UDC 664.715
DOI https://doi.org/10.15673/gpmf.v23i1.2583

D. Zhygunov [1], Doctor of technical sciences, Professor, *E-mail: dmytro.zhygunov@gmail.com*
ORCID: 0000-0001-9435-2266; ResearcherID: D-1372-2015; Scopus Author ID: 55820666600
S. Sots [1], PhD in technical sciences, Associate professor, *E-mail: sotsserega@gmail.com*
ORCID: 0000-0002-3267-2384; ResearcherID: G-9192-2019; Scopus Author ID: 57210357520
H. Zhyhunova [1, 2], *E-mail: hanna.zhyhunova@gmail.com*
ORCID: 0000-0003-3062-9320
Jiguo Liu [3], Chairman of the board, *E-mail: yudongmfd@163.com*
ORCID: 0000-0002-2852-870X
Fengcheng Wang [3], Technical director, PhD, Professor, *E-mail: wangxiaoling74@163.com*
ORCID: 0000-0003-4676-4834
Xinxin Liu [3], General manager, *E-mail: 659090030@qq.com*
ORCID: 0000-0002-4819-9245
Zhibing Wang [3], Technical consultant, *E-mail: Mf123624@163.com*
ORCID: 0000-0001-7652-4060
Xiyan Li [3], Project director, *E-mail: 413602599@qq.com*
ORCID: 0000-0002-8480-182X
[1] Odesa National University of Technology, 112, Kanatna Str., 65039, Odessa, Ukraine, +380674850063
[2] JUNIA, Graduate school of science and engineering, Norbert Ségard Str., 2, Lille, France, 59014
[3] Huimin County Yudong Wheat Flour Co. Ltd,
Development Zone Sun Wu San Lu, Huimin County, Binzhou City, Shandong Province, China

FORMATION OF WATER ABSORPTION CAPACITY OF FLOUR ON MILLS OF DIFFERENT PRODUCTIVITY

Abstract

This article presents the results of a study of the quality indicators of flour streams, which affect the formation of the water absorption capacity of the final flour. The studies were carried out on five mills with a productivity of 60 to 300 tons per 24 hours. With the help of an original technique for removing the quantitative balance of the milling process, the yield of each individual flour stream and the yield of the final flour were determined, which depended on the productivity of the mill and varied from 75.9-76.1% – for mills with low productivity to 79.0-80.6% – for mills with productivity above 150 tones per 24 hours. Significant changes in the quality indicators of flour streams have been established. During milling at the mill plant with productivity of 150 t / 24 h ash content increased from 0.39% to 2.21%, protein content – from 11.0% to 17.4%, starch damage – from 17.6 UCD to 32.5 UCD. As result the water absorption capacity increases during the milling process from 54.0 to 69.6%. The variation in ash content, protein content, starch damage and other properties of the mill streams are due to the anatomical parts they come from, as result it influence the quality of the final flour. A simple correlation analysis carried out made it possible to evaluate the effect of ash content, protein content, and damaged starch content on the evolution of water absorption capacity. The variations of starch damage and ash content in the flour streams seems to be the principal factor of the increase in water absorption variation, while protein content has the least influence. Despite fluctuations in flour quality indicators on individual systems, it was found that strongly determines the overall quality of the final flour is the mill stream flour yield. That's why optimization of grinding and sieving modes of systems (B1, B2, C1, C2, B3, Siz1) which have flour streams with the highest yield and the greatest impact on the grinding process is a fundamental step in achieving the set values for the final flour quality indicators. Knowledge and understanding of the patterns of change on individual systems of values of flour yield and their quality indicators that affect water absorption capacity will allow to more effectively manage the water absorption capacity. This will make it possible to optimize the properties of the dough according to the requirements of specific technological lines and to regulate the quality of the finished product at bakery and confectionery enterprises.

Keywords: wheat flour, milling, mill streams, flour yield, water absorption capacity, starch damage, protein content, ash.

Introduction

Wheat and rye are the main cereals that have a high nutritional value and are traditionally used for the production of flour all over the world [1]. In Ukraine, flour is divided into kinds, types, subtypes and grades [2]. The kind of flour is determined by the kind of processed grain. The main kinds of baking flour are wheat and rye. Oatmeal, rice, buckwheat, barley flour is produced for children's and dietetic food; triticale, corn and soy flour used for confectionery and food concentrate industries. Flour can also be produced from any crops: sorghum, millet, pea, chickpea [3].

The type of flour is determined by its purpose. Wheat flour is conventionally divided into bread flour, pasta flour, and confectionery flour. Only one type of rye flour is produced – bread flour. Other kinds of flour are not divided into types.

Depending on the specific intended use, wheat flour divided to subtypes: for toast bread, for puff pastry, for pancakes and fritters, for dumplings, for waffles, for muffins, for baguettes, for croissants, for pita, for pasta and panettone, for pizza , for the production of long-freeze bakery products, etc [4].

Within kinds, types and subtypes, flour is divided into commodity grades.

Wheat flour of bakery and confectionery types according to GSTU 46.004-99 is divided into four grades: high-grade (patent), 1-st clear (1-st grade), 2-nd clear (2-nd grade), dark (similar to wholemeal flour). Wheat pasta flour type is divided into 2 grades: semolina (high-grade) and semi-semolina (first grade). There are three types of rye flour according to DSTU 8791:2018: «siiane» (corresponds to Type 75), «obdyrne» (corresponds to Type 145) and wholemeal [2].

The way to achieve the difference between grades is to use the appropriate types of milling. Milling is a set of interrelated technological processes and operations of grain processing into flour grades with a given yield. Each milling is characterized by a certain structure – a milling diagram, which depends on the kind of grain being processed, the yield and range of flour to be obtained, the daily productivity and the brand of the main technological equipment for grinding, sieving and purification [1].

Milling are classified: according to the kind of grain – into wheat milling and rye milling; by mill productivity – for small (up to 100 t/24h), medium (up to 200 t/24h) and large (more than 200 t/24h) mill plants; by selectivity of grinding – into complex (graded) and simple; by number of grades – into single-grade and multi-grade; by milling structure – with a branched structure and a shortened structure; by purification process using – with and without using.

Roller mills are the most widely used mills for the production of wheat flour. The process of obtaining flour on them is built through a multistage process consisting of successive grindings with corrugated and smooth rolls, sieving and purifying [5]. In every step, a certain amount of flour is produced, forwarded to individual mill streams and later mixed in targeted flour [6]. Each individual flour stream has a different set of physical-chemical, functional-technological and rheological quality indicators. Initial grain quality indicators, which depend on the genetic properties of a certain variety, on geographical and climatic conditions of grain cultivation, primarily determine the quality indicators of each flour stream. At the same time, an important factor in the formation of the quality of the final flour is the milling diagram and the number of technological equipment for grinding, sifting and purification, tempering modes, break release, flour sieve hole sizes.

That's why, the deeper understanding of the milling process, process-induced structural changes and impact on final flour quality could enable a targeted optimization of the milling process of obtaining specialized flours, meeting customers' requirements and predicting product quality [5].

Literary review

Wheat flour is a multicomponent system that includes protein-proteinase, carbohydrate-amylase, pentosan-hemicellulase and lipid-lipase complexes, as well as minerals.

The term "protein-proteinase complex" includes protein substances, proteolytic enzymes and activators or inhibitors of proteolysis; the term "carbohydrate-amylase flour complex" includes carbohydrates (starch, sugar) and amylolytic enzymes (amylases); the term "pentosan-hemicellulase complex" includes water-soluble and water-insoluble pentosans and hemicellulase and xylanase enzymes; the term "lipid-lipase complex" includes simple and complex lipids, fat-soluble pigments, sterols, fat-soluble vitamins, lipolytic enzymes.

The totality of flour quality indicators determines the so-called strength of flour, it is an integral characteristic of flour that evaluates it: the ability to absorb water (water absorption capacity); the ability to hold water during mixing (water-holding capacity); the ability to ensure elasticity and extensibility of the dough; the ability to maintain the volume of the dough during long-term proofing (gas-retaining capacity); the ability to form high porosity, density and elasticity of finished products; the ability to provide a high volume of finished products.

Water absorption capacity (WAC) of flour is an extremely important property of dough that affects dough machinability [7], bread loaf volume [8], specific volume of bread [9], governs the dimensional and textural characteristics of final food products [10]. WAC is influenced by such factors as flour particle size, starch damage level, protein content, water-extractable arabinoxylans content [11]. According to [12], 1 g of protein can absorb up to 1.3 g of H2O, while gluten proteins can absorb up to 2.8 g of H2O per gram, but non-gluten proteins absorb a small amount of water [13]. Native wheat starch may contain only 0.3–0.45 g H2O per gram dry starch, while mechanically damaged starch may contain 1.5–2 g H2O per gram dry starch, and baked gelatinized starch may hold up to 10 g H2O per gram dry starch. Wheat pentosans, especially the water-soluble arabinoxylans, are the most water-retaining components of flour – can hold up to 10 g H2O per gram of arabinoxylan content on a dry matter basis. With an approximate content in the final flour: protein 12%, native starch 57%, damaged starch 8%, pentosans 2%, the proportion of water absorbed by these components is 15.6, 22.8, 16.0 and 14.0%, respectively, with total water absorption on dry matter WACd.m. – 68.4%, which corresponds to the basic moisture 14% WACb14% – 58.1% [13]. Thus, native starch occupies the first place in terms of the amount of water absorbed by the flour, followed by damaged starch, proteins and pentosans.

The starch in the whole grain is native in the form of starch granules, and when milled, various forces (such as shear, compression, impact and friction) act on the starch granules, causing them to break down into smaller particles. Damage level of milling-treated starch is influenced by three major factors, namely quality of raw materials, flour granularity and milling conditions [14]. Generally, the starch damage content is higher in harder grains than softer ones when the same milling treatments are used. In hard wheat flour the starch damage content caused by the mechanical action of the milling process is about 7% for typical hard wheat flours and 3% for typical soft wheat flours [4]. The starch damage content influence on pasting properties of flour, water hydration property, fermentation and starch gelatinsation process behavior, textural property of final food products (hardness, chewiness, gumminess), enzymatic digestibility of starch in final food products [14]. Damaged starch is also more susceptible to the action of α- and β-amylases, i.e. it forms simple sugars faster during fermentation. Some of the enzymes are unable to attack an intact granule at all because of the protective coating on its granules [15].

A high content of damaged starch in the presence of sufficient amylolytic enzymes leads to a sticky dough with a weak sidewall and a sticky pulp. Such dough is difficult to process on an automatic line: it is necessary to reduce the moisture content of the dough, use softer kneading modes, add flour as the dough moves along the line. It is difficult to process such dough on an automatic line: it is necessary to reduce the moisture content of the dough, use softer kneading modes, add flour while the dough is moving on the line. Even with a high farinograph water absorption capacity, in the industrial conditions, it is necessary to reduce the amount of water. Therefore, the volume of the bread is smaller, the moisture content of the pulp is lower, and the pulp itself is harder. In addition, there may be problems at the fermentation stage due to too high rate of sugar generation, when the gas generation process is very active in the first stage and ends earlier than the planned fermentation time. With insufficient gas-retaining capacity (with a low gluten content), this leads to a decrease in the loaf volume. Another possible problem is the red color of the bread crust due to the Mayard reaction – the interaction of a high amount of reducing sugars, which are formed during the fermentation of flour with a high content of damaged starch, with the amino acids of flour proteins under the influence of high temperature.

At the same time, insufficient starch damage leads to the opposite processes: a decrease in water absorption, an increase in the duration of fermentation, a decrease in the loaf volume, to the formation of a pale crust of finished products – which is also not suitable for production.

The next quality indicator of flour, which determines its water absorption, is the protein content. Although proteins rank behind native and damaged starch in terms of the amount of water absorbed in the dough, it is thanks to them that the gluten network is formed and the dough is obtained. In wheat grain, proteins are represented by water-soluble and salt-soluble fractions (albumins and globulins), and gluten proteins – gliadins and glutenins. Gliadins are predominantly monomeric proteins that are insoluble in salt solutions and water, but soluble in aqueous alcohols, e.g., 60% ethanol. Glutenins are high molecular weight proteins soluble dilute acid or alkali [16]. The dynamic interaction of gliadins and glutenins enables the formation of a viscoelastic gluten network when adding water to wheat flour [16]. Gluten plays an extremely important role in the formation of wheat dough and determines the baking properties of flour [17].

Starch damage and protein content are the two main factors affecting flour water absorption. Depending on the type of finished product, there is an optimal content of damaged starch, taking into account the protein content (Table 1) [18].

Another factor influencing the WAC is the pentosans content. Pentosans are any polysaccharide composed of five carbon sugars called pentoses. There is water extractable pentosans (arabinoxylans) and water unextractable pentosans (hemicelluloses). Pentosans have a significant effect on wheat flour functionality. Water extractable pentosans increase the viscosity of the aqueous phase of the dough, increase its stability, prevent early fusion of gas cells and increase the loaf volume.

Table 1 – Protein content and starch damage content in the specialized flour for different purposes

Purpose of flour	Protein content, %	Starch damage, UCD
Pan bread	11-14	19-23
Lavash	11-12	17-20
Baguette	9-12	16-20
Crackers	8-10	16-18
Noodles	9-11	14-17
Cookies	7-9	14-16

Also, arabinoxylans can form a secondary, weaker network that strengthens the gluten network. At the same time, water unextractable pentosans destabilize the structure of the test. They are present in discrete cell wall fragments and can form physical barriers to the gluten network during dough development. They also absorbs a large amount of water, which is therefore not available for gluten development and gluten network formation [19]. Both pentosans help absorb water in bread, slowing down staling.

The total pentosans content correlates well with the ash content and can serve as an indicator of the amount of bran in the flour streams as a whole [20]. At the same time, the content of water-soluble pentosans has a more limited relationship with ash [21].

The result of the interaction of the above components with water during the formation of the dough is the level of water absorption capacity and water-retaining capacity of flour. Optimal dough handling properties are critical in commercial bread production. Variation in flour water absorption tolerance dramatically affects dough handling. Flour with a low water absorption becomes sticky, slack, and difficult to process in a commercial bakery if the water absorption is slightly off target while flours with high water absorption are more robust, thus are capable of producing a machinable dough. Bread produced from wet or dry dough is inferior in volume and texture to bread produced with optimum water absorption. Understanding the factors that affect water absorption, such as wheat genotype, geographical and climatic factors, milling modes and milling diagram; studying changes in ash content, protein content, starch damage in individual flour streams and their interactions, will allow better control of water absorption in the final flour [7].

Purpose and objectives of the analysis

The purpose of this work was to establish the main factors influenced on water absorption capacity in resulted flour at the different mill plants. For this purpose, the following objectives were achieved:

- determining the flour streams and straight flour yield;
- determining the ash content, protein content, starch damage and water absorption capacity in different flour streams;
- establishing correlation relationships between the ash content, protein content, starch damage, and water absorption capacity of the flour streams.

Materials and methods

Flour samples and mill plants characteristics

149 samples of wheat flour streams from 5 mill plants with different productivity from 60 t/24h to 300 t/24h were investigated.

Taking into account the fact that different milling diagrams were used at the researched mills, which included a different number of systems, it became necessary to group the flour streams by quality groups for their comparative characterization. The data from all systems were combined and grouped into quality categories (Table 2).

To determine the overall quality of the flour streams, the weighted averages of the quality indicators for the mixed streams were calculated (Fig. 2-6). These averages were computed proportionally to the yield of each individual stream (Fig. 1).

Flour yield (material balance)

When collecting flour samples from each system, the percentage yield of flour was determined. To do this, the milling performance was determined by the amount of grain (q_{grain}) entering the first break system (B1), in tons per hour directly on the scales (Formula 1) or based on computer data (depending on its availability at the mill).

After that, the milling process was transferred to the single-grade milling mode for the time of balance removal, and all flour streams were sent to one screw for the formation of flour grades. Next, the milling productivity was determined in tons per hour according to the bran yield (q_{bran}) and total flour yield (q_{flour}) – directly on the scales (Formula 1) or based on computer data (depending on its availability at the mill).

Consistently each flour stream was redirected to a separate screw and after 10 minutes the mass of the portion for this stream (m_i) in kilogram was measured, which was weighed on the scales, and duration between plumb bob on the scales (τ_i) in seconds. The measurement was carried out at least 5 times and the result of calculating the productivity of the individual flour stream (q_i) in tones per hour was averaged.

$$q_i = 3.6 \cdot \frac{m_i}{\tau_i} \qquad (1)$$

In case that the calculated sum of productivity in tons per hour of all flour streams deviated from the productivity of total flour by more than 5%, the balancing procedure was repeated.

Then, the yield of each individual flour stream (MSY_i) was calculated using the formula:

$$MSY_i = \frac{q_i}{q_{flour}+q_{bran}} \qquad (2)$$

Table 2 – Distribution of systems by quality groups and short characteristics of studied mill plants

Quality groups	Mark	60 t / 24 h mill plant 1	100 t / 24 h mill plant 2	150 t / 24 h mill plant 3	200 t / 24 h mill plant 4	300 t / 24 h mill plant 5
Primary Break systems	PBS	B1A, B1B, B2A, B2B	B1/B2A, B1/B2B	B1/B2A, B1/B2B	B1/B2A, B1/B2B, B1/B2C, B1/B2D	B1/B2A, B1/B2B
Middlings Break systems	MBS	B3	B3C, B3F	B3	B3CA, B3CB, B3F	B3CA, B3CB, B3F
Tail-end Break systems	TBS	B4	B4C, B4F	B4/B5A, B4/B5B	B4CA, B4CB, B4F, B5A, B5B	B4C, B4F, B5
Primary Grading systems	PGS	Div1	Div1	Div1	Div1	Div1
Middlings Grading systems	MGS	—	Div2	Div2	Div2	Div2
Tail-end Grading systems	TGS	—	Div3	Div3	Div3	Div3, BF1, BF2
Sizing systems	Siz1	Siz1	Siz1, Siz2	Siz1/Siz2A, Siz1/Siz2B	Siz1,Siz2	Siz1C, Siz1F, Siz2
Primary Reduction systems	PRS	C1 C2	C1C, C1F, C2	C1/C2A, C1/C2B, C3	C1C, C1F, C2A C2B, C3	C1/C2A, C1/C2B, C3A, C3B
Middlings Reduction systems	MRS	C3	C4, C5	C5, C6	C5, C6	C5, C6
Middlings Collecting systems	MCS	C4	C3	C4, C7	C4, C7	C4, C7
Tail-end Reduction systems	TRS	BF1	—	C8, C9	C8, C9	C8, C9
Tail-end Collecting systems	TCS	—	C6	C10	C10	C10
Number of mill streams	—	20	29	29	35	36
Specific roller length, mm / 100 kg / 24 h	—	18.33	15.00	12.33	17.75	10.58

Flour quality analysis

Evaluation of flour quality indicators was performed by: moisture content (MC) – to ISO 712, protein content (PC) – to ISO 20483, ash content (AC) – to ISO 2171, starch damage (SD) content by the SDmatic device (Chopin, France) using amperometric method according to ISO 17715, water absorption capacity by Farinograph device (Brabender, Germany) according to ISO 5530.

Statistical evaluation

All the evaluation data was statistically processed by employing the least significant difference (LSD 0.05) at a 95% probability level and the correlations were calculated using the statistical processing built-in Microsoft Excel Software.

In the correlation analysis, it was determined whether the quality indicators have a correlation with each other and to what extent in accordance with the following division: extra high – $0.85<|r|\leq1.00$; high – for $0.70<|r|\leq0.85$; average – for $0.50<|r|\leq0.70$; low – for $0.30<|r|\leq0.50$; have no correlation – at $0<|r|\leq0.30$.

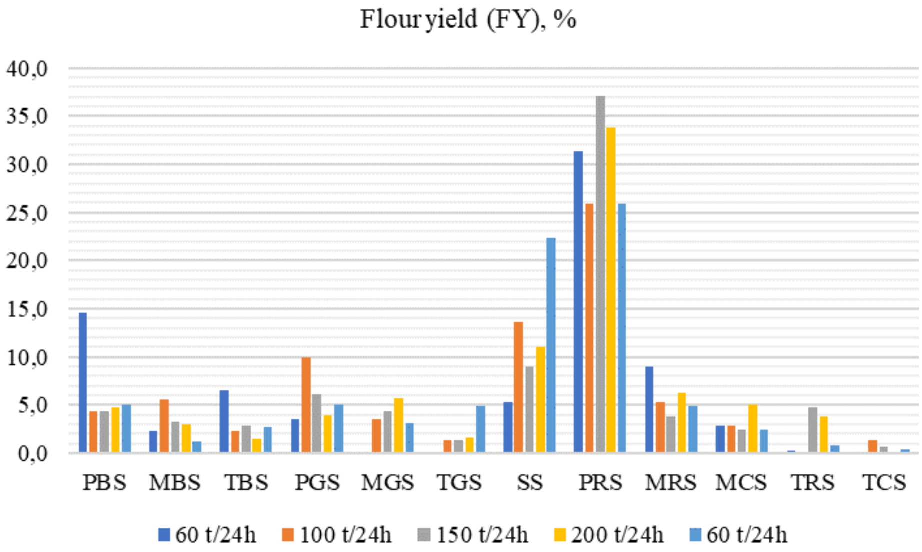

Fig. 1 – Flour yield of mill streams by quality groups for different mill plants

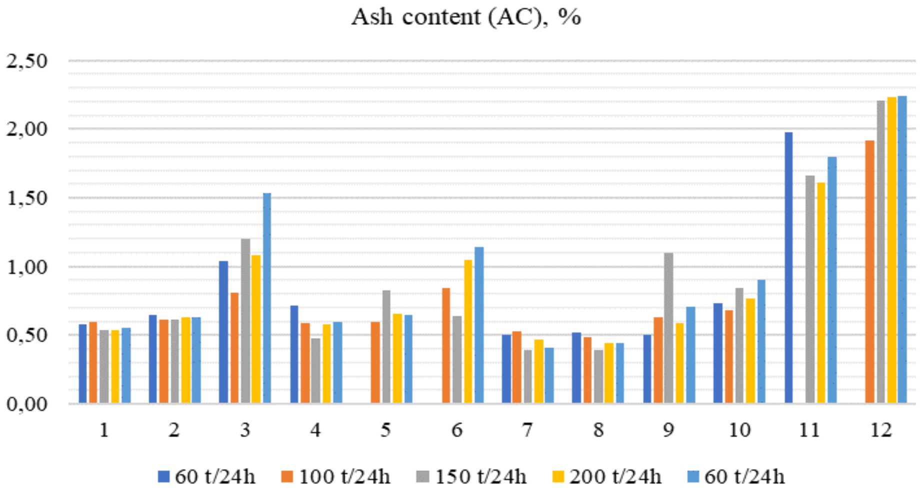

Fig. 2 – Ash content of mill streams by quality groups for different mill plants

Results and its discussion

The flour yield is one of the major quality criteria in wheat milling. The flour yield at each milling stage depends on the designed diagram, the number of main technological equipment (rollers, sifters and purifiers) and grinding modes [22].

Total flour yield of different milling processes was ranged from 75.9-76.1% for mill plants 1 and 2 which have low productivity to 79.0-80.6% for mill plants 3–5 which have productivity more than 100 tones per 24 hours. This is explained by a more developed milling diagram at plants with higher productivity, primarily due to a larger number of reduction systems (Table 2).

The results of the study of the yield of flour streams by quality groups are presented on Figure 1. The highest flour yield, regardless of the mill productivity, was on Primary Reduction systems – 24.8-37.1%. These systems are designed for reducing of fine semolina which is obtained at the previous stages of milling. 5.3-22.4% of the flour yield is obtained at the Sizing systems. These systems scraping the endosperm from the skin. Moreover, for the first four mills, the flour yield was 5.3-13.6%, and for mill 5 was significantly higher – 22.4%. In fact, the Siz1F system at this milling process works in the grinding system mode and gives a lot of flour – 11.1%.

As a result, it was found that Primary Reduction systems and Sizing systems are the main grinding systems. They produce 50-60% of the total flour yield.

Break systems are not designed to produce flour. Their main role is to overcome modulus of elasticity of the grain and to provide as many intermediate products as possible. Therefore, the total yield of flour on Primary Break systems (B1, B2) and Primary Grading systems (Div1) was 8.8-18.2%. Large values of 18.2% and 14.4% correspond to mills 1 and 2 of small productivity, which have the shortened diagram. As a result, large break release values are kept on these systems in order to ensure the highest possible of total flour yield. For the remaining three mills, the flour yield on these systems is much less – 8.8-10.6%.

In third place in terms of flour yield was Middlings Reduction systems. These systems include C3 for mill 1, C4 for mill 2, C5, C6 for mills 3–5. These systems regrind semolina and dunsts that were not ground on the first reduction systems. The flour yield on these systems ranged from 3.8% to 9.0%.

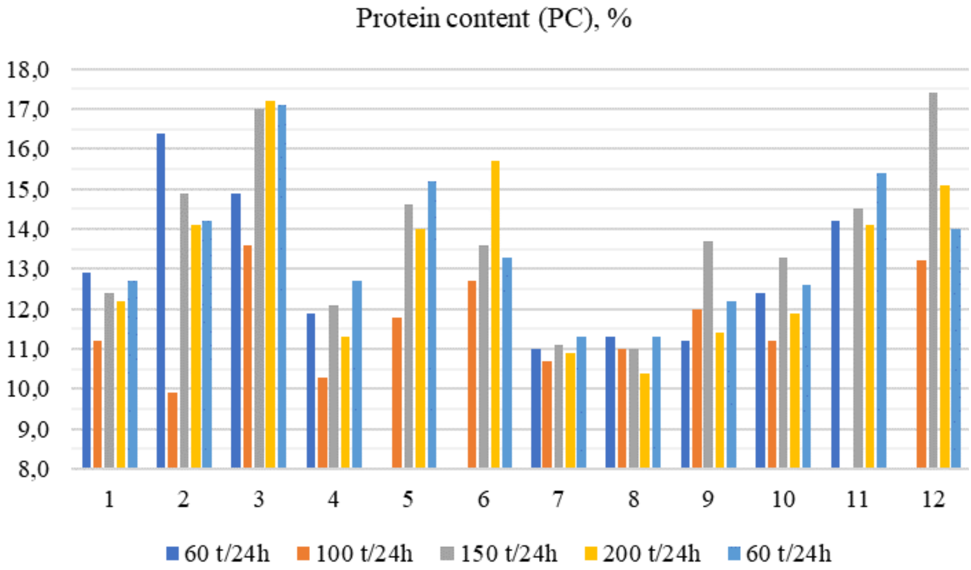

Fig. 3 – Protein content of mill streams by quality groups for different mill plants

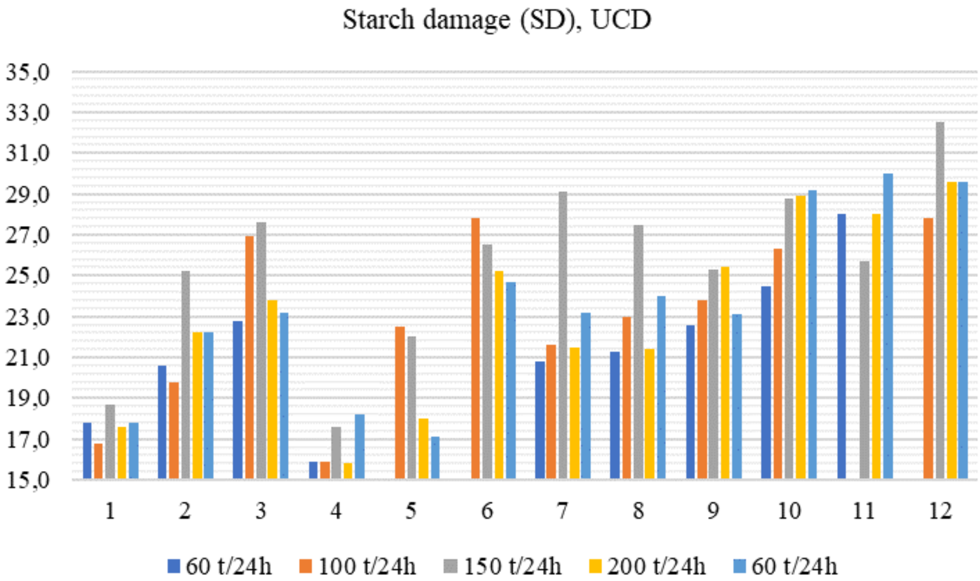

Fig. 4 – Starch damage of mill streams by quality groups for different mill plants

By systems for all stages of milling, the highest ash content was for Tail-end systems, the medium values were inherent for Middlings systems, the lowest – for Primary systems (Fig.2). If compared within each quality group (Primary, Middlings, Tail-end), then for Primary systems the ash content on sizing and reduction systems was less – 0.39-0.53% than on break systems and grading systems – 0.48-0.72%, while as for Tail-end systems, on the contrary, lower values were obtained for break systems and grading systems – 0.64-1.53% versus 0.73-1.80% for reduction systems and 1.92-2.24% for collecting systems. The same data were obtained in [24].

Fluctuations in Protein content in flour of mill streams for the milling stages are the same as they are for the ash content. From the first to the last systems, there is an increase in the protein content due to the fact that in the first systems, mainly the central particles of the endosperm pass into the flour, and in the last systems, particles from the aleurone layer and pericarp are concentrated (Fig. 3).

However, there are differences within quality groups. For Primary and Middlings systems, the protein content on break and grading systems was higher compared to reduction and collecting systems, while for Tail-end systems, protein content was higher on reduction and collecting systems compared to break and grading systems.

The minimum protein content was obtained on Sizing systems – 10.7-11.3% and on Primary Reduction systems – 10.4-11.3%. The maximum protein content – 13.6-17.2% was on Tail-end Break systems. At the same time, for mills 3-5, the protein content in these systems was 17.0-17.2%, which indicates a good bran finishing, and in mills 1-2, with lower productivity, the protein content was 13.6-14.9%. These data correlate with the total flour yield, which was significantly higher for mills 3-5 (79.0-80.6%) than for mills 1-2 (75.9-76.1%).

The flour yield on the B3 system, which belongs to Middlings Break systems, was only 1.2-5.6%. However, this system plays a key role in the formation of gluten in the final flour and the setting of its operation modes must be given no less attention than for systems B1, B2, C1, C2, Siz1.

Ash content is the main indicator that determines the grade (type) of flour [23]. Ash is the mineral residue remaining after organic matter has been incinerated. Peripherical parts of wheat contains in 15-20 times more minerals than does endosperm, so ash content correlates with flour type. Typical ash levels for Ukrainian flour are 0.45 to 0.55% for patent (high-grade) flour, 0.55 to 0.65% for straight (single-grade) flour, and approximately 0.70-0.75% for 1-st clear (1-st grade) and 1.10-1.25% for 2-nd clear (2-nd grade) flours. For the studied mills, which worked with the production of 2 or 3 flour grades (multi-grade milling), after mixing the flour grades in proportion to their yield, the ash content of straight flour was 0.59-0.61%.

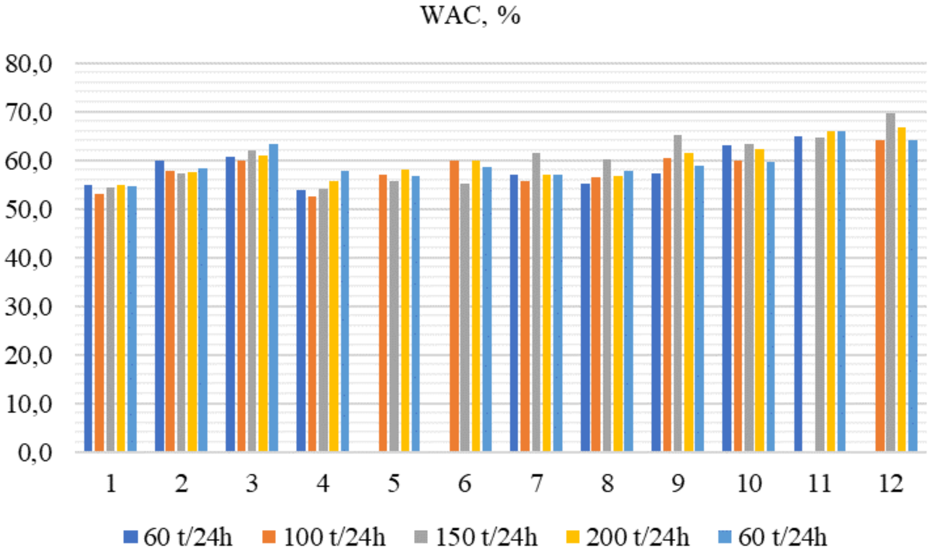

Fig. 5 – Water absorption capacity of mill streams by quality groups for different mill plants

As for ash content and protein content, values of starch damage increase from first systems towards the end As for ash content and protein content, values of starch damage increase from first systems towards the end systems (Fig. 4). On the first break systems (B1, B2) and first reduction systems (C1, C2) starch damage was 16.8 18.7 UCD and 21.3-27.5, respectively, while on the tail-end break systems, tail-end reduction systems and tail-end collection systems – 22.8-27.6 UCD, 25.7-30.0 UCD and 27.8-32.5 UCD.

However, for all three quality groups (Primary, Middlings, Tail-end), starch damage on break systems and grading systems is lower (and not higher, as for protein content) compared to reduction and collecting systems. This is due to an increase in the amount of deformation forces acting on each particle in grinding systems, a gradual decrease in the roller gap, which leads to a decrease in the number of agglomerates of starch granules with proteins and their damage. In this case, the size of the flour particles does not necessarily decrease, because peripheral parts of the grain are less amenable to grinding [25].

When studying the change in WAC for flour streams (Fig. 5), a clear dependence of the increase in this indicator from the first to the tailing systems at each stage is visible – break, grading, reduction systems. This is explained by the fact that the flour, obtained at the beginning of milling, come from the central part of endosperm, which is rich in starch; whereas at the end of milling, it was taken from the peripherical parts, which are rich in ash, pentosan and protein. During milling, mill rolls move closer and closer, which caused the starch granule to damage [26].

The lowest WAC value was seen on Primary Break systems – 53.0-55.0% and on Primary Grading systems – 52.5-57.8%. These systems are the initial ones in the technological process and the starch damage on them is minimal – 16.8-18.7 UCD and 15.8-18.2 UCD, respectively.

On Primary Reduction systems and Sizing systems compared to Primary Break systems and Primary Grading systems, despite the lower protein content (10.4-11.3%) and ash content (0.39-0.53%) compared to Primary Break systems and Primary Grading systems (10.3-13.5% and 0.48-0.72%, respectively), WAC on these systems increased to values of 55.1-61.5% from due to a sharp increase in starch damage to 20.8 29.1 UCD.

In general, the dependence for all three quality groups (Primary, Middlings, Tail-end) of WAC values is the same as for damaged starch: break systems and grading systems WAC is lower compared to reduction and collecting systems (Table 4).

Table 4 – Trend of changed flour quality indictors from Breaking and Grading systems to Sizing and Reduction systems

Quality groups	AC	PC	SD	WAC
Primary	↓	↓	↑↑	↑
Middlings	↑	↓	↑↑	↑
Tail-end	↑↑	↑	↑↑	↑

Note: ↑ – up; ↓ – down

Studies [12,25,27] have shown that the most important predictor of water absorption capacity was damaged starch content with high direct correlation between WAC and SD – r=0.90 [10].

In the studied quality-grouped of flour streams from 5 mill plants, the following correlation values were obtained: direct correlation between WAC and SD – r=0.82, high direct correlation between WAC and AC – r=0.79 and average direct correlation between WAC and PC – r=0.53 and (Fig. 6), which confirm that damaged starch and ach content are the mean factor of increase in water absorption capacity of flour during milling [27–29]. So, the increase in protein content during the milling seems to have a less influence on the increasing of water absorption capacity.

Fig. 7 shows the effect of flour streams grouped by quality on the value of ash content, protein content, starch damage, water absorption capacity in the total flour for a mill plant 3 of productivity 150 t / 24 h. Despite the variation in quality indicators across the systems discussed above, flour yield is the decisive factor in final flour quality. Therefore, systems in which a higher yield was observed have a greater effect.

Primary Reduction systems and Sizing systems have the greatest impact on the value of AC, PC, SD, WAC in total flour. 47 % of the final WAC for a

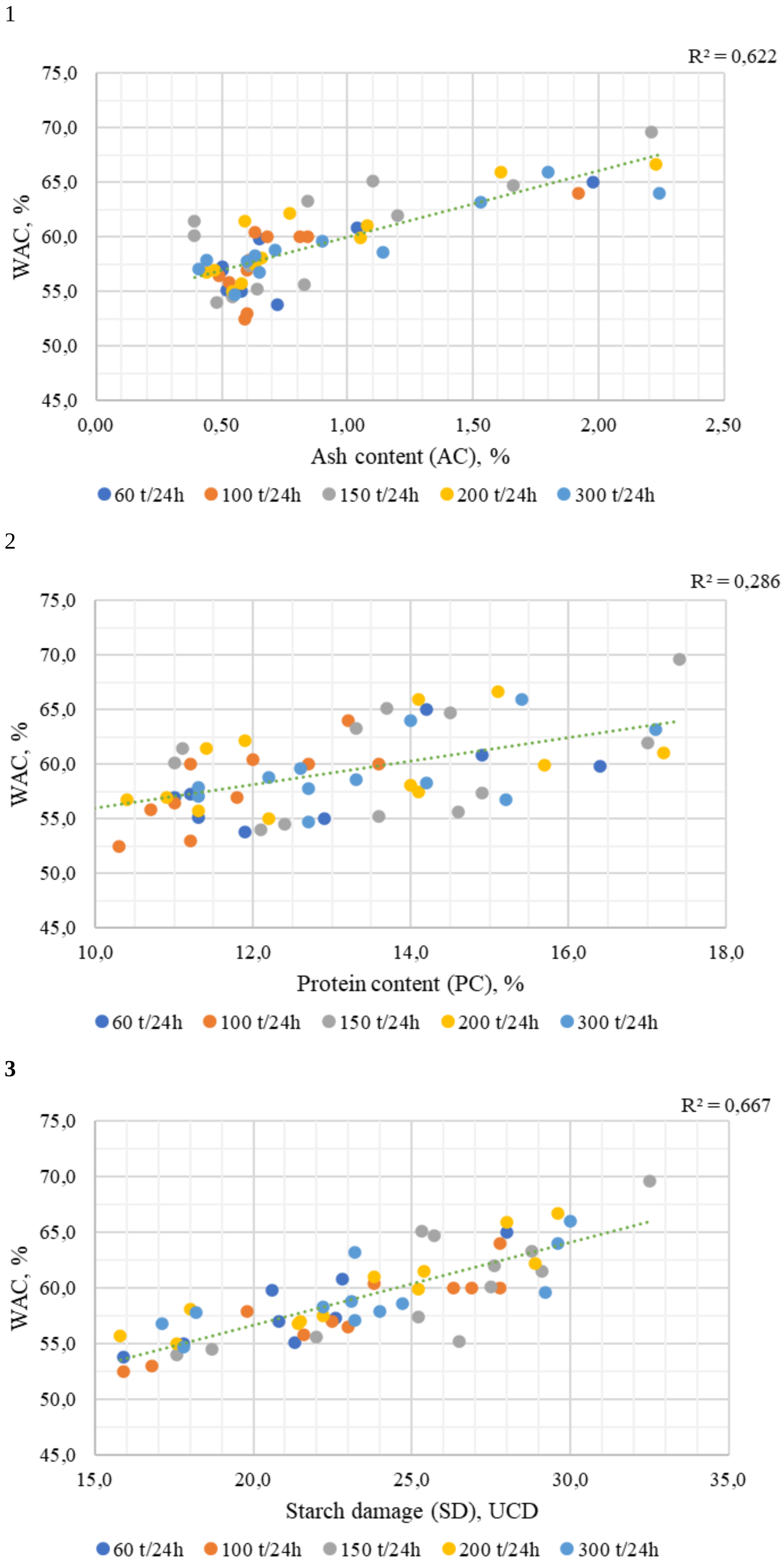

Fig. 6 – Correlation between WAC and: 1 – AC; 2 – PC; 3 – SD

150 t / 24 h mill plant is generated by initial reduction systems (C1, C2, C3) and 12% – by sizing systems (Siz1, Siz2). The share of Tail-end Reduction systems (C8, C9) in the formation of water absorption is 7%, Primary Grading systems (Div1) – 7%, Middlings Grading systems (Div2) – 5%. Despite the fact that on Primary Break systems (B1, B2) and Middlings Break systems (B3) the share of influence on the water absorption of total flour is only 5% and 4% (due to the relatively low flour yield on them), the setting of grinding modes on these systems determines the formation of quality indicators on other systems and in the final flour.

Conclusions

Obtained results showed a strong evolution of the composition and physico-chemical properties of flours during the milling process. The variation in ash content, protein content, starch damage and other properties (not shown in this article) of the mill streams are due with the anatomical parts they come from that influence the quality of the final flour. During milling at the mill plant with productivity of 150 t / 24 h, for example, ash content increased from 0.39% to 2.21%, protein content – from 11.0% to 17.4%, starch damage – from 17.6 UCD to 32.5 UCD. As result the water absorption capacity increased during the milling process from 54.0 to 69.6%.

The simple correlation analysis allows to evaluate the influence of biochemical and physical parameters on the evolution of water absorption capacity. The variations of starch damage and ash content in the flour streams seems to be the principal factor of the change in water absorption variation. Changing in protein content during the milling seems to have a less influence on the water absorption capacity.

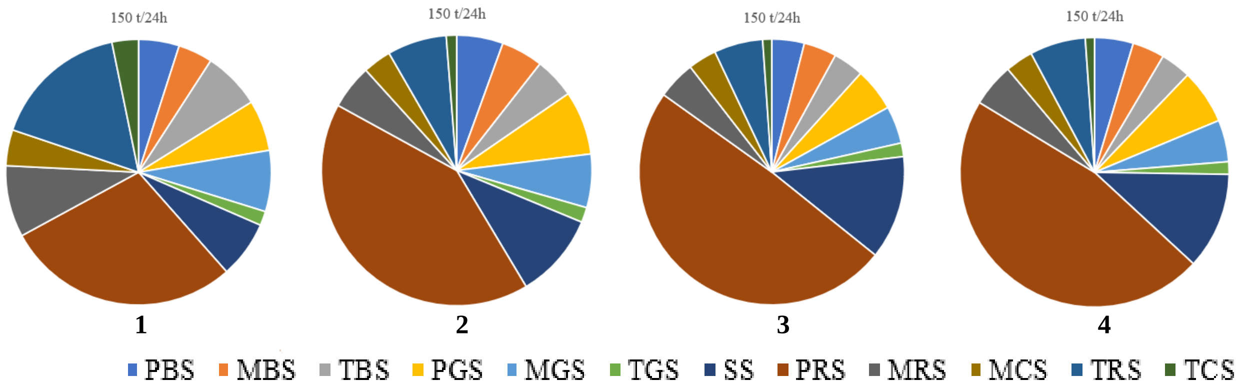

Fig. 7 – Share of flour streams quality groups for a mill with a productivity of 150 t / 24 h: 1 – ash content; 2 – protein content; 3 – starch damage; 4 – water absorption capacity

Despite fluctuations in flour quality indicators on individual systems, due to the ingress of particles from various histological zones of the wheat grain, the mechanical action of the rollers and possible temperature heating, it is the flour yield on the systems that forms the final flour quality. In order to form the set values of final flour quality indicators according to the specifications, it is first necessary to optimize the yield and quality of the flour streams with the highest yield and with the greatest influence on the grinding. These systems include – B1, B2, C1, C2, B3, Siz1.

Knowledge and understanding of the patterns of change in individual systems of values of flour yield and their quality indicators that affect water absorption capacity will allow to more effectively manage the WAC indicator. This will make it possible to optimize the properties of the dough according to the requirements of specific technological lines and to regulate the quality of the finished product at bakery and confectionery enterprises.

REFERENCE

1. Merko IT, Morhun VO. Naukovi osnovy i tekhnolohiia pererobky zerna. Odesa: Druk; 2001. 348.
2. Zhygunov DO, Voloshenko OS, Broslavtseva IV, Donets AO, Kovalov MO, Kovalova VP, et al. Tekhnolohiia ta otsinka yakosti zernovykh produktiv: monohrafiia. Odesa: Oldi-plius; 2021. 351.
3. Iorgachova K, Makarova O, Khvostenko K, Kotuzaki O. Improving and stabilizing the pastry quality due to the usage of various types of flour. Scientific works of National university of food technologies. 2017;23(5, 1): 217–228. https://doi.org/10.24263/2225-2924-2017-23-5-1-27.
4. Kamel BS, Stauffer CE. Advanced in Baking Technology. Springer; 1993. 408.
5. Brütsch L, Huggler I, Kuster S, Windhab EJ. Industrial roller milling process characterization for targeted bread quality optimization. Food and bioprocess technology. 2017;10(4): 710–719. https://doi.org/10.1007/s11947-016-1856-1.
6. Pomeranz Y. Wheat. Chemistry and Technology. Vol. 2. 3rd ed. St. Paul, Minnesota, USA: AACC; 1988. 562.
7. Buckley E. Factors in hard winter wheat affecting water absorption tolerance. Thesis. 2011; 51.
8. Xue C, Matros A, Mock HP, Mühling KH. Protein composition and baking quality of wheat flour as affected by split nitrogen application. Frontiers in Plant Science. 2019;10(642). 1–11. https://doi.org/10.3389/fpls.2019.00642.
9. Oyeyinka SA, Bassey IA V. Composition, functionality, and baking quality of flour from four brands of wheat flour. Journal of Culinary Science and Technology. 2023. 1–21. https://doi.org/10.1080/15428052.2023.2191874.
10. Ali R, Shakeel Khan M, Sayeed SA, Ahmed R, Gufran Saeed SM, Mobin L. Relationship of damaged starch with some physicochemical parameters in assessment of wheat flour quality. Pakistan Journal of Botany. 2014;46(6): 2217–2225.
11. Sapirstein H, Wu Y, Koksel F, Graf R. A study of factors influencing the water absorption capacity of Canadian hard red winter wheat flour. Journal of Cereal Science. 2018;81: 52–59. https://doi.org/10.1016/j.jcs.2018.01.012.
12. Stauffer CE. Chapter 4. Principles of dough formation. In: Technology of Breadmaking. 2007. 299–332. https://doi.org/10.1007/0-387-38565-7_11.
13. Kweon M, Slade L, Levine H. 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 Chemistry. 2011;88(6): 537–552. https://doi.org/10.1094/CCHEM-07-11-0092.
14. Wang Q, Li L, Zheng X. A review of milling damaged starch: Generation, measurement, functionality and its effect on starch-based food systems. Food Chemistry. 2020;315(126267): 1-12. https://doi.org/10.1016/j.foodchem.2020.126267.
15. Riad M. the effect of damaged starch on the quality of baked good. Miller Magazine. 2017;11(89): 94–96, 98.
16. Schopf M, Scherf KA. Water absorption capacity determines the functionality of vital gluten related to specific bread volume. Foods. 2021;10(2): 1–13. https://doi.org/10.3390/foods10020228.
17. Joseph FZ. Chapter 2. Water Holding Capacity of Proteins. in Functionality of Proteins in Food. 1997; 76–133.
18. Dubat A. The importance and impact of Starch Damage and evolution of measuring methods. Industries des cereales. 2004;137(Avril/Mai): 2–8.
19. Courtin CM, Delcour JA. Arabinoxylans and endoxylanases in wheat flour bread-making. Journal of Cereal Science. 2002;35(3): 225–243. https://doi.org/10.1006/jcrs.2001.0433.
20. Evers AD, Kelfkens M, McMaster G. Ash determination – a useful standard or a flash in the pan. In: ICC Technical Conference, Valencia, Spain, June. 1999.
21. Ramseyer DD, Bettge AD, Morris CF. Distribution of total, water-unextractable, and water-extractable arabinoxylans in wheat flour mill streams. Cereal Chemistry. 2011;88(2): 209–216. https://doi.org/https://doi.org/10.1094/CCHEM-10-10-0148.
22. Sabanci K, Aydin N, Sayaslan A, Sonmez ME, Fatih Aslan M, Demir L, et al. Wheat flour milling yield estimation based

on wheat kernel physical properties using artificial neural networks. International Journal of Intelligent Systems and Applications in Engineering. 2020; 8(2): 78–83. https://doi.org/10.18201/ijisae.2020261588.
23. Czaja T, Sobota A, Szostak R. Quantification of ash and moisture in wheat flour by Raman spectroscopy. Foods. 2020; 9(3): 1–7.
24. Sakhare SD, Inamdar AA, Indrani D, Madhu Kiran MH, Venkateswara Rao G. Physicochemical and microstructure analysis of flour mill streams and milled products. Journal of Food Science and Technology. 2015; 52(1): 407–414. https://doi.org/10.1007/s13197-013-1029-4.
25. Di Stasio M, Vacca P, Piciocchi N, Meccariello C, Volpe MG. Particle size distribution and starch damage in some soft wheat cultivars. International Journal of Food Science and Technology. 2007; 42(2): 246–250. https://doi.org/10.1111/j.1365-2621.2006.01221.x.
26. Prabhasankar P, Sudha ML, Haridas Rao P. Quality characteristics of wheat flour milled streams. Food Research International. 2000; 33(5): 381–386. https://doi.org/10.1016/S0963-9969(00)00059-4.
27. Berton B, Scher J, Villieras F, Hardy J. Measurement of hydration capacity of wheat flour: Influence of composition and physical characteristics. Powder Technology. 2002; 128(2–3): 326–331. https://doi.org/10.1016/S0032-5910(02)00168-7.
28. Iuliana B, Georgeta S, Violeta I, Iuliana A. Physicochemical and rheological analysis of flour mill streams. Cereal Chemistry. 2010; 87(2): 112–117. https://doi.org/10.1094/CCHEM-87-2-0112.
29. Wang M, Sapirstein HD, Machet AS, Dexter JE. Composition and distribution of pentosans in millstreams of different hard spring wheats. *Cereal Chemistry*. 2006; 83(2): 161–168. https://doi.org/10.1094/CC-83-0161

УДК 664.715

Д. О. Жигунов [1], д-р техн. наук, професор, *E-mail: dmytro.zhygunov@gmail.com*
С. М. Соц [1], канд. техн. наук, доцент, *E-mail: sotsserega@gmail.com*
Г. Д. Жигунова [1, 2], магістр, *E-mail: hanna.zhyhunova@gmail.com*
Йігуо Ліу [3], Голова правління, *E-mail: yudongmfd@163.com*
Фенгченг Ванг [3], технічний директор, PhD, професор, *E-mail: wangxiaoling74@163.com*
Хінхін Ліу [3], головний менеджер, *E-mail: 659090030@qq.com*
Жібінг Ванг [3], технічний консультант, *E-mail: Mf123624@163.com*
Хіян Лі [3], директор проекту, *E-mail: 413602599@qq.com*
[1] Одеський національний технологічний університет, вул. Канатна, 112, м. Одеса, Україна, 65039
[2] Вища школа науки та інженерії, 2-а вул. Норберта Сьогарда, м. Лілль, Франція, 59014
[3] Хуймін Коунті Юдонг Віт Флоур ко. Лтд, зона розвитку Сун Wy Сан Лу, округ Хуймін, м. Біньчжоу, провінція Шаньдун, Китай

ФОРМУВАННЯ ВОДОПОГЛИНАННЯ БОРОШНА НА МЛИНАХ РІЗНОЇ ПРОДУКТИВНОСТІ

Анотація

У статті наведено результати дослідження показників якості потоків борошна, що впливають на формування водопоглинальної здатності. Дослідження проводили на п'яти млинах продуктивністю від 60 до 300 тон на добу. За допомогою оригінальної методики зняття кількісного балансу процесу помелу визначено вихід кожного окремого потоку борошна та загальний вихід борошна, який залежав від продуктивності млина і коливався від 75,9-76,1% для млинів з низькою продуктивністю до 79,0-80,6% для млинів продуктивністю понад 150 т/24 год. Встановлено суттєві зміни якісних показників потоків борошна. При помелі на млині з продуктивністю 150 т/24 год, зольність борошна зростає з 0,39% до 2,21%, вміст білка – з 11,0% до 17,4%, пошкодження крохмалю – з 17,6 UCD до 32,5 UCD. В результаті водопоглинаюча здатність збільшується в процесі помелу з 54,0 до 69,6%. Змінність вмісту золи, вмісту білка, пошкодження крохмалю та інші властивості потоків млина пов'язані з анатомічними частинами, з яких вони виходять, і в результаті це впливає на якість загального борошна. Проведений кореляційний аналіз дав змогу оцінити вплив вмісту золи, вмісту білка та вмісту пошкодженого крохмалю на зміну водопоглинальної здатності. Варіація пошкодження крохмалю в потоках борошна є основним фактором варіації водопоглинальної здатності, тоді як вміст білка має менш суттєвий вплив, а вміст золи – найменший вплив, очевидно, через відсутність сильної кореляції з вмістом пентозанів. Незважаючи на коливання показників якості борошна на окремих системах, встановлено, що саме вихід потоків борошна найбільшою мірою визначає якість загального борошна. Тому оптимізація режимів помелу та просіювання систем (B1, B2, C1, C2, B3, Siz1), які мають потоки борошна з найбільшим виходом і найбільшим впливом на процес помелу, є фундаментальним кроком у досягненні заданих значень кінцевих показників якості борошна. Знання та розуміння закономірностей зміни на окремих системах виходу борошна та їх якісних показників, що впливають на водопоглинальну здатність, дозволить більш ефективно управляти показником водопоглинальної здатності. Це дасть змогу оптимізувати властивості тіста відповідно до вимог конкретних технологічних ліній та регулювати якість готової продукції на хлібопекарських і кондитерських підприємствах.

Ключові слова: пшеничне борошно, помел, потоки борошна, вихід борошна, водопоглинальна здатність, пошкоджений крохмаль, вміст білка, зольність.

Received 24.12.2022 **Revised 05.01.2023**
Reviewed 18.01.2023 **Approved 20.03.2023**

Cite as Vancouver Citation Style
Zhygunov D., Sots S., Zhyhunova H., Jiguo Liu, Fengcheng Wang, Xinxin Liu, Zhibing Wang, Xiyan Li. Formation of water absorption capacity of flour on mills of different productivity. Grain Products and Mixed Fodder's, 2023; 23 (1, 89): 4-13.
DOI https://doi.org/10.15673/gpmf.v23i1.2583

Cite as State Standard of Ukraine 8302:2015
Formation of water absorption capacity of flour on mills of different productivity. / Zhygunov D. et al. // Grain Products and Mixed Fodder's. 2023. Vol. 23, Issue 1 (89). P. 4-13. **DOI** https://doi.org/10.15673/gpmf.v23i1.2583