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Recent past, present and hoped-for future of cereal science and plant protein research

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1. SUMMARY

The fields of science indicated in the title represent centuries old research and development activities of the current department and its legal predecessor institutions, matching the standards, expectations and possibilities of the given era. It is of course impossible to summarize all this in a few pages. A tangential or more detailed description of some areas can be found in other chapters of this issue compiled to review the scientific activities of the department (e.g., in the articles of András Salgó and Ferenc Békés, Zsuzsanna Bugyi et al., Eszter Schallet al.) and in the summary article presenting the department's food science activities [1]. In our current paper, we attempt to provide a brief overview of research directions and results that, from the 1990s to the present day, have played a decisive role in the activities of the department, including the Cereal Science and Food Quality Research Group, as well as in the development and shaping of its research profile.

The years following the regime change were decisive in the lives of all of us. The conditions for education and the cultivation of science changed continuously and significantly, mostly worsening in this transition period. Many people questioned whether it was worth continuing to cultivate the old, traditional areas, or whether we should be more open, modernize and look for new ways, taking advantage of the extremely slow but continuously opening opportunities for building domestic and, especially, international relations, and later for tenders and financing. Progress, development, and openness to new ideas should be essential qualities for an educator and researcher. However, the acquisition of knowledge, experience, and skills takes time, as does the creation and maintenance of the conditions necessary for the cultivation of old or new fields.

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In this uncertain operating matrix, in the mid-1990s we decided to move towards new areas (modernization of food analysis, automatic and rapid test methods, food safety), while trying to maintain and strengthen the cultivation of traditional fields (such as research related to cereal science and plant proteins, development of analytical methods and instruments) that had gained national and international recognition thanks to the work of our predecessors [1]. In the following sections, a brief summary of grain qualification and related method and instrument developments enabling the examination of typically small amounts of material, research on the qualification of small and pseudocereals and improving their possibilities of use, as well as analytical and product development results for increasing food safety, partially related to the previous topic, is given.

2. Development of grain qualification instruments and methods suitable for testing small amounts of samples

Practically until the beginning of the 20th century, the concept and content of grain quality were primarily limited to the development of cultivation indicators, possibly cleanliness, and the sensory assessment of the quality of foods made from the crop. As the milling industry, and later the baking industry became medium, then large-scale, quality, especially wheat quality became a critical issue **[2]**. At the end of the 19th century and at the beginning of the 20th century, research aimed at promoting technological developments, then aimed at influencing technological quality, as well as examining the relationships between composition and quality began. A key issue in the development of the field has become the development of methods and instruments that provide objective results suitable for determining technological quality (milling behavior, rheological properties of doughs made from ground flour, etc.), including the determination of gluten content, gluten strength and kneading properties, in which Hungarian researchers have also played a pioneering role on a global scale from the beginning **[3]**.

By the last quarter of the 20th century, it became clear that to investigate the relationship between composition and quality, and to understand unique rheological factors or those influencing the quality of the complex product, it is not enough to apply the „analytical approach", that is, knowledge of the macro- (e.g., protein or gluten content) and micro-composition (e.g., amino acid or protein subunit composition and size distribution). Determining the properties of the individual protein molecules was the next step in both understanding quality and improving it. Individual protein molecules and groups can also be produced using more traditional separation methods, but the biotechnological development of the last decades of the last century made it possible to use molecular biological methods and to express individual gluten proteins as well **[4, 5]**.

The possibility of examining the unique role of proteins, and macromolecules in general, has also created a new demand for the development of methods and measuring devices that are suitable for studying the complex rheological properties and final product quality of small amounts of samples. Not long after, the need for micro methods also appeared in the fields of breeding using traditional or biotechnological methods (e.g., the possibility of qualification in the earlier phases of breeding), then in research and development for different purposes (e.g., examination of the role of macromolecules, the effect of additives or treatments) and partly in routine analytics.

First, the 2 g version of the Mixograph, standardized mainly in the American and Australian regions, with a mixing bowl containing needle mixing elements, was completed **[6]**, which was successfully used as a revolutionary new research tool to identify the role of expressed proteins **[5, 7]**, in incorporation experiments **[8]**, and in the testing of breeding lines **[9]**, among other things. As a result of the successful application of micro methods, and in parallel with these, measuring devices and methods suitable for testing other parameters (e.g., one-dimensional extensibility **[8,10]**, multi-dimensional extensibility **[11]**, intensive kneading **[12]**), in addition to normal kneading properties have also appeared. This process can be viewed in a way that test techniques with small sample requirements proved their right to exist in this period and gained wider acceptance **[13,14]**.

The employees of our department managed to connect to this fantastically exciting field almost from the beginning. Despite the success of using the 2 g Mixograph, it became necessary for both Australian developers and international researchers using the method to move on. It is an undoubted professional fact that the physico-chemical effects of needle and Z-arm (farinograph and variograph) kneading are partially different **[15, 16]**. On the other hand, it is indisputable that the use of qualification methods based on standard Z-arm mixers, including the sample preparation for mono- and biaxial extensibility tests, is significantly more common and widespread than mixograph methods **[17, 18].**

Therefore, the possibility arose to continue instrument and method development at the Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation) institute and with its partners, which at that time also covered micro extensograph **[8,19]** and micro baking processes **[20]**, together with the Hungarian specialists experienced in valorigraph measurement technology. A part of the funds necessary for the joint work was provided by the OMFB (Hungarian National Technical Development Committee) grant awarded in Hungary, which was considered to be a significant amount at the time. In addition to the staff of CSIRO and BME, Metefém Szövetkezet and Lab-Intern Kft. from the Hungarian side, and Newport Scientific Pty Ltd., the developer and manufacturer of rapid viscosity analyzers (RVA) from the Australian side, took part in the collaboration. The most significant part of the consortium work was aimed at the development of the hardware and software of the micro Z-arm mixer, its working name being the "micro-valorigraph and suitable for the determination of the kneading properties of 4 g of flour, and the related measurement methods. At the same time, we can only take advantage of the possibility of testing small amounts of material, especially in the field of breeding, if we have a suitable sample preparation procedure (grinding and separation). Therefore, on the Hungarian side, the tender also included the design of a micro mill and sieving machine, which is suitable even for grain-by-grain grinding.

Scientific articles usually do not include the details and steps of instrument development. This may partly be due to commercial or intellectual property protection reasons, and researchers and systems evaluating research work rarely give such developments their proper due. In cereal science research, as everywhere else, the results obtained using the measuring devices have a real scientific value, and today there is also talk about the reliability, validation, and performance characteristics of the application of the methods. Naturally, we will not go into the technical details here either. However, we would like to emphasize that it is a very long road and hard work from the birth of an idea to its realization. A lot of brainstorming, consultation, and laboratory experiments are necessary to find the right proportions, lengthy design and mechanical work are required to produce the small parts, miniaturize the drive mechanism, to solve thermostatic or automatic water feeding, which was considered to be a novelty at the time, to solve the processing of the analytical signal, to create the control and evaluation software, then from the creation of the prototype to establishing the conditions for serial production. This path was followed for all instrument development, but due to the learning process, the path leading to the development of the micro-Z arm kneading unit was, by definition, the most difficult. The more than 5 years, during which the idea gave birth to the prototypes of the first working micro-devices, partially with domestic cooperation, were hard but, especially in retrospect, incredibly exciting and useful in terms of gaining knowledge and experience. In addition to the colleagues named in the articles, software, and hardware development colleagues, and in the experimental work and testing, many of our students took part, and they also deserve a huge thank you from us. Maybe not from a professional point of view, but definitely a symbolic milestone in the development of the micro valorigraph and the micro mill was the Hannover Industrial Fair organized between April 21-28, 2001, where it was possible to present the functional equipment to the international public for the first time (***Figure 1***).

Figure 1. Presentation of the prototypes of the micro-mill and the micro-valorigraph at the Hannover Industrial FairMesse in 2001

Back to the grain science orientation, the initial focus was on validating the justification for instrument and method development, and on comparisons with the results of standard methods using large amounts of samples. The first scientific papers were published, first in the form of conference articles and presentations, and later in the form of scientific manuscripts in Hungarian and English **[21, 22, 23, 24, 25, 26, 27, 28, 29, 30]**. From the micro valorigraph prototype, Newport Scientific Pty Ltd. Later launched an improved version of the prototype suitable for routine testing purposes under the name micro-doughLab, which was marketed by the Perten Company until 2020. In addition, the micro mill manufactured by METEFÉM Cooperative has also reached many countries and research sites. Much information on the development and application results of the microvalorigraph and the mill can be found in the current and previous **[31]** issues of the Journal of Food Investigation (Élelmiszervizsgálati Közlemények), in the writings of Ferenc Békés. Therefore, in the following, we will give a brief overview of the later developments of instruments and methods and their role in research so far, mentioning some examples.

Subsequent instrument developments are mainly linked to Hungarian activities, primarily from the cooperation of the BME-ABÉT Cereal Science and Food Quality Research Group and Lab-Intern Kft., partly also with the involvement of grant funds. The second member of the instrument family was the instrument suitable for the automated and small sample quantity (0.4 g of flour) version of the standard Zeleny sedimentation test (SediCom® System). With the help of the sedimentation test, we follow the swelling process of the polysaccharides and proteins of the flours, which can be linked to certain quality properties of the wheat. The method is widely used around the world, the sedimentation value is considered to be a general acceptance and quality classification parameter **[32, 33]**. As a result of the instrument development, a modular, automatic, combined measuring technique, containing digital signal processing and capable of handling both macro and micro test tubes and the related processing software were developed, a first at the international level, followed by the development and validation of the measurements. The prototype of the instrument also received an innovation award at the ICC conference held in Vienna in 2005 **[34, 35, 36]**.

The determination of gluten content is one of the oldest and still most frequently used wheat qualification methods **[37]**. In this area as well, there was a demand, mainly from breeding professionals, for the development of a method with a significantly smaller sample requirement than the standard one, which enables the screening of lines in significantly earlier breeding phases. With a cereal chemistry approach, it is also possible to further study the isolated gluten. Not to mention that another main actor in the hydration and dough formation processes is starch, and the investigation of its properties and role has gained new momentum when varieties with, for example, special carbohydrate composition (low amylose or waxy) coming to the fore. Previously, there was no gluten-washing equipment available, which was suitable for both the examination of smaller than standard sample quantities and the separation of the washed-out starch. With this in mind, we also launched the development of our combined macro and micro gluten-washing instrument, later named the GluStar® System, together with Lab-Intern Kft., which debuted at the 13th Gluten Workshop in China in 2011 **[38].**

The rheological behavior of the dough structure formed after the hydration of ground wheat (water absorption, product-dependent optimal consistency, dough formation process, time, stability, etc.) is an extremely complex process in itself, we know a lot and we don't know or understand even more. This is also a reason why only a total of several rheological tests (kneading tests, mono- and biaxial extensibility, viscosity, falling number, etc.) can provide more detailed information about dough properties **[39]**. However, it is still the final products that are consumed directly, the quality of which is the result of even more complicated, not unrelated factors. The quality and composition of the raw material, the biochemical and physico-chemical processes that take place during leavening (fermentation) and baking (heat treatment), then cooling and storage (aging) all influence the quality of the final product in ways that are partly known and partly still being researched. The question becomes particularly exciting if it is not white flours, but, e.g., whole grinds, also containing shell parts, whose properties are investigated. Here, in addition to protein and starch, the (bio) chemically much less reactive fibers, hydrophobic lipids, and even the different ionic strength, pH, etc., also enter the picture as structure-forming factors **[40]**. In order to be able to carry out comparative tests between the quality of the raw material and the quality of the final product, and to enable the examination of the influencing factors, reproducible laboratory bakery tests are needed. Such standard tests have been used in domestic and international practice for a long time **[41, 42, 43]**. However, the biggest problem is exactly the precision (repeatability, reproducibility) of the implementation of the methods. Currently used standard methods are based on manual execution, with all its "beauty" and reliability problems. Improving the reproducibility of the methods can be achieved by reducing the occurrence of random errors, primarily by at least partially eliminating the human factor. An obvious solution seems to be the at least partial automation of the test loaf production operations (kneading, shaping, leavening, baking, cooling) and evaluation methods (volume, height, texture, etc.).

From the point of view of our topic, it is important that the required amount of samples for traditional baking industry tests is also large, which can be problematic from the point of view of both research and development and breeding. Of course, improvements were also made earlier for instrumentation **[44]** and size reduction **[10,13,45, 46, 47]**. However, the possibility of a complex, partly automated, traditional standard and reduced sample quantity laboratory testing was missing from the toolbox of cereal research. Based on these considerations, as well as with the courage gained from the results of previous instrument developments, the development of methods and instruments suitable for performing automated macro and micro baking tests was launched, again with the help of Lab-Intern Kft.'s employees. Following the determination of the possible extent of size reduction **[46]** and after rejecting several technical ideas, the instrument version with computer control and data collection was completed in 2017, which is suitable for carrying out leavening and baking under controlled conditions after kneading **[48]**. The measurement method developed by us includes the standardized farinograph dough preparation, kneading, and leavening, then the evaluation of the dimensions of the finished test loaves based on laser scanning, the evaluation of the pore distribution of the crumb based on digital image processing, as well as the characterization of its texture using an instrumental texture testing method **[49, 50]**.

By supplementing our own instrument, built with the cooperation BME, with equipment from other manufacturers, we managed to create a wheat and grain testing capacity for the characterization of the rheological and final product properties of small quantities of samples that is rare even on an international scale (***Figure 2***). In the following, some of the research results obtained using micro instruments and methods are presented.

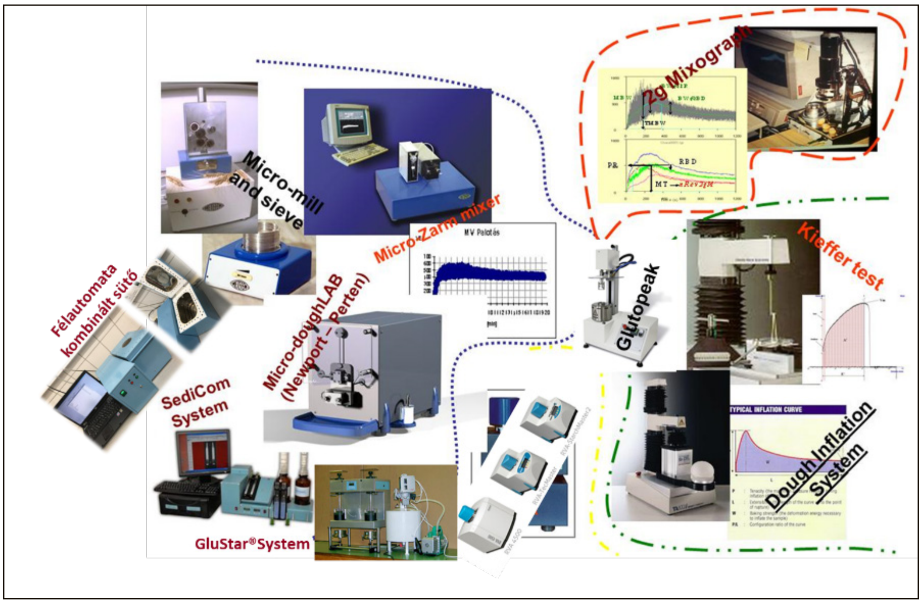

Figure 2. Overview of the currently most commonly used instruments for testing small quantities of grain samples, including equipment completed with the cooperation or coordination of BME on the left

In parallel with the development of instruments and methods with small sample requirements, naturally, their application in various research areas also began. In the beginning, in accordance with the original objectives of the instrument developments, the role of wheat gluten proteins was investigated with variety of comparison experiments, the dosing of expressed proteins, or by studying genetically modified samples. Some of these experiments were performed using a wheat matrix **[16, 51, 52, 53, 54]**. Later, the unique role of wheat proteins was studied by following the changes in the rheological properties of gluten-free rice dough matrix as a result of dosing or experimental genetic modifications **[55, 56, 57]**.

In addition to grain proteins, the properties of other plant proteins were also studied with the help of micro-instruments. The goal of these researches, for example in the case of wheat germ or pseudocereal proteins, was to determine to what extent and in which direction high-protein isolates added to wheat flour in order to increase its nutritional value and modify the technological behavior of it. Behind the experimental ideas, however, there was also a basic research idea. Among other things, we tried to understand how the gluten modifying effect of the isolated less hydrophobic germ, legume and pseudocereal (e.g., amaranth) proteins with better surfactant activities and containing primarily albumins and globulins can be explained **[25, 58, 59]**.

In many respects (e.g., biodiversity, increasing nutritional value, expanding product range, handling food safety problems, etc.), we consider the development of the technical classification of grains (e.g., spelt, triticale, rye, oats, millet) and pseudocereals (amaranth, buckwheat) currently produced in small quantities in more detail than before to be an important and exciting line of research, as well as getting to know the genetic and environmental variability of these crops and understanding the macromolecular relationships behind these properties. The use of equipment requiring small sample amounts is also of great help in this respect, while also improving cost-effectiveness in the process. Without claiming to be exhaustive, we mention here as examples the results of research aimed at the complex technological qualification of triticale varieties **[60]** and our experiments aimed at improving the kneading properties of dough matrices made from gluten-free, buckwheat and millet flours **[61, 62]** (***Figure 3***).

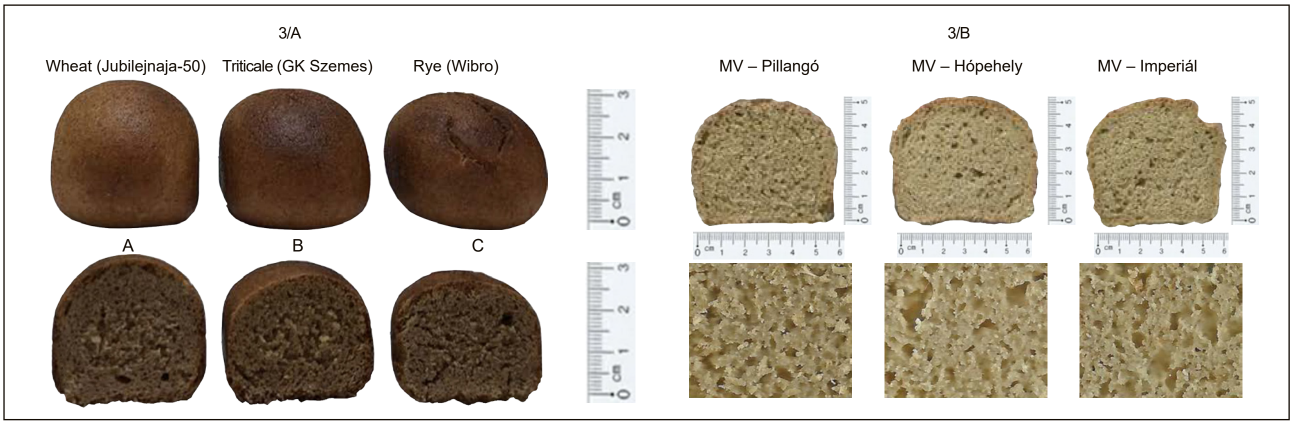

Figure 3. Example of the application of the small-scale baking test
A: Investigation of test loaves made from whole grain triticale with varietal identity ***[60]***
B: Examination of the crumb properties of reduced size test loaves made from oat flours ***[62]***

Apart from proteins, the quality of bakery and other products intended for direct consumption is also fundamentally influenced by the other two groups of macromolecules, starch and non-starch carbohydrates (dietary fibers). The issue becomes particularly acute in the case of the slow but welcome spread of health-conscious eating, where the consumption of whole-grain, fiber-rich cereals is constantly increasing. However, relatively little is known about the structure-forming properties of the fiber components. Our equipment with small sample requirements is also of great help in our research aimed at getting to know them. Some of the recent and current research topics were directed at the investigation of the role of arabinoxylanes, the defining fiber components of wheat flours, in wheat flours and gluten-free matrices **[63, 64, 65, 66]**. Recently, a basic research project was launched, which aims to extend the reduction and reoxidation incorporation technique previously developed by Békés et al. To fiber components **[67]** ***(Figure 4)***. It may also be interesting to investigate the changes in the dough-forming properties of fiber-rich flours due to heat treatment **[68]**. Heat treatment is a well-known process for changing the technological properties of wheat flours or, for example, to increase the shelf life of oatmeals, however, little is known about the molecular processes that take place in the case of fiber-rich samples, and their effects on technological behavior.

Naturally, it is impossible to highlight and mention every application example from the decades-long professional history in such an overview. We would like to apologize to those colleagues and cooperating partners whose joint work and results could not be included here for reasons of scope. But perhaps the above can provide some overview of the possibilities of using grain testing micro methods, the possible directions of development and the results achieved so far.

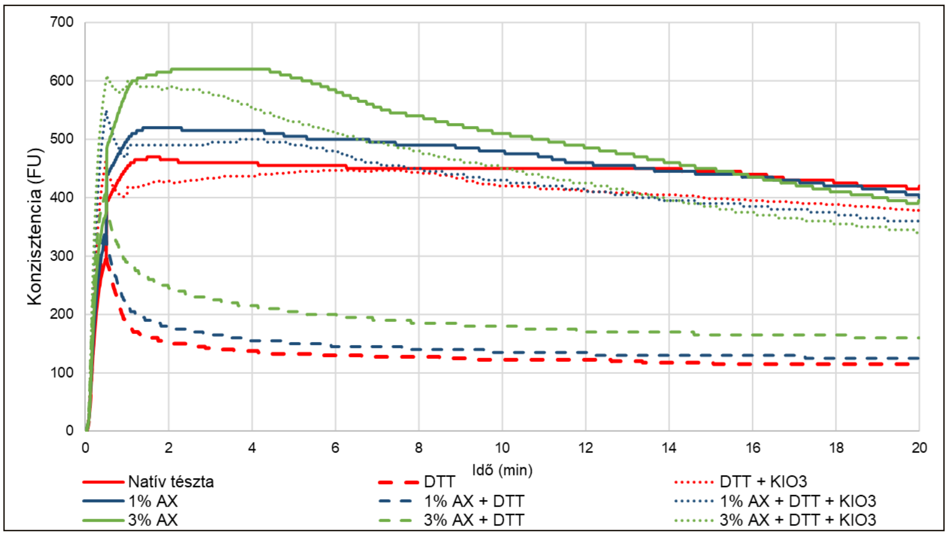

Figure 4. Example of the use of micro-doughLAB (Newport Scientific, later Perten Instruments): The effect of the addition and incorporation of arabinoxylan isolate on the development of the mixing properties of wheat dough ***[67]*** *(Natív tészta: native dough matrix; DTT: reduced wheat dough; DTT+KIO_3: reduced, then reoxidized wheat dough; 1% or 3% AX: proportion of isolated arabinoxylan dosage, for native, reduced or reduced-reoxidized dough)*

3. Possibilities for improving cereal quality and classification

In the past decades, together with domestic and foreign research institutes, universities, economic enterprises and social organizations, we have participated in and initiated many large-scale R&D programs, the objectives of which included the modernization and harmonization of cereal, especially wheat, classification system, as well as the exploration of the application possibilities of new qualification methods and instruments. Perhaps one of the most influential of these was the launch of the Pannonbúza programs (Pannon Wheat Programme). In the framework of these, in the 1990s and 2000s, we determined the detailed composition and technological properties of the wheat varieties that played a decisive role in domestic public cultivation and breeding programs and compared them with the quality requirements of domestic standards, on the one hand, and those appearing in international trade, intervention and on stock exchanges, on the other hand. It has been clearly proven that although the majority of domestic wheat varieties performs exceptionally well in the traditional Hungarian and partly in Central European classification systems, it is more difficult to comply with the alveographic or extensographic parameters, for example, included in export requirements. A related problem is that wheat acceptance and classification and, consequently, the breeding practice in Hungary was determined by the completely coherent, professionally sound domestic wheat standard centered on gluten quality and farinographic value. This did not include the new requirements for wheat for export. At the same time, a significant part of domestic wheat production (30-50%) is sold internationally. Further problem was the obligation to harmonize methods is a legal consequence of joining the EU. However, for example, the farinograph or valorigraph values that have been used to this day and have become ingrained in domestic practice, in a completely justifiable way from a professional point of view, were not included in the international standards, and the evaluation of the curves also differed somewhat.

As an attempt to resolve all this, first, the system of quality requirements for the Pannon Wheat Trademark was developed in two categories ***(Figure 5)*** **[69,70]**. Although this was not accepted by the economic reality of the time, the results and the approach were successfully transferred to the process of renewing the standard for domestic bread wheat. As a result of long discussions and negotiations, the new wheat standard that is still in force and contains one of the most detailed requirements at the international level **[71]**. Its most important innovation is considered to be the possibility of classification according to alternative approaches (farinographic, extensographic, alveographic), as well as the updating and harmonization of the related test standards with international regulations, on the one hand, and with the relevant chapter of the Hungarian Food Codex, on the other hand **[72]**. We would like to believe that, with this solution, we have succeeded in creating a system that is able to exploit the quality advantages of the Hungarian range of varieties, and at the same time encouraging the cultivation of quality wheat which better aligns with sales requirements **[73, 74]**.

Quality criteria of Pannon Wheat	Premium category	Standard category
Wheat quality		
Purity criteria		
- Cracked seeds maximum (m/m%)	2.0	2.0
- Bug-stung seeds	0.5	1.0
Hectoliter-weight	80.0	78.0
Raw protein content in dry material min. (m/m%)	14.5	13.0
Falling number	300.0	250.0
Laboratory quality of flour		
Ingredient		
- Wet gluten minimum (m/m%)	34.0	30.0
Reological quality		
Farinograph value		
- Absorption of water to 14% minimum (m/m%)	60.0	55.0
- Stability minimum (min)	10.0	6.0
Alveograph values		
- W minimum (10-4 J/g)	280.0	220.0
- P/L maximum	1.0	1.5
Extenzograph value		
- Energy at 135 minutes, minimum (cm^2)	120.0	75.0

Figure 5. Quality requirements of the Pannon Wheat Trademark from 2008

The assessment of the nutritional role of wheat and other cereals has changed significantly in recent decades. In the past, the production of white flour containing mainly the kernel and the production of baking, confectionery, and pasta industry products, and other foods from them was decisive. Therefore, the majority of methods suitable for characterizing compositional and technological quality also served this (gluten) protein and starch „centered approach" (see above). A more complete understanding of the role of dietary fibers and bioactive ingredients and the spread of conscious nutrition has resulted in the rise of whole grain flours and flours richer in fibers and non-starch carbohydrates, and also of cereal-based foods. However, the definition of dietary fiber did not develop until the beginning of the 2000s **[75]**, and the methods suitable for their determination then became standard, routine procedures. However, it is also clear that the various fiber components (cellulose, hemicelluloses, pentosans, pectins, lignin, in other groupings, soluble and insoluble fibers) have different nutritional and physiological properties, and their functions influencing technological behavior also differ, and the clarification of these issues required numerous methodological developments and the adaptation of new analytical techniques. We first used in our joint programs with companies and research institutes aimed at the development of health-promoting grain-based products, for example, the mixolab measurement technique suitable for determining the primarily protein-dependent kneading properties and the mainly starch/non-starch carbohydrate-dependent viscous properties to characterize the rheological behavior of milling industry wheat fractions of a new type, rich in aleurone layer, and to examine the function of fibers, among other things ***(Figure 6)***, **[76, 77]**. Also, these researches made it necessary to adapt methods mainly based on separation techniques and suitable for the quantitative and later qualitative determination and comparison (e.g., molecular size, solubility) of individual fiber components, first arabinoxylans (AX), then β-glucans and, currently, arabinogalactan (peptides), then their further development **[78-80]**.

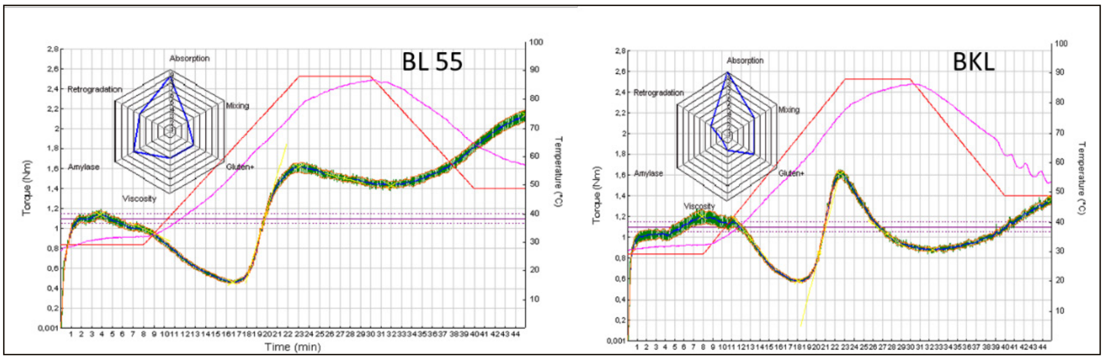

Figure 6. An example for Mixolab application: complex rheological characterization of general (BL55) and special, aleurone-rich wheat flours (BKL)

The centuries-old good reputation of Hungarian wheat cultivation and quality was founded first on conscious selection, land varieties adapted to growing conditions, and later, with the development of breeding methods, on the creation of genetically stable wheat varieties with excellent baking quality. The breeding of the "Bánkúti" wheat varieties **[81]**, which are known to have excellent baking quality, can be considered a milestone in this process, and their quality characterization and the exploration of the molecular background behind the good quality have been partially achieved **[82, 83, 84]**. In recent decades, these varieties have lost their importance in public cultivation, mainly due to their agrotechnological properties. At the same time, due to their excellent technological quality, they still play an important role in breeding programs, or at least they can. However, exploring the composition and technological potential of old species, lines and ancient wheat varieties (e.g., spelt, emmer) using a modern approach and testing methods is an even less well-developed field. Based on such considerations, together with breeding houses and economic enterprises, we launched our R&D program aimed at characterizing old wheat genotypes from a new perspective and improving their use, as well as our complementary basic research. In these, too, we used and further developed our new methods for determining rheological properties and carbohydrate (fiber) content. It was found, for example, that while the kneading characteristics of the Bánkúti varieties and lines are similar with a few exceptions, there are significant differences in their viscous behavior ***(Figure 7a)*** **[54]**. Also, was found to be new information that the white flours of the Bánkúti lines have significantly different soluble arabinoxylan contents, and in some cases, their AX content exceeds that of the international comparative varieties ***(Figure 7b)***, **[85,86]**.

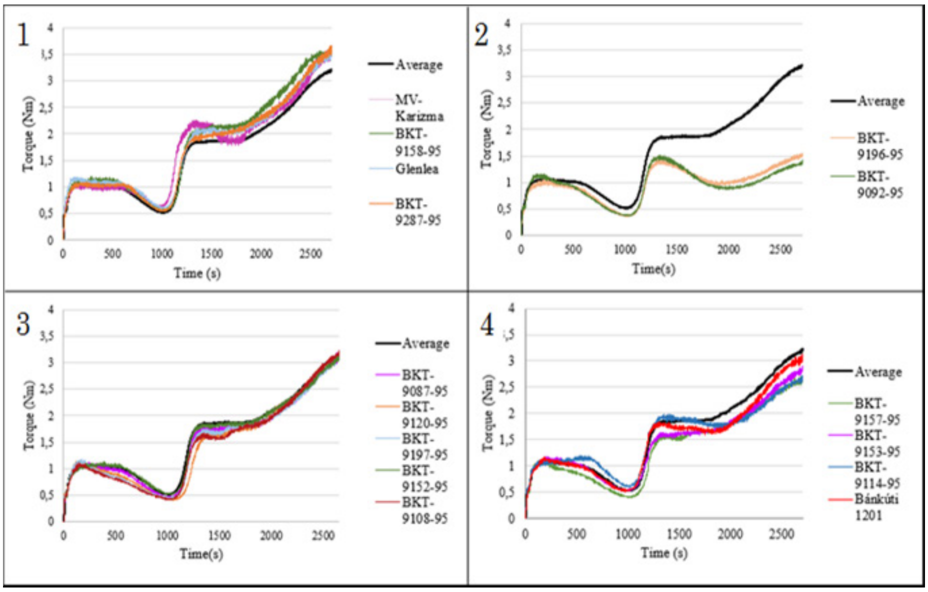

Figure 7/A. Characterization of Bánkúti varieties and lines
Determination of their complex rheological properties with Mixolab

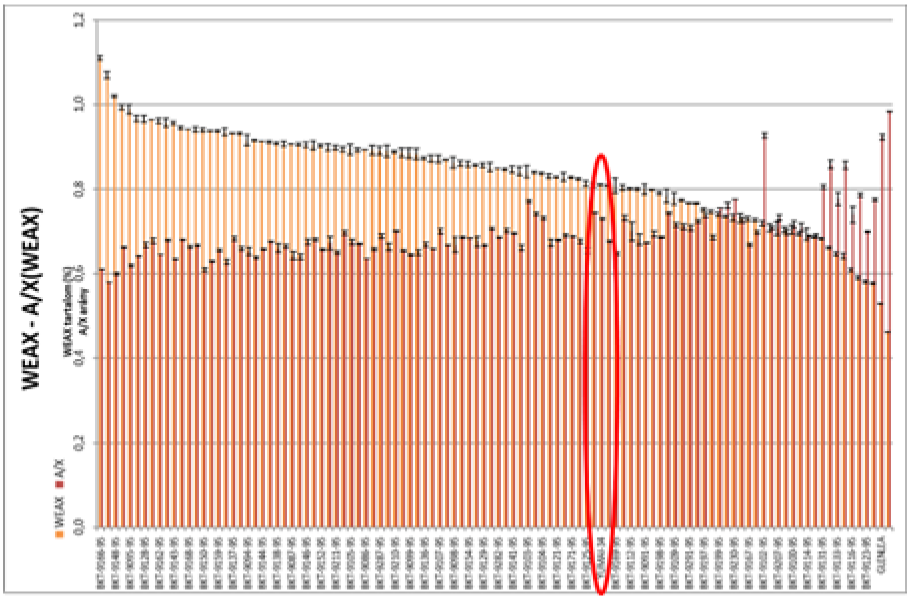

Figure 7/B. Characterization of Bánkúti varieties and lines
Variability of their soluble arabinoxylan content and arabinose/xylose ratio

4. Improving the utilization possibilities of small grains and pseudocereals – two examples

Large grains, including primarily wheat, have a system of qualification criteria based on a significant tradition and knowledge base, and a widely accepted, standardized method and tool background that serves it. However, grains (such as rye, oats, sorghum, millet, triticale) or pseudocereals (amaranth, quinoa, buckwheat), which are currently produced in significantly smaller quantities but are of growing importance due to special nutrition needs, selection expansion, or even fashion, do not have a detailed qualification procedure. Little is known about the differences between species and varieties, compositional and technological quality differences, effects of growing areas, and quality stability. In many cases, even the definition of the quality requirements corresponding to the specific purpose of use is incomplete. For this reason, together with domestic and foreign research centers and colleagues, several basic and applied research and development programs have been launched, to develop the classification methods of small grains, on the one hand, and in the direction of the product, developments promoting the broadening of their utilization, as well as to learn about the molecular background in order to be able to improve their technological behavior, on the other hand. Due to space limitations, the research and development potential and possibilities of these areas will be presented with the help of two examples. Within the framework of our recently completed project, the classification methods of domestically grown and partly domestically bred oat and rye varieties were developed further and, by applying them, the variability of the varieties' compositional and technological properties was examined. In milling industry experiments, by examining 54 fractions, we „drew up" the fraction map of milling and identified some new rye flours that had more favorable properties than traditional flours in terms of nutritional value and health-promoting composition. The rheological and baking industry final product quality of the doughs were characterized in detail, and with the help of the results, it was possible to manufacture new types of products that are favorable from both a compositional and sensory point of view ***(Figure 8)*** **[87]**.

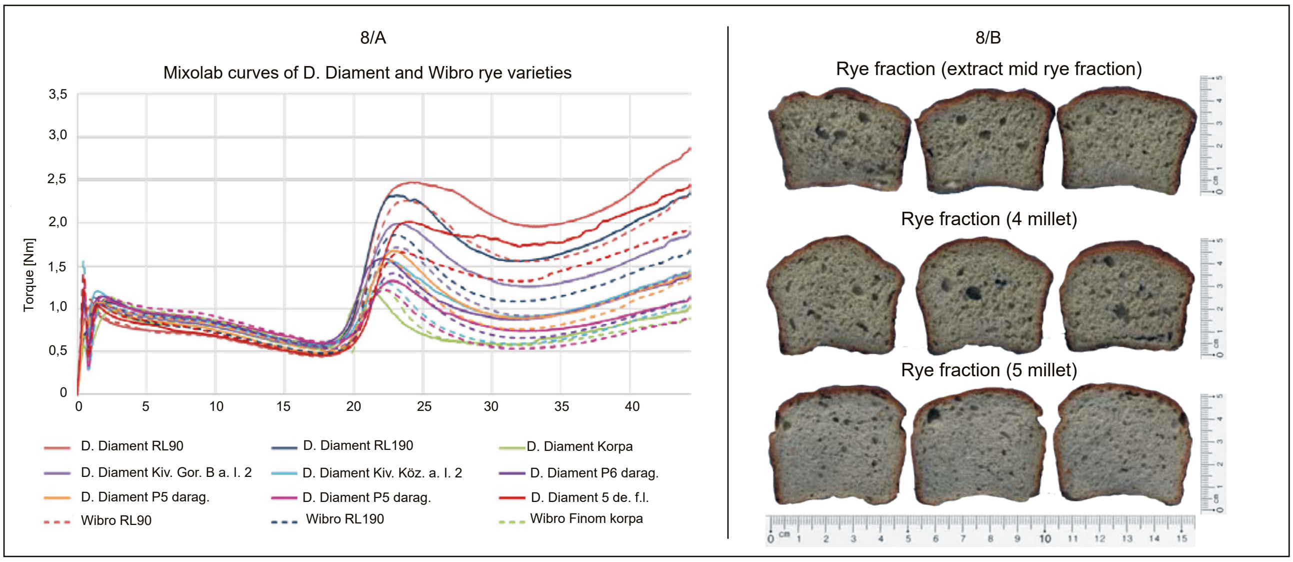

Figure 8. Rheological characterization of rye varieties and their special fractions with Mixolab (A) and results of small-scale baking tests with special fractions of the Dankowskie Diament rye variety (B)

Our other example shows the possibility of improving the nutritional and technological properties of gluten-free dough matrices. The dough-forming properties of gluten-free raw materials (e.g., millet or buckwheat) are relatively weak, in the absence of structure-building macromolecules (gluten proteins), the viscous structure of dough matrices necessary for product preparation is provided by carbohydrates and, in many cases, added hydrocolloids. The technological behavior of this "fragile" molecular system is adversely affected by the presence of fibers. Among other things, this is the reason why the nutritional value of gluten-free baking and pasta industry products is in many cases less favorable compared to the gluten-containing version. At the same time, it is known, for example, that fiber-forming arabinoxylans are capable of forming a macromolecular network partially similar to the gluten structure by connecting their side chains in an oxidative environment. In our experiments, it was possible to prove that hydrogen peroxide produced in enzymatic reactions, in a suitable concentration, can induce the polymerization of arabinoxylans added to gluten-free dough matrices, and thus improve the kneading properties of the dough and the complex quality of the final bakery products, while the nutritional value also increases with the addition of fibers ***(Figure 9)*** **[62, 66]**.

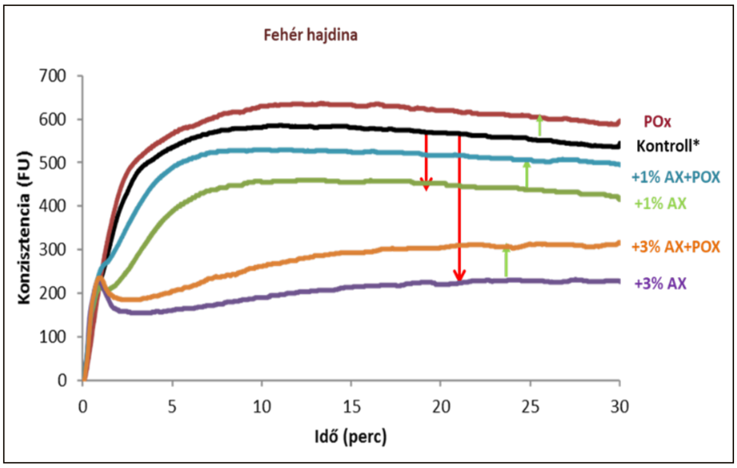

Figure 9. Changes in the mixing properties of dough made from white buckwheat flour measured with a micro-doughLab instrument as a result of arabinoxylan addition and oxidation

5. Excerpts from research activities related to food safety

The complex assessment of cereal quality is further complicated by the emergence of special expectations and food safety requirements (e.g., being gluten-free, low content of fermentable oligo-, di- and monosaccharide and polyol (FODMAP) content, etc.) arising from digestive system disorders (celiac disease, allergies, irritable bowel syndrome) in some consumer groups.

The quality of life of persons with celiac disease, also known as people allergic to gluten, can be ensured by maintaining a gluten-free diet. According to current legislation, the gluten content of gluten-free products cannot exceed the value of 20 mg/kg. Maintenance of the production process, product qualification, and food safety are not possible without the use of analytical methods. ELISA tests operating on the immunoanalytical principal can be considered the most common routine method, but it is also possible to use measuring techniques operating on the basis of molecular biology (based on DNA determination), or using a mass spectrometric detector either alone (MALDI-TOF) or coupled with a separation technique (HPLC-MS). Different ELISA kits and methods operating on other principles usually provide significantly different results. The harmonization and validation of the methods are hindered by the fact that neither a reference method nor a reference material is available. Recognizing this, our research group started a research work aimed at comparing the methods, exploring the reasons for the differences between the results, investigating the effects occurring during product manufacture, and then producing native wheat flour and model products labeled with isolated protein-based reference material. The research work that began more than ten years ago has been carried out in an international cooperation, first as a sub-program of a European framework program, and then as an independently maintained joint work. The most important result is that it was possible to produce a matrix based on wheat flour for the first time, which is likely to meet the requirements of reference materials **[88, 89, 90, 91].** Work is still underway with the inclusion of other gluten-containing cereals (rye, barley, oats).

From the point of view of FODMAP composition, the majority of cereals have an unfavorable perception. It is a particular problem that the FODMAP content of flours, which are favorable in terms of nutritional value and rich in fiber, is usually higher. At the same time, there is almost no information on the variability between cereal species and varieties, on the technological properties of variants with lower FODMAP content, on the joint development of changes in the FODMAP content and fiber composition of flour fractions, and on the effect of the operations used during the technological process (fermentation, heat treatment, pH change, etc.). A comprehensive research project was also recently launched by us in collaboration with others to jointly examine the non-starch carbohydrate (fiber) composition and the content and composition of short-chain carbohydrates also containing FODMAPs. Here again, it became necessary to execute a multi-stage methodological development ***(Figure 10)***, by using which it became possible to compare rye and oat varieties, flour fractions, heat-treated products and bakery end products, among other things **[92, 93].**

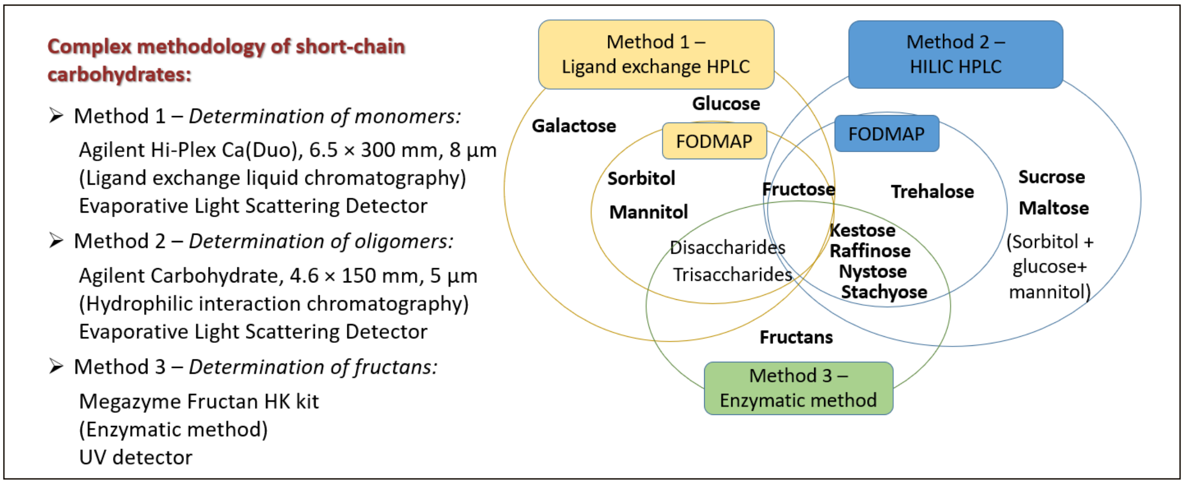

Figure 10. Development of a complex analytical methodology for the examination of the content of short-chain carbohydrates, including FODMAP, in cereals and food products

6. Conclusion

It is difficult to write a short summary at the end of such a large-scale paper, reviewing the research work of several decades and shamelessly exceeding the limits of its scope. We would like to believe that the results presented as examples add something to the development of grain testing methodology, with their use we can get a little closer to understanding the behavior of complex dough and product matrices, and we can contribute to broadening the use of cereals and pseudocereals, to the development of their value-added utilization. In addition, we would like to repeatedly emphasize the importance of cooperation at the individual and institutional level. It is impossible to implement this intensive creative process without our university, research institute, and industrial partners. We would like to thank all our partners for the opportunity of cooperation so far and, hopefully, in the future.

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9. List of basic and applied projects

2020-2024 National project 'Exploring of the genetic, compositional and processing potentials of spelt' (Project ID: OTKA K 135343)

2017 – 2021 National project (GalgaGabona), "Developments to improve the conditions of human utilization of oats and rye in terms of food safety, agrotechniques, processing technology and nutritional value" (Project ID: 2017-1.3.1-VKE-2017-00004)

2015 – 2019 "Consortional assoc. New aspects in wheat breeding: improvement of the bioactive component composition and its effects" (Project ID: OTKA K112179)

2015 – 2018 Austrian - Hungarian bilateral project, "Improving gluten-free dough by a novel hemicellulose network" (Project ID: OTKA ANN 114554)

2016 – 2018 Austrian - Hungarian bilateral project, "Fundamental study on the structure, rheological and functional properties of model gluten-free dough and products based on modified carbohydrate systems" (Project ID: TÉT_15-1-2016-0066)

2013 – 2016 National project, "Quality characterization and applicability study in market-oriented breeding of old wheat genotypes" (Project ID: AGR_PIAC-13- 2013-0074)

2012 – 2014 Austrian - Hungarian bilateral project, "Improvement and optimisation of the nutritional value and technological properties of gluten-free products – study on the effect of newly developed food additives and alternative crops" (Project ID: TÉT_10-1-2011-0731)

2009 – 2013 National Project - "Development of breeding, agricultural production and food industrial processing system of Pannon wheat varieties" (Tech_09-A3-2009-0221)

2010 – 2012 National Project - "Development of quality-oriented and harmonized R+D+I strategy and functional model at BME" (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002)

2009-2012 National project - “Development of R+D environment and tools for improvement the technology- and knowledge transfer activity at Budapest University of Technology and Economics” (Project ID: TÁMOP-4.2.1-08/1/KMR-2008-000)

2009 - 2012 Hungarian Scientific Research Fund - “The relationships of breadmaking quality properties of wheat with the composition of gluten and pentosan” (Project ID: OTKA CK 80334)

2009 – 2012 National Project - “Health Promotion and Tradition: Development of raw materials, functional foods and technologies in cereal-based food chain” (Project ID: TECH_08_A3/2-2008-0425)

2010 – 2011 Austrian – Hungarian Action Fund - Use of pentosans for the production of bread, bakery goods and gluten-free bread of enhanced nutritional value (Project ID: 77öu12)

2009-2011 EU-supported national program “Development of curriculum for MSc education on the area of Food safety and quality” (Project ID: TÁMOP-4.1.2-08/2/A/KMR-2009-0011)

2009 – 2011 Hungarian – Turkish bilateral project – “Improvement of quality and safety of cereals and cereal based food products” (Project ID: TR-16/2008)

2007 – 2011 EU FP6 - MoniQA Network of Excellence (Monitoring and Quality Assurance in the Food Supply Chain (Project ID: FOOD-CT-2006-036337)

2008 – 2009 Austrian – Hungarian Bilateral project - “Functional foods from underutilized cereals and pseudocereal; optimisation of processing parameters and evaluation of its health promoting properties” (Project ID: AT-12/2007)

2003 – 2008 Hungarian Scientific Research Fund - “The effect of low molecular weight polypeptides on the polymerization degree distribution of polymeric glutenin” (Project ID: OTKA K 42703)

2004-2007 National R+D Program - „Scientific program for development of Pannon wheat quality - (Project ID: GAK-ALAP-00126/2004)

2004 – 2005 Scientific-technical cooperation, Austria – Hungary - „Comparison of different amaranth species (regarding chemical composition, functional and sensory properties) for the production of amaranth beverages and amaranth bread” (TéT Program, Project ID: A-20/03)

2001-2005 National R+D Program - „Improvement the utilisation of basic materials in cereal industry” (Project ID: NKFP (4/035/2001)

2001 – 2005 Hungarian Scientific Research Fund – “Development of micro-scale methods for determination of cereal quality” (Project ID: OTKA K 34486)

2003 – 2004 Scientific-technical cooperation, Poland – Hungary “Study of functional, rheological and surface properties of mixed protein systems containing wheat and other plant protein fractions” (TéT Program, Project ID: PI 05/99)

2001 – 2004 Hungarian Economic Competitiveness Program – “Pannon Wheat Program” (Project ID: ALAP1-00126/2004)

2000 – 2003 Hungarian Scientific Research Fund - “Investigation of nutritional and functional properties of pseudo cereals” (Project ID: OTKA T-032650)

1996-2000 National Committee for Technical Development (OMFB) Program – “Development of micro-scale Z-arm mixer and laboratory mill” (Project ID: 96-97-68-1354)

1994 – 1998 PHARE-PMU Program – “An educational, retraining and continuing education project in the field of food and pharmaceutical industries and environmental protection” (Project ID: HU-94.05 0101-L015/20)