The Thesis of the PhD dissertation

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Rapid Quality Assessment of Bakery Products Using Machine Vision

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1. Introduction & Aim

The leavened bakery products are known as stapled food products in families' food baskets over the past century. These products such as bread, cakes, and buns can be manufactured using various formulations and processes; however, the primary ingredients used in their recipes are flour, water, and yeast. Depending on the final product, other ingredients including sugar, shortening, and egg may or may not be added. (Rathnayake, Navaratne, and Navaratne 2018).

Pogácsa, a popular salty cake, is a traditional leavened product made of wheat flour, cheese, margarine, yeast, and salt. Hungarian *pogácsa* cake has a specific texture, tender on the inside and crispy on the outside, which endows a unique and desired sensorial perception. Although this product is widely produced at the domestic and industrial levels, the number of research attempts to improve its physical and sensorial quality parameters are scarce. Therefore, there is a very good scope for processors to further work on quality improvement of this traditional product (Amani et al. 2021).

Quality parameters of *pogácsa* are highly related to the mechanical and sensory characteristics of the crumb, ingredients, and baking conditions that may influence consumer purchase. Various quality parameters of *pogácsa* products are correlated to the appearance criteria such as size, colour, shape, and crumb texture (Lassoued et al. 2007; Puerta et al. 2021). The availability of accurate, robust, and efficient analytical techniques is one of the big concerns in monitoring the quality of bakery products. The routine quality assessment methods have limitations of low capacity, using instrumentation, high expenses, and needs of skilled personnel (Ye, Guo, and Sun 2019).

Image processing is the core of computer vision system, which allows analysing various appearance parameters (e.g., size, colour, shape, and texture) from a digitalized image (Amani et al. 2020). This method has numerous advantages in speed, cost-effectiveness, and flexibility over conventional analytical methods. This superiority has made this method a useful non-invasive technique for grading, quality evaluation of morphological and textural features, as well as identification in bakery products (Abdollahi Moghaddam, Rafe, and Taghizadeh 2015; Ghasemi-Varnamkhasti and Lozano 2016; Gunasekaran 1996). Although considerable studies have been focused on employing image-based texture analysis in leavened bakery products, to our knowledge, no study has focused on pores structure and porosity measurement of *pogácsa* using image processing. Currently, the only analytical prediction for porosity measurement is available for bread, but no reliable method is available for porosity measurement of other bakery products like *pogácsa* cake. This hypothesis indicates a potential application of digital image processing as a simple technique for pore characteristic evaluation of *pogácsa*.

In view of the aforementioned points, this study has been designed with the following objectives:

1. To develop robust methods to evaluate the internal structure of the *pogácsa* cake.
2. To evaluate the effect of baking conditions (different time and temperature) and formulations (using cheeses with different moisture content (MC)) on the pores structure and sensory properties of *pogácsa*, with the help of image analysis.
3. Relationship between selected image texture features and physicochemical parameters of density, volume, colour, moisture, porosity, and mechanical texture parameters in *pogácsa*.

2. Materials & Methods

My thesis is separated into two main parts, therefore the materials and methods are sub-sectioned accordingly. The first part of the experiment was investigate the correlation between the results of image analysis and internal structure. For this purpose, the effect of different processing conditions was evaluated, by means of changing time and temperature of baking, on the quality of *pogácsa,* with the help of image analysis. In the second part, the effect of formulations (using cheeses with different levels of moisture content (MC)) and baking temperature on the porous structure and sensory properties of *pogácsa* was evaluated. The sample preparation and the methods described in this chapter.

2.1. Dough preparation

2.1.1. Dough preparation for the first part of the experiment

In order to prepare the dough for the experiment 1, different ingredients were mixed as following: First, 700 g cottage cheese (Real Nature Co., Budapest, Hungary) were mixed with 630 g margarine (Rama Co., Katowice, Poland), 42 g yeast (Lesaffre Yeast Co., Budapest, Hungary), 42 g salt, and additive (a mixture of spice made by Primer kft. Co.) using a pilot-scale blender (C.P Co., Brescia, Italy). Afterward, 700 g BL55 type wheat flour (Nagyi titka Co., Budapest, Hungary) was added to the mixing chamber and mixed for 3 min to obtain a homogenous dough.

2.1.2. Dough preparation for the second part of the experiment

Three different groups of dough were prepared for the experiment 2 of the study. In the first and second groups, the dough preparation was the same as the experiment 1, with modification in cottage cheese. Two cottage cheese with two different MC of 58% and 65 % were used in dough formulations. MC of aforementioned groups were measured using oven drying method (AACC 1995). Third group of *pogácsa* dough was prepared without cottage cheese. For this purpose, first margarine, yeast, salt, and additive were mixed using the pilot-scale blender (C.P Co., Brescia, Italy), wheat flour was then added and mixed for 3 min using the blender.

2.2. Molding the samples

All the groups of the prepared dough were then rested in cold storage (4°C ± 2°C) for overnight. After cold storage, the dough was rolled out, folded, and again rolled out and uniformly plated into smooth flat shape with 6 mm thickness. Finally, the rolled dough was cut into small pieces by a 4 cm diameter cutter.

2.3. Proofing process

The moulded dough was placed on baking trays and transferred to a proofing chamber (S-200, SvebaDahlen AB, Fristad, Sweden). All samples were subjected to a similar proofing setting of 40 °C and 20 min.

2.4. Baking settings

2.4.1. Setting for the first part of the experiment

Preliminary trial was conducted to find the desired ranges for the temperature and time of baking. Based on the preliminary observations, different temperatures (200, 215, and 230 °C) and times (5 and 7 min) were selected for further study of internal structures in *pogácsa*. Six different groups of *pogácsa* samples were prepared under different baking conditions (A: 200 °C, 5 min; B: 200 °C, 7 min; C: 215 °C, 5 min; D: 215 °C, 7 min; E: 230 °C, 5 min; F: 230 °C, 7 min). The baking setting of the group D was regarded as the industrial recipe.

2.4.2. Setting for the second part of the experiment

Baking temperatures of 200 and 215°C were selected based on the results of the previous part of the internal structure inspiration. The baking temperature of 200 and 215°C demonstrated the highest effect on changing the porous structure of the *pogácsa.* While the impact of baking time on the internal structure was meager. Therefore, for this part of the study, all samples were baked for 7 min (standard time for industrial recipe). Six different *pogácsa* groups (A1, baked at 200°C, cheese with less MC (58%) in formulations; A2, baked at 200°C, cheese with high MC (65%) in formulations; A3, baked at 200°C, no cheese in formulation; B1, baked at 215°C, cheese with less MC (58%) in formulations; B2, baked at 215°C, cheese with high MC (65%) in formulations; B3, baked at 215°C, no cheese in formulation) were prepared.

2.5. Baking processes

After proofing, the baking process was performed using an oven (S-200, SvebaDahlen AB, Fristad, Sweden). The baked samples were cooled down to room temperature and packed in air-tight plastic containers and labelled with three-digit codes for further analyses. Each group of *pogácsa* was prepared separately in three separate batches, and pieces were randomly selected from each batch. Evaluation of the PVI, TPA, GLCM, MC, volume, porosity, colour, and sensory analysis were conducted with 10,12, 22, 10, 10, 10, 3,15 replication for each sample group, respectively.

2.6. Image analysis

For image processing of *pogácsa* samples (22 replicates per samples), first, the images of the cross-sectioned samples were captured using a DFK 33UX273 USB colour camera (The Imaging Source Co., Germany) equipped with a CMOS sensor and F:1.8 lens (type VS-2518VM). Algorithms for GLCM extraction were developed in MATLAB software (version R2018a, MathWorks Inc. Natick, MA, USA) conducting sequence of acquisition of colour picture, ROI selection, median filter, histogram equalization, otsu's thresholding, morphological operation, gray scale, watershed segmentation, Graycomatrix calculation, and ellipses were fit on holes. Study the internal structure and pore characteristics of *pogácsa* samples were carried out using Fiji ImageJ software (National Institutes of Health, USA) using the following sequence of pixel calibration, ROI selection, contrast enhancement, channel splitting, applying median filter, thresholding, applying median filter, and extracting data.

2.7. Physical and textural properties

The volume (10 replicates) was estimated by calculating the volume based on the surface area of the sphere pores. For this purpose the height and diameter of the all the baked *pogácsa* samples were measured using a digital calliper (General Tools & Instruments, New York, N.Y., U.S.A.). *Pogácsa* volume were then calculated using equation:

$$\text{Sample volume (mm}^3\text{)} = 1/4\ \pi h d^2$$

The moisture content of *pogácsa* samples (10 replicates) was estimated using standard method (AACC 1995). Crust surface colour and crumb colour were determined in three replicates per sample, using a chromameter (Minolta CR-310, Apeldoorn, Netherlands).

A texture analyser (model TA-XT2i, Stable Microsystems, Surrey, UK) was used to determine the mechanical properties of *pogácsa* with 12 replicates per sample. Following parameters were calculated using the Exponent software (version 6.1.16.0, Stable Microsystems, London, UK): hardness, cohesiveness, gumminess, resilience, springiness, and chewiness.

The porosity (10 replicates) of the samples was measured using the reference method designed for bread (Lásztity and Törley 1980). For this purpose, a regression model was built based on the table of MC and absolute density (AD) of bread to predict the AD of *pogácsa* for different MC levels. Porosity was estimated using initial weight of the product (W_0), predicted absolute density (AD), and sample volume (V), as following:

$$Porosity\ (\%) = (1 - \frac{W_0}{AD \times V}) \times 100$$

2.8. Sensory evaluation

The sensory evaluation was performed on *pogácsa* samples by 15 trained panellists. The evaluation was done under similar illumination conditions at room temperature according to ISO 8589. Panellists were asked to complete questionnaires by scoring on taste, colour, aroma/odour, oiliness, chewiness, hardness, elasticity, pores structure, and crumb structure of more or less crumbliness. Samples were evaluated using a 5-point scale, "Just About Right" (JAR) and the product's overall liking (OL) on a 9-point hedonic scale. Penalty analysis was used to statically analyse the JAR data. Mean drops (penalties) were calculated as the differences between means of the JAR and the mean of two categories of non-JAR, and consequently, to determine which sensory attributes differentiate the *pogácsa.*

2.9. Statistical analyses

All statistical analyses were performed using IBM SPSS™ software (version 29.01.0 Inc., Chicago, USA). The Analysis of variance (ANOVA) was applied to the obtained data and Duncan's multiple range test was performed to detect the differences among means at the significance level of α=0.05. A completely randomized design (CRD) was applied for data collocation. Factorial design was also used to assess the main effect for each independent variable of time and temperature of proofing and baking. Two-way ANOVA was used to calculate the effect of the two independent variables of baking temperature and formulation, in combination, on structural properties of *pogácsa* samples and overall liking. The statistical test was performed at a 5% significance level. The correlation coefficients (R) between images data and mechanical parameters were obtained with the help of Pearson correlation test. In order to investigate the relationship between imaging parameters and porosity of the product, the regression equations also build using SPSS and the best selected based on the R^2 value. The penalty analysis of sensory data was carried out using XLSTAT software (version 2020.5, Addinsoft, New York, USA).

3. Results & Discussion

3.1. Results of the experiment 1

3.1.1. Results of the PVI evaluation

Sample C had the highest pore volumetric index (PVI) value (24.26%), followed by samples B (21.34%), D (21.28%), E (20.35%), and A (19.73%). The lowest PVI was found for sample F (baked at 230°C for 7 min) with a value of 12.81. Temperature and duration of baking are crucial factors that affect the PVI of the *pogácsa*. The temperature of 215°C and shorter baking time (5 min) resulted in the highest PVI value (sample C), while the longer baking time (7 min) and higher temperature (230°C) resulted in lower PVI values (sample F). The difference in the PVI values could be also ascribed to the increased yeast activity, which causes a larger production of CO_2 in the dough when exposed to the higher temperature. However, other factors might cause changes in the PVI of *pogácsa* samples such as fast water evaporation during the baking and low gas diffusion rate in the dough, which resulted in gas expansion during the baking (Chiotellis and Campbell 2003).

3.1.2. Results of changes in physical and textural properties of pogácsa due to variation in baking time and temperature

With increasing baking time and temperature, the hardness was drastically increased. While, in case of cohesiveness, gumminess, chewiness, and springiness, both increasing and decreasing trends were observed. However, no noticeable change (except for sample F) was recorded in adhesiveness when different time and temperature settings were applied. This might imply that bakery products are not generally adhesive. Samples D and E showed the highest and lowest values of cohesiveness, respectively. By increasing temperature (at any baking time), gumminess was monotonically increased. Moreover, monotonically incensement was observed in gumminess when the baking time increased from 5 to 7 minutes at any temperature. Therefore, sample F with the highest temperature and time demonstrated the maximum gumminess, whereas sample A, which was baked under the lowest temperature and time, had the minimum gumminess. Chewiness, which depends on springiness and gumminess, showed the same tendency as gumminess; monotonically increased by both increasing the temperature at any baking time and increasing the baking time at any baking temperature. Since *pogácsa* has a gas-filled cellular texture, it can be fractured by mechanical force. Therefore, the present result obtained for hardness might be useful to calculate the required force for breaking the structure. The results of the hardness test showed that maximum baking temperature had the maximum hardness value (sample F). On the other hand, with increasing the hardness of samples, springiness decreased. This implies that increasing baking parameters (time and temperature) may result in a firmer and harder texture.

The study's findings highlight the influence of baking conditions on *pogácsa* characteristics. Sample A exhibited the highest MC, significantly different from other samples, while sample F had the lowest MC. Sample D had the highest volume and sample F the smallest. Porosity results revealed that sample E had the highest porosity, while sample F had the lowest. These results emphasize that variations in baking temperature and time have a substantial impact on the crumb MC, volume, and porosity of *pogácsa*. Sample F, baked at 230°C for 7 minutes, displayed the lowest crumb MC, volume, and porosity, resulting in a denser and drier product.

3.1.3. Results of GLCM textural features

Sample D showed the highest value (7.74) for entropy, whereas the lowest belonged to group C with a value of 7.48. The difference recorded between the entropy of samples C and D indicated the importance of the baking time, as the same temperature (215 °C) was used for both samples. Interestingly, no significant difference ($p > 0.05$) was found amongst other groups (A, B, E, and F) when the time of baking increased from 5 to 7 min. In case of contrast parameter, sample D had the highest value, followed by samples A, and C, while the value for sample F was the least. Sample C exhibited the highest value for energy, which was noticeably reduced (from 0.2 to 0.16) when the baking time increased from 5 to 7 min. In contrast, the increasing baking time did not show any marked effect on the energy values of other *pogácsa* samples, which were prepared at 200 and 230 °C.

3.1.4. Results of correlation coefficient among the different parameters

The hardness showed strong positive correlation with contrast ($p < 0.01$) and strong negative correlations with both homogeneity and correlation ($p < 0.01$). This may imply that the softer texture of *pogácsa*, the lower contrast and vice versa. Hence, it can be interpreted that the increase in hardness might lead to changes in the visual appearance of *pogácsa* as well as its image textural features (Karimi et al. 2012). Springiness had positive and negative correlations with homogeneity and contrast, respectively. Among all parameters, gumminess exhibited the best correlation coefficients, in particular for contrast, correlation, and homogeneity, having suitable relationship with instrumentally measured texture parameters. Among the image textural features, contrast and homogeneity showed the best correlation coefficients with the sensory features.

3.1.5. Results of the effect of the temperature and time of baking on PVI and overall liking of pogácsa cake

A two-way ANOVA was conducted to assess the impact of baking time and temperature on PVI and overall liking (OL). It was found that baking time had a statistically significant individual effect on PVI ($p < 0.05$), with the highest values observed in groups baked for 5 minutes. However, the effect of baking time on OL was not statistically significant ($p > 0.05$). Regarding baking temperature, it had a statistically significant individual effect on OL ($p < 0.05$) but did not significantly affect PVI ($p > 0.05$), with higher temperatures (230°C) leading to lower values for both PVI and OL. Additionally, the interaction between baking time and temperature did not have a significant impact on either PVI or OL ($p > 0.05$).

3.1.6. Results of the sensory evaluation

Panellists presented that the oiliness of *pogácsa* was "too much" in all six sample groups. Therefore, less oily products would probably have higher acceptability. The values of "percentage of consumers" in sample D were markedly lower than the other five samples. This indicated that respondents considered sample D closer to non-optimal compared to the other five groups.

3.2. Results of the experiment 2

3.2.1. Results of the PVI evaluation

Sample A2 exhibited the highest PVI value (26.64%), followed by samples B2, A1, and B1 with PVI values of 18.52%, 18.43%, 17.33%. Therefore, it can be assumed that presence of cheese in the samples significantly impacted the PVI, suggesting the importance of the MC in affecting the textural properties of the final product.

3.2.2. Results of changes in physical and textural properties of pogácsa due to increase in baking temperature and addition of cheese

Hardness and chewiness values showed that higher baking temperature (215 °C) along with less moist cottage cheese (58% MC) in the formulation led to harder crumb and higher chewiness. Sample A1 exhibited the highest value for cohesiveness (0.61), whereas the lowest belonged to sample B3 with the value of 0.32. In case of gumminess, sample B1 showed a value of 694.81, which was noticeably higher than other groups, while the lowest was belonged to sample A3 (191.51). Changes in the springiness values could be related to the variation in hardness, in such a way that increasing the hardness could cause a reduction in springiness and vice versa. This signifies that the increasing in baking temperature (from 200 to 215 °C) may result in a harder crumb texture.

The study's results indicate significant impacts of different recipes and baking conditions on MC, volume, and porosity of *pogácsa*. High moisture cheese in the recipe maximizes crumb moisture, while its absence minimizes it. The presence or absence of cheese plays a key role, with cheese-free samples having lower volumes. Higher baking temperatures lead to increased volume. The highest porosity value was found for sample B1 (72.75%), followed by samples A1 (69.63%), B2 (62.20%), A2 (53.36%), and B3 (38.83%). Whereas the lowest value (32.66%) for this parameter was observed in sample A3, which was cheese-free and baked at 200°C. Therefore, it can be interpreted that higher baking temperature had significant effect to increase the porosity in *pogácsa* cake.

The results of the colour measurements showed that L* values of crumb and crust decreased with increasing MC of the product. This indicated the impact of moisture content on the colour surface. Cottage cheese contains protein which might contribute to a lower L* values in both crust and crumb. In addition, increasing the baking temperature could reduce crust L* values. Values of a* for both crumb and crust were higher in groups B1, B2, and B3 compared to groups A1, A2, and A3. The highest yellowness (b*) value was observed in sample A1 with values of 52.03 for crust and 29.38 for crumb, while the minimum value of b* was found for crust (40.90) and crumb (20.71) of the sample A3.

3.2.3. Results of correlation coefficient among the different parameters

The PVI and MC showed a strong negative correlation ($p < 0.01$) with hardness, gumminess, and chewiness, strong positive correlation ($p < 0.01$) with resilience, cohesiveness, and springiness. In addition, strong positive correlation ($p < 0.01$) was observed between PVI and porosity results. It can be interpreted that the less firm *pogácsa* texture resulted in the higher PVI, and vice versa.

3.2.4. Results of the effect of the baking temperature and formulation on PVI and overall liking of pogácsa cake

The study's findings highlight the significant impact of both baking temperature and variations in cheese MC on OL and PVI of the *pogácsa*. Changing the MC of cheese and the interaction between cheese MC and baking temperature had significant effects on PVI, with p values of 0.017, 0.002, and 0.019, respectively. For OL, the mean value for samples baked at 200°C and 215°C were 5.93 and 6.6, respectively. For changing the cheese moisture of high and low, the mean scores were 8.20 and 8.0, respectively. Samples without cheese in the formulation had a mean acceptability score of 2.6. The results emphasized the considerable influence of baking temperature and changes in cheese MC, as well as their interaction, on the overall liking of the *pogácsa*.

3.2.5. Results of the sensory evaluation

40% of respondents rated colour, chewiness, and hardness as "too much" and elasticity as "not enough". The values of "mean drops" in sample B3 were found to be negative (below zero). This indicated that sample B3 was considered by panellists as non-optimal compared to other *pogácsa* samples. Therefore, increasing the baking temperature from 200 to 215°C along with removing the cottage cheese from formulation might lead to a marked decrease in the overall acceptability of the baked product like *pogácsa*.

3.3. Influence of baking conditions and cheese variations on *pogácsa's* overall liking (experiments 1 & 2)

The experiments revealed that baking conditions significantly affect the OL of *pogácsa*. In the first experiment, sample E (baked at 230°C for 5 minutes) received the highest OL score, while sample F (baked at 230°C for 7 minutes) had the lowest score, indicating the sensitivity of liking to baking time and temperature. In the second experiment, the presence and moisture content of cheese played a significant role in OL, with samples featuring high-moisture cheese generally scoring higher. The absence of cheese had a negative impact on OL. These findings underscore the importance of baking conditions and cheese content in determining the texture and overall liking of *pogácsa*.

3.4. Development of prediction models for porosity measurement of the *pogácsa* cake using image features and regression analysis

Linear, quadratic and multivariate regression models built by three parameters (contrast + homogeneity + correlation) exhibited the highest R^2 which was 84.4 ($p < 0.05$). Using "homogeneity + correlation" as inputs showed a model with the same R^2 as the previous model (84.4), while a slightly lower determination coefficient ($R^2 = 81.1$) achieved when "correlation" used as input. Therefore, using the combination of the GLCM parameters of contrast, homogeneity, and correlation as the input variables for predicting porosity, generated a model with highest R^2. The same modelling technique also applied to those *pogácsa* samples which formulated with different cheese materials (having different MC ranging from 58 to 65% and samples without cottage cheese in the formulation). Following model with PVI variable was found to be statistically significant, indicating the robustness and accuracy of the PVI as a predictive tool for assessing the porosity parameter of *pogácsa* samples, even under conditions where the production recipe exhibits variations (R^2 = 75.5 and RMSE = 2.13):

$$Porosity = 3.48PVI - 0.086PVI2 + 32.30$$

The findings of present study indicated the suitability of image processing and modelling techniques for prediction of porosity values in *pogácsa* cake.

4. Conclusion & Recommendations

The thesis focused on developing a robust methods to evaluate the internal structure of the *pogácsa* cake. In addition, the effect of formulations (using cheeses with different moisture contents (MC)) and baking conditions (different time and temperature) on the porous structure and sensory properties of *pogácsa*, was investigated with the help of image analysis. Also, relationship between selected image texture features and physicochemical parameters of *pogácsa* was studied. The general results obtained in this study are presented below:

- The TPA results revealed that the change in baking settings (time and temperature) could substantially influence the product texture and change hardness, cohesiveness, springiness, gumminess, and chewiness.
- *Pogácsa* samples prepared with high moist cheese (65% MC) showed the highest PVI. In addition, increase in baking temperature from 200 to 215◦C caused an increase in the PVI value. However, increasing the baking time from 5 to 7 minutes along with increasing the baking temperature to 230◦C led to a decrease in the PVI value. Using cheese in *pogácsa* formulation could generate bigger particle sizes occupied in the crumb of baked samples. While lowest values for pore characteristics were achieved with cheese-free samples.
- The GLCM textural features extracted from *pogácsa* images were found to be varied when different times and temperatures were applied. In addition, GLCM imaging analysis found to be suitable for porosity measurement and prediction the textural properties of *pogácsa*.
- The results of colour measurements revealed that L* values of crumb and crust decreased with increasing MC of the product. *Pogácsa* groups with high moist cheese in the formulation exhibited the lowest values of L* and vice versa. In groups, which were baked under higher temperature (215°C), water migration from crumb to crust increased a* values and thus changed the visual appearance of the *pogácsa*.
- Penalty analysis revealed that oiliness, pore structure, and colour of products were linked with baking time and temperature. High percentage of consumers felt that the oiliness was more than enough in the samples, which were prepared with higher moist cheese. Also, increasing the baking temperature resulted in an undesirable colour score.
- The results of OL revealed that baking temperature and time significantly impact OL, with moderate conditions receiving higher scores. Positive influence of cheese was observed on OL, particularly

when it had a higher moisture content. Conversely, the absence of cheese had an adverse effect on liking. Therefore, delicate balance required in *pogácsa* preparation, where optimal baking parameters and the inclusion of cheese contribute to a more enjoyable sensory experience.

It is known that important parameters of temperature and time of the baking in addition to the heat flow inside the oven can affect the results of the internal structure of the baked product. In the scope of this thesis the first two parameters have been studied in detail. As an extension to this thesis for the future works it is recommended to perform the detail analysis on the effect of heat flow inside the oven. This effect has been previously studied for bread and some other bakery products but to the best of authors knowledge, this study has not been done for evaluating the internal structure of the *pogácsa* (Standing 1974; Litovchenko 2013). Furthermore, it is advisable to explore various metrics such as the ratio of pore area to segmented area, in order to gain additional insights in this context. It has the potential to reveal novel correlations and offer valuable supplementary information.

5. New Scientific Results

1. The structural properties of bakery products can be affected by changes in baking conditions, and a reliable method for quantifying these changes is essential. The PVI (pore volumetric index) has been proposed as a promising approach for evaluating the structure of *pogácsa* samples, based on cross-sectional images. This method involves segmenting the pores using Otsu's thresholding technique and projecting the total pore area to volume, with the PVI expressed as the percentage of pores in the segmented sample. The PVI was observed to respond sensitively to changes in baking time ($p < 0.01$), baking temperature ($p < 0.01$), and recipe variation ($p < 0.002$) due to the use of cheese with different MC, demonstrating its potential as a useful tool for monitoring and characterizing the effects of baking conditions on the structural properties of *pogácsa* cake.

2. New model has been created to predict porosity of *pogácsa* of given recipe using digital image processing, utilizing pattern descriptors of homogeneity, correlation and contrast. The model fit well on experimental data with $R^2 = 0.844$, RMSE = 1.56, and RPD = 2.33:

Porosity = – 65.9 Homogeneity – 88.09 Correlation – 0.58 Contrast + 207.63

3. A singular visual parameter, PVI, and a statistical parameter representing the pattern of correlation were selected as potential predictors of porosity for an experimental investigation where varying time and temperature of baking was applied. When each of these selected parameters was used separately, they resulted in good estimations of porosity, as evidenced by the appropriate R^2 value:

Porosity = 659.16 Correlation^2 – 1443.89 Correlation + 839.25 (R^2: 0.81)

Porosity = 2.47 PVI2 – 0.07 PVI + 41.44 (R^2: 0.80)

4. The most influential parameter impacting the sensory attributes of a given *pogácsa*, particularly the critical factor affecting consumer overall liking, was the amount of cheese in the recipe (F=252.33, $p < 0.001$). Following this, baking temperature had a noticeably smaller effect (F=8.333, $p < 0.006$), and there was also a significant interaction effect (F=7.583, $p < 0.001$) between baking temperature and cheese content. It's worth noting that the interaction effect accounted for only 3% of the influence of cheese quantity on overall liking. This hierarchy of parameters underscores the scale of their respective impacts on the sensory attributes of the *pogácsa*.

5. The porosity prediction model for *pogácsa* remained unaffected by variations in MC. Remarkably, a single model exhibited a strong fit when applied to the entire dataset, in which comprised a range of formulated samples with distinct cheese moisture content levels (65% and 58%), as well as samples prepared without cheese in their formulation. This comprehensive model had a R^2 of 0.75 and a RMSE of 2.13, demonstrating its efficacy in accommodating diverse sample compositions and moisture conditions:

$$\text{Porosity} = 3.48\ \text{PVI} - 0.086\ \text{PVI2} + 32.30$$

6. List of Publications in the Field of Study

6.1. Publications in journals with peer review process

Amani, H., Baranyai, L., Badak-Kerti, K. Mousavi. K, A. (2022). Influence of baking temperature and formulation on physical, sensorial, and morphological properties of *pogácsa* cake: an image analysis study. *Foods*, 11, 321. https://doi.org/10.3390/foods11030321. **Q1 - IF 5.561.**

Amani, H., Firtha, F., Jakab I, Baranyai, L., Badak-Kerti, K. (2021). Non-destructive evaluation of baking parameters on *pogácsa* texture. *Journal of Texture Studies*, 52: 510–519. https://doi.org/10.1111/jtxs.12619. **Q2 - IF 3.942.**

Amani, H., Badak-Kerti, K., Mousavi. K, A. (2020). Current progress in the utilization of Smartphone-based imaging for quality assessment of food products: A review. *Critical Reviews in Food Science and Nutrition*, 1-13. https://doi.org/10.1080/10408398.2020.1867820. **Q1 - IF 11.208.**

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6.2. Presentations in international conferences

Amani, H., Firtha, F., Baranyai, L., Badak-Kerti, K. Evaluation of the effect of internal structure on texture profile of *pogácsa* at International Conference of Food Physicists, Iasi, Romania, November 2020.

Amani, H., Firtha, F., Kovács, A., Baranyai, L., Badak-Kerti, K. Comparison of crumb structure in sponge cakes prepared with different sweeteners using computer vision system at BiosysFoodEng, Budapest, Hungary, December 2019.

Amani, H., Baranyai, L., Badak-Kerti, K. Computer vision system as rapid tool for volume inspection of *pogácsa* at 1st International

Conference on Advanced Production and Processing, Novi Sad, Serbia, October 2019.

Amani, H., Baranyai, L., Badak-Kerti, K. Development of a computer vision technique for evaluating crumb structure in sponge cake at Spring Wind Conference. Debrecen, Hungary, May 2019.

Amani, H., Baranyai, L., Badak-Kerti, K. Evaluation of the relationship between protein content and color of fish fillet using modeling method: A preliminary study at PhD conference on nutrition research, Budapest, Hungary, January 2019.

Amani, H., Baranyai, L., Badak-Kerti, K. Smart vision system for quality control of cocoa flavored swirl bun at Third International Conference on Food Science and Technology, Budapest. Hungary, November 2018.