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Instrument and method development for the determination of baking quality and application in the analysis of wheat-based and gluten-free model products

PhD thesis booklet

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2019

1. Introduction, objectives

There are several methods available for the determination of wheat quality and for testing its technological properties. Among wheat flour properties, baking performance has a particular importance, which can be examined directly only by baking tests. These are usually time-consuming and labor-intensive procedures requiring large amount of sample. Furthermore, the reliability of the results is influenced by the experience of the person performing the analysis and by the circumstances of the measurement. One possible way to improve analytical performance is the instrumental support of the methodology. Accordingly, our goal was to develop a measuring instrument and methodology that is suitable for partially automated baking tests in macro and micro scale. Macro mode can be an alternative to standard routine measurements, while the micro method could be useful in reducing sample quantity, among others, on the field of research and breeding.

The consumption of wheat proteins and other gluten-containing cereals for certain consumer groups is not possible due to celiac disease or other hypersensitivity. Currently, the only existing therapy is the gluten-free diet. However, the nutritional value and sensory properties of gluten-free bakery products may fall short of similar wheat-based products. In the second part of my work, our aim was to improve both the nutritional value and the technological properties of gluten-free model products. A possible solution to this may be the enrichment of gluten-free dough matrices with dietary fiber components (arabinoxylans) that can be crosslinked by the formation of an oxidative medium based on enzyme reactions, enabling the partial substitution of the gluten network. The question arises whether the rheological methods developed for determination of wheat quality can be used to assess the effect of the treatments on dough properties and what conclusions can be drawn from the results they provide. Another question is the extent and nature of the effects of AX dosing and enzyme treatment in the properties of the final products. Due to the limited amount of experimental AX isolate and enzyme, only the micro-scale baking test developed in the first part of my work can be applied.
Accordingly, the detailed objectives of my doctoral work are the following:

- Investigation of the boundaries and applicability of size reduced baking tests.
- Development of the instrumental version of baking test including the design and testing of the hardver and the software, which enable baking tests on macro- and micro-scale.
- Method development to perform instrumental macro- and micro-scale baking tests and the partial validation of the methods.
- Examination of the applicability of rheological methods used for determination of wheat quality, and the utilisation of their modified versions to characterize the technological properties of gluten-free flours.
- Investigation of the effect of fiber addition and enzyme treatment on the rheological properties of gluten-free dough/slurry as well as on the structure of macromolecules and micromorphological properties.
- Development of conventional and instrumental micro-scale baking tests and their application to examine the effect of the treatments on the properties of end products prepared by yeast or sourdough fermentation.

2. Background

The wheat testing methods include the characterisation of the kernel, flour yields, the quality of the milling fractions, and the end product tests. Among these, baking tests enable to judge the complex quality of the grain. One of the main directions of development of the baking tests is the reduction of the required sample amount, which can be useful in several fields (eg. research, product development, early stages of breeding), where experimental materials (flour, various additives, auxiliaries, etc.) are only available in a limited amount. Among size-reduced methods, the international AACC 10-10.03 standard using 10 g flour is the officially approved method. Similarly, the MRMT (Micro Rapid Mix Test) method of Kieffer, Belitz, Zweier, Ipfelkofer, & Fischbeck, (1993)[1] and its different adaptations require 10 g flour, and recently a micro-baking test needing 15 g flour was also developed[2]. However, there is relatively little information available on the evaluation of micro-loaves, especially in terms of crumb properties. Another limitation of the end product tests for routine application is the relatively long analysis time, its reduction is also the subject of instrument developments, nowadays. As an example, the significant reduction of baking time can be reached using microwave[3] baking or Ohmic heating[4] technique. The disadvantage of these methods is that the crust formation only takes place to a small extent, however, the color, taste and texture of the crust are also important for the assessment of the product quality. Doğan, Yildiz, & Taşan (2012)[5] investigated the possibility of the automation of baking tests using household bread baking machines. Their results showed that each device had different performance, but was fundamentally suitable for detecting the effect of the additives used. In their review article, Trinh, Campbell & Martin (2016)[6] give a detailed overview of the application of automatic bread making machines in research. Based on literature and their own results, it was concluded that the results obtained by breadmaking machines do not usually reflect the characteristics of the conventional breadmaking process and could possibly give misleading information about the effects of certain additives. Accordingly, the instrumental laboratory baking test is still a missing link in the classification system of wheat and other cereals.

Gluten-free minor cereals (e.g. millet, sorghum), as well as pseudocereals (e.g. buckwheat, amaranth, quinoa) can contribute to a more varied gluten-free diet due to their nutrient composition and partly technological properties. In my work, millet and buckwheat were investigated, therefore their properties are presented in more detail as follows.

The term "millet" refers to a group of highly variable small-seeded species belonging to the *Panicum* and *Pennisetum* genus. Buckwheat (*Fagopyrum esculentum Moench* and *F. tataricum Gaertn*.) is a dicotyledonous plant belonging to the genus Polygonaceae, so it is not a real cereal (so-called pseudocereal), but since it is rich in starch, its seeds are

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[1] Kieffer, R. et al. (1993) 'Der Rapid-Mix-Test als 10-g-Mikrobackversuch', Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 197, pp. 134–136.

[2] Frauenlob, J. et al. (2017) 'A new micro-baking method for determination of crumb firmness properties in fresh bread and bread made from frozen dough', Die Bodenkultur: Journal of Land Management, Food and Environment, 68(1), pp. 29–39. doi: 10.1515/boku-2017-0003.

[3] Dogan, I. S., Yildiz, Ö. and Taşan, B. (2010) 'Spread and microwave oven baking test for bread making quality', International Journal of Agriculture and Biology, 12(5), pp. 697–700.

[4] Gally, T. et al. (2016) 'Bread baking using ohmic heating technology; a comprehensive study based on experiments and modelling', Journal of Food Engineering. Elsevier Ltd, 190, pp. 176–184. doi: 10.1016/j.jfoodeng.2016.06.029.

[5] Dogan, I. S., Yildiz, Ö. and Taşan, B. (2012) 'Determination of the bread-making quality of flours using an automatic bread machine', Turkish Journal of Agriculture and Forestry, 36(5), pp. 608–618. doi: 10.3906/tar-1202-48.

[6] Trinh, L., Campbell, G. M. and Martin, P. J. (2016) 'Scaling down bread production for quality assessment using a breadmaker: Are results from a breadmaker representative of other breadmaking methods?', Food and Bioproducts Processing. Institution of Chemical Engineers, 100, pp. 54–60. doi: 10.1016/j.fbp.2016.06.004.

consumed like cereals.
To characterize the technological properties of millet and buckwheat (and other cereal and pseudocereals) meals, no classification system similar to wheat is currently available. The technological behavior of wheat flour is influenced by a number of factors, of which the composition and quality of gluten proteins and starch are of paramount importance. Therefore, the flour testing methods were primarily designed to investigate properties dependent on these ingredients (kneading and viscous properties, extensibility, etc.). In the case of millet, results of flour mixtures (wheat-millet, gluten-free mixtures) are mainly available in the literature. The addition of millet flour to wheat flour greatly affects the mixing properties of the dough measured by farinograph. In the ratio of its dosed quantity lower water absorption, longer dough formation time and weaker dough stability were resulted. The addition of millet flour reduces the extensibility of the dough and its resistance to stretching, also. Generally, buckwheat flour has lower water absorption and longer dough formation than wheat flour, and the resulting dough is generally characterized by a lower maximum consistency than wheat dough[7].
Rapid visco analyser technique (RVA) is a common method for testing the starch-dependent viscous properties of liquid flour-water suspensions. Millet and buckwheat starches typically have a lower peak viscosity, but have a more stable gel structure (lower breakdown) and higher final viscosity than wheat starch[8].
Mixolab is a technique to analyse mixing and viscous properties of dough systems, which is also a promising method for testing raw materials other than wheat. The lack of gluten network poses a number of problems in gluten-free dough systems (dilute, viscous batter, poor gas retention, etc.) which need to be remedied in order to provide products of acceptable quality to consumers.
A possible solution to the partial substitution of the gluten structure may be the network formation of non-starch carbohydrates such as arabinoxylan molecules. Arabinoxylans (AX) are member of hemicelluloses (pentosans) occurring especially in rye and wheat. The role of AXs in wheat and rye-based dough matrices and end product properties is the subject of many studies, but there is relatively little information available on their use in gluten-free matrices[9,10].
The molecular size of the AXs and thus their physico-chemical and rheological properties can be influenced by oxidative enzymes (laccase, oxidases) or chemical oxidizing agents. From the point of view of food safety and consumer acceptance, the use of enzymes could be more advantageous than chemical oxidizing agents and can be incorporated into the fermentation step of bread making using suitably selected yeast strains. According to the literature, the use of pyranose-2-oxidase (POx) can be a possible solution. POx catalyzes the oxidation of a number of mono- and disaccharides at C2 or C3 producing dicarbonyl derivatives and H_2O_2. In this medium, the feruloyl groups of AX molecules may oxidize and thus intermolecular cross-links can be introduced[11]. This process can lead to the formation of AX network, which might be suitable for substitutioning of gluten structure.
The effect of POx is mainly studied on the components of wheat flour during dough

[7] Marcela, S. et al. (2017) 'Effect of the dough mixing process on the quality of wheat and buckwheat proteins', Czech Journal of Food Sciences, 35(No. 6), pp. 522–531. doi: 10.17221/220/2017-cjfs.
[8] Wu, K. et al. (2016) 'Buckwheat and Millet Affect Thermal, Rheological, and Gelling Properties of Wheat Flour', Journal of Food Science, 81(3), pp. E627–E636. doi: 10.1111/1750-3841.13240.
[9] Bagdi, A. et al. (2016) 'Effect of aleurone-rich flour on composition, baking, textural, and sensory properties of bread', LWT - Food Science and Technology. Elsevier Ltd, 65, pp. 762–769. doi: 10.1016/j.lwt.2015.08.073.
[10] Buksa, K. et al. (2018) 'Arabinoxylan-starch-protein interactions in specially modified rye dough during a simulated fermentation process', Food Chemistry, 253, pp. 156–163. doi: 10.1016/j.foodchem.2018.01.153.
[11] Decamps, K. et al. (2012) 'Glucose and pyranose oxidase improve bread dough stability', Journal of Cereal Science. Elsevier Ltd, 55(3), pp. 380–384. doi: 10.1016/j.jcs.2012.01.007.

preparation and bread making. The results confirmed the cross-link formation of AX molecules and the oxidation of free thiol groups of proteins. In addition, cross-linking between AX molecules and gluten proteins can be also assumed[12]. In addition to their potential beneficial effects on the technological properties of gluten-free dough matrices, AXs have a number of health-promoting effects as a dietary fiber or bioactive component[13].

3. Materials and methods

3.1. Materials

Samples of wheat varieties were received from the Agricultural Institute, Centre for Agricultural Research, Hungarian Academy of Sciences (Martonvásár). The grains of GK-Piroska variety millet and the buckwheat seeds were provided by the Cereal Research Non-Profit Ltd (Szeged) and by Caj. Strobl Naturmühle GmbH (Linz, Austria), respectively. The chemicals used for the measurements were of analytical purity. In addition, experimental AX concentrates and pyranose-2-oxidase (POx) enzyme were produced by our partner institute, BOKU (University of Natural Resources and Life Sciences, Vienna).

3.2. Applied methods

From wheat grains, flours suitable for bread making were produced (based on MSZ EN ISO 27971: 2015), while from millet and buckwheat grains white (250μm>) and wholemeal flour were made. The composition of wheat samples and flours (protein, moisture, ash, wet gluten) was determined by NIR method (Infratec 1241 Gran Analyzer, Foss Tecator, Sweden).

In the case of buckwheat and millet flours, standard methods were used to determine chemical composition (moisture (MSZ EN ISO 712: 2010), ash (MSZ EN ISO 2171: 2010), protein (MSZ EN ISO 16634-2: 2016), fat (ICC Standard Method No 136), dietary fiber (AOAC 991.43 and AACC32-07).
Arabinoxylan content (TOTAX, WEAX) was measured according to the method of Gebruers et al. (2009)[14] using gas chromatography. Water absorption and mixing properties of wheat flours were determined by the Farinograph method (ICC Standard No. 115/1). Micro-doughLAB, RVA (ICC Standard Method No. 162) and Mixolab (modified MSZ EN ISO 17718: 2015) were used to test the mixing and viscous properties of millet and buckwheat flours and model systems. The baking quality of wheat flour was tested on the basis of ICC Standard Method No. 131 and a self-developed micro method, which was adapted to develop instrumental and gluten-free baking tests.
The size distribution of AXs was analyzed based on the HPLC method of Bagdi et al. (2017)[15]. The molecular size of proteins was investigated according to the Larroque and Békés (2000)[16] using SE-HPLC method. Examination of the size distribution of starch

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[12] Decamps, K. et al. (2014) 'Impact of pyranose oxidase from Trametes multicolor, glucose oxidase from Aspergillus niger and hydrogen peroxide on protein agglomeration in wheat flour gluten-starch separation', Food Chemistry. Elsevier Ltd, 148, pp. 235–239. doi: 10.1016/j.foodchem.2013.10.036.
[13] Bagdi, A. et al. (2016) 'Effect of aleurone-rich flour on composition, baking, textural, and sensory properties of bread', LWT - Food Science and Technology. Elsevier Ltd, 65, pp. 762–769. doi: 10.1016/j.lwt.2015.08.073.
[14] Gebruers, K., Dornez, E., Bedõ, Z., Rakszegi, M., Courtin, C.M., Delcour, J.A., 2010. Variability in xylanase and xylanase inhibition activities in different cereals in the HEALTHGRAIN diversity screen and contribution of environment and genotype to this variability in common wheat. J. Agric. Food Chem. 58, 9362–9371. https://doi.org/10.1021/jf100474m
[15] Bagdi, A., Tömösközi, S., & Nyström, L. (2017). Structural and functional characterization of oxidized feruloylated arabinoxylan from wheat. Food Hydrocolloids, 63, 219–225. https://doi.org/10.1016/j.foodhyd.2016.08.045
[16] Larroque, O. R., & Bekes, F. (2000). Rapid size-exclusion chromatography analysis of molecular size distribution

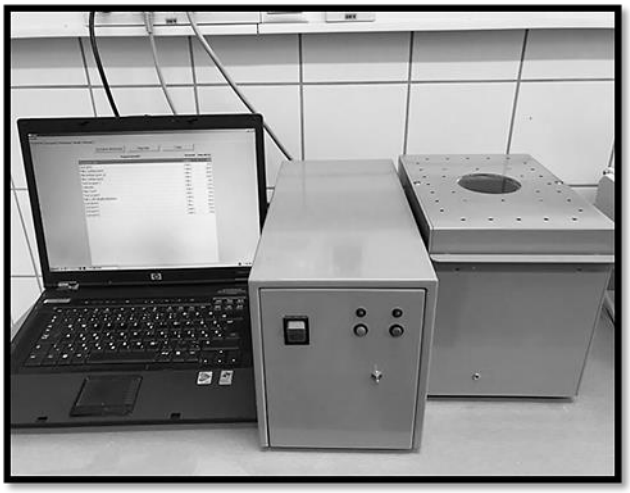
molecules was performed by SE-HPLC according to Simsek et al. (2013)[17]. The free ferulic acid content was determined spectrophotometrically according to Buksa et al. (2012)[18]. Micromorphological properties were investigated by scanning electron microscopy (SEM) technique based on the protocol of Marcela et al. (2017)[19].
Statistical analysis of the results was performed by variance analysis (ANOVA) using TIBCO Statistica™ 13.5.0 (TIBCO Software Inc., USA) software. Statistical tests were performed at a significance level of $\alpha = 0.05$.

4. Results

4.1. Instrument and method development to perform baking test

One of the aims of our work was to investigate what extent the required sample amount can be reduced, so that the qualities of the test loaf are still suitable for qualification, and represent the results of conventional, larger-scale tests. Our experiments have shown that these conditions can still be met with the use of 10 g of flour. Accordingly, a micro-scale method was developed, and compared with the international standard (ICC Nr. 131).

According to the results the parameters obtained by the micro-scale test and the standard method showed a similar tendency, with a significant linear relationship between the specific volume values (r = 0.712). Using this experience, the tools and methods for the macro and micro versions of instrumental baking test were developed. Developments were implemented in collaboration with our industrial partner, Labintern Ltd., which included the development of the hardware (instrument, baking molds, other tools) and the software (1. Figure).



1. Figure: Prototype of self-developed laboratorial bread making instrument

During the methodological developments the process of dough preparation was standardized first, and then the program settings were developed in both macro and micro

for wheat endosperm protein. Cereal Chemistry, 77(4), 451–453. https://doi.org/10.1094/CCHEM.2000.77.4.451
[17] Simsek, S., Whitney, K., & Ohm, J. B. (2013). Analysis of Cereal Starches by High-Performance Size Exclusion Chromatography. Food Analytical Methods, 6(1), 181–190. https://doi.org/10.1007/s12161-012-9424-4
[18] Buksa, K., Ziobro, R., Nowotna, A., Praznik, W., & Gambuś, H. (2012). Isolation, modification and characterization of soluble arabinoxylan fractions from rye grain. European Food Research and Technology, 235(3), 385–395. https://doi.org/10.1007/s00217-012-1765-0
[19] Marcela, S. et al. (2017) 'Effect of the dough mixing process on the quality of wheat and buckwheat proteins', Czech Journal of Food Sciences, 35(No. 6), pp. 522–531. doi: 10.17221/220/2017-cjfs.

mode. According to our results, besides the program settings for the instrumental macro method, the volume of loaves have been sufficiently increased, and the crust had a relatively uniform brown color. The repeatability of parallel measurements proved to be adequate, and the relative standard deviation of the volume was only 1.42%. Based on this, the instrumented macro method was considered suitable for further qualifying tests.

The development of the instrumental micro method was based on the macro method, which had to be modified only to a small extent to produce micro loaves having uniformly colored crust and appropriate crumb quality. Parallel measurements of the final program were performed with a low relative (1.7%) standard deviation, so the micro method was also found suitable for subsequent studies.

To test the applicability and partial validation of the instrumental macro and micro methods, baking trials were performed using the flours of 10 wheat varieties. Comparing the results with the ICC Standard Nr.131, it can be stated that the differentiation of the varieties gave similar results to the standard method. There was significant correlation between the standard and macro/micro loaves based on the crumb hardness, and similarities can be observed also in crumb porosity.

In continuation of the work, there is aimed the further improvement of the operation of the instrument, primarily in terms of regulation, and the full validation of the instrumental macro and micro method by applying a series of samples covering a wider range of quality.

4.2. Modification of the nutritional and technological properties of gluten-free model systems by fiber addition and enzyme treatment

In the composition characterization of the raw materials (millet and buckwheat flours), it was found that white flours are simpler systems in chemical terms than the wholemeal flours and contain mainly the starchy endosperm. As a result, they are characterized by significantly lower fiber and/or AX content, resulting in fewer reactive groups. In these systems, therefore, the effect of AX addition and enzyme treatment is likely to be more clearly identifiable than that of wholemeal flours. The latter, however, are closer to the real matrices therefore their analysis is also reasonable.

The mixing properties tested by micro-doughLAB and Mixolab changed similarly but in different extent due to AX addition and enzyme treatment in all investigated model systems, therefore, it can be assumed that similar molecular processes could occur in millet and buckwheat-based systems. In most cases, AX addition resulted in a significant reduction of dough consistency, which was greater in case of white flours. This can be explained by the fact that the amount of added AX compared to the total fiber content of the wholemeal flours resulted a smaller change than in the case of white flours. Enzymatic treatment of the systems containing the AX isolate has been shown to have a higher consistency than untreated AX dosed doughs. This may indicate cross-linking between AX molecules. However, it has been observed that the oxidative medium caused changes in the properties of doughs without AX addition too. This can be explained by the native AX content of the wholemeal flours, but for white flours containing little or no AX, this phenomenon can be attributed to other reasons. Of course, the H_2O_2 produced during the enzyme activity does not specifically affect the individual flour constituents, for example, it can induce the formation of ditirosin or disulfide bonds between proteins, but also AX-protein interactions between the ferulic acid moiety of AX and protein tyrosyl groups cannot be excluded either.

Significant changes were observed also in the viscous properties studied by RVA and

Mixolab methods. For systems containing AX concentrate, the viscosity of both the dough and the slurry was significantly lower than that of the corresponding controls. The addition of AXs also showed a similar trend in the work of Ayala-Soto, Serna-Saldívar, & Welti-Chanes (2017)[20], when AX extracted from corn was added to gluten-free composite flours. In most cases, the use of POx also in systems without AX had an effect on viscous behavior. In the case of wholemeal flour, this can be explained by the cross-linking of native AX molecules[21,22]. In the case of white flours, the effect of the enzyme was less obvious. In these cases, the oxidation of other ingredients, such as starch, may also be the cause of the change in viscosity. This can be deduced based on the research of Pereira et al. (2017)[23], who have studied the thermal and gelling properties of oat starch oxidized by H_2O_2. The oxidation of native starch has led to an increase in gel hardness and stickiness, due to the increased number of hydrogen bonds due to the formation of carbonyl and carboxyl groups. Starch can also interact with phenolic groups of AXs (e.g., ferulic acid groups) inducing inhibited starch retrogradation[24].

The results of rheological studies provide indirect proof that cross-linking between AX molecules and other macromolecules may occur. To confirm this, the effect of experimental conditions on the size distribution of AX molecules, proteins and starch, the free ferulic acid content, and the micromorphology of dough and gel systems were studied. According to the results it can be stated that due to the enzyme treatment a significant change took place in the size of the added AX molecules in case of both millet and buckwheat systems, which was also supported by the decrease of free ferulic acid content. Based on this, it is highly probable that the cross-linking of AXs has occurred in the gluten-free systems tested. As a result of enzyme treatment, the amount of protein fractions tested also decreased significantly, suggesting aggregation or macromolecular complex formation. Significant increase in size distribution of starch molecules may also be indicative of the oxidation of starch molecules. Thus, our studies also confirmed that the alteration of proteins and starch molecules, as well as their interaction with AX molecules, may have played a role in the changes in rheological properties.

In accordance with our objectives, as a last step the impact of the phenomena presented on the quality of the final product was investigated. Overall, it has been shown that the effect of AX and enzyme treatment was also reflected in the quality of end products. As a result of AX addition, the lower baking loss can be explained by the water-absorbing capacity of soluble AX molecules. Parallel to this, the crumb of the loaves was typically softer. The specific volume in the sourdough systems is generally reduced by the AX content, while in the case of yeast fermented loaves it has not or only slightly changed. Our results showed that the instrumental baking test developed for wheat analysis can also be used to test gluten-free loaves.

The final development of the instrumental gluten-free baking method and the more

[20] Naqash, F., Gani, A., Gani, A., & Masoodi, F. A. (2017). Gluten-free baking: Combating the challenges - A review. Trends in Food Science & Technology, 66, 98–107. https://doi.org/https://doi.org/10.1016/j.tifs.2017.06.004

[21]Decamps, K., Joye, I. J., Rakotozafy, L., Nicolas, J., Courtin, C. M., & Delcour, J. A. (2013). The bread dough stability improving effect of pyranose oxidase from trametes multicolor and glucose oxidase from aspergillus niger: Unraveling the molecular mechanism. Journal of Agricultural and Food Chemistry, 61(32), 7848–7854. https://doi.org/10.1021/jf4021416

[22] Piber, M., & Koehler, P. (2005). Identification of dehydro-ferulic acid-tyrosine in rye and wheat: Evidence for a covalent cross-link between arabinoxylans and proteins. Journal of Agricultural and Food Chemistry, 53(13), 5276–5284. https://doi.org/10.1021/jf050395b

[23] Pereira, J. M., Evangelho, J. A., Moura, F. A., Gutkoski, L. C., Zavareze, E. R., & Dias, A. R. G. (2017). Crystallinity, thermal and gel properties of oat starch oxidized using hydrogen peroxide. International Food Research Journal, 24(4), 1545–1552.

[24] Karunaratne, R., & Zhu, F. (2016). Physicochemical interactions of maize starch with ferulic acid. Food Chemistry, 199, 372–379. https://doi.org/10.1016/j.foodchem.2015.12.033

detailed study of interactions between macromolecules are the main objectives of my further work.

5. Theses

1. In my preliminary experiments I found that the test loaves made from 10 g flour could be still suitable for the detailed evaluation tests. Based on this, a micro-scale baking method was developed and compared to the standard method. Significant correlation was found between the specific volumes of the micro and the standard loaves, therefore the micro-baking method was found suitable to represent the standard test results. (I. article)

2. With my colleagues a prototype of instrument and methods suitable for macro- and micro-scale baking tests were developed. (IV. article)

3. The comparative studies confirmed that instrumental baking tests can differentiate samples similarly to the standard method (IV. article)

4. I concluded that the rheological properties of gluten-free dough systems can be significantly influenced by the use of oxidative media created by pyranose oxidase and by AX addition. (II-III. article)

5. I confirmed the AX network formation using separation technique and structure testing methods. However, I proved that the structural changes of other macromolecules (proteins, starch) can also play a role in the rheological behaviour of dough systems. (III. article)

6. I proved that the micro-baking methods developed for wheat testing are suitable for the production and testing of gluten-free yeast and sourdough leavened loaves. It was also found that changes in the dough can be clearly detected in the quality of the final product.

6. Potential applications

With the further developments of the instrument and the methods and with the refinement of the control, they can be suitable for the routine performance of semi-automated laboratory finished product tests. Macro mode can be an alternative to standard routine measurements, while the micro method could be useful in reducing the need for sample, among others, in the field of research and breeding. Based on our preliminary results, the instrumental baking test can basically be used to compare the final product quality of gluten-free products.

Adding of AXs as bioactive dietary fiber components to gluten-free bakery products can help improve the nutritional value and the structure of the product through its network forming and water-binding properties. For the practical implementation further developments are needed, because the production of AX isolates is not cost-effective yet. At the same time, the enzymatic process used for the formation of the oxidative medium can be incorporated into the process of leavening, by the selection of the appropriate microorganism (yeast), similarly to other existing enzymatic solutions.

7. Publications

Publications related to the PhD theses

I. Németh, R., Bánfalvi, Á., Csendes, A., Kemény, S., Tömösközi, S., 2018. Investigation of scale reduction in a laboratory bread-making procedure: Comparative analysis and method development. *Journal of Cereal Science*. 79, 267–275. https://doi.org/10.1016/j.jcs.2017.11.009, **IF: 2,302**

II. Bender, D., Nemeth, R., Cavazzi, G., Turoczi, F., Schall, E., D'Amico, S., Török, K., Lucisano, M., Tömösközi, S., Schoenlechner, R., 2018. Characterization of rheological properties of rye arabinoxylans in buckwheat model systems. *Food Hydrocolloids*.80, 33–41. https://doi.org/10.1016/j.foodhyd.2018.01.035, **IF: 5,089**

III. Németh, R., Bender, D., Jaksics, E., Calicchio, M., Langó, B., D'Amico, S., Török, K., Schoenlechner, R., Tömösközi, S., 2019. Investigation of the effect of pentosan addition and enzyme treatment on the rheological properties of millet flour based model dough systems. *Food Hydrocolloids*. 94, 381–390. https://doi.org/10.1016/j.foodhyd.2019.03.036, **IF: 5,089**

IV. Németh, R., Farkas, A., Tömösközi, S., 2019. Investigation of the possibility of combined macro and micro test baking instrumentation methodology in wheat research. *Journal of Cereal Science*. 87, 239–247. https://doi.org/10.1016/j.jcs.2019.04.006, **IF: 2,302**

Other related publications

Langó, B., Fehér, A. G., Bicskei, B. Z., Jaksics, E., Németh, R., Bender, D., D'Amico, S. Schoenlechner, R., Tömösközi, S. (2018). The Effect of Different Laboratory-scale Sample Preparation Methods on the Composition of Sorghum (Sorghum bicolor L .) and Millet (Panicum miliaceum L .) Milling Fractions. Periodica Polytechnica Chemical Engineering, 62(4), 426–431. https://doi.org/10.3311/PPch.12846, **IF: 0.877**

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