



Impact of gluten content and baking method on volume and crumb formation in wheat bread

A pre-study to in-situ 4D synchrotron-based X-ray tomographic analysis of bread during baking

Master's Thesis in Biotechnology

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Abstract

The baking industry looks forward to the use of non-conventional heating oven to speed up the baking process, increasing yield while improving product quality with reduced processing cost. Microwave-baking has shown good potential to contribute with several advantages in this context. However, the final quality of bread baked with microwaves does not match the quality of bread baked with convection. Therefore, combination-baking might be a promising heating technique for bread baking to obtain the advantages with microwave heating but still get the same quality as conventionally baked bread.

Additionally, gluten content varies between different kinds of wheat but also from year to year due to fluctuation in the weather. Using a low protein flour when baking bread often results in low volume and poor internal crumb structure. Microwaves have however shown possibilities to increase volume in bread; hence incorporation of microwaves in the baking process might enable usage of weak wheat for bread baking.

In this project the impact of gluten content and baking technique on volume and crumb of wheat bread is examined. Volume measurements are made with seed dispersal method and crumb structure is analyzed using image analyses.

As a final step in the project, buns are analyzed with X-ray microtomography to prepare for a subsequent in-situ 4D synchrotron-based X-ray tomographic analysis

Results showed that gluten content to some extent influence the volume of bread since high protein flour seems to result in higher volume regardless of which baking method that is used. However, the total impact seems to be much more complex than just gluten content since when adding gluten to a low protein flour, the volume of the bread did not reach the same volume as the bread with high protein flour, although the protein content was the same.

Further, baking with microwaves seems to encourage the formation of larger pores in bread regardless of which flour that is used.

KEYWORDS: gluten, bread crumb, bread, baking, microwaves, X-ray microtomography.

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1. Introduction

1.1 Background

There is a high potential to reduce costs within the baking industry by reducing the energy consumption. The energy consumption can often be reduced by optimizing the baking process, while at the same time keeping the quality of the baked product. Combination-baking with alternative techniques such as microwaves combined with infrared or microwaves combined with convection has shown good possibilities to reduce energy consumption during bread baking. At the same time, these combinations of techniques can give the same bread quality as conventional baking processes (Raaholt, 2011).

Protein content of wheat flour is crucial when baking bread (Johansson et al., 2002). When using flour with too low protein content the dough will have high gas permeability which further will result in bread with low volume and poor internal crumb structure (Chamberlain, 1973). The genetic background of wheat is affecting the protein content of wheat flour. However, the protein content is also largely influenced by environmental conditions and can therefore vary between seasons (Johansson et al., 2002). Microwaves might however help to encourage the generation of carbon dioxide and steam in bread baked with low protein flour, hence preventing low volume in the baked bread (Chamberlain, 1973).

By including microwaves in the baking process energy consumption and cost could be lowered within the bread industry, and it might also enable usage of weak wheat (wheat with low protein content) without compromising the final bread quality.

1.1.1 Bread crumb structure

Crumb structure of bread, i.e. the exposed cell structure of crumb when bread is sliced, is one of the major quality attributes of bread (Rathnayake et al., 2018; Mills et al., 2003). The final crumb structure in bread is a result of starch gelatinization and protein coagulation during baking and consists of a solid phase apparent in the cell wall structure and a fluid phase made up of air (Rathnayake et al., 2018; Chhanwal et al., 2019). The formation of porous crumb structure in bread is mainly influenced by dough ingredients, processing conditions, yeast activity, temperature during fermentation, and formation of gas bubbles. There are several processing steps that convert the ingredients into a well-developed porous structure, but the main processes are kneading, fermentation, and baking (Rathnayake et al., 2018).

During the dough kneading process of bread-making, air is incorporated into the dough matrix and a foam-like structure is developed. As the kneading process continues the air bubbles incorporated into the dough matrix are broken up, resulting in an increased number of bubbles and reduced mean bubble size. Bubble size is in general important since it can have an impact on bubble expansion during proving, and hence influence the texture of finished bread (Mills et al., 2003).

During fermentation, the yeast cells produce energy, alcohol, and carbon dioxide by utilizing carbohydrates (Rathnayake et al., 2018). The bubbles that were formed during dough kneading

then act as nucleation sites for the carbon dioxide that is produced by the yeast. The mass transfer of carbon dioxide into the bubbles allow the dough to rise, expanding the volume of the bread. A more rapid development of the bubbles occurs during later stages of proving and early stages of baking as an effect of both increased carbon dioxide production by the yeast and formation of steam due to heating in the oven (Mills et al., 2003).

During bread baking, heat and mass transfer phenomena are taking place simultaneously. This causes physical, chemical, and structural alteration due to evaporation of water, volume expansion, gelatinization of starch, and denaturation of protein (Rathnayake et al., 2018). It is in the later stages of the baking process, when the dough reaches a temperature of around 60°C, that the starch gelatinizes, and the final bread crumb structure is set. Whilst changes might occur in the gluten network on reaching such temperatures, it is the starch gelatinization which effectively sets the crumb structure hence halting further pore expansion (Mills et al., 2003).

1.1.2 Gluten

Gliadins and glutenins are two groups of proteins that, during kneading of the dough, are combined and form a viscoelastic gluten network. This viscoelastic gluten network can retain leavened gas during fermentation and baking, hence impact the volume of the final bread. During baking, gluten denatures and releases its water to starch which gelatinizes. This leads to formation of the final structure of the bread crumb. Too low protein content in the wheat flour leads to poor gluten network which cannot hold the gas and steam produced during the fermentation and baking (Rathnayake et al., 2018). It will also increase the tendency for bubbles to merge because of the weak gluten-starch matrix forming the cell walls (Mills et al., 2003). Poor gluten network will result in limited number of gas-filled cells and the dough will not expand to a desired level (Rathnayake et al., 2018). Protein content of wheat flour is therefore crucial when baking bread (Johansson et al., 2002).

The protein content in wheat is determined by the genetic background but it is also largely influenced by environmental factors such as temperature and access to water and nitrogen. This means that the protein content in one wheat cultivar can vary from year to year due to fluctuations in the weather. However, it seems like it is not only the protein content that is of importance for the bread-making quality of wheat, but also the proportion of specific protein subunits (Johansson et al., 2002). Therefore, selection of flour with better protein quality may result in a product with higher volume due to better porous structure with uniform sized gas cells (Rathnayake et al., 2018).

1.1.3 Baking techniques

The heat during baking in an oven generally occurs in three modes, convection, conduction and radiation, to create crust and crumb. Heat is transferred to the bread by radiation from hot metal parts in the oven, by convection from hot air developed in the oven and by conduction from the heated surface of the bread to the inside. In the initial stage of the baking process, water evaporates from the bread surface and crust is formed. Further, this restricts evaporation of water from the inside of the bread as the heat penetrates. The crust is the result of non-enzymatic browning (Maillard browning) and caramelization reactions while the crumb is the result of starch gelatinization and protein coagulation (Chhanwal et al., 2019).

The bread characteristics, i.e. crumb and crust formation, browning and flavor development, are largely affected by the heating mode. The most important aspect in baking industries for receiving a good quality product is optimization of various oven parameters. This since temperature uniformity, heating efficiency, baking time and humidity level in the oven influence the final product. The baking industry looks forward to the use of a non-conventional heating oven to speed up the baking process, increasing yield while improving product quality with reduced processing cost (Chhanwal et al., 2019).

Microwave heating is gaining importance in the food industry for several operations, including bread baking. The increasing interest in microwave heating is due to various advantages such as instant and rapid heating, precise process control, shorter start-up time, energy efficiency, space savings, selective heating and food with high nutritional value (Chhanwal et al., 2019; Sumnu, 2001).

Microwaves interact with charged particles and polar molecules within the food to generate heat. (Sumnu, 2001) When charged particles are exposed to a microwave field, the net force of the field will accelerate the particles in one direction. In which direction the particle will be accelerated depends on its charge, e.g. a positively charged particle will accelerate in the direction of the externally applied electric field. As the field is altered the moving particles will change direction. Additionally, polar molecules in a microwave field will orient themselves in the direction of the field. Since the field is altered the direction of the field will change thus the molecules will reorient themselves. Moving particles and molecules will result in collisions and the kinetic energy will turn into thermal energy. (Buffer, 1995; Sumnu, 2001)

However, the cool surrounding temperature in a microwave oven fails to induce Maillard browning and caramelization reactions, preventing brown, hard crust to form. Further, this results in bread with a different flavoring profile than bread baked conventionally since different chemical reactions occurs and the short microwave baking time inhibits the opportunity for some flavoring compounds to form. Thus, the speed and mechanism of microwave heating is a major disadvantage in the formulation of bakery products (Sumnu, 2001).

Since microwave heating is unable to provide some desired quality characteristics in bread but offers other advantages in the process, hybrid heating techniques might be a promising technology for baking processes. However, there is a lack of knowledge and complete understanding of the baking process in combined heating modes. Every different heating mode influence the quality of bread in its own unique way which further makes combination-baking very complex (Chhanwal et al., 2019). Therefore, further research is needed before combination-baking can be incorporated in the industrial baking processes.

1.1.4 X-ray microtomography

To understand the properties and performance of materials it is essential to characterize their microstructure. X-ray microtomography is a method used to analyze the three-dimensional (3D) internal structure and material properties of opaque objects (Marone et al., 2011). This is done in a non-destructive manner, meaning that further investigation can be done on the object since it is not destroyed during the scan (Fifer et al., 2012). Acquired 2D radiographic images of an object scanned over 180 or 360 degrees, can be used to mathematically reconstruct a 3D map of the

linear attenuation coefficient (LAC) [1/cm] of the sample. Synchrotron X-ray microtomography (also referred to as X-ray tomographic microscopy when the resolution is increased), utilizes a coherent and monochromatic parallel X-ray beam with a very high flux [photons per second per unit area], which in combination with a fast detector will enable the capturing of fast dynamic processes in 3D over time of various samples. (Marone et al., 2011).

Furthermore, X-ray microtomography is a well-established technique for analyzing the microstructure of cellular food products (Falcone et al., 2006), such as porous bread (Falcone et al., 2005; Lassoued et al., 2007). By studying the microstructure of food products, improved food quality can be obtained by optimizing the processing parameters (Laverse et al., 2012). Synchrotron-based X-ray tomographic microscopy could hence enable analyses of the development of the porous structure in bread throughout a whole baking procedure. As a result, one may get a better understanding for how protein contents and baking methods influence the crumb formation and volume development in bread.

1.2 Aim

The aim of this project was to analyze the impact of gluten content in wheat flour on crumb formation and volume of bread baked with convective hot air, microwaves and combination oven (convection and microwaves) using techniques available at RISE including volume measurements and image analyses. To do this a baking procedure was developed and optimized, where temperatures, microwave power settings and times for the different baking techniques were decided.

Further, the impact of gluten and baking method on the crumb formation of bread was analyzed using X-ray microtomography. This served as a pre-trial for the planned in-situ 4D synchrotron-based X-ray tomographic analysis of bread planned at PSI, Switzerland after the master thesis has been finalized.

The project is a pre-study to the Vinnova Pilot-project *In-situ microwave-convective baking of bread by means of time-resolved Synchrotron X-ray microtomography* (Reference number: 2019-02572). The Vinnova Pilot-project is a collaboration between RISE, Lund University and Finax bakery.

1.3 Limitations

Other components besides gluten might have great impact on the crumb formation during baking but will not be analyzed in this project. Here the focus lies on the impact of gluten.

There are other properties than crumb formation, e.g. crust formation, that are important for the final quality of bread. In this project only the crumb formation and volume will be analyzed.

In this project, three different baking techniques will be used, microwaves, conventional hot air (convection) and combination baking (combining microwaves and convection). Other studies have shown promising results in baking with combination ovens using microwaves together with convectional hot air but, also microwaves combined with IR. Here however, IR will not be used.

Other parts of the baking procedure, such as kneading and proving also have great influence on the final

quality of bread. However, different kneading or proving settings are not tested during this study, only different oven settings are examined. For the kneading and proving, a standardized methodology was decided for all types of dough, regardless of which flour or heating method that was used.

The work of this thesis will form a fundament for the in-situ 4D synchrotron-based X-ray tomographic microscopy beamtime experiment of baked bread that is planned this summer at PSI in Switzerland. This will however be performed after the master thesis has been finalized, and results from that analysis will not be included in the thesis. However, lab-based X-ray microtomography is performed during the project to prepare for this beamtime.

2. Materials and method

A detailed schedule of the baking method can be found in Appendix. Below follows a more informative description of the materials and method.

2.1 Materials

Doughs were prepared using different wheat flours containing different amounts of gluten. Flours used: Kondis (Finax) and spring wheat (Finax). Original protein content of Kondis is 10.4% and for spring wheat is 14.6%. Protein content was measured using Dumas method where samples are combusted at high temperature and nitrogen is converted into nitrogen gas. The nitrogen gas is measured by a detector and can then be converted into amount of protein by multiplying with a factor specified for the sample that is analyzed (Müller, 2017). Additionally, Kondis was strengthened i.e. the gluten content was increased, and spring wheat was weakened i.e. the gluten content was decreased, resulting in 4 different flours used during this project (Kondis, spring wheat, strengthened Kondis and weakened spring wheat). To obtain strengthened Kondis, wheat gluten (Manildra Milling Corp., 79.2% protein) was added to Kondis to obtain the same protein content as spring wheat and to obtain weakened spring wheat, wheat starch (Finax) was added to spring wheat to obtain the same protein content as Kondis. The protein content of strengthened Kondis and weakened spring wheat were calculated and the final protein contents were not measured. Kondis and spring wheat did not include improvers. Other ingredients were used in the formulation: water, sugar, salt, rapeseed oil (Ica) and dry yeast (Jästbolaget).

2.2 Baking procedure

2.2.1 Dough preparation

All ingredients were weighed, and the dry ingredients were mixed together. All ingredients with specified amounts are listed in Table 1 below (Thorvaldsson & Skjöldebrand, 1998). Four different flours were used in this study and every dough was prepared with one of the four alternatives stated in the first row in Table 1 below. All ingredients were then added to a laboratory kneader from VMI Linix group (SPI-LAB) and mixed for 2 minutes at low speed (dough hook rotating at 60rpm, bowl rotating at 6rpm) and then for 7 minutes at higher speed (dough hook rotating at 180rpm, bowl rotating at 15rpm). The temperature of the dough after the mixing ranged from 22°C to 28°C (Mouneim et al., 2012).

Table 1: *Dough recipe.*

Ingredients	Weight (g)
1. Kondis	1110
2. Kondis + gluten	1042 + 68
3. Spring wheat	1110
4. Spring wheat + starch	761 + 349
Salt	18
Sugar	18
Rapeseed Oil	18
Water	600
Dry yeast	13.5

After the kneader the dough was left for resting for 10 minutes and then rolled into buns weighing 90g (89,5g - 90,5g) each. This resulted in 19 buns which were placed into the proving cabinet at 36°C and 85% humidity for 1 hour. For pre-trials a proving cabinet from Sveba Dahlen was used and for further studies a proving cabinet from Metos (Chef 200) was used.

2.2.2 Baking

The buns were baked with different baking techniques, convective hot air, microwave and combination (microwave and convection). Baking temperatures, microwave power settings and times can be seen in Table 2 below. For the sake of efficient work-flow, two ovens of the same type from Electrolux (OOM1000CZ, 800 FLEX CombiQuick) were used.

Table 2: *Baking properties.*

Method	Temperature (°C)	Power (W)	Time (min)
Microwaves	-	533	1
Convection	220	-	11
Combination 1*	230	200	1
Combination 2	230	-	7

* *Combination baking starts with microwaves and convection and then continue with only convection in order to get a good color. It was judged that usage of microwaves all through the baking program in this case would likely risk over-bake the breads.*

For microwave baking, the oven was set to 400W in 4 minutes which results in pulsing microwave field that will generate 400W over 4 minutes. This corresponds to 6 pulses, 16 seconds each, at maximum power of 1000W. The buns were only baked for 1 minute each which resulted in 2 pulses, 16 seconds each, at maximum power of 1000W, so the average power for one baked bun was thus 533W $((2 \times 16 \times 1000) / 60)$.

For combination baking, the oven was set to 200W in 1 minute resulting in 2 pulses, 6 seconds each, at a maximum power of 1000W. The average power for one baked bun was thus 200W.

The baking conditions were chosen based on temperature measurements with optical fibres from Fiso inside the buns. When the whole bun had reached 96°C it was considered done (Pylar, 1988). Different parts of the bun reached 96°C at different time points hence fibres were placed in different parts of the bun to estimate when the whole bun likely had reached 96°C (in reality, some parts might reach

a few degrees higher, or lower). The temperature measurements that were done in order to define baking conditions, were done before the actual experiments, hence no optical fibres were used in the buns that later were analyzed. Different oven temperatures and microwave power settings were tested to obtain buns with desired color while not reaching above 98°C (for microwaves the color was not considered). However, for combination baking, the final microwave power and oven temperature were chosen so that the buns did not reach much higher temperatures than 98°C before desired color was reached (since it was hard to obtain desired color without the temperature rising above 98°C inside the buns).

Different buns and different parts of the buns reached 96°C at different time points even though they were baked under the same baking condition. However, the baking times, powers and temperatures for the different baking techniques were chosen so that the final temperature inside the buns were in the interval 96°C and 98°C. This was ensured by a series of measurements (3 replicates) and the baking times were selected as an average time that it took for the buns to reach 96°C to 98°C.

In addition to the temperature measurements with optical fibres, bake-losses were measured. Buns were weighed after the proving cabinet, directly after baking and one last time after they had cooled down to 30°C. The bake loss is the difference in weight before and after baking. A too high bake loss (too reduced weight after baking) will indicate that the buns have been baked too much and might become dry. Measuring bake loss gives a wider understanding of the differences between the baking methods used in this study and will indicate whether the chosen times, oven temperatures and microwave power settings are appropriate for bread with desired final quality.

2.3 Analyses

2.3.1 Volume measurement

Seed displacement method was used to measure the volumes of the buns. A bun was weighed, placed in a bowl and covered in seeds. The bowl with seeds and bun was then weighed. From the total weight, the weight of the bun and bowl was deducted to obtain the weight of the surrounding seeds. From the weight of the total amount of seeds that could fit into the bowl, the weight of the surrounding seeds was subtracted to obtain the weight of the seeds corresponding to the volume of the bun. The weight of the seeds corresponding to the volume of the bun was then divided with the bulk density of the seeds, and hence the volume of the bun was obtained.

Buns were baked according to section 2.2 and volume measurements were done on buns after they had cooled down to 30°C (after the oven: 40 minutes for microwave baked, 45 minutes for combination baked and 50 minutes for conventionally baked).

For pre-trials (using Sveba Dahlen proving cabinet), volume measurements were done on buns baked with Kondis and spring wheat using microwaves and convection (no combination-baked), in total 4 different kinds of buns. This was done in replicates. For each different kind of bun in total 12 buns were analyzed, baked at three different occasions, i.e. originating from three different doughs.

For further trials (using Metos proving cabinet) in total 10 different buns were analyzed. The different kinds of buns whose volume were analyzed can be seen in Table 3 below. This was done in replicates which also is stated in the table.

Table 3: *Buns analyzed.*

Flour	Baking method	Replicates (doughs)
Spring wheat	Microwaves	5 (2)
Spring wheat	Conventional	5 (2)
Spring wheat	Combination	6 (2)
Kondis	Microwaves	5 (2)
Kondis	Conventional	5 (2)
Kondis	Combination	6 (2)
Weakened spring wheat	Microwaves	6 (2)
Weakened spring wheat	Conventional	6 (2)
Strengthened Kondis	Microwaves	6 (2)
Strengthened Kondis	Conventional	6 (2)

2.3.2 Crumb structure

Buns were baked according to section 2.2, and when the buns had cooled down to room-temperature they were sliced vertically with an electrical knife from Team Kalorik (EM 1001) to obtain 1.5cm thick slices. Sliced buns were photographed with DigiEye. Photos were cropped to obtain square images that visualize only the breadcrumb inside the bun. Cropped photos were run in a Matlab (2014) code developed at RISE to obtain values for porosity listed below.

- Void fraction = total area of cells / total area of image.
- Mean cell area = total area of cells / total number of cells (mm^2).
- Fineness/cell density = total number of cells / total area of image ($cells/cm^2$).
- Cell wall thickness = average weighted distance between two cells (mm).
- Uniformity = number of cells >2 mm / number of cells <2 mm x 100%.

The different buns that were analyzed with this method can be seen in Table 3 together with the number of replicates. The fundamental principle of the algorithm is described below.

The underlying algorithm converts the picture of the bun into a gray-scaled image and further segments it to a black and white image, visualizing pores as white (scale 0) and cell walls as black (scale 1). It is the segmented image that the algorithm uses to obtain values for porosity. The algorithm also gives an image where pores are highlighted to make it easier to distinguish between cells visually. An example of the obtained images from the Matlab algorithm can be seen in Figure 1 below.

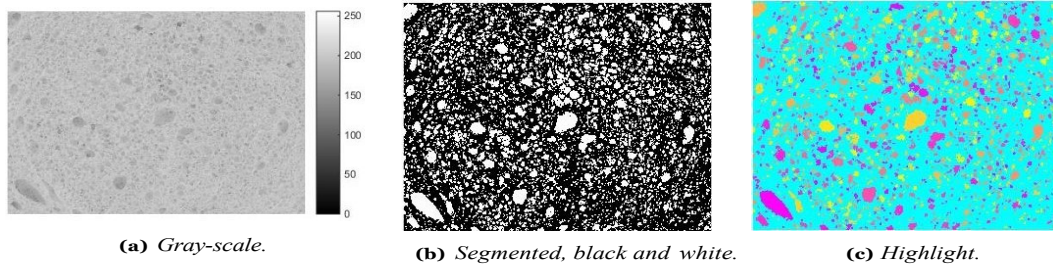


Figure 1: Example of images obtained from MatLab algorithm. Images are from a spring wheat bun baked with microwaves.

2.3.3 Lab-based X-ray microtomography

Buns were baked according to section 2.2 and placed in the freezer after they had cooled down to room-temperature. Buns were kept frozen until analyses were performed.

After baking, the buns were sent to Lund, Sweden where X-ray microtomography was carried out using a ZEISS Xradia VXR520 (Carl Zeiss, Germany) at the 4D Imaging Lab at Lund University. The samples were scanned in a so-called local geometry, meaning that only a central part of the buns was scanned. The scanning parameters were the following, source-voltage: 80kV, power: 7 W, filter: LE1, effective pixel size: $45.2 \mu\text{m}$, exposure time: 1 s, number of projections: 1001, Field-of-View: $44.8 \times 44.8 \text{ mm}^2$, binning: 2x2, optical magnification: 0.4 x, source-to-sample distance: 120.0 mm, sample-to-detector distance: 58.3 mm. Reconstruction was performed using the built-in Zeiss reconstructor software. The linear X-ray attenuation coefficient (LAC) was reconstructed on a 32-bit grey-level scale, with a cubic voxel length of dimension $21 \mu\text{m}$. The reconstructed μCT slices were used as complimentary images, in reference to the feature quantification performed via light scattering.

In Figure 2 below there is a picture of the set-up for the analyses with lab-based X-ray microtomography.

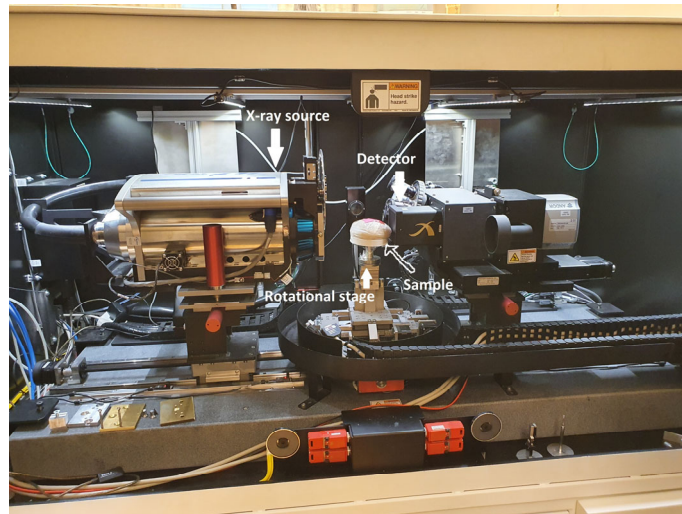


Figure 2: Set-up of lab-based X-ray microtomographic analyses of buns.

In total 4 buns were scanned. The different types of buns that were scanned are buns baked with spring wheat and Kondis using convection and microwaves (not combination-baked). The scanning was not performed on replicates. The tomographic 3D data sets make a set of virtual slices of the bun.

Image processing

First, images were cropped to obtain a cubic representative volume of the buns (each side with a length of 8.4 mm). The images obtained were analyzed in ImageJ-Fiji (Schindelin et al., 2012; Schindelin et al., 2015). A median filter (core: 3x3) was applied on the original slices to reduce noise. Further, the images were segmented using standard grey-level thresholding. The generated binary mask was then used to compute local thickness variations of the cell walls. In another step the mask was multiplied with the median filtered images, which created a clean segmentation, free from background noise.

Figure 3 below shows an example of the carried-out image-processing steps for one slice in one bun.

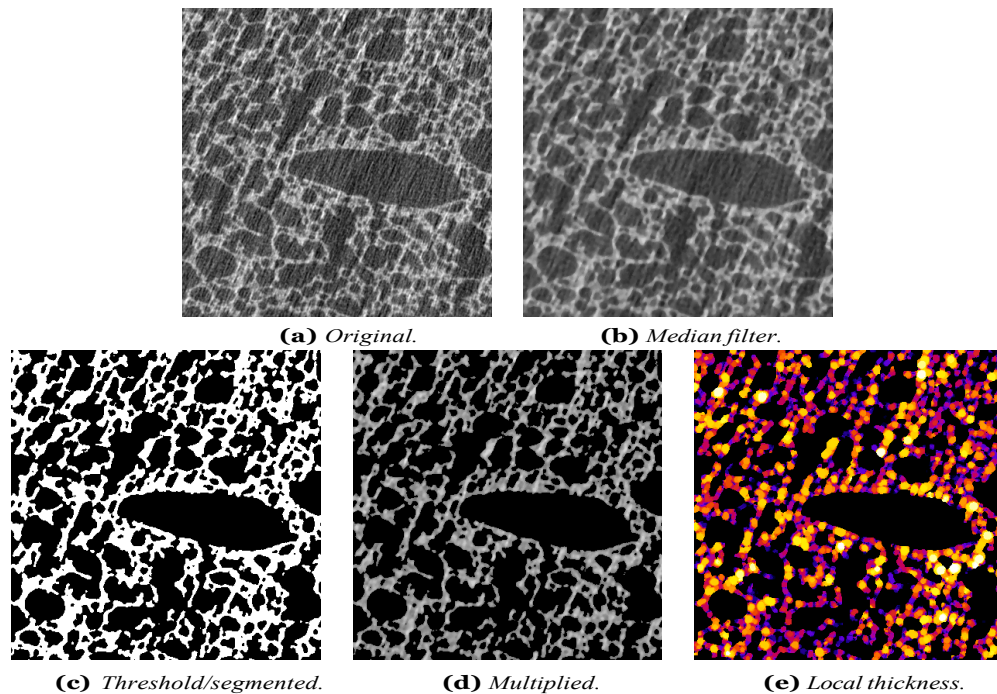


Figure 3: *Image processing steps in Fiji-ImageJ.*

3. Results

3.1 Volume

In the pre-trials, using proving cabinet from Sveba Dahlen, buns baked with Kondis (low protein flour) had a significantly ($p < 0.05$) higher volume when baked with microwaves than when baked with convective hot air. This was however not the case when baking with spring wheat (high protein flour). For buns baked with spring wheat the volume difference between microwave and conventionally baked buns was not significant ($p > 0.05$). Microwave baked buns with Kondis had a significantly ($p < 0.05$) lower volume than conventionally baked buns with spring wheat.

In Figure 4 the mean volume of the buns baked with Kondis and spring wheat using microwaves (MW) and convection (CV) can be seen.

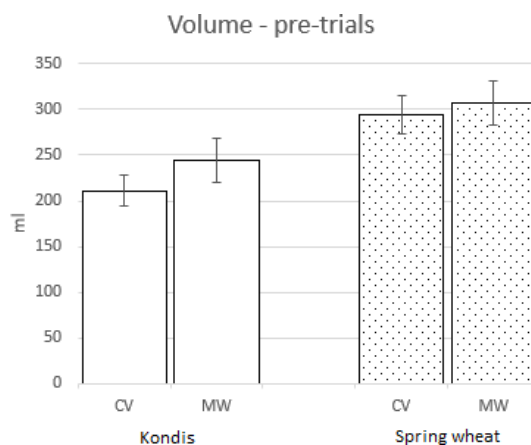


Figure 4: Mean volumes for buns baked with Kondis and spring wheat using convection (CV) and microwaves (MW) in pre-trials.

In contrast to some results from the pre-study, in further trials where a proving cabinet from Metos (Chef 200) was used, the volume difference between microwave baked buns with Kondis and conventionally baked buns with Kondis was not significant ($p > 0.05$). Corresponding results was obtained for buns baked with spring wheat, see Figure 5.

However, when comparing conventionally baked buns with combination-baked, buns baked with convective hot air got a significantly ($p < 0.05$) higher volume for both Kondis and spring wheat. When comparing microwave baked with combination-baked there was no significant ($p > 0.05$) difference in volume for either Kondis or spring wheat.

Buns baked with strengthened Kondis (same protein content as spring wheat) using microwaves had significantly ($p < 0.05$) higher volume than buns baked with strengthened Kondis using convective hot air. The same result was obtained when baking with weakened spring wheat (same protein content as Kondis).

In Figure 5 below the mean values for buns baked with the different flours and baking techniques can be seen.

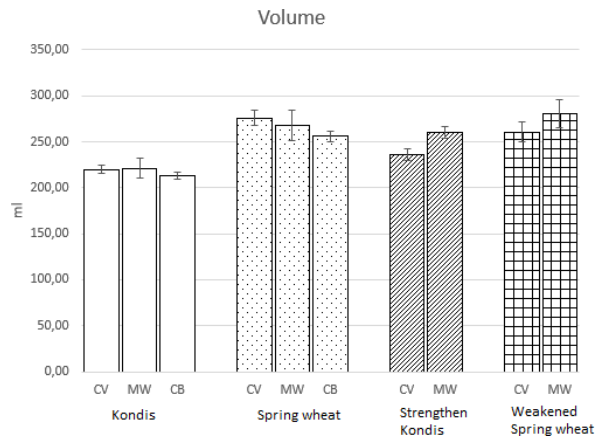


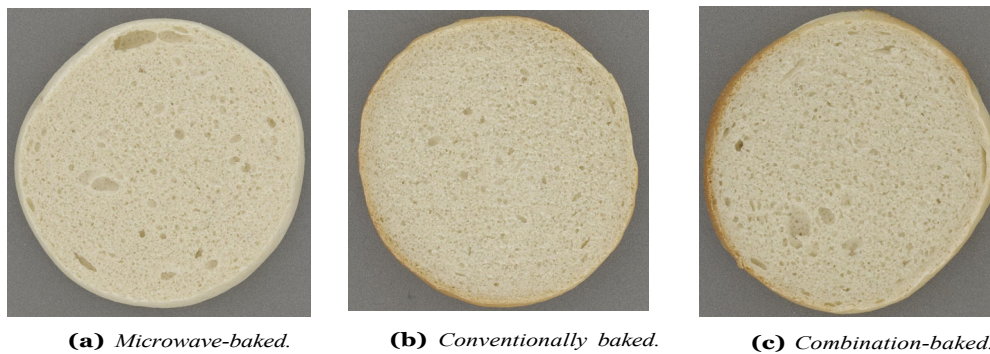
Figure 5: Mean volumes for buns baked with the different flours and baking techniques.

As can be seen in Figure 4 and Figure 5, buns baked with spring wheat seems to get higher volume than buns baked with Kondis, regardless of which baking method that was used. Additionally, strengthen Kondis seems to get higher volume than Kondis. However, weakened spring wheat did not get significantly lower volume than spring wheat.

3.2 Bread crumb

3.2.1 2D

Buns baked with microwaves tend to have a higher number of larger pores than conventionally baked buns regardless of which flour that is used (Kondis, spring wheat, strengthen Kondis or weakened spring wheat). Buns baked with combination seems to get a pore structure somewhere between microwave-baked and conventionally baked buns. Buns baked with combination, however, had a more varied crumb structure where individual buns looked quite different from each other. In Figure 6, 7, 8 and 9, examples of pictures for every baking method using the four different flours are shown. All buns however, have their own unique crumb structure and every bun might not look like the pictures below. But the selected pictures give a good overview of the trends that can be seen visually for the different baking techniques.



(a) Microwave-baked.

(b) Conventionally baked.

(c) Combination-baked.

Figure 6: Sliced buns baked with Kondis.

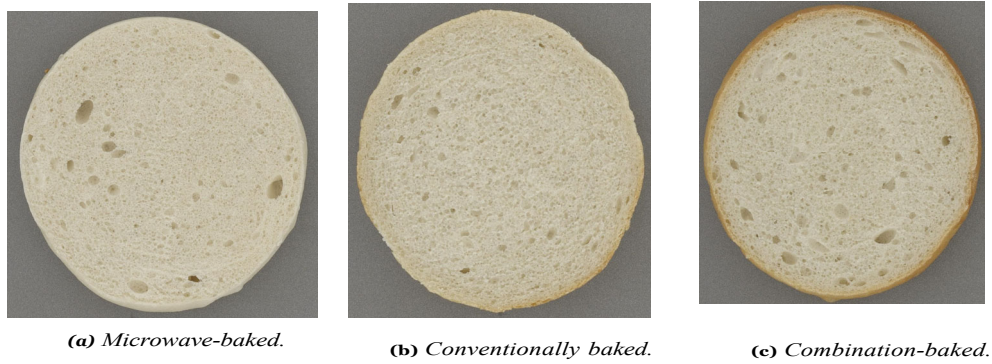


Figure 7: Sliced buns baked with spring wheat.



Figure 8: Sliced buns baked strengthen Kondis.

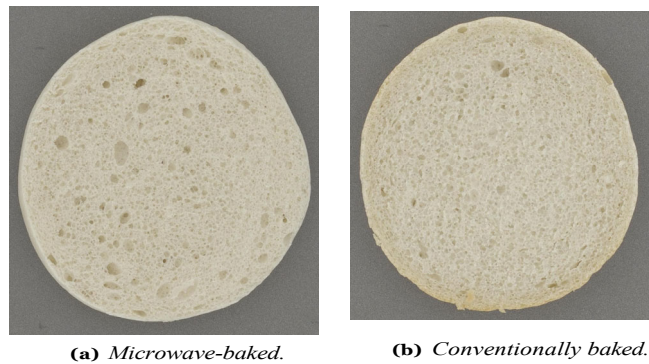


Figure 9: Sliced buns baked weakened spring wheat.

In Figure 10 below, mean values for porosity for the different buns can be seen. Microwave-baked buns seem to have lower void fraction, mean cell area and uniformity but higher fineness and cell wall thickness than conventionally baked. Combination baked buns seem to end up somewhere in between microwave-baked and conventionally baked buns for all porosity parameters.

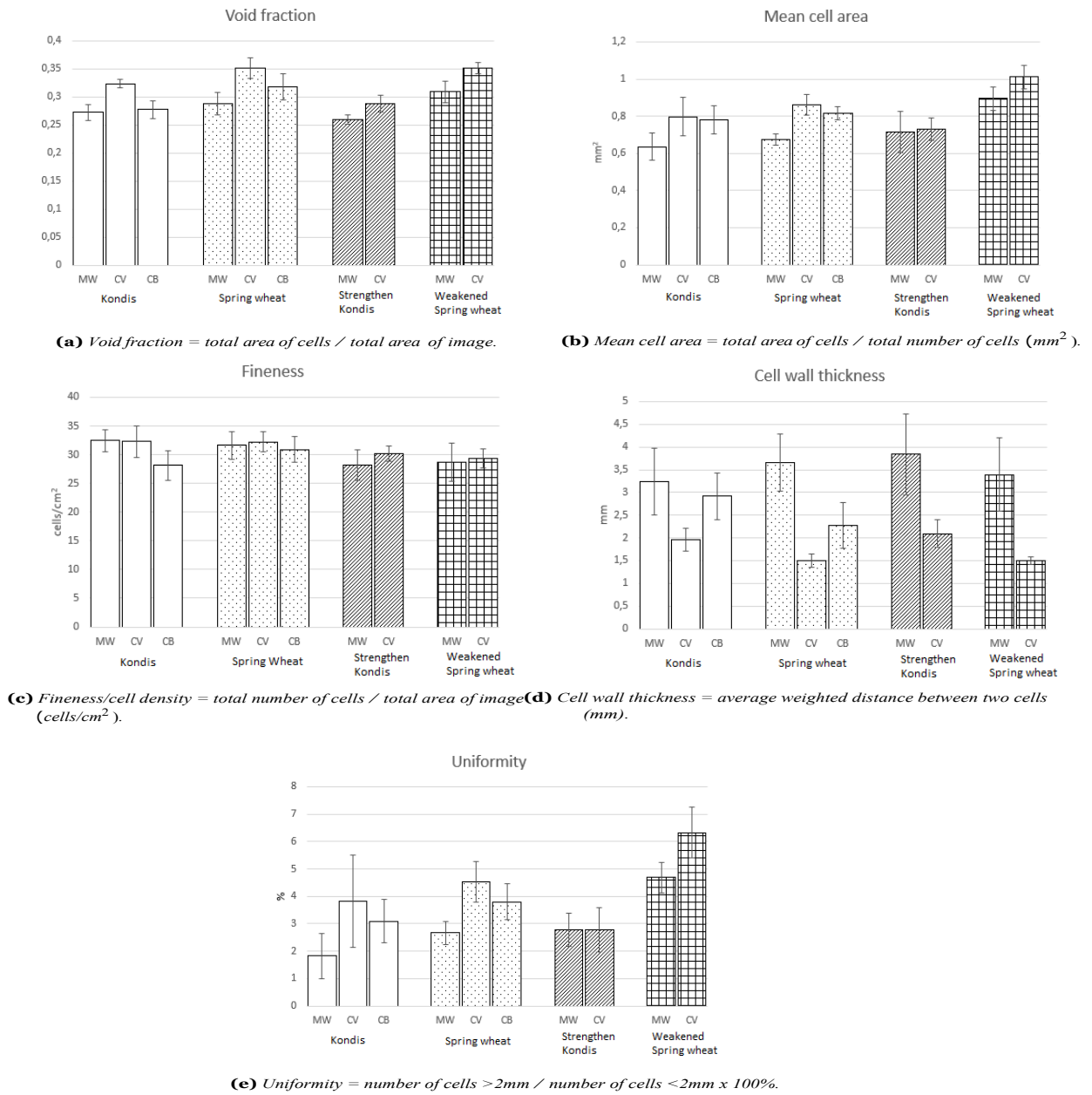


Figure 10: Parameters for porosity for the different buns baked with different flours and baking techniques. MW = microwaves, CV = convection, CB = combination.

Figure 10 indicates trends for the different baking techniques since the baking techniques follow a pattern for the different flours in the same graph. For example, microwave baked buns have highest cell wall thickness for all flours, conventionally baked the lowest and combination-baked end up somewhere in between. However, differences between different flours are not that clear.

3.2.2 3D

In Figure 11 below the result of image analysis for local thickness is shown for one slice for each baking method (microwaves and convection) using Kondis and spring wheat.

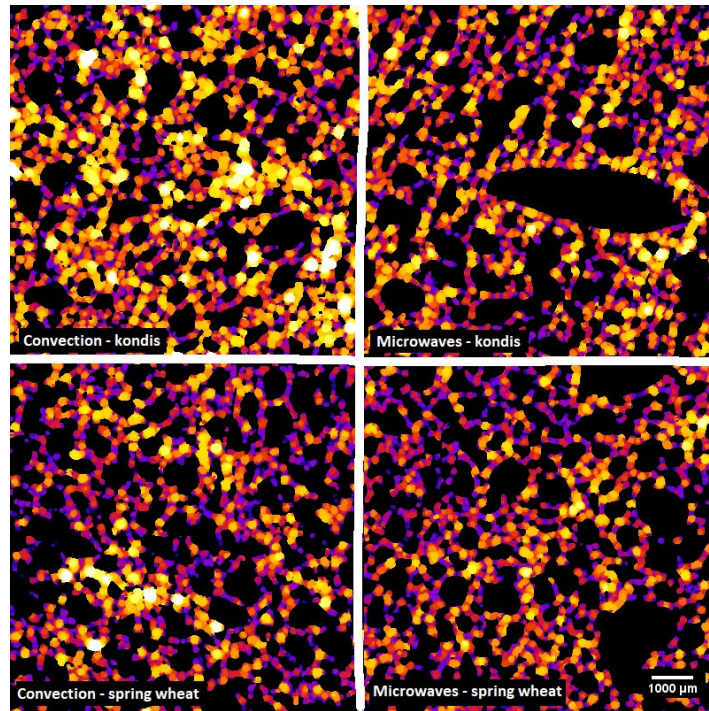


Figure 11: Local thickness of different buns scanned with X-ray microtomography. Warmer colors indicate thicker structures while colder colors indicate thinner structures.

There seems to be a higher number of larger pores in microwave baked buns regardless of which flour that is used (Kondis or spring wheat). Further, conventionally baked buns with Kondis seems to have thicker walls between the pores, seen in the same figure (warmer colors indicate thicker structure while colder colors indicate thinner structure).

The local thicknesses of a baked bun can also be visualized in 3D. The 3D local thickness of a bun baked with Kondis using microwaves can be seen in Figure 12 below.

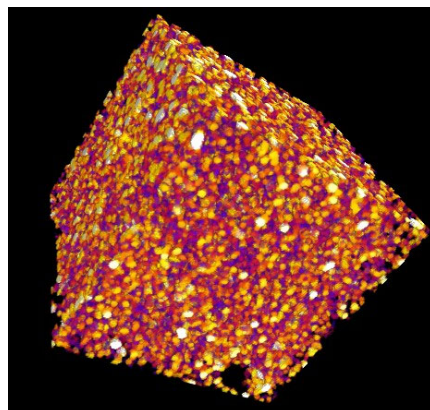


Figure 12: 3D rendering of local thickness of bread crumb on bun baked with Kondis and microwaves. The length of each side is 8.4 mm.

4. Discussion

4.1 Volume

Volume measurements at an early stage in this study indicated that gluten content might have an impact on volume in bread. This was assumed since the low-protein flour Kondis resulted in buns with lower volume than buns baked with spring wheat, a high protein flour. However, when strengthening the low protein flour, the same volume as the naturally high-protein flour was not achieved. Additionally, when weakening the high-protein flour the same volume as the low-protein flour was not achieved. The impact of volume seems to be much more complex than gluten content alone, and other components in the flour might affect the volume to the same extent or even more.

Pre-trials gave indication that microwaves could be used to improve volume in bread baked with Kondis (low protein flour) since the microwave baked buns with Kondis had significantly higher volume than the conventionally baked buns with Kondis. As stated in the background, microwaves might have the potential to help to encourage the generation of carbon dioxide and steam in bread. However, microwaves did not significantly increase the volume in spring wheat which indicate that microwaves might not improve volume in all cases.

For further volume measurements, when changing proving cabinet, the same results were not obtained. Here there was no significant difference in volume between the microwave baked and conventionally baked buns when using Kondis as flour. The results obtained from the volume measurements might be due to the performance of the proving cabinet or due to coincidence. How microwaves actually increase volume or not needs to be investigated further.

Baking is in general a complex method. There are a lot of different ingredients and steps that impact the final result, as for example batch to batch variation for yeast and flour. In this project same batch of flour was used but different batches of yeast. However, different flours are used which has different composition and there is more than protein content that can vary between them. Also, as stated in the background, not only the total protein concentration seems to have an impact on volume but also the subunits of the proteins. No additives should be included in the flour but there are still differences in different wheat cultivars. However, since spring wheat in general got the highest volume, both for weakened and non-weakened, spring wheat might contain something different than Kondis, either different combination and concentrations of subunits of gluten or some other component.

The methodology for the baking was done according to a consistent procedure where all steps, kneading, resting, rolling and proving were performed the same every time. However, the technology is not perfect and some variations between different baking occasions may have appeared. The human factor might also have resulted in variations between baking occasions since, for example, rolling was performed by hand.

Temperature and humidity in the room vary from day to day depending on the outside climate, affecting the temperature of the ingredients since they are stored in room temperature. Temperature of the water used to make the dough as well as the temperature in the room will affect

the final temperature of the dough which further might influence the final quality of the buns. The temperature of the dough is considered “good” as long as it ends up between 22°C and 28°C after mixing. Nonetheless, since individual doughs ended up at different temperatures in this interval, this might be one factor that caused variability in the results.

4.2 Bread crumb

4.2.1 2D

Microwave-baked buns seem to get a higher number of large pores than buns baked with conventional baking method. Since buns baked with combination also seems to get more large pores than conventionally baked buns, it might be the microwaves that impact the formation of larger cells. It might be the instant and rapid heating from the microwaves that encourage the generation of gas and steam and further increase the tendency of pores to merge, thus creating large pores.

The algorithm indicates trends for different baking techniques regardless of which flour that is used but no clear differences between different flours. The different pores are characterized based on color measurements made by the algorithm. Since different pores can have different depth, they get different scales of brightness meaning that some pores might not be identified as pores and some big pores with irregular shape might have different deepness within the same pore, thus making the algorithm think that it is several pores instead of one big.

Further, only a cross section of the bun is analyzed which might not give a fair picture of what the whole bun looks like. Additionally, the photographs are cropped to square images leaving out some part of the bun. As can be seen in Figure 6, 7, 8 and 9 for microwave baked buns, many big pores appear at the edge of the bread crumb. These parts are not represented in the cropped photos.

Since images are digitally processed, as part of the software analysis, the values obtained are not a perfect representation of reality. When images are processed, information is lost. The actual truth might be another thing, but when the algorithm consistently indicates some trends, this likely means that there might be special characteristics, e.g. for specific buns baked with one kind of baking method.

4.2.2 3D

Results obtained from the image processing of images from X-ray microtomography indicates that conventionally baked buns with Kondis have slightly thicker cell walls than microwave-baked buns. This might indicate that buns baked with a low protein flour might not have the same potential to keep the steam and gas produced in the bun and therefore prevent the generation of pores and increase the tendency for pores to merge. However, since the microwave-baked bun using Kondis did not seem to get thicker cell walls the result might have to do with a combination of low protein flour and baking method. Only one bun of each kind was however analyzed with this method, and hence the result might be due to coincidence and more analyses need to be made in order to draw any conclusions.

Local thickness might erase some smaller pores since the algorithm seems to give slightly thicker cell walls than there actually are if comparing image (d) with image (c) in Figure 3. Since this is

done for all images, the colors still indicate the relative differences between the buns.

Additionally, it indicates that microwave baked buns, regardless of which flour that is used (Kondis or spring wheat), get higher number of larger pores than conventionally baked buns. This was also seen visually in the pictures in Figure 6, 7, 8 and 9 hence strengthens that result.

Like the 2D digital analyses, images are digitally processed, as part of the software analysis, and information is then lost. Additionally, results from the 3D analyses were somehow contradictory to the results from the 2D analyses. Results from the 2D analyses indicated that microwave-baked buns got thicker cell walls than conventionally baked buns, the 3D analyses indicated the opposite. The algorithms process images in different ways hence results cannot be directly compared. More analyses and modifications of the algorithms could improve the results and make them closer to the reality.

5. Conclusion

Baking is a complex method and there are a lot of different ingredients, steps and conditions that impact the final result of bread. Therefore, it can be hard to predict what actually causes the different results.

However, protein content seems to impact the volume of bread in some way since spring wheat results in the highest volume and Kondis the lowest. Since the weakened spring wheat (with same protein content as Kondis) does not result in the same low bread volume as Kondis, and since strengthened Kondis (with same protein content as spring wheat) does not result in the same high bread volume as spring wheat, the impact on volume seems to be more complex than only the gluten content.

Additionally, image analyses indicate that microwave-baked buns get a higher number of large pores than conventionally baked buns, regardless of which flour that is used. Since combination-baked buns also tend to have somewhat higher amounts of larger pores than conventionally baked buns it is possible that it is the microwaves that influence the formation of larger pores.

Parameters for porosity showed trends for the different baking techniques however no clear differences between different flours. This indicates that there might be some specific crumb characteristics in bread when baked with a specific baking method.

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A. Appendix

A.1 Baking procedure

1. The prover is turned on (36°C, 85% humidity).
2. All ingredients are weighed, and the dry ingredients are mixed together. Recipe can be found in Table 1 under section 2.1 Baking procedure in chapter 2 Materials and method.
3. All ingredients are put into a kneader and the dough is kneaded for 9 minutes in total with two different rotational speeds (2 minutes with dough hook rotating at 60rpm and bowl rotating at 6rpm and 7 minutes with dough hook rotating at 180rpm and bowl rotating at 15rpm).
4. After the kneader the dough is moved from kneader to bench and left for resting for 10 minutes.
5. After resting the dough is divided into 19 pieces weighing 90g each (89,5-90,5g) and then rolled into buns. The buns are placed on two baking pans (9 buns on one pan and 10 buns on the other pan).
6. The first baking pan is placed in the proving cabinet.
7. The second baking pan is placed in the proving cabinet (22 minutes after the first one).
8. One oven is preheated to 220°C (takes approximately 10 minutes when using Elektrolux CombiQuick).
9. The first baking pan is taken out from the proving cabinet after 1 hour.
10. The two first buns are placed in each oven. One baked with microwaves in the non-heated oven and the other bun is baked with hot convective air in the heated oven.
11. After 11 minutes both buns are baked, and two new buns are placed in the ovens for baking. One will be baked with microwaves and the other with convection.
12. As soon as the buns are baked the ovens are pre-heated to 230°C to prepare for combination baking.
13. The second baking pan is taken out from the proving cabinet (after 1h).
14. The first two buns from the second baking pan are placed in the ovens and baked with combination.
15. After 11 minutes the first buns from the second baking pan are baked and two new buns are placed in the ovens to be baked with combination.
16. When the baked buns have cooled down to approximately 30°C their volumes are measured (40 minutes after oven for microwave-baked, 45 minutes for combination-baked and 50 minutes for conventionally baked).

17. When the buns have reached room temperature, they are sliced vertically with an electrical knife using a template to get 1.5 cm thick slices.
18. The slices are then photographed with DigiEye for digital analyses.

Before baking, directly after baking and after the baked buns have cooled down to approximately 30°C they are weighed. This is done to evaluate the bake-loss.

Different baking techniques were used during the same baking procedure (same dough). The different baking conditions can be seen in Table 2 under section 2.1 Baking procedure in chapter 2 Materials and method. If only microwave-baked and conventionally baked buns are desired, step 12 is ignored and microwaves and convection are used instead of combination-baking. If 3 microwave-baked, 3 conventionally baked and 2 conventionally baked buns are desired, step 12 is moved to after step 14.

For tomographic analyses of buns only microwaves and convection were used on buns baked with Kondis and spring wheat. Buns were not sliced with electrical knife. This means that step 12 and 16-18 were ignored. Instead, buns were frozen.