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Overview of test methods used to classify wheat flour and bread samples – REVIEW

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SUMMARY

In Hungary, common wheat (Triticum aestivum ssp. vulgare) is of good quality and world famous. In addition, it plays an important role in the human diet. The classification of flours ground from wheat is quite decisive and there are several methods for its examination. The most important flour testing requirements include moisture content, protein content gluten properties and the most important bakery value number. The measured characteristics give us the opportunity to conclude about the properties of the dough, and then bakery products. Several dynamic and static methods have been developed to study the physical properties of dough. The evaluation of products can be carried out in several respects with the help of a baking test. The multitude of methods currently used to qualify flour, dough and finished products also proves that the overview of the methods is quite topical.

Keywords: *flour test; bread test; test loaf; quality; technological property*

INTRODUCTION

The main expectation is that flour ground from wheat should have excellent bakery quality. The classification of flour varies from country to country. Among the countries, the quality standards in our country are the strictest, which is why it is important to examine them. By performing both physical and chemical methods, we can qualify the grain from several points of view. There are various methods for determining the quality characteristics, which show the nutritional properties of flour and the rheological properties of dough and carry a wide variety of information. In the following, we would like to compare the methods for the qualification of flours and breads with each other.

FLOUR TEST METHODS

The expectations of flour are always determined by the purpose of its use (Győri and Győriné, 2011). After determining the purpose, we need to determine whether the flour to be used is suitable for making a finished product from it. This requires taking measurements.

Sensory criticism

Of the evaluated quality parameters, organoleptic properties have already been dealt with in the past and are examined upon the acquisition of the grain. In order to be suitable for use, flour must be free of foreign matter in the first place. Furthermore, among the organoleptic properties, it is worth examining the color, bran content, smell and taste of flours. The color of the flour is determined organically with the help of the Pekár test associated with the name of Imre Pekár in relation to the character model adopted by the Association of Hungarian Cereal Processors, Feed Manufacturers and Traders. Today, there are methods that allow quick measurement. Fast and accurate instrumental measurement for color determination is provided by the CIE type colorimeter (Fratianni et al., 2005). Color tests can be performed in a dry, wet and post-drying state for easier determination. Changes in odor are evaluated in a warm state due to the more intense evaporation of volatile compounds. Fermented, sour, musty, rancid and sultry smell can be better noticed when heated to 60–65 °C. A foreign odor other than the characteristic flour smell can be caused by various microorganisms or weed seeds. Volatile compounds can also be detected using a novel technological method using the electronic nose (Li et al., 2022). Tognon et al. (2005) investigated the mycotoxin contamination of flours using the electronic nose. It is prescribed that the flour sample must be fresh and that no incidental taste is observed during its examination. Substances with characteristically stronger odor (e.g. ethanol, acetone, lactic acid, acetic, butyric, propionic acid, phenols, carbonyl compounds) can cause the strong smell and taste of flour (Lorenz and Maga, 1975).

Moisture and ash content (MSZ 6369-4:1987; MSZ 6369-3:1987, AACC 08-01.01)

When storing flour, it is important to determine the moisture content. In addition, moisture content, as a quality parameter, can also affect the technological suitability of grinders (Husejin et al., 2009). From a bakery's point of view, a maximum of 14.0±0.5 $^{m}/_{m}$% moisture-content flour can be used for the production of dough of the right consistency (Kweon et al., 2011). The method in the oven is time consuming and slow. Therefore, there are also moisture meters based on electrical conductivity or the measurement of a dielectric constant (Győri, 2003). Among the measurement methods, infrared spectroscopy procedures are also becoming more and more widespread. The test is fast and reliable. Among the tests that determine the internal properties of flour, the determination of ash content is also very important. Among the elements, sulfur, potassium and phosphorus play the most significant role in dough formation (Helou et al., 2016). The determination of moisture and

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incineration ash content is very time-consuming, which is why these parameters can also be determined using Raman spectroscopy in addition to the NIR procedure (Czaja et al., 2020).

Enzyme activity (MSZ EN ISO 3039:2010, AACC 22-10.01)

In order to investigate more diversely, the study of amylase, the most important enzyme that breaks down starch in flours – has also become very important in the recent period, which has been proven to play an important role in dough preparation (Miyazaki et al., 2006). The enzymatic state may be characterized by the Hagberg fall number. The activity of enzymes is studied in a flour-water suspension. In the process, a mixing rod begins to sink due to the pasting of the starch. The time of descent is proportional to the activity of the enzyme amylase and is characterized by the fall number (HFN=Hagberg Falling Number). An amylograph is also a suitable tool for measuring the activity of this enzyme. The test is based on the measurement of viscosity. Under the influence of continuous heating, the pasting temperature, the maximum viscosity and the corresponding temperature can also be determined. The significance of the enzyme in the formation of the crust and crumb structure of breads is Leitbeg et al. (2022). It was found that the loaf volume has a negative relationship with the fall count. Enzyme-poor (HFN>400 s) flours result in small volumes of breads with solid, dry crumbs. Flat bread can be baked from flours with a high fall number (HFN<300 s). The bread crumb becomes sticky and difficult to toast (Szilli, 1972). The quality of gluten is also characterized by its spreading. It expresses the value of the change in the diameter of the gluten ball in millimeters at room temperature after resting for 1 hour. The size of the spread shows how well the dough retains its shape. If the diameter of the gluten ball is less than 6 mm after resting, it is too convex, with a small spread, while, if the spread value is greater than 12 mm, a very spreading, flat product is obtained. If the spread of gluten is between these two values (6–12 mm), then the shape of the loaf will be correct (Győri, 2003). With the spread of gluten, one can characterize the activity of the enzyme protease.

From the study of enzyme activity, it becomes clear that it also plays an important role in the formation of the color of the product. Measurement results show and summarize that the rheological structure of dough is also largely determined by the starch used (Agyare et al., 2006).

Crude protein content (MSZ 6369-13:79, MSZ EN ISO 20483:2014)

In addition to studying the ash content and the enzymatic state of the flour, it is quite important to determine the protein content. An indicator characterizing the most important bakery property, which has an inverse relationship with the starch content of wheat. It is not possible to determine the protein content of flour directly, therefore it is measured on the basis of nitrogen content. Using the Kjeldahl method (Győri and Győriné, 2011). The Dumas-Pregl method is used to determine the total nitrogen-containing compounds, taking into account the nitrate and nitrite content (Győri, 2006; Carver, 2009). Since 1826, it has been the best-known combustion method (700–1000 °C) (Serrano et al., 2013). The main advantage of the procedure is that it is fast (analysis of 1 sample takes 3–4 minutes) and is based on dry ashing, therefore no chemicals are required, and the process is made automatic with a computer program. Its main disadvantage is that it is costly and, like the Kjeldahl method, it does not measure the protein content directly. The nitrogen content of wheat protein is 17.54%, therefore, if we multiply the resulting nitrogen content by a multiplying factor of 5.7, we get the crude protein content of wheat (Mariotti et al., 2008). Szeverényi and Házkötő (1965) highlight that there is a positive relationship between protein content and – as described later – wet and dry gluten, water intake and loaf volume. There are also spectrophotometric procedures for determining the protein content, allowing direct measurement. The most common of these procedures is the near-infrared (NIR) rapid method (Győri and Győriné, 2011). The separation of proteins in wheat can be carried out using HPLC – high-efficiency liquid chromatography – method (Lásztity, 1996). In addition, the Lowry method is widely used to study the protein content of wheat (Mæhre et al., 2018). The advantage of the method is that it is simple, has a high sensitivity and is specific. The disadvantage is that the accompanying components of the matrix can interfere with the measurement. The Bradford method for determining the protein content of wheat is also very widespread (Thanhaueser et al., 2015). It is inexpensive, simple and easy, as well as an extremely sensitive method. Furthermore, it is important to point out that the measurement is not affected by intrusive elements. The disadvantage of the test is that it is often necessary to dilute the sample before taking the measurement.

Today, more and more people suffer from coeliac disease, which is caused by the most essential components of flour - the reserve proteins. This is why the classification of proteins is of paramount importance. The total protein content of flour is 7–15%, of which 90% is water-insoluble gluten (Atwell, 2016). The most important gluten proteins are the elasticity-inducing gliadin (50–55%) and the stretchability-inducing glutenin (45–50%) (Veraverbeke and Delcour, 2002; Day 2011), the quantity of which can be determined after washing the flour. During dough formation, the chicory proteins form a uniform coherent viscoelastic structure (Auger et al., 2008). The rheological properties of the dough are determined by the chicory proteins (Schopf et al., 2021). In addition, the starch and fibre content of the flour also influence the structure of the dough to a lesser extent (Capelli et al., 2018). The rheological analysis of dough structure is also important for

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workability, processability and product quality (Weipert 1990; Guy et al., 2022). It follows that chicory proteins influence the shape, water absorption, gas retention and leavening properties of the product (Palvel et al., 2022). Research results by Park (2006) and Knezevic (2017) demonstrate that there is a significant relationship between the amount of gluten proteins and the volume of the loaf. Strong chicory is characterised by high kneading stability, long dough development time and low softening rate (Parenti et al., 2022). The quality of chicory can be characterised by its toughness, swelling capacity, elasticity and extensibility. Chicory is a bright, yellow-coloured, rubbery, elastic and stretchable material (Győri and Győriné, 1998).

Wet gluten is a substance left over after washing out the water-soluble substances (starch, proteins, etc.) of the dough made from flour. The most common device for washing gluten is Perten's Glutomatic device. The higher the percentage of wet gluten, the better the water absorption capacity of the flour. The quantity and quality of gluten also affects the stretchability, elasticity of the dough. To determine the gluten content instead of gluten washing, Nazarova and Zhdanova (2017) developed an electrophoretic fast method. The test of gluten content can also be performed using NIR (Salgó and Szilveszter, 2012). This method allows you to get a measurement result in a short time.

A wet gluten ball can be squeezed through a sieve after centrifugation. From the passed and remaining quantity, we can determine the gluten index, which characterizes the quality of gluten. If the amount of gluten pressed through the sieve is low, the gluten index is close to 100% and the gluten is strong, elastic. If the gluten index is 0%, then the gluten is weak, powerless and torn.

Since 1998, we have been able to investigate the properties of gluten proteins in more detail with the Zeleny test, during which gluten proteins can swell in a medium containing acids (Győri and Győriné, 2011). The Zeleny sedimentation index expresses the volume of sediment that gluten proteins, expressed in cm^3, can produce after shaking and resting in an acidic medium. The dough is the more stable and the better its bakery properties, the greater the volume of sedimentation. Based on their measurement results, Różyło and Laskowski (2011) and Hrušková and Aměra (2003) found that there is an association between the Zeleny index and the loaf volume. In the course of their measurements, they proved that there is a significant relationship between the protein content of the flour and the Zeleny index. The tests were conducted using the NIR method. The quality of the protein is also characterized by wet gluten content, gluten index, gluten spreading and Zeleny sedimentation volume.

From what has been described, it can be clearly seen that there are several methods for determining the most basic requirements for flour – the right organoleptic properties, a strong gluten content, and the correct amylite state.

DOUGH TESTING METHODS

KNEADING METHODS

Farinograph (MSZ EN ISO 5530-1:2015)

The physical and mechanical analysis of flour dough has a long history (since the 1910s). The most important of the kneading methods is the farinographic analysis. The farinographic dough tester is the brainchild of the Hungarian inventor Jenő Hankóczy. The process of dough formation can be followed throughout the process using the method he developed (Autio et al., 2001). The valorigraph measures the resistance to kneading. The change in consistency is evaluated using a valorigram as a function of kneading time. The parameters that can be determined from the curve are the maximum consistency (C), water absorption, dough development time (DDT), stability, softening rate and time, the kneading tolerance index (MTI), the farinographic quality number (FQN) and the Hungarian quality index (MÉSZ) (Matz, 1960). The parameters that can be determined also allow the properties of the gluten to be inferred. One of the most important quality characteristics is the water absorption capacity, expressed in milliliters, which is the amount of water at which the dough reaches a maximum consistency (hardness) of 500 FE and absorbs all the water available. This indicator determines the physical properties of the dough. Examples of such properties are consistency, elasticity, extensibility and flatness (Győri and Győriné, 1998). When the dough regains its original shape by the elimination of deformation, it is elastic. If the gluten is strong and can absorb large amounts of water, the amount of gluten that can be washed out is large and the dough can be made with elasticity and excellent looseness. The stretchability depends on the quantity and quality of the gliadin. The higher the amount of gliadin, the softer, stickier, less elastic the dough, the more difficult it is to process and the more flaky the product (Uthayakumaran et al., 2001). These results indicate that the volume of the loaf depends on the amount of gliadin. The degree of extensibility expresses how viscous the dough is before it breaks. In addition, there is a significant relationship between water absorption and protein content. Water absorption is also influenced by the quantity and quality of the flour protein and the ash content of the flour. Flours with higher hull contents absorb more water and the dough becomes harder. Strong flours are characterised by a dough rising time of approximately 5 minutes. Weaker flours require less time for kneading (2–3 minutes). The dough rising time is influenced not only by the quality and quantity of the gluten but also by the starch content of the flour (Haraszi et al., 2004). The value of the area between the center line of the plot and the distance between the consistency line (planimetric area) is used to determine the baking industry index. On the basis of these values (0–100), the baking scores (A, B, C) give the usability of the flour (Csonka, 1998). Flours with good water absorption, good extensibility, elasticity, shape, gas retention and high protein content have a higher baking

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score (Loch, 1999). The score determines the water absorption capacity of the flour and the physical properties of the dough.

TEARING METHODS

Alveograph (ISO 27971:2015, AACC 54-30.02)

The alveograph was conceived by Jenő Hankóczy and was implemented by Marcel Chopin in 1927 (Indrani et al., 2007). The most important difference with the farinograph is that in this case the amount of water added is the constant. The amount of water in the ration is not affected by the water absorption capacity of the flour itself. A dough is prepared by adding 2.5% sodium chloride to the amount of flour given during the test, and after resting from the dough discs, a bubble is blown by stretching in several directions. The expansion of the bubbles formed is detected as a function of time. The following parameters can be determined from the alveogram: the strength of the dough (P), its extensibility (L), the ratio of these values (P/L), the area under the curve (deformation work required to deform the dough disc (W)) and the volume of air (G) required to inflate and break the dough bubble (the swelling index). The value of the P/L form quotient, which shows the bakery usability of the dough, ranges from 1.0 to 1.5, while the value of the deformation work is suitable for breads if its value is 180–240 W (Győri and Győriné, 1998). There is a positive relationship between the energy (W) required to tear the dough disc and the protein content (Sipos et al., 2007). Furthermore, they found that there is also a strong correlation between protein and stretchability, wet gluten content, bakery value.

Extensograph (MSZ ISO 5530-2:2013, AACC 54-10.01)

The extensograph is an instrument used to measure the extensibility and resistance to stretching of dough. However, this method differs from the alveograph described above in that it does not stretch the dough from all directions and can also analyse the effect of added additives on the structure of the dough (Győri and Győriné, 2011). The parameters that can be determined with the help of the extensograph are the maximum resistance of the dough to stretching (R_{max}), the elongation (E), their ratio and the area under the curve – the deformation work (Pongráczné et al., 2010). The consistency of the kneaded dough can usually be tested after 45, 90 and 135 min according to the force-stretch curve. Based on the area under the curve, we distinguish between weak, medium and very strong flours. An area of less than 80 cm^2 yields a weak dough, 80–120 cm^2 a medium dough, 120–200 cm^2 a strong dough and above 200 cm^2 a very strong dough (Pongráczné and Tarján, 2010). The force required to stretch and tear the dough is greater the stronger the flour (Zheng, 2000; Kim, 2007). The extensograph measures directly the resistance to stretching and thus the strength of the dough can be directly determined. A strong correlation between extensograph extensibility and farinograph softening has been investigated by Sipos et al. (2007).

Promylograph

The promylograph is similar in its measurement method to the extensograph. The difference between the two methods is in the amount of flour to be weighed. With the help of torque acting on the kneading arms, the promilograph also expresses the strength of the flours as a function of time. The measurement results of Hrušková and Faměra (2003) proved that there is a significant relationship between the rheological results of the dough measured by the promylograph and the alveograph.

Laborograph

In 1959, Lásztity and Bárány investigated the resistance of dough to stretching and tearing with a laborograph. The dough discs were evaluated at 30°C after 30 minutes of rest. In his experiments, it was found that the water content added to the flour and the energy required for deformation have a negative relationship with each other.

Mixograph (AACC 54-40.02)

In the early 21st century, the mixograph became common in America. Today it is also used in Canada and Australia. It is a mixing device that monitors the consistency of the dough while it is forming its structure by means of two mixing paddles moving in opposite directions, and can measure the volume increase during baking, the amylase enzyme activity and the shelf life (Hódsági et al., 2010). The mixograph is based on the farinograph and amylograph measurement methods. Mann et al. (2008) described that the device differs from the farinograph in that the amount of water added does not change when using the mixograph, which is tested using 75 g of dough. When examining the characteristics measured by the mixograph, Dabčević et al. (2009) found that water absorption (r=0.9816) and dough rise time (r=0.9668) were closely related to the values measured by the farinograph. Papouskova et al. (2009) and Banu et al. (2011) found a significant relationship between the measured parameters and technological characteristics. The difference between the mixolab and the mixograph methods is that the mixolab requires more time and a larger amount of flour to operate. The results of Treml (2010) show that there is a correlation between the parameters measured by mixolab and mixograph, such as water absorption, dough rise time, dough stability, softening and gluten index.

In order to reduce the amount of flour used, devices requiring a smaller amount of flour have also been developed. For industry, there is a microfarinograph requiring 50 g of flour (Tömösközi et al., 2002); 4 g of flour to be weighed is required to measure the microvalorigraph (Haraszi, 2004) and 2 grams of flour is required for the micromixograph (Gras et al., 2000; Győri and Győriné, 2011), and there is also a microextensograph requiring 1.7 g of flour (Haraszi, 2002).

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FERMENTATION METHODS

Maturograph

The maturograph measures the change in the height of the dough during baking. With the help of the maturograph, it is possible to study the degree of looseness in the yeast dough. The diagram maturogram describes the rate of gas production, so with its help it is also possible to study the dough rising time. Based on their measurement results, Hrušková and Skvrnová (2003) found that the rheological parameters (dough formation time, stability, elasticity) and the volume of the discharged loaf are correlated with each other.

Rheofermentometer

The change in the volume of yeast dough can be investigated with a rheofermentometer. The device is able to test the gas generating and retention capacity at the same time. Its inventor is Chopin, who also discovered the alvegraph. Using a rheofermentometer, we can determine whether the amount of gas produced in the dough and its retention capacity are in equilibrium with each other (Kostyuchenko et al., 2021). The looseness of the doughs can be determined with its aid. The instrument determines the maximum volume, the amount of gas produced, the percentage of relapse after a given time and the time of fermentation. The fermentation time is negatively correlated with gas production and the height of the dough (Codină et al., 2013), which means that if the gas produced leaves quickly the product will become flat and spreading. The enzyme amylase is responsible for gas formation, from which it follows that there is a close relationship between the number of falls and the parameters measured with a rheofermentometer. In his experiments, Markovics (2001) found that the volume of the dough, in addition to the fall number, has a positive correlation relationship with the degree of water absorption and the elasticity of the dough.

BREAD TEST METHODS

The most direct complex test method for the above-described flour characteristics is the baking test. Breads can be evaluated based on the ingredients needed to prepare the dough, the processing of the dough, the method of making bread and the mass of the baked breads.

The test loaf is assessed using a sensory scoring method. The evaluation is based on a score of 0–5 (Curic et al., 2008). If the product has positive attributes, it is given the higher score. Quality indices are assigned to the product characteristics. For the rating of 1 kg white bread, Molnár (2015) developed a 20-point weighting factor rating scale. The following weighting factors were assigned to the sensory parameters shape, crust, smell, taste, and casing: 0.6; 0.6; 0.4; 1.0; and 1.4. After processing, the shape of the dough is considered satisfactory if the slice area is small (GS=6–10 mm). If the dough is flat, the bread is also flat and has a poor shape retention. The shape of baked bread can be more accurately described by the shape quotient. A dimensionless number that is the product's bottom width divided by its maximum height. If the shape quotient is greater than 2, the product is spherical, whereas if it is less than 1.7, the product is very convex, with a small volume and a compact core (Szalai, 1980). The value obtained gives an indication of the nature of the proofing process. Good gas production and gas retention results in a good volume. To determine the volume, a mustard or rapeseed displacement method is used. The volume of the loaves is influenced by the quality of the gliadins (Gasztonyi, 2002). These show that the higher the protein content of the flour, the larger the volume of the loaf and, from a technological point of view, the longer the kneading time. Looking at the volume of bread, Markovics (2001) reports that the higher the gluten content of flour, the smaller the loaf. Markovics (2001) also reported that the ash content of the flour, the softening of the dough and its looseness have the greatest influence on the shape characteristics. The color of the crust of breads can be assessed not only by sensory means but also by means of a CIE-type colourimeter (Castro et al., 2007). The color of the crust of bread is considered to be correct if the color of the dough does not change after kneading. The structure of the crust of the resulting breads can also be studied using a scanning electron microscope (Jusoh et al., 2009). If deep cracks are visible on the surface of the bread and the casing is separating from the crust, the dough is hard, poorly stretchable and tough. A stiff, non-pliable crust is the result of excessive protease enzyme activity. However, a coherent surface of the dough after ripening indicates good gas retention. The smell of the bread, both warm and cold, should be characteristic of the baked product. Foreign odours on a cut surface may indicate a leavening defect, too much yeast or the addition of inappropriate raw materials (In and Devin, 2010). The nearly 500 volatile compounds in bread can be analysed by GC-MS (gas chromatograph mass spectrometer) (Song and Liu, 2018). The structure of the casing is evaluated by cutting the casing in half at its maximum height (Horváthné, 2002) and by determining its color, uniformity and elasticity. It is important that the color of the casing should be characteristic of the type of flour. Products made from flours with higher ash content (BL80, BL112) will have a darker lining (Bagdi et al., 2016). A suitable dough lining will be formed if the structure of the gluten is moderately elastic during processing. When studying the lining, it is important to determine its porosity and elasticity (Guessasma et al., 2011). Its elasticity can be tested by elastography, during which a vertical force is applied to the bread when it is pierced and the degree of volume change can be used to infer the lining properties. From the elastogram, the total deformation rate (D), the plastic deformation (P) and the elastic deformation (R) and their ratio (R/D) can be read (Lambertné, 2012). Elasticity can be measured directly using an elastometer. Elasticity is determined by the quantity and quality of glutenins. If the proportion of glutenins is high, the workable dough is hard, which results in a product with a dense core. In addition, the amount of

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glutenin determines the kneading time. The casing can also be tested by penetrometer. Measurement results by Sluková et al. (2015) have shown that rheological and penetrometric measurements are related.

CONCLUSIONS

In our work we wanted to give an overview of the most important flour and bread testing procedures. The above shows that there are different methods for testing the quality of flour and bread. The range of quality tests is very wide and varied. There are many methods for qualifying the basic grain, flour and bread on the consumer's table, which shows the importance of the subject. Hungary has the widest range of parameters for measuring wheat and wheat-related quality indicators in the world.

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REFERENCES

Agyare, K.–Xiong, Y.–Addo, K.–Akoh, C. (2006): Dynamic Rheological and Thermal Properties of Soft Wheat Flour Dough Containing Structured Lipid. *Journal of Food Science. 69*.7. 297–302. https://doi.org/10.1111/j.1365-2621.2004.tb13633.x

Atwell, W. (2016): Wheat Flour. Second Edition. USA, pp. 164.

Auger, F.–Morel, M.–Lefebvre, J.–Dewilde, M.– Redl, M. (2008): A parametric and microstructural study of the formation of gluten network in mixed floure-water batter. *Journal of Cereal Science. 48*. 349–358.

Autio, K.–Flander, L.–Kinnunen, A.–Heinonen, R. (2001): Bread Quality Relationship with Rheological Measurements of Wheat Flour Dough. *Cereal Chem. 78*. 6. 654–657.

Bagdi, A.–Tóth, B.–Lőrincz, R.–Szendi, S.–Gere A.–Kókai, Z.–Sipos, L.–Tömösközi S. (2016): Effect of Aleurone-Rich Flouron Composition, Baking, Textural, and Sensory Properties of Bread. *Lwt-Food Science and Technology. 65*. 762–769.

Banu, I.–Stoenescu, G.–Ionescu, V.–Aprodu, I. (2011): Estimation of the Baking Quality of Wheat Flours Based on Rheological Parameters of the Mixolab Curve. *Czech Journal of Food Sciences. 29*. 1. 35–44.

Capelli, A.–Cini, E.–Guerrini, L.–Masella, P.–Angeloni, G.–Parenti, A. (2018): Predictive models of the rheological properties and optimal water content in doughs: An application to ancient grain flours with different degrees of refining. *Journal of Cereal Science. 83*. 229–235.

Carver, B.F. (2009): Wheat Science and Trade, Wheat Science and Trade. pp. 569.

Castro, W.–Oblitas, J.–Chuquizuta, T.–Avila-George, H. (2017): Application of image analysis to optimization of the bread-making process based on the acceptability of the crust color. *Journal of Cereal Science. 74*. 194–199.

Codină, G.–Mironeasa, S.–Daniela, V.–Voica-Mironeasa, C. (2013): Multivariate Analysis of Wheat Flour Dough Sugars, Gas Production, and Dough Developmental Different Fermentation Times. *Czech Journal of Food Sciences. 31*. 3. 222–229.

Csonka, K. (1998): Textbook for milling and compound feed technician and miller. Institute of Agricultural Education. pp. 158.

Curic, D.–Novotni, D.–Skevin, D.–Rosell, C.–Collar, C.–Le, B.–Colic,B.–Gabric D. (2008): Design of a quality index for the objective evaluation of bread quality: Application to wheat breads using selected bake off technology for bread making. *Food Research International. 41*. 7. 714–719.

Czaja, T.–Sobota, A.–Szostak R. (2020): Quantification of Ash and Moisture in Wheat Flour by Raman Spectroscopy. 9. 3. 280–287.

Dabčević, T.–Hadnađev, M.–Pojić, M. (2009): Evaluation of the Possibility to Replace Conventional Rheological Wheat Flour Quality Control Instruments with the New Measurement Tool – Mixolab. *Agriculturae Conspectus Scientificus. 74*. 3. 169–174.

Day, L. (2011): Wheat gluten: Production, properties and application, Handbook of Food Proteins. Woodhead Publishing Limited. 267–288.

Fratianni, A.–Irano, M.–Panfili, G.–Acquistucci, R. (2005): Estimation of Color of Durum Wheat. Comparison of WSB, HPLC, and Reflectance Colorimeter Measurements. *J. Agric. Food Chem. 53*. 7. 2373–2378.

Gras, P.–Carpenter, H.–Anderssen, R. (2000): Modelling the Developmental Rheology of Wheat-Flour Dough using Extension Tests. *Journal of Cereal Science. 31*. 1. 1–13.

Guessasma, S.–Chaunier, L.–Della-Valle, G.–Lourdin D. (2011): Mechanical modelling of cereal solid foods. *Trends in Food Science & Technology. 22*. 4. 142–153.

Guy, D.–Maude, D.–Firenze, H.–Hubert, C.–Luc, S.–Kamal K. (2022): Rheology of wheat flour dough at mixing. *Food Physics&Materials Science. 47*.

Győri, Z. (2003): Storage and processing of agricultural products. Agricultural Science Centre of the University of Debrecen. Department of Food Science and Quality Assurance. pp. 148.

Győri, Z.–Győriné, M. I. (1998): Agricultural Knowledge Publishing House, Budapest. 83 p.

Győri, Z.–Győriné, M. I. (2011): Quality and quality of maize and corn. Budapest. pp. 185.

Haraszi, R. (2002) Functional characterization of cereal germ and amaranth proteins in model and complex systems. PhD dissertation, Budapest. pp. 99.

Haraszi, R.–Gras, P.W.–Tömösközi, S.–Salgó, A.–Békés, F. (2004): Application of a Micro Z-Arm Mixer to Characterize Mixing Properties and Water Absorption of Wheat Flour. *Cereal Chem. 81*(5):555–560.

Helou, C.–Widehem, P.–Robert, N.–Branlard G. (2016): The impact of raw materials and baking conditions on Maillard reaction products, thiamine, folate, phytic acid and minerals in white bread. *Food & Function. 7*. 2498–2507.

Hódsági, M.–Gelencsér, T.–Salgó, A. (2010): The applicability of the Mixolab technique. *Élelmiszervizsgálati Közlemények. 56*. 3. 142–152.

Horváthné, A.–Ács, P.–Baráné, H. O.–Deák A. (2002): Estimation of the quality of meat flours by means of a pasta stretching-stretching instrument. *Acta Agraria Debreceniensis. 1*. 38–44.

DOI: 10.34101/ACTAAGRAR/2/12116

Hrušková, M.–Faměr, O. (2003): Evaluation of wheat flour characteristics by the alveo-consistograph. *Polish Journal of Food and nutrition sciences. 12*. 2. 25–28.

Hrušková, M.–Faměra O. (2003): Prediction of wheat and flour Zeleny sedimentation value using NIR technique. *Czech Journal of Food Sciences. 21*. 3. 91–96.

Hrušková, M.–Skvrnová, J. (2003): Use of Maturograph and Spring Oven for the Determination of Wheat Flour Baking Characteristics. *Czech Journal of Food Sciences. 21.* 2 71–77.

Husejin, K.–Mirsad, S.–Amra, O.–Midhat, J.–Nihada, A.–Indira S. (2009): The Importance of Determination of some Physical – Chemical Properties of Wheat and Flour. *Agricultueae Conspectus Scientificus. 74*. 3.197–200.

In, H.–Devin G. (2010): Chemistry of Bread Aroma: A Review. *Food Science and Biotechnology*. *19*. 3. 575–582.

Indrani, D.–Sai Manohar, R.–Rajiv, J.–Venkateswara G. (2007): Alveograph as a tool to assess the quality characteristics of wheat flour for parotta making. *Journal of Food Engineering. 78*. 4. 1202–1206.

Jusoh Mohd, Y.M.–Chin, N.L.–Yusof, Y.A.–Abdul Rahman, R. (2009): Bread crust thickness measurement using digital imaging and Lab colour system. *Journal of Food Engineering. 94.* 3–4. 366–371.

Kim, Y.–Cornillon, P.–Campanella, O. H.–Stroshine, R.–Lee, S.–Shim J. (2007): Small and Large Deformation Rheology for Hard Wheat Flour Dough as Influenced by Mixing and Resting. *Food Engineering and Physical Properties. 73*.1. DOI: 10.1111/j.1750-3841.2007.00599

Knezevic, D.–Rosandic, A.–Kondic, D.–Radosavac, A.–Rajkovic, D. (2017): Effect of glutenformation on wheat quality. *Columella. Journal of Agricultural and Environmental Sciences. 4.* 1. 169–174. DOI: 10.18380/SZIE. COLUM.2017.4.1. suppl

Kostyuchenko, M.–Martirosyan, V.–Nosova, M.–Dremucheva, G.–Nevskaya, E.–Savkina, O. (2021): Effects of α-amylase, endo-xylanase and exoprotease combination on dough properties and bread quality. *Agronomy Research.19.* 3. 1234–1248.

Kweon, M.–Slade, L.–Levine, H. (2011): Solvent Retention Capacity (SRC) Testing of Wheat Flour: Principles and Value in Predicting Flour Functionality in Different Wheat-Based Food Processes and in Wheat Breeding—A Review. *Cereal Chem. 88*. 6. 537–552.

Lambertné, M. A. (2012): Módszer kenyérbélzet állományjellemzőinek meghatározására. Doktori értekezés. Budapest. 112. p.

Lásztity, R. (1996): The Chemistry of Cereal Proteins. Second Edition, CRC Press Inc. 328.

Lásztity, R.–Bárány A. (1959): A tészta relaxációjának vizsgálata laborgráffal (I. rész). *Élelmiszervizsgálati Közlemények. 5*. kötet 3. füz. 48–51.

Leitgeb, M.–Knez, Ž.–Podrepšek, G. (2022): Enzyme Activity and Physiochemical Properties of Flour after Supercritical Carbon Dioxide Processing. *Foods. 11.* 13 1826. https://doi.org/10.3390/foods11131826

Li, N.–Wang, S–Wang, T.–Liu, R.–Zhi, Z.–Wu, T.–Sui, W.–Zhang, M. (2022): Valorization of Wheat Bran by Three Fungi Solid-State Fermentation: Physicochemical Properties, Antioxidant Activity and Flavor Characteristics. *Foods. 11.* 12. 1722.

Loch, J. (1999): Agrokémia. Egyetemi jegyzet. Debreceni Egyetem Agrártudományi Centrum Mezőgazdaságtudományi Kar, Debrecen. 124.

Lorenz, K.–Maga, J. (1975): The Fatty Acid, Carbonyl, n-Hydrocarbon, and Phenolic Acid Composition of Wheat and Triticale Flours. *Journal of Milk and Food Technology. 38*. 2. 84–86.

Mæhre, H.K.–Dalheim, L.–Edvinsen, G.K.–Elvevoll, E.O.–Jensen, I.J. (2018): Protein Determination—Method Matters. 7. 1. 5.

Mani, K.–Trägårdh, C.–Eliasson, C.–Lindahl, L. (1992.): Water Content, Water Soluble Fraction, and Mixing Affect Fundamental Rheological Properties of Wheat Flour Doughs. *Journal of Food Science. 57*. 5. 1198–1209.

Mann, G.–Diffey, S.–Allen, H.–Pumpa, J.–Nath, Z.–Morell, M.K.–Cullis, B.–Smith, A. (2008): Comparison of Small-Scale and Large-Scale Mixing Characteristics: Correlations Between Small-Scale and Large-Scale Mixing and Extensional Characteristics of Wheat Flour Dough. *Journal of Cereal Science.* Vol. *47*, No. 1. pp. 90–100.

Mariotti, F.–Tomé, D.–Mirand, P. (2008): Converting Nitrogen into Protein—Beyond 6.25 and Jones' Factors. Critical Reviews in *Food Science and Nutrition. 48.* 2. 177–184.

Markovics, E. (2001): Sütőipari szempontú búzaliszt-minőség vizsgálata. *Tudományos Közlemények. 22.* 90–102.

Matz, S. A. (1960): Bakery Technology and Engineering.3rd Edition. 696 p.

Miyazaki, M.–Hung, P.V.–Maeda, T.–Morita, N. (2006): Recent Advances in Application of Modified Starches for Breadmaking. *Trends in Food Science & Technology,* Vol. *17*, No. 11, pp. 591–599

Molnár, P. (2015): Alakfelismerési kutatások néhány eredménye érzékszervi élelmiszer-minősítő módszerek továbbfejlesztéséhez sütőipari termékekre. *Élelmiszervizsgálati közlemények. LXI.* évf. 1. szám. 425–555.

Nazarova, V.–Zhdanova, O. (2017): Development of a rapid method for determination of gluten content in wheat flour. *Agronomy Research. 15.* 2. 1369–1374.

Papouskova, L.–Dvoracek, V.–Chrpova, J.–Horakova, V. (2009): Rheological paramters of white flour and whole flouir in modern wheat varieties evaluated by mixolab new profiler system. Proceedings of the 5th international congress flour-bread '09 and 7th croation congress of cereal technologists. 246–251.

Parenti, O.–Zanoni, B.–Giuffrè, M.–Guerrini, L. (2022): The effect of kneading speed on breadmaking from unrefined wheat flour dough. *European Food Research and Technology. 248.* 543–551.

Park, S.–Bean, S.–Chung, O.–Seib, P. (2006): Levels of protein and protein composition in hard winter wheat flours and the relationship to breadmaking. *Cereal Chemistry. 83.* 418–423. https://doi.org/10.1094/CC-83-0418

Pavel, M.–Luis, M.–Norma, M. (2022): Protein Ingredients in Bread: Technological, Textural and Health Implications. Fortified Cereal-Based Food stuffs: *Technological, Sensory, and Nutritional Properties. 11.* 16. 2399. https://doi.org/10.3390/foods11162399

Pongráczné, B. Á.–Tarján, Zs. (2010): Őszi búza lisztek extenzográfos követelményei. *Gazdálkodás. 54.* évf. 7. szám. 762–764.

Pongráczné, B. Á.–Tarján, Zs.–Sipos, P. (2010): Extenzográfos minősítés a nemzetközi búzapiacon. *Élelmiszervizsgálati Közlemények. 56.* 1. 18–23.

Różyło, R.–Laskowski, J. (2011): Predicting Bread Quality (Bread Loaf Volume and Crumb Texture). *Polish J. Food Nutr. Sci. 61.* 1. 61–67.

Salgó, A.–Szilveszter, G. (2011): Analysis of wheat grain development using NIR spectroscopy. *Journal of Cereal Science. 56*. 1. 31–38.

DOI: 10.34101/ACTAAGRAR/2/12116

Schopf, M.–Wehrli, M.–Becker, T.–Jekle, M.–Scherf, K. (2021): Fundamental characterization of wheat gluten. *European Food Research and Technology*. *247.* 985–997.

Serrano, S.–Rincón, F.–García-Olmo, J. (2013): Cereal protein analysis via Dumas method: Standardization of a micro-method using the EuroVector Elemental Analyser. *Journal of Cereal Science. 58*. 1. 31–36.

Sipos, P.–Tóth, Á.–Pongráczné, B. Á.–Győri, Z. (2007): A búzaliszt reológiai vizsgálata különböző módszerekkel. *Élelmiszervizsgálati Közlemények. 53.* 3. 145–155.

Sluková, M.–Kubín, M.–Horáčková, Š.–Příhoda, J. (2015): Application of Amylographic Method for Determination of the Staling of Bakery Products. *Czech J. Food Sci. 33.* 6. 507–512.

Song, H.–Liu, J. (2018): GC-O-MS technique and its applications in food flavor analysis. *Food Research International. 114.* 187–198.

Szalai, L. (1980): A sütőipar távlati fejlesztésével kapcsolatos lisztminőség-kérdések. Tudományos Közlemények. 43–49.

Szeverényi, E.–Házkötő, É. (1965): Gabona- és takarmányféleségek fehérjetartalmának vizsgálatáról. Magyar Országos Söripari Vállalat. Budapest. 213–218.

Szilli, M. (1972): Az amilázok szerepe a sütőipari technológiában és az alfaamiláz aktivitás mérése. *Élelmiszervizsgálati Közlemények. 1–2.* 51–57.

Tognon, G.–Campagnoli, A.–Pinotti, L.–Dell'Orto, V.–Cheli, F. (2005): Implementation of the electronic nose for the identification of mycotoxins in durum wheat (*Triticum durum*). *Veterinary Research Communications, 29.* 2. 391–393.

Tömösközi, S.–Békés, F.–Haraszi, R.–Salgó, A. (2002): Application of Micro Z-arm mixer in wheat research – Effects of protein addition on mixing properties of wheat dough. *Periodica Polytechnica Chemical Engineering. 46.* 1. 31–38.

Treml, M.–Glover, K.–Krishnan, P.–Harelan, G. (2010): Variability and Relationships Among Mixolab, Mixograph, and Baking Parameters Based on Multienvironment Spring Wheat Trials. *Cereal Chem. 87.* 6. 574–580. https://doi.org/10.1094/CCHEM-04-10-0068

Uthayakumaran, S.–Tömösközi, S.–Tatham, A.–Savage, A.–Gianibelli, M.–Stoddard, F.–Békés, F. (2001): Effects of gliadin fractions on functional properties of wheat dough depending on molecular size and hydrophobicity. *Cereal Chem. 78*. 2. 138–141.

Veraverbeke, W. S.–Delcour, J. A. (2002): Wheat Protein Composition and Properties of Wheat Glutenin in Relation to Breadmaking Functionality. *Critical Reviews in Food Science and Nutrition,* Vol. *42,* No. 3, pp. 179–208.

Weipert, D. (1990): The Benefits of Basic Rheometry in Studying Dough Rheology. *Cereal Chemistry,* Vol. *67,* No. 4. pp. 311–317.

Zheng, H.–Morgenstern, M.–Campanella, O.–Larsen, N. (2000): Rheological Properties of Dough During Mechanical Dough Development. *Journal of Cereal Science. 32.* 293–306. doi:10.1006/jcrs.2000.0339