed using a test mode of 10-fold cross-validation [18]. The results were evaluated based on the accuracies for the classes of pickled cucumber and fresh cucumber, overall accuracy and the values of F1-score, Precision and Recall. A set of selected textures and algorithms providing the highest results were chosen to present in this paper.

3. Results and Discussion

The highest discrimination accuracies and other metrics were obtained for the models built based on a set of textures selected from the color channel *L*. The Naive Bayes

(Bayes), Multilayer Perceptron (Functions), KStar (Lazy), LMT (Trees), Logit Boost (Meta) and PART (Rules) proved to be the best algorithms. This was confirmed by the values of F1-score, Precision, Recall and overall accuracy presented in Table 1 and the discrimination accuracies for the pickled and fresh cucumber slice images shown in Figure 2. The overall accuracy and the accuracies of discrimination of both pickled and fresh cucumber samples reached 100% in the case of the model developed using the Multilayer Perceptron algorithm. The values of F1-score, Precision and Recall were equal to 1.000 for both pickled and fresh cucumber classes. The images of pickled and fresh cucumber slices were completely discriminated. Very high results were observed also for the KStar and LMT. Both algorithms provided an overall accuracy equal to 99.5%. In the case of KStar, only one slice belonging to pickled cucumber was classified incorrectly as a fresh cucumber and all one hundred slices of fresh cucumber were correctly classified as a fresh cucumber. Whereas the LMT algorithm incorrectly classified only one slice of fresh cucumber as pickled cucumber and all slices belonging to pickled cucumber were included in the class of pickled cucumber. A slightly lower overall accuracy of 99% was obtained for the Naive Bayes and Logit Boost algorithms. However, in the case of Naive Bayes, all pickled cucumber slices were correctly classified. A very satisfactory overall accuracy of discrimination was also determined for the model built using the PART algorithm even though neither fresh nor pickled cucumber slices were classified correctly in 100%. The overall accuracy reached 98.5%. In the available literature, there are reports on the application of image analysis for the quality evaluation of preserved fruit and vegetables, for example, for pickles [19,20] and lacto-fermented beetroot [21,22]. The results of our research confirmed the usefulness of image processing for the evaluation of preserved products.

Table 1. The evaluation metrics of discrimination of pickled and fresh cucumber slice images based on textures from the color channel *L*.

Algorithm	Class	F1-Score	Precision	Recall	Overall Accuracy (%)
Naive Bayes	pickled cucumber	0.990	0.980	1.000	99
	fresh cucumber	0.990	1.000	0.980	
Multilayer Perceptron	pickled cucumber	1.000	1.000	1.000	100
	fresh cucumber	1.000	1.000	1.000	
KStar	pickled cucumber	0.995	1.000	0.990	99.5
	fresh cucumber	0.995	0.990	1.000	
LMT	pickled cucumber	0.995	0.990	1.000	99.5
	fresh cucumber	0.995	1.000	0.990	
Logit Boost	pickled cucumber	0.990	0.990	0.990	99
	fresh cucumber	0.990	0.990	0.990	
PART	pickled cucumber	0.985	0.990	0.980	98.5
	fresh cucumber	0.985	0.980	0.990	

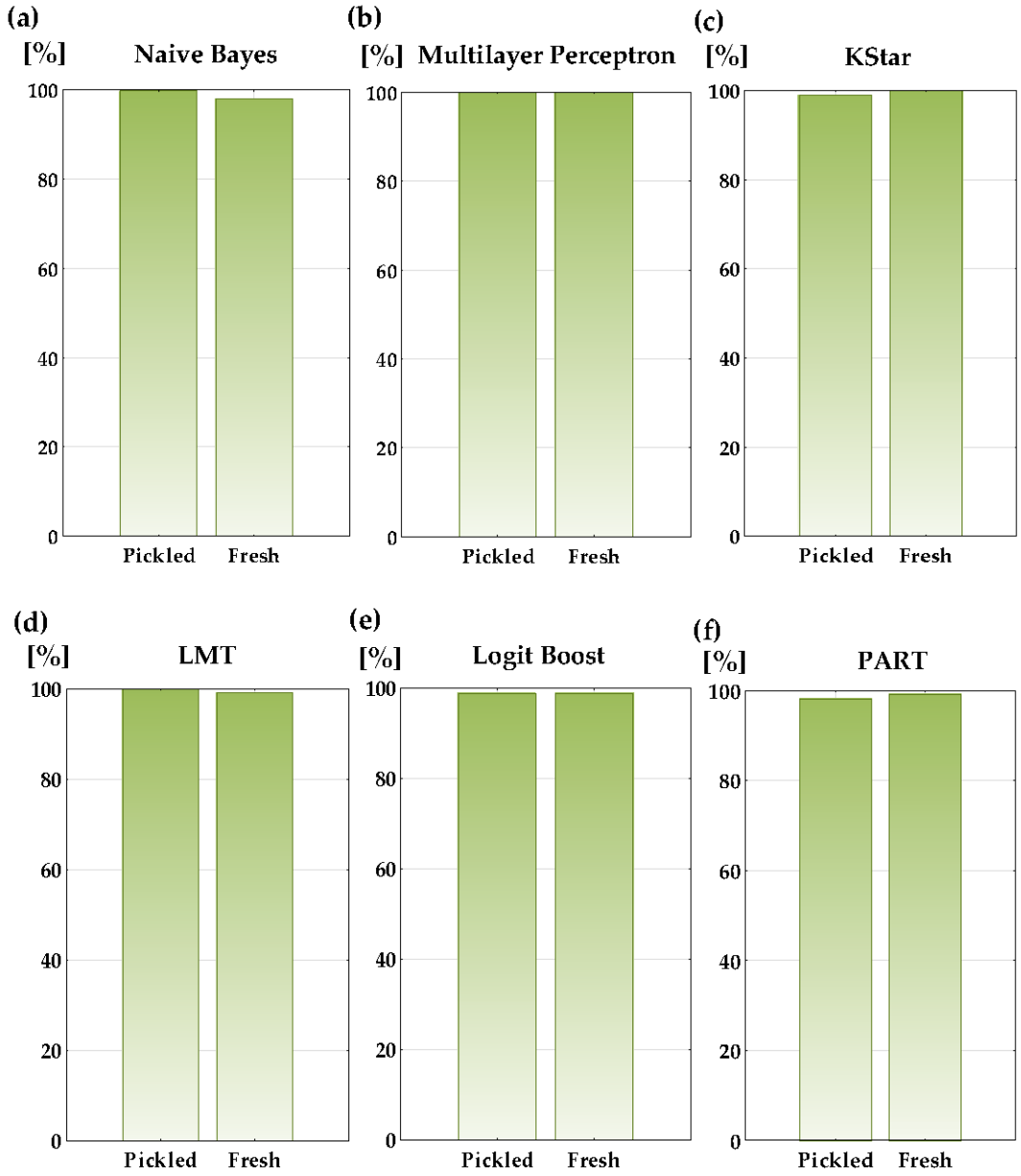

Figure 2. Accuracies of discrimination of pickled and fresh cucumber slice images for the models developed based on textures from the color channel *L* using different machine learning algorithms: Naive Bayes (**a**), Multilayer Perceptron (**b**), KStar (**c**), LMT (**d**), Logit Boost (**e**), PART (**f**).

4. Conclusions

The obtained results proved the usefulness of models based on selected texture parameters of slice images built using machine learning algorithms for the successful discrimination of pickled and fresh cucumbers. It also confirmed that the pickling affects the cucumber flesh that is reflected in the differentiation of the image textures. The pickled and fresh cucumber slices were discriminated with an overall accuracy reaching 100% for the model built based on a set of image textures selected from color channel *L* in the case of the Multilayer Perceptron algorithm. The effectiveness of the features obtained using image processing may be tested in future research for other methods or techniques of cucumber preservation. The procedure can also be used for other fruit and vegetables.

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