INFLUENCE OF GRAIN QUALITY INDICATORS ON THE FLOUR QUALITY INDICATORS AT THE LABORATORY MILLING

Abstract

In the conditions of high competition in the flour market, the development of models that allow to predict the quantitative and qualitative indicators of flour during grain milling and to understand the correlation between grain and flour quality indicators is extremely relevant and requires efforts in this direction. 64 samples of wheat grain from mills situated in different regions of Ukraine, grown in 2019 and 2020 and straight flour obtained from this wheat in the laboratory at the mill MLU-202 were investigated. The data obtained confirmed great variability of grain and flour quality indicators which can depend on many factors: from agro-climatic conditions to milling conditions and tempering conditions before milling. Wheat quality indicators are shown next results: test weight values ranged from 727 to 845 g/l, vitreousness – from 25 to 83%, initial moisture content – from 10.4 to 13.7%, protein content – from 11.3 to 17.2%, ash content – from 1.35 to 1.73%, gluten content – from 17.6 to 38.3%, gluten deformation index – from 46 to 96 units and Falling Number – from 309 to 500 seconds. Analyzing of correlations between grain quality indicators and flour quality indicators shown: the direct extra high correlation between grain protein content and flour protein content (r=0.95) and also between grain gluten content and flour gluten content (r=0.87); average correlation between ash content of grains and ash content of flour (r=0.68). According to milling properties was found: average correlation of initial grain moisture content and flour yield (r=0.52), a direct high correlation between grain vitreousness and the ratio of reduction and break flour (r=0.70), and an inverse average correlation of test weight with ratio of break and reduction bran (r=−0.61). It has been established that the flour strength W is affected by a set of grain quality indicators: grain protein content with high coefficient correlation (r=0.70), grain gluten content and grain Falling Number with average correlation coefficients – r=0.53 and r=0.56, respectively. For other rheological indicators, such as stability, water absorption capacity and P/L, no high correlation coefficients were found, since their values depend on a complex of various indicators of grain. The obtained correlations can be used to improve the efficiency of grain blending before milling, to substantiate the modes of tempering, grinding, and flour mixing stage in existing mills, as well as to design a milling flow diagram for new mills.

Keywords: wheat, grain, flour, laboratory milling, test weight, vitreousness, protein content, quality indicators

Introduction

Milling of wheat is a physical or mechanical process of separating the peripheral parts of the grain (shells and germ) from the internal endosperm and turning the latter into flour. Complete separation is never achieved, but when milling due to special methods of preparation and milling, try to achieve the greatest possible release of endosperm into flour – to carry out the so-called “selective grinding” [1].

The most important factor that determines the consumer properties of flour is the quality of grain, which is determined by the chemical composition and technological properties. The concept of “quality” is an integrated indicator that evaluates the physical, biochemical and flour-milling properties of grain, as well as the baking properties of flour obtained from it. In the technology of flour-milling production, “high-quality” grain is understood as the grain from which the maximum yield of grade flours with high whiteness, low-ash, high-gluten, high-elasticity and stretchable flour is obtained, which allows to obtain the best quality bread [2].

The quality of wheat depends on a complex number of factors that depend on how it grows, grinds and adapts to end use in any of the many products. Wheat
is the main raw material, which has changes in composition and usefulness depending on the variety and growing conditions in a particular geographical location during the year of its growth and production. Complex and diverse processing methods and a variety of products made from wheat have created significant requirements for wheat, which has specific quality characteristics and nutritional value [3].

When choosing grain before milling and forming a milling batch by blending of grain of different quality, the question often arises as to how well it is possible to predict the real commercial quality of processing of this grain and what quality indicators of finished products could be. This can be done by laboratory milling of a small amount of grain, considering how different laboratory milling flour will be from flour obtained in industrial conditions.

**Literary review**

One of the most common and simplest criteria for wheat quality is test weight and 1000 kernel weight. These indicators have influence on the potential yield of flour because larger grains usually have a higher ratio of endosperm to peripheral parts. The test weight and 1000 kernel weight depend on the differences in the genetic makeup of wheat variety, growing location, different growing and environmental conditions prevailed during growing periods of wheat in each region [4, 5], using an artificial irrigation [6], particularly high temperature during the final phase of grain filling [7]. Ultimately, high values of test weight and 1000 kernel weight are determined by the wheat grain size and shape of individual grains [8], surface condition, grain density, which, in turn, is determined by the biological structure of the grain, its chemical composition [9]. The grain is rounded, even in size, denser in consistency, has a higher test weight and 1000 kernel weight, and they have affected end-use quality and market price [10].

Some authors considered, that the 1000 kernel weight may been used as an good parameter of wheat milling value [10]. Some authors have the opinion that 1000 kernel weight affects the milling properties only in the case of very low or very high value. [11]. Other considered, that 1000 kernel weight is strongly inheritable in wheat and 1000 kernel weight as an index of milling value should be used only for the same wheat varieties, but cultivated under different agro-environmental conditions [12].

Agro-environmental conditions are also a determining factor of the initial moisture content of wheat grains after harvesting, in the future this indicator may vary depending on storage conditions due to the hygroscopic properties of the grain [4, 13].

The main indicator of quality, which determines the type of flour, is the ash content. This indicator in grain is influenced by various factors such as wheat variety, geographical location, crop years. Interactions among these factors determine flour ash content, flour color value and flour extraction yield [14, 15]. At the same time, the ash content of flour is a very variable indicator due to the large differentiation of the ash content of the endosperm [16].

The next important criteria of grain quality are hardness and vitreousness. Grain hardness is arguably the most important single determinant of wheat grain quality and utilization, it forms the basis of differentiating world trade of wheat grain [17]. The hardness of wheat determines the grain milling properties and the end use of its processed products [18]. Hard wheat varieties have higher protein content than soft ones. Hard wheat has a compact homogeneous structure of the endosperm with predominantly small starch granules firmly linked to the surrounding protein matrix.

Vitreousness is natural kernel translucence and a means of describing the appearance of wheat grains [19]. Vitreous kernels have a dark, translucent, glassy appearance, as opposed to mealy kernels which have a light, opaque appearance. Usually vitreous kernels are harder and have higher protein content that mealy kernels, but hard wheat kernels may look like non-vitreous, and, conversely, yellow-sided grains with viscous endosperm after soaking, when visually inspected, look like vitreous grains – the so-called false vitreousness [20]. Hard and generally vitreous grains are more difficult to grind during milling with increased energy per mill, requiring more grinding systems [21].

The protein content is closely related to grain hardness – it is a very important quality indicator for bread-making quality and end-use of flour [5]. Protein content is inversely proportional to grain yield [9], directly proportional to the amount of nitrogen fertilization [22], while the protein quality is determined primarily by the wheat genotype [23]. On the other hand, both indicators – the quality and the protein content are affected by the climatic conditions during wheat maturation [24].

The main feature of wheat proteins is the ability of those proteins to form viscoelastic networks, i.e. gluten [25]. The gluten proteins have very low extractabilities in water or salt solutions and consist of gliadins (extractable in aqueous ethanol) and glutenins (unextractable in aqueous ethanol). Gliadins are a heterogeneous polypeptide mixture, while glutenins consist of peptide polymers connected by di-sulphide bonds [26]. Gluten is responsible for physical dough properties. It has been generally accepted that any increase in total protein content of the flour results in an increase in the gluten content, increase the strength of flour and the bread volume [27]. The quality of gluten is a genetically determined trait, but growing conditions also have a strong influence on it. In this case, the most important factors are temperature and humidity, especially in the grain filling period [28], as well as the provision of plants with nitrogen [29].

Precipitation during harvest period has an impact on the quality indicator such as Falling Number [30]. Low Falling Number in wheat grain means high α-amylase activity, which causes poorer wheat quality [31]. But for Ukraine in past seasons the opposite situation is typical, due to an increase in average annual temperatures, especially in summer, and a small amount of precipitation, the grain has a low amylolytic activity [32].

To ensure the required quality of flour, when processing wheat at flour mills, the principle of forming a milling batch before milling is used, which is based on blending grain with known indicators and predicting flour quality indicators after processing [32].
Full understanding of the features of the change in the quality indicators of grain in modern conditions under the influence of changeable agro-climatic factors, as well as the prediction of the flour-milling properties of grain and dough properties of flour, is an urgent and important practical task [33, 34].

**Purpose and objectives of the analysis**

The purpose of this work was to establish the relationship between grain quality indicators and laboratory milling indicators, flour quality indicators and indicators of physical properties of the dough. For this purpose, the following objectives were achieved:

- determining the indicators of grain quality and the establishment of a correlation between themselves;
- determining the milling properties, indicators of flour quality and indicators of the physical properties of the dough and establishment a correlation relationship between themselves;
- establishing a correlation relationship between indicators of grain quality and milling properties, indicators of flour quality and physical properties of the dough.

**Materials and methods**

**Samples.** 64 samples of wheat grain from mill plants situated in different regions of Ukraine, grown in 2019 and 2020, and straight flour obtained from this wheat in the laboratory at the mill MLU-202.

**Grain tempering.** The grain was tempered according to AACC 26-10A for 16-18 hours (depending on the sample vitreousness) before milling to permit uniform distribution of the moisture. Tempering (Water-thermal processing stage) of the hard type wheat grain with vitreousness >60% was carried out with moistening to 16.0% within 18 hours, while wheat with vitreousness <40% was tempered within 16 hours to 16.0% tempering moisture.

The required water quantity to raise the moisture content of grain to 16.0% was calculated using following equation:

\[
\text{Amount of water} = \frac{\text{grain moisture} - \text{grain tempering moisture}}{100 - \text{grain tempering moisture}} \times \text{weight} (1)
\]

Before milling moisture content of grain was controlled by AquaMatic 5200-A and if moisture content was less required value, the grain was additionally moistened. The amount of water was calculated according to formula 1.

**Experimental milling.**

Buhler MLU-202 mill (Buhler Industries, Uzwil, Switzerland) was used to mill the wheat samples according to AACC International Approved Method 26-21.02, and the flour extraction was determined as the percentage of straight-grade flour produced on a product basis. A 10xxx polyamide screen (132 µm) was used for obtains flour. With a standard procedure, as a result of grinding, you get:

- break flour – from three break systems on which corrugated rolls are installed;
- reduction flour – from three reduction systems on which smooth rolls are installed;
- break bran (large);
- reduction bran (small).

The total flour yield was determined as the sum of all 6 flour streams (B1, B2, B3, C1, C2, C3) relative to the mass of grain taken for milling (weight of grain was 3 kg).

To evaluate the efficiency of milling, the following criteria were used:

\[
\text{Flour ratio} = \frac{\text{Reduction flour yield}}{\text{Break flour yield}} \quad (2)
\]

\[
\text{Bran ratio} = \frac{\text{Break bran yield}}{\text{Reduction bran yield}} \quad (3)
\]

**Grain and Flour quality analysis.** Evaluation of grain and flour quality indicators was performed by:

- physical-technological and chemical-technological indicators of grain (moisture performed by air-thermal direct method according to ISO 712, test weight according to ISO 7971, vitreousness according to GOST 10987, protein content according to ISO 20483, ash content in accordance with ISO 2171, wet gluten was washed out according to GOST 27839 – by manually washing of dough from 25 g of flour with 14 ml of water, the gluten deformation index (GDI) – on the IDK-M device. Falling Number method performed according to ISO 3093);
- indicators of laboratory milling (total yield of flour, the ratio of bran and flour from break and reduction systems – according to formulas 2 and 3); physical-technological and chemical-technological indicators of flour (moisture according to ISO 712, protein content by Kjeldahl method according to ISO 20483, ash content according to ISO 2171, gluten content and gluten deformation index (GDI) according to GOST 27839. Falling Number (FN) according to ISO 3093, starch damage content by the SDmatic amperometric method (AACC 76-33));
- physical properties of the dough on Alveograph PC following the method ISO 27971 (flour strength W and P/L ratio) and on Mixolab device (Simulator Protocoll) which determine the parameters (water absorption capacity (WAC) and stability (St)) described in the method 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|≤1.00; high – for 0.70<|r|≤0.85; average – for 0.50<|r|≤0.70; low – for 0.30<|r|≤0.50; have no correlation – at 0<|r|≤0.30.

When analyzing the variation of quality indicators, the range was divided into 5 groups and the obtained variation histograms were compared with the normal distribution law of the random variable.

**Results and its discussion**

Based on the results of quality indicators shown in Table 1, it can be seen that the average indicators of wheat, received for processing at flour mills, indicate...
Table 1 – Physical-technological and chemical-technological properties of wheat grain (n=64, p=0.95)

| Quality indicator | TW (grain) | V (grain) | MC (grain) | PC (grain) | AC (grain) | GC (grain) | GDI (grain) | FN (grain) |
|-------------------|------------|-----------|------------|------------|------------|------------|-------------|------------|
| Minimum           | 727        | 25        | 10.4       | 11.3       | 1.35       | 17.6       | 46          | 309        |
| Maximum           | 845        | 83        | 13.7       | 17.2       | 1.73       | 38.3       | 96          | 500        |
| Average           | 794        | 53        | 12.1       | 13.9       | 1.55       | 27.2       | 73          | 423        |

Note to Table 1, 3, 4: TW (grain) – test weight, g/l; V (grain) – vitreousness, %; MC (grain) – initial moisture content, %; PC (grain) – protein content, %; AC (grain) – ash content, %; GC (grain) – gluten content, %; GDI (grain) – gluten deformation index, units; FN (grain) – Falling Number, seconds.

relatively high initial grain quality indicators. In these 2019 and 2020 harvest years in Ukraine (except for some southern regions) there were favorable conditions for growing wheat and, according to FAOSTAT data, record wheat yield of 28.3 million tons were grown in 2019 and 24.9 million tons in 2020.

Although there were wide fluctuations in quality indicators due to various agro-climatic conditions and varietal characteristics of grain grown in different regions, but only 6 of 64 grain samples had a test weight with less than 760 g/l, 12 samples had low vitreousness (less than 40%), 9 samples in terms of protein content and 7 samples in terms of gluten content had insufficient indicators for the subsequent processing of grain for bread. Most of the samples (30 of 64) had an ash content of 1.51 to 1.60%, which is typical for Ukrainian wheat grown today (Figure 1).

GDI and FN indicators – the indicators characterizing the quality of the protein-protease and carbohydrate-amylase complexes, as well as indirectly characterizing the enzymatic activity of the corresponding enzymes of proteolytic and amylolytic action. According to GDI, only 8 samples were insufficient values for bread (with considering the relationship of this indicator with flour [35]), when for the Falling Number only 3 samples belonged to the group with normal amylolytic activity. The remaining samples were characterized by insufficient amylolytic activity to obtain bread of good volume, which is a feature of the quality of Ukrainian wheat in recent times, which is associated with an increase in average annual temperatures and a decrease in the amount of rain in the spring and summer period [36].

Analyzing the type of histograms, it can be concluded that the variation in test weight, vitreousness, ash content, GDI were close to the normal distribution of a random variable with an average value in the central group, then in terms of moisture content, protein content and gluten content, quality indicators are distributed relatively evenly across groups without a pronounced predominance of the central group. This suggests that these indicators are more influenced by agro-climatic conditions, agro-technological conditions (fertilization), genetic characteristics of grain.

The standard laboratory milling process assumes 70% flour yield. According to our results was obtained lower indicators which associated with quality and varieties of wheat samples and features of laboratory milling (Table 2).

Due to the fact that bran finishers were not used in laboratory conditions for additional flour extraction, bran yield was high, especially break bran yield, so the ratio between break bran and reduction bran was more than 3:1, although in industrial conditions usually 2:1. This feature of laboratory milling also affected such indicators as flour ash content, starch damage, and, as a result, WAC, which are much higher for industrial flour – 0.48-0.60% for ash content, 20-22 UCD – for starch damage, 58-60% – for WAC.

Fig. 1. Histograms of distribution of grain quality indicators by groups
Table 2 – Milling properties, flour quality indicators and rheological properties of the dough (n=64, p=0.95)

|          | FY  | FR  | BR  | PC  | AC  | GC  | GDI | FN  | SD  | WAC | St  | W   | P/L |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Minimum  | 63.1| 2.4 | 1.7 | 9.7 | 0.31| 21.8| 45  | 333 | 10.8| 51.3| 1.0 | 173 | 0.31|
| Maximum  | 72.5| 5.9 | 7.5 | 15.8| 0.55| 36.8| 82  | 501 | 21.1| 57.7| 25.4| 393 | 3.15|
| Average  | 68.4| 3.3 | 3.2 | 12.2| 0.41| 28.1| 65  | 402 | 15.7| 54.2| 3.3 | 261 | 0.98|

Note to Table 2, 4, 5: FY – flour yield, %; FR – flour yield ratio; TW – bran yield ratio, %; PC – protein content, %; AC – ash content, %; GC – gluten content, %; GDI – gluten deformation index; MC – moisture content; FN – Falling Number, seconds; SD – starch damage, UCD; WAC – water absorption capacity, %; St – dough stability, min; W – strength of flour, 10^x J; P/L – configuration ratio.

For other quality indicators, on average, good results were obtained, but their wide variability in obtained flour indicates its high instability. In order to increase the stability of the quality of the produced flour in the future, or to predict these indicators, it is desirable to establish which quality indicators of the initial grain predetermine one or another flour quality indicator. For this, a correlation analysis was carried out between grain quality indicators among themselves (Table 3) and grain quality indicators with milling properties, flour quality indicators and rheological properties of dough (Table 4). For convenience, all missing correlations (r≤0.3) are extracted from the Tables.

According to the obtained data results shown in Table 3, test weight has a good direct correlation with vitreousness and average inverse correlation with initial moisture content of grain. The average correlation coefficient of test weight and vitreousness (r=0.45) can indicate the presence of influence of the agroclimatic conditions, due to the rather hot weather in crop years, but not dry, because test weight has shown high values. Test weight and moisture content of grain correlation (r=-0.51) indicating larger grains are less hydrated and more moisture remains in the peripheral layers, thereby reducing flour moisture. Low inverse correlation between test weight and grain ash content (-0.37) is observed by considering the finer grain with a wrinkled surface and a large proportion of surface shells. In addition, dust can settle on a wrinkled surface, which also increases the ash content.

The vitreousness indicator of grain has a weak correlation with most of the studied quality indicators of grain, except average inverse correlation (r=-0.54) with moisture content. This can be explained by the fact of influencing of hot weather on hardness and vitreousness of grain. Consistently, the high vitreousness means that the consistency of the endosperm is harder and the distribution of moisture is poorer. Obviously, these same fac-

| TW (grain) | V (grain) | MC (grain) | PC (grain) | AC (grain) | GC (grain) | GDI (grain) | FN (grain) |
|------------|-----------|------------|------------|------------|------------|-------------|------------|
| TW (grain) | 1         | 0.45       | -0.51      | -0.37      |            |             |            |
| V (grain)  | 1         | 0.87       | 0.53       |            |            |             |            |
| MC (grain) | 1         |            |            |            |            |             |            |
| PC (grain) | 1         |            |            |            | 0.54       | 0.42        |            |
| AC (grain) | 1         |            |            |            | 0.54       | 0.42        |            |
| GC (grain) | 1         |            |            |            | 0.54       | 0.42        |            |
| GDI (grain)| 1         |            |            |            | 0.54       | 0.42        |            |
| FN (grain) | 1         |            |            |            | 0.54       | 0.42        |            |

Table 3 – Correlation of grain quality indicators among themselves

Table 4 – Correlation between grain quality indicators and milling properties, flour quality indicators and rheological properties

| TW (grain) | FY  | FR  | BR  | PC  | AC  | GC  | GDI | FN  | SD  | WAC | St  | W   | P/L |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| FY         | -0.31| 0.35| -0.61| -0.51|      |      |      |      |      |      |      |      |      |
| FR         |      | 0.70|      | 0.47| 0.32| 0.53|      | 0.40| 0.40| 0.41|      |      |      |
| BR         |      |      |      | 0.52| -0.35| 0.95| 0.80| 0.40| 0.35| 0.42| 0.35| 0.70|      |
| PC         |      |      |      |      | 0.47|      |      | 0.43| -0.45| -0.35| -0.41| -0.41|      |
| AC         |      |      |      |      |      |      |      | 0.68|      |      |      |      |      |
| GC         |      |      |      |      |      |      |      |      |      |      |      |      | 0.87|
| GDI        |      |      |      |      |      |      |      |      |      |      |      |      |      |
| FN         |      |      |      |      |      |      |      |      |      |      |      |      | 0.58|
| P/L        |      |      |      |      |      |      |      |      |      |      |      |      |      | 0.56|
tors cause a direct low correlation between the vitreousness and grain protein content ($r=0.48$) and the grain Falling Number ($r=0.45$).

Protein content of grain have a direct extra high correlation with gluten content of grain, that it is generally accepted that the direct relationship between vitreousness and protein content has [37]. Direct average correlation of protein content with FN ($r=0.53$) could be related to growing weather conditions, since warm and sunny weather influences the high amount of protein, which in turn reduces the chance of sprouting and the amylolytic activity of the grain. Gluten content showed direct average correlation with GDI ($r=0.54$), which is associated with an increase in the proportion of the hydrophilic gliadin fraction of gluten during protein accumulation [38], and direct low correlation with FN ($r=0.42$).

Test weight has an inverse average correlation with bran ratio ($r= -0.61$), which is explained by the fact that with an increase in test weight, grain completion and the amount of endosperm increase. As a result, there is an increase in the amount of break bran results which leads to a decrease in bran ratio (Figure 2A). Contrariwise test weight had a low correlation with flour yield and flour ratio ($r= -0.31$ and $r=0.35$ respectively), which is associated with a short milling flow diagram of laboratory milling and tempering conditions. As can be seen from Figure 2B, test weight leads to a decrease in amount of ash content in flour, which is related to increase of yield of break flour, which contains less bran amount.

The only quality indicator that has a high correlation ($r=0.70$) with grain vitreousness is the ratio of reduction and break flour (Figure 3A). This fact can be considered when projecting flow diagram of new flour mills or for improving the stage of formation of flour grades in existing mills. And there is direct average correlation between grain vitreousness and grain FN ($r=0.53$) (Figure 3B), which is related to the weather conditions in the grain filling stage, as described above [28, 30].

As can be seen from the Table 4, the vitreousness of the grain has a low correlation with most of the studied indicators of flour quality: WAC of flour, stability of the dough during kneading and strength of flour (W), i.e. processing of high vitreousness grain does not mean guaranteed quality of finished products. Although the tendency to improve all indicators of flour with increasing vitreousness of grain exists, which is described in source [38], and the absence of the effect of vitreous-
ness on flour yield is consistent with data [36].

It is noteworthy that there is no correlation between grain vitreousness and starch damage (SD) in laboratory milling flour, which is probably due to the lack of mechanical action of roller mills in a short laboratory milling flow diagram.

A direct average correlation was obtained between initial moisture content of grain and flour yield (r=0.52) (Figure 4A), which appears to be related to the tempering and milling conditions in the laboratory. Because according to the experimental method, the grain moisture content before milling was constant 16.0%, and the difference in the duration of moistening of high vitreousness and low vitreousness grain was only 2 hours, this did not contribute to the effective penetration of moisture into the central part of the grain (endosperm) when tempering grain with low initial moisture. Although, the total grain moisture differed from the specified one by no more than ±0.1%. As a result, the grain did not soften so much, due to the same gaps between the roller mills, the grain was more difficult to grind to the particle size of flour and larger endosperm particles fell into the bran, reducing the overall flour yield [39].

The higher the ability of the grain to give a greater yield of flour with a lower ash content (greater whiteness) is, the higher the flour milling properties of the grain will be. At the same time, it is important to provide certain functional properties in flour that are suitable for a particular bakery or flour confectionery product. According to the source [40], the higher the initial ash content of grain is, the higher the ash content of flour will be. Therefore, it shows a correlation coefficient between ash content of grain and ash content of flour (r=0.68) (Figure 4B).

It is a known fact that the protein content of grain directly affects protein content of flour (r=0.95). Roughly 80% of the crude protein of wheat flour is gluten [41] which corresponds with strong correlation between protein content of grain and gluten content of flour (r=0.80), between gluten content of grain and protein content of flour (r=0.87) and gluten content of grain and gluten content of flour (r=0.92) (Figure 5B, 6A, 6B).
Most importantly, a high correlation was found between protein content and gluten content of grain and strength of flour W (\(r=0.70\)) and \(r=0.53\), respectively (Figure 7A, 7B), which is consistent with the data [42]. A lower correlation with protein content is apparently associated with different hydrophilic properties of the gliadin fraction of proteins in the studied samples and the effect of the degree of starch damage on flour strength.

Gluten quality is determined by its composition, by the presence or absence of specific protein types and their concentrations, in a result direct average correlation showed GDI of grain with gluten content (Figure 8A) and GDI of flour (\(r=0.58\) and \(r=0.59\) respectively), but no correlation was found with flour strength W and other indicators of the physical properties of the dough, that will not allow using this indicator as a predictor of flour strength without considering the influence of other indicators.

The lower the amylolytic activity of grain enzymes is, the more executed and larger grain will be. This is due to an increase in average annual temperatures, especially in summer, and a small amount of precipitation. The lower the amylolytic activity of grain enzymes is, the more executed and larger grain will be. This is due to an increase in average annual temperatures, especially in summer, and a small amount of precipitation.

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According to the data obtained (Table 5), the protein content, gluten content and WAC have the greatest effect on flour strength (W). Our results showed that flour protein content has direct strong correlation with flour strength W (\(r=0.70\)) and confirmed research concluded that flour protein content is a primary factor contributing to dough strength [43]. Gluten content of grain influenced on W with direct average correlation coefficient (\(r=0.53\)).
Fig. 8. Impact of GDI of grain on the GDI of flour (8A) and FN of grain on FN of flour (8B)

Table 5 – Correlation between milling properties, flour quality indicators and rheological properties among themselves

|    | FY | FR | BR | PC | AC | GC | GDI | FN | SD | WAC | St | W | P/L |
|----|----|----|----|----|----|----|------|----|----|------|----|---|-----|
| FY | 1  | 0.38 |    |    |    |    |      |    |    | -0.40 |    |    |      |
| FR | 1  | 0.36 | 0.36 |    |    |    | 0.43 | 0.34 |    |      |    |    | 0.38 |
| BR |    | 1   | 0.32 |    |    |    |      | -0.58 | 0.30 |    |      |    | -0.35 |
| PC |    | 1   |    | 0.85 | 0.47 | 0.42 | -0.30 | 0.41 | 0.46 |      |    | 0.70 |
| AC |    |    | 1   |    | 0.49 |    |      |    | -0.36 |      |    |      |
| GC |    |    |    | 1  |    |    |      |    |      | 0.53  |    |    |      |
| GDI|    |    |    |    | 1  |    |      |    |      |      |    |    |      |
| FN |    |    |    |    |    | 1  | 0.34 |    |      |      |    | 0.44 |
| SD |    |    |    |    |    |    | 1    |    |      |      |    |    | 0.55 |
| WAC|    |    |    |    |    |    |      | 1  |      |      |    |    |      |
| St |    |    |    |    |    |    |      |    | 1    |      |    | 0.40 |
| W  |    |    |    |    |    |    |      |    |    | 1    |    |    |      |
| P/L|    |    |    |    |    |    |      |    |      |      | 1  |    |      |

WAC have positive average correlation with strength of flour W (r=0.55) by means of which the increasing of WAC is stronger flour. Also, standard alveograph test is designed for WAC=53% and variations in this indicator in one direction or another will also affect the value of W. No significant correlations with coefficient configuration (P/L) were found due to the fact that the P and L indicators depend on various factors and their influence in total does not correlate with the P/L indicator.

Low correlations were obtained between flour ratio, flour protein content, flour ash content and WAC, which is related to the short laboratory milling flow diagram, in which flour had lower SD and WAC values. Protein content (r=0.41) has a slightly greater effect on water absorption capacity which partially confirms the studies [44] in which the authors identified four flour components affect WAC: protein, intact starch, damaged starch, and pentosans.

Conclusions

According to the achieved results, the quality indicators of grain harvested in 2019 and 2020 and the flour obtained from it, were found that quality indicators vary greatly in their values, which depends on many factors: from the differences in the genetic properties of wheat variety, growing location, different growing and environmental conditions prevailing during growing periods; to milling flow diagram and tempering conditions before milling. Wheat quality indicators are shown next results: test weight values ranged from 727 to 845 g/l, vitreousness – 25-83%, moisture content – 10.4-13.7%, protein content – 11.3-17.2%, ash content – 1.35-1.73%, gluten content – 17.6-38.3%, gluten deformation index – 46-96 units and Falling Number – from 309 to 500 seconds. Such a range in indicators led to their different behavior during the laboratory milling process and to different quality indicators of flour.

During the study of the influence of grain quality on its milling properties, the following results were obtained. The flour yield was affected only by initial grain moisture content (r=0.52), which is explained by the features of the short laboratory milling flow diagram and tempering conditions before milling. It was found a direct high correlation (r=0.70) of grain vitreousness with the ratio of reduction-break flour, and an inverse average.
correlation of test weight with the ratio of break/reduction bran (r = 0.61), which is explained by the influence of these indicators on the amount and structure of the grain endosperm.

When establishing the dependences of grain quality indicators and flour quality indicators, we can conclude that protein and gluten content of grain are good predictors of protein and gluten content of flour with high correlation coefficients (r=0.80). At the same time, the protein content of grain correlates with the protein content of flour with a coefficient (r=0.95), and the gluten content of grain correlate with gluten content of flour with a coefficient (r=0.92). Average correlation was obtained between ash content of grain and ash content of flour (r=0.68), which says that the higher the initial ash content of grain is, the higher the ash content of flour will be. Another indicator that correlated with flour ash content is test weight (r = 0.51), it leads to a decrease in amount of ash content in flour, which is related to increase of yield of break flour, containing less bran amount. Direct average correlation was found between GDI of grain with gluten content and GDI of flour (r=0.58 and r=0.59 respectively).

Rheological properties of flour, such as water absorption capacity, stability, strength of flour W and coefficient configuration (P/L) – the main criteria for the end use of flour and behavior of dough during kneading. Our results shown that protein content of grain has direct strong correlation with strength of flour W (r=0.70), which confirms that protein content is a good predictor of strength of flour. Gluten content of grain and Falling Number of grain have positive average correlation with strength of flour W (r=0.53 and r=0.56 respectively). No significant correlations with stability, water absorption capacity and coefficient configuration (P/L) of flour were found due to the fact that these indicators depend on complex of various factors.

The obtained correlations can be used to improve the efficiency of grain blending before milling, to substantiate the modes of tempering, grinding, and flour mixing stage in existing mills, as well as to design a milling flow diagram for new mills.

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ВПЛИВ ПОКАЗНИКІВ ЯКОСТІ ЗЕРНА НА ПОКАЗНИКИ ЯКОСТІ БОРОШНА ЛАБОРАТОРНОГО ПОМЕЛУ

Анотація

В умовах високої конкуренції на ринку борошна розробка моделей, які дозволяють прогнозувати кількісні та якісні показники борошна при помелі зерна та розуміти співвідношення між показниками якості зерна та борошна, є надзвичайно актуальним завданням та потребує зусиль у цьому напрямку. Досліджено 64 зразки
зерна пшениці з млинів з різних регіонів України, вирощених у 2019 та 2020 роках, та борошна, отриманого з цієї пшениці в лабораторії на млині МЛУ-202. Отримані дані підтвердили велику варіабельність показників якості зерна та борошна, що зазначалося від багатьох факторів: від агроекологічних умов і освітністю сорту до технологічної схеми подрібнення та умов темперування зерна перед подрібненням. Показники якості пшениці представлені наступними результатами: натура змінювалася від 727 г/л до 845 г/л, склоподібність – від 25 до 83%, початкова вологості – від 10,4 до 13,7%, вміст білка – від 11,3 до 17,2%, зольність вміст – від 1,35 до 1,73%, вміст клейковини – від 17,6% до 38,3%, індекс деформації клейковини – від 46 до 96 однини, а число падіння – від 309 до 500 секунд. Аналіз кореляції між показниками якості зерна та показниками якості борошна показав: пряму надвисоку кореляцію між вмістом білка в зерні та вмістом білка в борошні (r=0,95), а також між вмістом клейковини в зерні та вмістом клейковини в борошні (r=0,87); середню кореляцію між зольністю зерна та зольністю борошна (r=0,68). За мукомельними властивостями встановлено середнє корелювання початкової вологості зерна та виходу борошна (r=0,52), пряму високу кореляцію між склоподібністю зерна та співвідношенням розмелювального та драного борошна (r=0,70) та обернену середню кореляцію на турі зерна з відношенням драних та розмелювальних висвіюв (r=0,61). Встановлено, що на силу борошна W впливає такі показники якості зерна: вміст білка з високим коефіцієнтом кореляції (r=0,70), вміст клейковини та число падіння із середніми коефіцієнтами кореляції – r=0,53 та r=0,56, відповідно. Для інших розглянутих показників, таких як стабільність, водопоглинна здатність та P/L, високих коефіцієнтів кореляції не вия вано, оскільки їх значення залежать від комплексу різноманітних показників зерна.

Ключові слова: пшениця, зерно, борошно, лабораторний помел, натура, склоподібність, вміст білка, зольність, вміст клейковини, вміст білка в борошні.

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