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Design and development of software for objective evaluation visual characteristics of extruded foods

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Abstract. Nowadays, the rapid development of computer technologies provides numerous approaches and methods for objective non-destructive assessment of quality characteristics of different food products. The aim of this study is to present the development and implementation of a software designed for the objective evaluation of visual characteristics of extruded food products in the process of their production. Utilizing advanced methods for computer vision and digital image processing techniques, the software enables precise measurement of both color and dimensional attributes, specifically width variations, in extruded samples. The system provides a non-invasive and reproducible method for assessing product consistency, supporting quality control and process optimization in food manufacturing. The results obtained show that the developed software can be effectively used in assessing uniform color distribution during the extrusion process. The results demonstrate the software's effectiveness in capturing subtle visual changes such as the width of extrudes, thereby contributing to more reliable product assessment and standardization in the food industry.

1 INTRODUCTION

Extrusion technology has become one of the most widely applied processes in the food industry, enabling the production of a diverse range of products such as breakfast cereals, snacks, and textured protein ingredients. The appeal of extruded foods is strongly influenced by their visual characteristics—including shape, color, and surface texture—which directly affect consumer perception and market acceptance. Traditionally, the evaluation of these attributes has relied on subjective sensory analysis, where trained panels or consumers assess product quality. While sensory testing provides valuable insights, it is inherently limited by human variability, fatigue, and bias, making it difficult to ensure consistency across large-scale production environments [1, 2, 3, 4].

To overcome these limitations, researchers and industry practitioners have increasingly turned to objective, computer-based methods for food evaluation. Advances in computer vision, image processing, and machine learning have enabled the development of systems that can quantify visual attributes with high precision and reproducibility. Such systems allow manufacturers to monitor product quality in real time, reduce reliance on human judgment, and establish standardized metrics for product comparison. For example, recent studies have demonstrated the feasibility of using automated image analysis to evaluate the visual characteristics of corn-based extruded snacks, highlighting the potential of software-driven approaches to enhance quality control [5].

The design and development of specialized software for objective evaluation of extruded foods is therefore a critical step toward modernizing food quality assessment. By integrating image acquisition, feature extraction, and statistical analysis into a unified platform, such software can provide reliable and scalable solutions for both research and industrial applications. Moreover, objective evaluation supports innovation in product design, enabling manufacturers to tailor visual properties to consumer preferences while maintaining strict quality standards.

This research presents the design and development of a specialized software system aimed at the objective evaluation of visual characteristics of extruded foods such as color consistency. The proposed solution leverages computer vision methods to quantify key visual metrics, ensuring consistency, reducing human bias, and enhancing quality control processes.

The system is based on vision techniques to analyze product images, extract different features, and generate reproducible assessments of quality. The work contributes to the growing body of research on digital food evaluation and offers practical tools for enhancing quality assurance in extrusion-based food production. The system is tailored to meet the practical needs of food manufacturers, offering flexibility, accuracy, and integration potential with existing production workflows.

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2 MATERIALS AND METHODS

2.1 Extruded samples

For the purpose of this research a set of extruded samples of rice semolina produced by Mill Sliven AD under TD 141-2017 was used. The semolina used in the research had an initial moisture content of 12.6%, with an average particle diameter of 0.302 mm. To determine the moisture content of the extrudates, samples were first ground and then dried in an oven at 105 °C. The drying process continued until a constant weight was achieved, using an analytical balance to ensure precise measurement [8].

The extrusion experiments were performed using a single-screw extruder Brabender 20 DN (Brabender GmbH, Duisburg, Germany). The equipment was configured with a nozzle diameter of 4 mm and a screw compression ratio of 1:1. The thermal profile was maintained by fixing the temperatures of zone 1 and zone 2 at 80 °C and 100 °C, respectively. These operating conditions were selected to ensure stable extrusion and reproducibility of product characteristics. Raw material was fed at a controlled rate, and samples were collected under steady-state conditions for subsequent analysis of their visual properties.

RTD (Rest Time Distribution) as a metric in the extrusion process describes how long the different material particles remain in the machine from the inlet to the die. This parameter is important because it determines the quality of mixing, uniform melting and process stability. If the RTD is too short, the material may remain insufficiently melted or inadequately homogenized, while an excessively long RTD carries the risk of thermal degradation, color change or unstable properties of the final product. RTD is also crucial when changing the material or color - the narrower the distribution, the faster and cleaner the flow is renewed.

The measurement of RTD is usually carried out by briefly introducing a tracer into the hopper – for example, a colorant, chemical marker, or temperature impulse. The concentration of this tracer is then monitored as it appears at the outlet over time. The resulting curve (Figure 1) shows the residence time distribution and makes it possible to evaluate the efficiency of mixing as well as the presence of dead zones or excessive material retention [8].

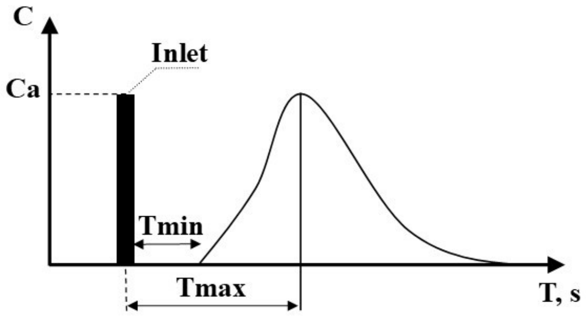


Fig. 1. RTD (Rest Time Distribution) curve.

In the production of extrudates, quality control of the final product is a critical factor for the sustainability and competitiveness of the technological process. One of the primary indicators of the quality of extruded materials is color uniformity, which reflects the even distribution of additives, the stability of thermal regimes, and the consistency of the raw material composition. Deviations in color homogeneity may serve as indicators of mixing deficiencies, temperature instability, improper extruder settings, or malfunctions in dosing systems. Consequently, systematic monitoring and analysis of the color characteristics of extrudates represent an essential tool for process optimization and the prevention of production defects.

The dynamic nature of the extrusion process necessitates the use of reliable and sensitive measurement methods that enable timely evaluation of color uniformity, including surface characteristics. In modern production lines, solutions based on computer vision and color analysis in RGB and CIE L*a*b* spaces are increasingly integrated, providing the capability for objective and automated real-time monitoring of the product. These approaches allow for improved assessment of color variations.

From a technological perspective, the determination of the RTD (Residence Time Distribution) curve was traditionally carried out by the expert technologist using a manual approach. This method, however, proved to be slow and unreliable due to the inherent influence of the human factor, which increases the likelihood of errors in measurement and interpretation. As a result, the need arose to develop dedicated software that supports and automates the process of generating the RTD curve. Such a solution not only minimizes human error but also enhances accuracy, efficiency, and consistency in evaluating the extrusion process.

2.2 Experimental setting

For the purposes of the research presented in this paper and for the automated evaluation of certain visual characteristics of extruded foods, an experimental setting illustrated in Figure 2 was used. It consists of several main modules that work together to ensure reliable and objective measurement.

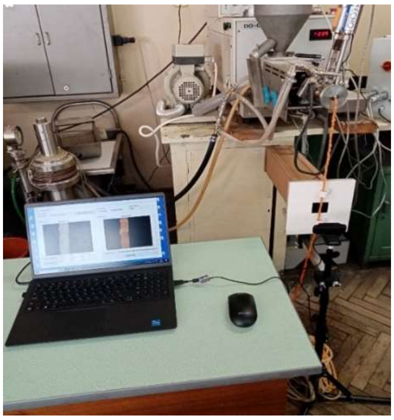


Fig. 2. The experimental setting.

The modules of the experimental setting are as follows:

- A single-screw extruder "Brabender 20 DN", manufactured by Brabender Gmbh, Duisburg, Germany;

- Special designed module for background suppression;

- HD camera, used for capturing video footage and obtaining high-quality images of the examined object;

- Portable computer system, serving as the control and computational unit;

- Image processing module, implemented through the developed software, which performs analysis and classification of the visual parameters of the extruded products.

2.3 Initial images for objective evaluation

Since the extrudate and its behavior over time are being investigated, video recording followed by frame extraction represents an appropriate method for obtaining primary images. When frames are sampled at fixed intervals, a sequence of time points is generated that reflects changes in coloration or the appearance of the tracer over time. This approach makes it possible to track when the tracer first emerges at the outlet, how its concentration or intensity evolves, and when it completely exits the system. Through video analysis, a detailed RTD curve of the extrudate can thus be obtained. The method is particularly suitable for visually distinguishable tracers and provides good temporal resolution under real production conditions.

To obtain primary visual data for each extruded product, video recordings were captured using high-definition camera. These videos served as the basis for image extraction, where individual frames were segmented at equal time intervals. This approach ensured consistent sampling of visual information across all products, enabling reliable analysis of their surface characteristics and geometric features. Examples of initial images are shown in Figure 3.

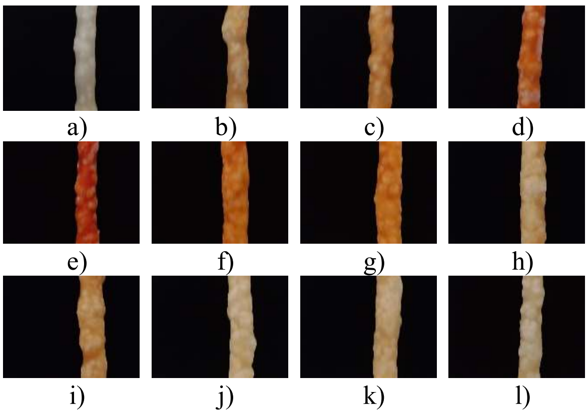


Fig. 3. A set of initial images – color distribution during the extrusion process.

To ensure maximum reliability of video recording, a specialized black tunnel was developed and extruded samples pass in front of it. Its purpose is to provide a fully controlled and perfectly black background. The dark background eliminates glare, external lighting, and parasitic reflections that could interfere with automated image processing and color intensity analysis. This setup maximizes the contrast between the extrudate and the background, allowing the tracer to be detected even with minimal changes. As a result, the accuracy of the method is significantly improved, making video-based RTD evaluation reliable for both laboratory and industrial applications. Figure 4 shows the image of this module. A pair of guide rings is used for stabilizing the extruded sample during the process of extrusion.

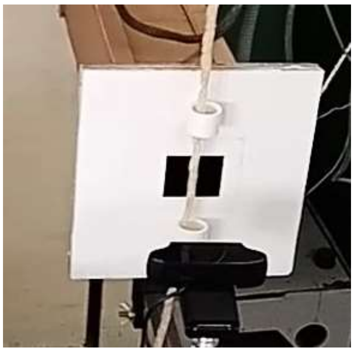


Fig. 4. Module for background suppression.

2.4 Software development and digital image processing techniques

This paper present a software solution as a part of a CV system designed to provide an objective evaluation of the visual characteristics of extruded foods by integrating digital image processing methods into a user-friendly application. The program is based on using C# programming language, chosen for its robust libraries, flexibility, and ability to support graphical user interface (GUI) development. The GUI enables intuitive interaction, allowing users to easily upload product images, configure analysis parameters, and visualize results without requiring advanced technical knowledge.

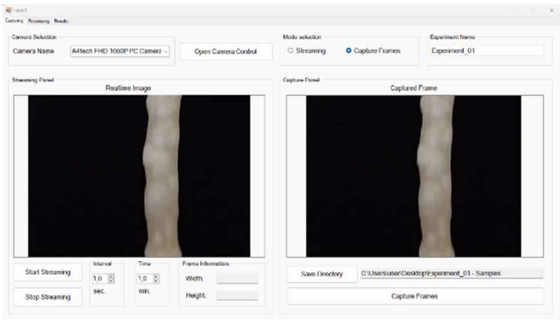
Core image processing techniques were incorporated to ensure reliable quantification of visual attributes. These include pre-processing operations, segmentation to isolate the product from the background, and feature extraction to measure parameters like, color distribution. The extracted descriptors are then statistically analyzed to provide reproducible metrics that can be compared across different samples or production batches.

By combining software engineering principles with computer vision algorithms, the system offers a practical solution for food scientists and manufacturers seeking to standardize quality assessment. The integration of a GUI ensures accessibility, while the underlying algorithms guarantee precision and consistency in evaluating extruded food products.

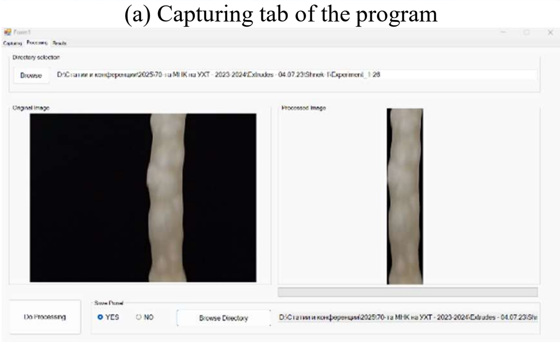
3 RESULTS AND DISCUSSION

3.1 Graphical user interface of the software for objective evaluation visual characteristics of extruded foods

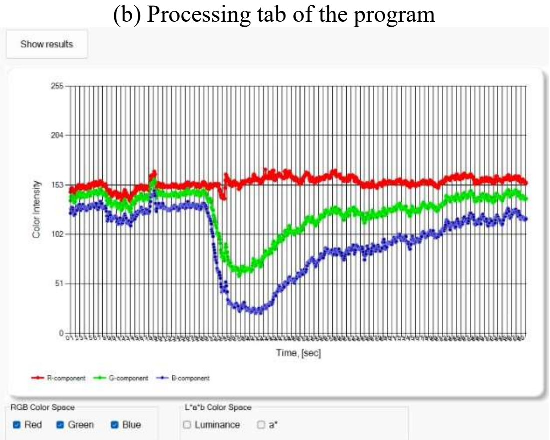
The developed software incorporates a modular graphical user interface (GUI) designed to facilitate standardized, reproducible, and user-friendly evaluation of visual attributes in extruded food products. The GUI is structured into three functional tabs - Capturing, Processing, and Results, each corresponding to a distinct stage in the analytical workflow.



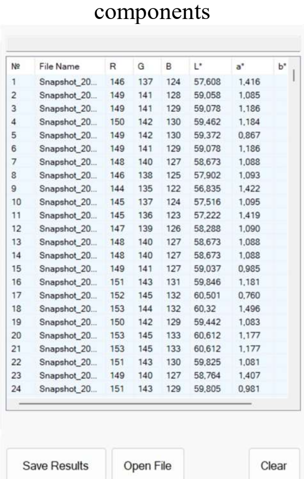
(a) Capturing tab of the program



(b) Processing tab of the program



(c) Graphical presentation of the results for R, G and B components



№	File Name	R	G	B	L*	a*	b*
1	Snapshot_20...	146	137	124	57,608	1,416	
2	Snapshot_20...	149	141	128	59,058	1,085	
3	Snapshot_20...	149	141	129	59,078	1,186	
4	Snapshot_20...	150	142	130	59,462	1,184	
5	Snapshot_20...	149	142	130	59,372	0,867	
6	Snapshot_20...	149	141	129	59,078	1,186	
7	Snapshot_20...	148	140	127	58,673	1,088	
8	Snapshot_20...	146	138	125	57,902	1,093	
9	Snapshot_20...	144	135	122	56,835	1,422	
10	Snapshot_20...	145	137	124	57,516	1,095	
11	Snapshot_20...	145	136	123	57,222	1,419	
12	Snapshot_20...	147	139	126	58,288	1,090	
13	Snapshot_20...	148	140	127	58,673	1,088	
14	Snapshot_20...	148	140	127	58,673	1,088	
15	Snapshot_20...	149	141	127	59,037	0,985	
16	Snapshot_20...	151	143	131	59,846	1,181	
17	Snapshot_20...	152	145	132	60,501	0,760	
18	Snapshot_20...	153	144	132	60,32	1,496	
19	Snapshot_20...	150	142	129	59,442	1,083	
20	Snapshot_20...	153	145	133	60,612	1,177	
21	Snapshot_20...	153	145	133	60,612	1,177	
22	Snapshot_20...	151	143	130	59,825	1,081	
23	Snapshot_20...	149	140	127	58,764	1,407	
24	Snapshot_20...	151	143	129	59,805	0,981	

(d) Results data presented in table view

Fig. 5. GUI of the developed software.

In the Capturing Tab, users can select an imaging device from a dropdown list and initiate either live streaming or frame-by-frame acquisition. The interface allows precise configuration of capture intervals and duration, ensuring consistent temporal sampling across experiments. Captured frames are automatically stored in a designated directory, labeled by experiment name to support traceability and data management.

The Processing Tab enables users to browse and load previously acquired images. A dual-display panel presents both the original and processed image side-by-side. Users may optionally save the processed images for subsequent analysis.

The Results Tab provides quantitative analysis of colorimetric data extracted from each image. The system computes RGB and L*a*b values and visualizes temporal changes in color intensity through dynamic plotting. A structured data table lists individual frames alongside their corresponding metrics, enabling statistical evaluation and comparison (Figure 5 d).

Figure 5 (a, b and c) shows the graphical user interface of the developed software, where a) shows the main window of the program used for capturing the initial images; b) shows the user interface of the Processing window and c) shows the Results window.

3.2 Workflow of the software

The developed software follows a modular workflow that enables objective evaluation of visual characteristics of extruded foods through image acquisition, processing, and analysis. The system is organized into three main functional stages:

- Image Acquisition (Capturing Tab);
- Image Processing (Processing Tab);
- Quantitative Analysis (Results Tab).

Figure 6 shows graphical representation of the workflow of the software.

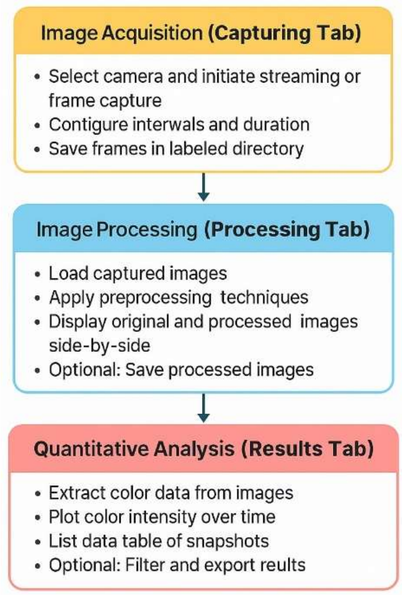


Fig. 6. Workflow of the software for objective evaluation visual characteristics of extruded foods.

3.2.1 Image Acquisition

In this tab the user can select the camera device from a dropdown menu and initiate live streaming or frame capture (Figure 7 a) and b)).

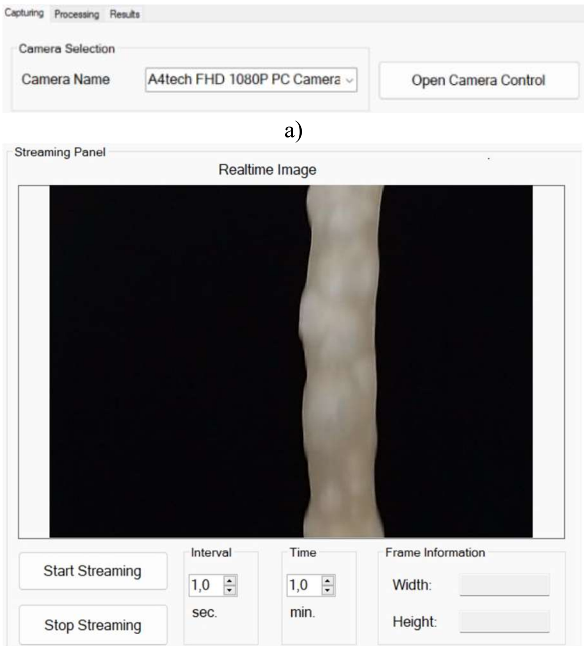


Fig. 7. Capturing tab – a) controls for camera device selection, and camera control settings; b) streaming preview.

The software also incorporates the capability to adjust the scanning interval, i.e., to regulate the time between individual frames. This setting is of critical importance, as it allows the measurement to be adapted to the specific process speed and to the dynamics of color changes in the extrudate. Captured frames are shown on the screen to ensure that the image is captured correctly and it is saved in a designated directory, labeled by experiment name for traceability (Figure 8).

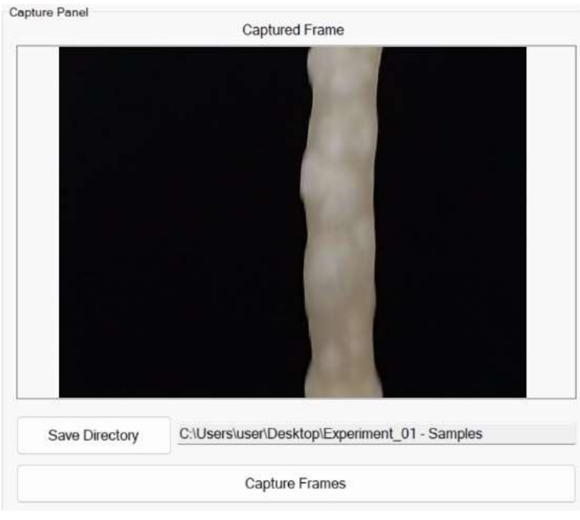


Fig. 8. Capturing panel and saving controls.

Differences in frame capture intervals have a significant impact on the results. Several advantages of small intervals can be recognized - higher temporal resolution – all small and rapid changes in the color of the tracer are captured; more precise determination of the moment of first appearance and peak concentration; smoother and more detailed RTD curve, especially important in fast processes or short residence times. There are a few disadvantages - generates a large number of frames which means significant amount of data to process; requires more analysis time or more powerful algorithms/hardware; higher risk of noise or small fluctuations that need to be filtered out. On the other hand, if the intervals of frame capturing are big there are also advantages and disadvantages. Advantages of bigger intervals - less data generated which means easier and faster processing; reduced computational resources and simpler analysis; suitable for slow processes or when RTD change is smooth. There are several disadvantages - lower time resolution which means important transients may be missed; less accuracy in determining the start and end times of tracer appearance; the RTD curve may become jagged or partially inaccurate in fast processes.

The ability to freely adjust the capture interval allows the method to be adapted to both laboratory conditions and real production lines. This makes video-based RTD evaluation flexible, accurate and applicable to different types of extruders and materials, while providing an optimal balance between measurement detail and processing efficiency.

The selection of the time interval between frames in video recording for RTD analysis is critical because it determines the balance between measurement accuracy and data volume. The interval is not universal - it is selected according to the characteristics of the specific extrusion process.

3.2.2 Image Processing

In this tab the users can browse and load previously captured images. The software applies preprocessing techniques to isolate the extruded object. A side-by-side display of the original and processed image enables visual verification of transformation accuracy. Users can choose whether to save processed images for further analysis (Figure 5 b).

The workflow of the software presented in this paper ensures a standardized and reproducible evaluation pipeline, from image capture to quantitative analysis. The integration of a graphical interface in C# makes the system accessible to non-programmers, while the underlying image processing algorithms provide robust and objective metrics for assessing extruded food quality.

3.2.3 Quantitative Analysis

For the purpose of this research and to evaluate the effectiveness of the developed software system, a total of 27 controlled experiments were conducted within a single day. Each experiment involved the acquisition and analysis of multiple image frames capturing extruded food samples under consistent lighting and spatial conditions. The software automatically extracted colorimetric data from each image, including both RGB and CIELAB (L*a*b*) values. For each processed

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image, the color values of all individual pixels are extracted and averaged to obtain a single representative color for the entire image. A dynamic graph module within the Results Tab visualizes temporal changes in color space (RGB or L*a*b*) component values across the captured frames.

The interface includes filtering options that allow users to isolate specific color components (e.g., R, G, B or L*, a*, b*) for targeted analysis. All extracted data can be exported in tabular format for further processing, reporting, or integration into external statistical tools. Figure 5 (c) illustrates the filtering and export functionality within the Results Tab.

In addition to in-app visualization, the software provides a dedicated result window where users can view and copy the complete dataset. This facilitates seamless transfer to spreadsheet applications such as Microsoft Excel, where advanced statistical operations such as regression analysis, clustering, or variance testing can be performed if required.

Figure 9 and Figure 10 shows graphical presentation of results correspondingly for RGB and L*a*b* color space, obtained after analysing batches of images obtained during conduction of the first experiment – Experiment 1.

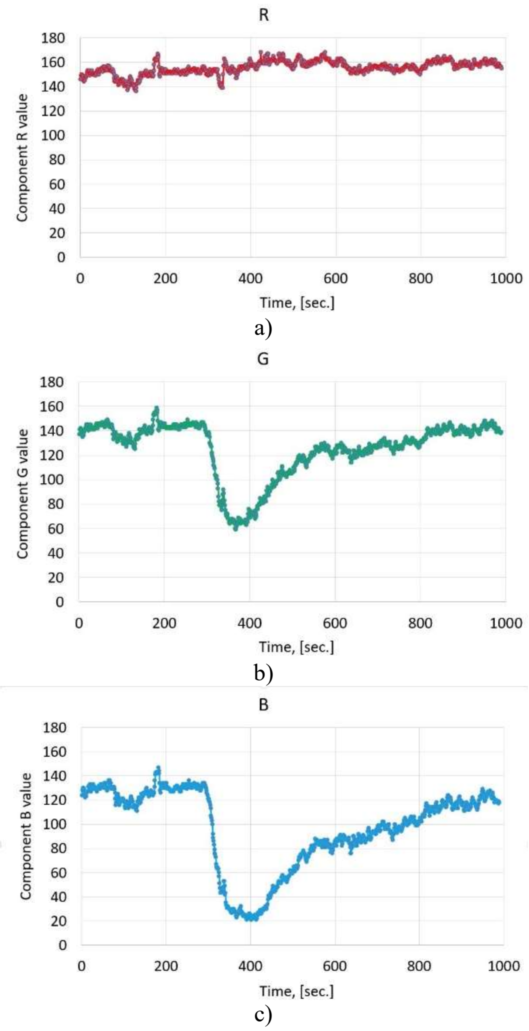


Fig. 9. Color distribution during extrusion in RGB color space – Experiment 1.

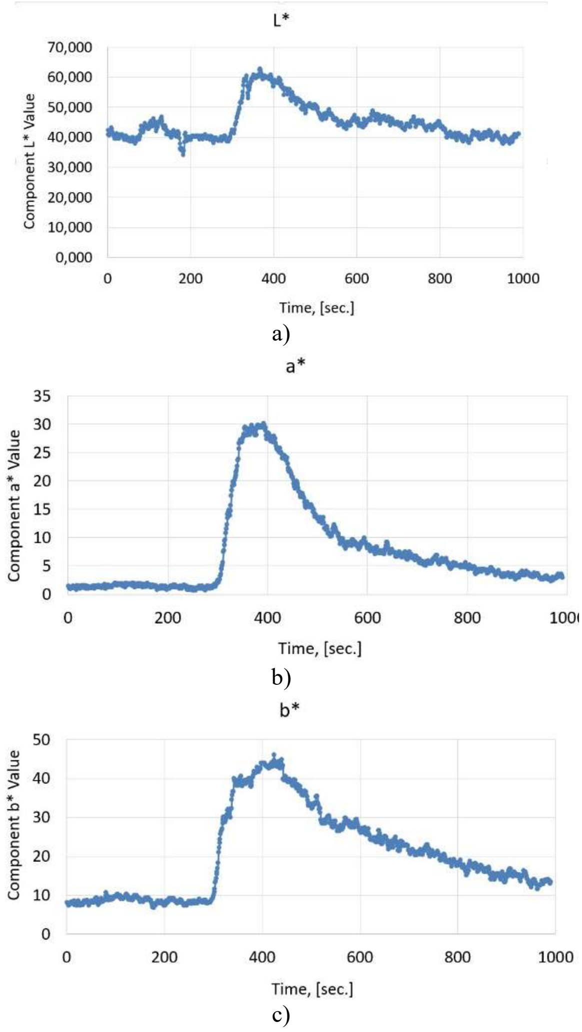


Fig. 10. Color distribution during extrusion in L*a*b* color space – Experiment 1.

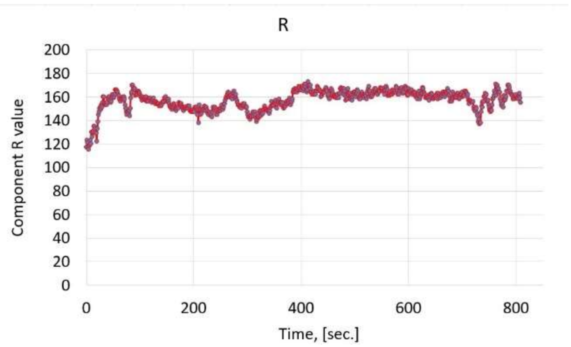
Figure 11 and Figure 12 shows graphical presentation of results correspondingly for RGB and L*a*b* color space, obtained after during conduction of the second experiment – Experiment 2.

As can be observed from the graphical outputs presented in Figure 11 and Figure 12, the RGB color system does not provide a reliable basis for assessing the distribution of color in this experiment. Although RGB values are widely used in digital imaging, their dependence on device-specific characteristics and lack of perceptual uniformity limit their effectiveness for quantitative evaluation.

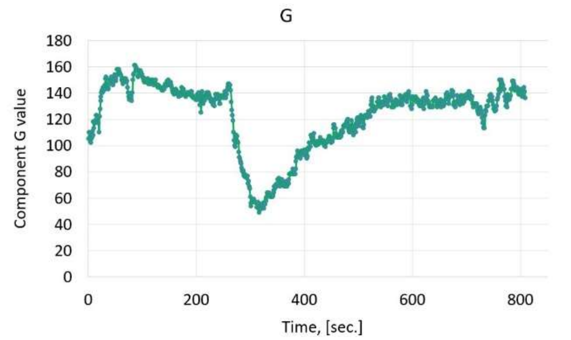
By contrast, the CIELAB color space offers a more robust framework for objective color assessment. Among its components, the a* channel, representing the green–red axis, produces the most distinct and interpretable graphical shape.

This outcome confirms the advantage of employing perceptually uniform color models, where numerical differences correspond more closely to human visual perception.

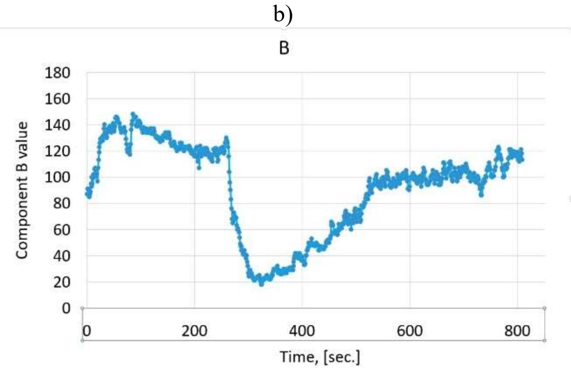
The performance of the a* parameter in this experiment demonstrates its potential as a primary indicator for monitoring visual changes in extruded foods.



a)

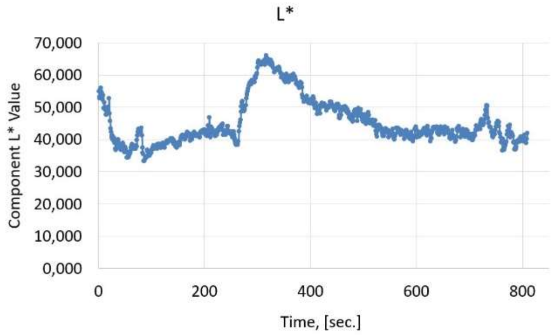


b)

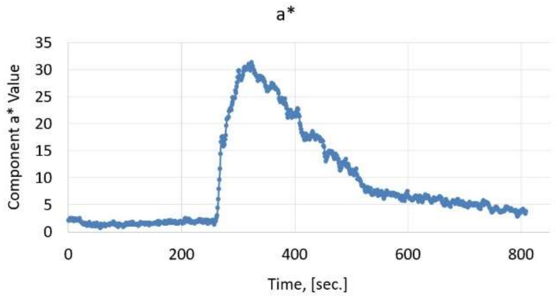


c)

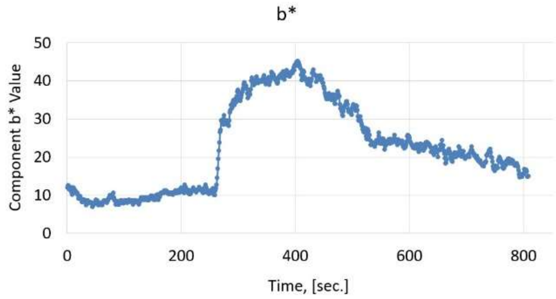
Fig. 11. Color distribution during extrusion in RGB color space – Experiment 2.



a)



b)



c)

Fig. 12. Color distribution during extrusion in RGB color space – Experiment 2

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4 CONCLUSION

The developed software successfully processed images of extruded food samples and generated quantitative descriptors of their visual characteristics. Color distribution were extracted with high reproducibility across multiple trials. The graphical user interface facilitated straightforward interaction, enabling rapid evaluation without the need for advanced technical expertise. Results demonstrated that objective measurements provided by the software were consistent with sensory panel observations, but offered greater precision and eliminated subjective bias. The results confirm the potential of computer vision–based systems to complement or even replace traditional sensory evaluation in extrusion research. Moreover, the integration of C# programming with digital image processing techniques highlights the feasibility of developing accessible, customizable tools for food scientists and industry practitioners. The outcomes support previous studies emphasizing the importance of automated image analysis in food quality control, particularly for extruded snacks where visual appeal strongly influences consumer acceptance.

Future research will extend the capabilities of the developed software by incorporating advanced algorithms for the evaluation of shape uniformity and surface texture, two critical parameters that strongly influence consumer perception of extruded foods. Enhancing the system to capture geometric consistency and microstructural details will provide a more comprehensive assessment of product quality.

References

1. A. Danev, A. Bosakova-Ardenska, R. Gabrova, & H. Andreeva, Automatic Evaluation Visual Characteristics of Corn Snacks Using Computer Vision. Engineering Proceedings, **104**(1), 81, (2016)
2. C. Yi; N. Qiang; H. Zhu; Q. Xiao; Li, Z. Extrusion processing: A strategy for improving the functional components, physicochemical properties, and health benefits of whole grains.

Food Res. Int., **160**, 111681. [CrossRef] [PubMed] (2022)

3. J. Koji´c; M. Belovi´c; J. Krulj; L. Pezo; N. Tesli´c; P. Koji´c; L.P. Tukuljac; V. Šeregelj; Ili´c, N. Textural, Color and Sensory Features of Spelt Wholegrain Snack Enriched with Betaine. Foods, **11**, 475. [CrossRef] [PubMed], (2022)
4. F.H. Fan; Q. Ma; J. Ge; Q.Y. Peng; W.R. William; S.Z. Tang, Prediction of texture characteristics from extrusion food surface images using a computer vision system and artificial neural networks. J. Food Eng., **118**, 426–433. [CrossRef] (2013)
5. M. Yizhou; J. Potappel; A. Chauhan; A.I.S. Maarten; R.M. Boom; L. Zhang, Improving 3D food printing performance using computer vision and feedforward nozzle motion control. J. Food Eng. **339**, 111277. [Google Scholar] [CrossRef], (2023)
6. Y. Chalamov, A. Simitchiev, V. Nenov, A. Danev, H. Andreeva, Effect of propeller use on residence time distribution (rtd) in single-screw cam-flow rice semolina extrusion, BIO Web Conf. **102** 03003 (2024), DOI: 10.1051/bioconf/2024102030