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COMPARISON OF TECHNOLOGICAL PROPERTIES OF DIFFERENT WHEAT SPECIES

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Abstract. Technological properties of grain of four different wheat species and the laboratory milling flour obtained from them were investigated. It was found that according to grain quality indicators, milling properties and quality flour indicators, 4 species of wheat grain grown in the same agro-climatic conditions showed significant differences. Hard wheat with GPC-B1 gene (breeding line) has a superior baking strength due to the GPC-B1 gene, which significantly increases the protein content in grain (13.51%), gluten content (26.1%), test Zeleny (58 ml) and ash content (1.69%) compare to common hard wheat (Kuyalnyk variety). As a result, flour shown high values of: strength ($W=396\cdot10^{-4}$ J), high solvent retention capacity in lactic acid (160%), high dough stability (>30 minutes), low degree of softening of the dough (43 UF). According to the obtained data, waxy wheat (Sofiika variety) consimilar with common baking wheat, excluding low value of Falling Number (FN=70 seconds). When determining on the alveograph, the dough is very tight (L<40 mm) due to high water absorption capacity (WAC=67.3%). The results of SRC test in sodium carbonate (108%) confirmed the high value of starch damage. Soft wheat (Bilyava variety) differs significantly from common hard wheat flour and characterized by less ash content (0.47%), but higher whiteness (70.7 units), less protein content (10.79%), less elasticity (Ie=44.3), but greater extensibility, resulting in a lower P/L ratio (0.83) and less water absorption capacity (WAC=52.7%). According to milling properties was investigated that hard wheat with the GPC-B1 locus and common hard wheat Kuyalnik shown similar results. The total yield of flours from these wheats during milling is above 70%, which indicates the economic feasibility of their processing into flour. During milling waxy wheat has a decrease in the reduction flour yield and an increase in the reduction bran yield, on the contrary, during milling soft wheat the break flour yield increasing, the reduction flour yield decreasing.

Key words: wheat, species of wheat, GPC-B1, hard, soft, waxy, milling, quality indicators, Alveograph, Mixolab, water absorption capacity, rheological properties.

Introduction. Formulation of the problem

Wheat is a cereal grain that has fed human beings since ancient times, and the technology for the production of flour from grain (milling) is one of the first and key technologies created by people [1]. Wheat accounts for about a third of the total grain production. Currently, according to FAOSTAT data about 770 million tons of wheat are pro-duced in the world per year. A key reason for this crop's popularity is its ability to be used as a main ingredient in a variety of products. The most significant of these are breads, pastries, cookies, crackers, noodles and pasta, each of which has an almost limitless number of variations [2]. In addition, wheat is an important source for feed production.

There are about 30 species of wheat [3,4], 16 of them are cultivated [5] but only two most important are used in modern production: bread (or common) wheat, T. aestivum, and durum wheat, T. durum (T. turgidum ssp. durum), which is less common wheat and is mainly used for the production of pasta and whole grain products [6].

Bread wheat is typically divided into hard and soft classes. This classification is genetically determined by the presence of Hardness locus (Ha) [7], which is located on the short arm of chromosome 5D. Marker of hardness can be the absence of 15kDa endosperm specific protein – friabilin on water-washed starch granules from hard wheat [8,9]. Friabilin composed mainly of two proteins, puroindoline A (PinA) and puroindoline B (PinB) [10]. These puroindoline proteins are involved in the binding of phospholipids to the surface of starch granules [11].

The hardness of the wheat determines the grain milling properties and end use of its processed products [12]. Hard wheat varieties have higher protein contents 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. By contrast, soft wheat has a much more disordered structure, with the protein matrix coming loose from the starch grains in many cases. Soft wheat has many more large A-type starch grains [13].

Due to the greater hardness, more energy is required when grinding hard varieties to a flour of the desired particle size, starch granules of hard wheats are damaged more. Soft wheat requires less energy to mill, yields smaller flour particles with less starch damage, and absorbs less water compared to hard wheat [14]. Soft wheats are generally used to make cookies and pastries while hard wheats are typically used to make breads [11].

Analysis of recent research and publications

Recently, technologies that use the stages of freezing or dough pieces, or already semi-finished bakery products have gained wide popularity in bakery [15]. Such products require “strong” flour with high gas-holding capacity, which is capable of preserving the gluten framework during defrosting, which is subjected to the destructive action of ice crystals formed during freezing [16,17].

Flour type and flour protein quality are important variables in the proof-time stability of frozen dough [18]. Doughs made from strong high protein flours are generally more resistant to freeze damage. However, flour protein content is found to be less important than flour protein strength for optimum frozen dough performance [19]. The protein content of grain is a complex polygenically determined trait, which depends much more on agro-climatic growing conditions than on genotype, so a significant increase in the protein content in grain by traditional breeding methods is a difficult task [20].

When searching for high-protein wheats in the collection of wild wheat in National Funds for Embryonic Plasma of Israel wild wheat was discovered T. turgidum ssp. dicoccoides, in chromosome 6B identified the wild-type gene NAM-1 or GPC-B1 (grain protein concentration), which significantly increases not only the protein content in grain, but also several key micro-elements due to accelerated physiological aging of plants and more efficient nitrogen removal from nitrogen vegetative organs in grain [20-22].

The GPC-B1 gene has a positive effect on increasing protein content, increasing iron and zinc. At the same time, the ash content of the grain increases, the test weight (bulk density), 1000 kernel weight and the yield of laboratory flour slightly decreases [23,24]. However, it is very important from a technological point of view, processing products of wheat with the GPC-B1 gene improve the rheological properties of the dough and pasta-making properties.

In addition to the properties of the protein-protease complex in the production of bakery and flour confectionery products, the properties of the carbohydrate-amylase complex are of great technological importance. Starch consists of two monomers: 20–25% amylose and 75–80% amylopectin, which have different technological properties [25,26]. For example, when storing dough pieces or already finished products, especially in cold conditions, the soluble part of starch (amylose) recrystallizes. This process is called starch retrogradation. At the same time, the ability of starch to retain water decreases, the dough structure is partially destroyed, and its viscosity decreases [27,28].

Amylopectin is able to stay in an amorphous state for a longer time during storage of dough or flour products, thereby reducing the intensity of the syneresis process, which is characterized by the separation of free moisture as a result of compaction of the starch gel structure. This causes a higher viscosity and slows down its decrease during storage [29].

In the mid-90s Japanese, US and Australia breeders produced the world's first completely waxy wheats by method of traditional hybridization between the Wx-D1 single null line «BaiHuo» and the Wx-A1/Wx-B1 double null line «Kanto 107» [30-32]. The first Ukrainian variety of such wheat was obtained by the Department of Genetic Breeding Basics of the Breeding and Genetic Institute (Odesa) under the guidance of Dr. O. Rybalka [33,34].

At the present stage of development of the flour-milling and baking industry, the technology of obtaining and subsequent application of flour with desired properties is becoming increasingly polar [35-37].

According to the classification of methods of production of flour of a given quality [4] there are three directions of production such flour:

– the first – agro-technological (genetic), by selection and cultivation of wheat species (varieties) with the necessary properties or by regulating the quality of grain by forming grinding batches;

– the second – technological, by means of carrying out special grindings, the directed formation of finished products from separate individual streams of flour, regulation of modes of hydrothermal processing of grain, modes of systems of grinding and sorting;

– the third – biochemical, by adjusting the technological properties of flour with food additives, including enzyme preparations, acidity regulators, dry wheat gluten, cysteine, etc.

The first method is most effective if there is a grain with specific properties. Such grains include hard wheat with gene GPC-B1, which gives it high baking properties, hard waxy wheat – with altered starch structure, which does not contain amylose; and soft wheat, with a more fragile endosperm consistency.

For the widespread introduction of new species of wheat into processing, it is necessary to understand the features of the physicochemical properties of these wheats, which determine the behavior of the grain during its milling and the resulting flour during the dough making process.

Therefore, the **purpose** of this research work was to study the technological properties of grain and flour of laboratory milling obtained from various species of wheat grain. For this purpose, the following **objectives** were achieved:

– investigation of the technological properties of different species of wheat grain;

– evaluation of milling properties of different species of wheat grain;

– investigation of the quality indicators of the milling products (flour and bran);

– establish the main features of grains and flours from different species of wheat and identify possible directions for their end use.

Research materials and methods

Samples. Four samples of wheat grain were investigated: strong hard red winter wheat (strong wheat), hard red winter wheat (hard wheat), waxy hard red winter wheat (waxy wheat) and soft white winter wheat (soft wheat). Sample of strong wheat was presented by breeding line with gene GPC-B1, hard wheat – by Kuyalnik variety (2003 year of registration), waxy wheat – by Sofiika variety (2015 year of registration), soft wheat – by Belyava variety (2015 year of registration) [38]. All samples were bred by O. Rybalka at the Breeding and Genetic Institute and grown at the same field of Odessa region of Ukraine in 2020.

Samples of flour and bran were obtained from grain under laboratory milling.

Grain tempering. The grain was tempered according to AACC 26-10A for 16–24 hours before milling to permit uniform distribution of the moisture. Water–thermal processing (tempering stage) of the hard-grained type wheat grain was carried out with tempering to 16.0% within 24 hours (waxy wheat) or 20 hours (hard wheat with GPC-B1 gene and common hard wheat). Soft wheat was tempered within 16 hours to 15.0% tempering moisture.

The required water quantity to raise the moisture content of grain to 15.0% or 16.0% was calculated using following equation:

$$\text{Amount of water (L)} = \text{Grain weight} \cdot [(\text{grain tempering moisture} - \text{grain moisture})/(100 - \text{grain tempering moisture})] \quad (1)$$

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. Milling was carried out on a Bühler pneumatic laboratory mill (MLU–202) according to AACC 26-21A with some modifications. A 10xxx polyamide screen (132 μm) was used to obtain flour.

With a standard procedure, as a result of grinding, you get:

– break flour – from three break systems on which corrugated rolls are installed (B1, B2, B3);

– reduction flour – from three reduction systems on which smooth rolls are installed (C1, C2, C3) and from additional system (C4);

– break bran (large);

– reduction bran (small).

In order to increase the flour yield, a modernized procedure was used, for this, reduction bran was additionally ground, and the resulting flour (C4) was additionally added to the total flour.

The total straight-grade flour yield was determined as the sum of all 7 flour streams (B1, B2, B3, C1, C2, C3, C4) relative to the mass of grain taken for grinding (weight of grain was 3 kg).

Long patent flour yield defined as the sum of streams from first and second break and from first and second reduction systems (B1, B2, C1, C2).

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

$$\text{Flour ratio} = \text{Reduction flour yield} / \text{Break flour yield} \quad (2)$$

$$\text{Bran ratio} = \text{Break bran yield} / \text{Reduction bran yield} \quad (3)$$

Indicator Milling Score 1, which is used in the laboratory grinding of wheat at Washington State University [39], given for grinding 3 kg of grain:

$$\text{MS 1} = 100 - [(80 - \text{straight flour yield}) + 50 \cdot (\text{straight flour ash} - 0.30) + 0.48 \cdot (\text{milling time} - 19) + 0.5 \cdot (65 - \text{long patent flour yield}) + 0.5 \cdot (16 - \text{grain tempering moisture})] \quad (4)$$

Indicator Milling Score 2 – grinding efficiency criterion developed by Professor G.A. Egorov [40,41]:

$$MS\ 2 = \text{straight flour yield} \cdot [(\text{grain ash} - \text{straight flour ash}) / \text{grain ash}] \quad (5)$$

Indicator Milling Score 3 is a criterion for the effectiveness of grinding by whiteness, used in the practice of flour milling:

$$MS\ 3 = \text{straight flour yield} \cdot \text{straight flour whiteness} \quad (6)$$

Grain, Flour and Bran quality analysis

Known standards and special methods were used to determine the quality indicators of grain and products of its processing. Test weight of grain determined on AquaMatic 5200-A. This device also was used to control moisture content of grain before milling. 1000 kernel weight was determined manually according to ISO 520. To determine the vitreousness of wheat, a diaphanoscope DSZ-3 was used according to the procedure described in GOST 10987. The granulometric composition was determined by sifting a 50 g sample of grain on a laboratory sifter RLU-1 for 10 min on a set of punching metal sieves: 3.0x20; 2.5x20; 2.2x20; 1.7x20. After sifting, the following indicators were calculated:

$$\text{Average size} = \sum \text{fraction yield} \cdot \text{fraction size} / 100 \quad (7)$$

$$\text{Residue on the sieve } 2.5\text{x}20 = [\text{fraction } (- / 3.0\text{x}20) \text{ weight} + \text{fraction } (3.0\text{x}20 / 2.5\text{x}20) \text{ weight}] \cdot 100 / 50 \quad (8)$$

Moisture content of cereals and derived products performed by air-thermal direct method according to ISO 712; ash content defined as the residue remaining after controlled incineration according to ISO 2171. Protein content determined by Kjeldahl method according to ISO 20483.

Wet gluten in grain and flour was manually washed out according to procedure described in GOST 13586.1 and GOST 27839, the gluten deformation index (GDI) determined on the IDK–M device.

For a preliminary assessment of the condition of protein-protease complex, the criterion was calculated:

$$\text{Gluten/Protein Ratio} = \text{Wet Gluten Content} / \text{Protein Content} \quad (9)$$

Falling number method performed according to ISO 3093. Zeleny test performed immediately after adding the solution according to ISO 5529 (Test Zeleny) and after 120 minutes of standing (Test Zeleny 120). Whiteness of flour investigated in accordance with procedure described in GOST 26361 on the device Blick–M.

For evaluation of Solvent Retention Capacity of flour in different solvents (distilled water, sucrose, sodium carbonate, and lactic acid) have used manual SRC method according to AACC International Approved Method 56-11. Flour (5 g) was suspended in 25 g of each solvent (deionized water, 5% sodium carbonate, 5% lactic acid, and 50% sucrose) for 20 min with intermittent hand shaking at 5, 10, 15, and 20 min. Flour suspension was centrifuged at 1,000 × g for 15 min and drained for 10 min. The tube was weighed and SRC value was calculated. Besides, Gluten performance index (GPI) was calculated with the SRC values by using the formula below:

$$GPI = \text{Lactic acid SRC value} / (\text{Sodium carbonate SRC value} + \text{Sucrose SRC value}) \quad (10)$$

Rheological properties of the dough were determined on the Alveograph PC following the method ISO 27971. The following parameters have been defined: resistance to extension (P), dough extensibility (L), curve configuration ratio (P/L ratio), deformation energy (W), swelling index (G) and elasticity (P200/P ratio).

Water absorption capacity (WAC) was determined on mechanical device Mixolab (Simulator Protocol). Also determined the following quality indicators: dough development time (DDT), stability, degree of softening.

Statistical Analysis. All analyses were conducted in triplicates and results were reported in average mean (with rounding of significant digits) and confidence interval (CI), which was determined by the formula:

$$CI = t_{(q\,;\,n-1)} \cdot S / \sqrt{n} = 2.48 \cdot S \quad (11)$$

Where:

q – is the confidence level. q = 0.95;

n – is the number of parallel definitions. n = 3;

f – is the degree of freedom. f = n – 1 = 2;

t – Student's criterion. t ((0.95; 2) = 4.30;

S – standard deviation.

Statistical processing of the results was carried out using Microsoft Excel Software.

Results of the research and their discussion

Analysis of the technological properties of grain, which are determined by various indicators, allows us to divide them into 3 groups: physical and technological, chemical and technological and milling characteristics. According to this classification, the grain physical-technological characteristics include test weight, 1000 kernel weight, vitreousness, grain average size and residue on the sieve 2.5x20 (Table 1). Grain chemical and technological properties evaluated by: ash content, protein content, gluten content, gluten deformation index, Falling Number and test Zeleny (Table 2). Evaluation of milling properties of grain is carried out by laboratory grinding. At the same time were determined: flour yield, bran yield, flour ratio, bran ratio, Milling Score (Table 3, Figure 1).

Table 1 – Physical and technological properties of wheat (n=3, P≥0.95)

Sample name	Moisture content, %	Test weight, kg/hl	1000 kernel weight, g	Vitreousness, %	Average size, mm	Residue on the sieve 2.5x20, %
Strong Wheat	12.63 ± 0.14	74.1 ± 0.45	41.77 ± 1.65	55 ± 5.16	2.61 ± 0.06	69.33 ± 3.79
Hard Wheat	12.70 ± 0.25	76.0 ± 0.50	39.13 ± 2.24	59 ± 3.79	2.51 ± 0.04	50.57 ± 1.49
Waxy Wheat	12.40 ± 0.25	73.2 ± 0.19	41.93 ± 2.73	72 ± 7.44	2.41 ± 0.07	29.67 ± 1.41
Soft Wheat	12.73 ± 0.14	73.8 ± 0.52	41.33 ± 3.79	33 ± 4.96	2.58 ± 0.05	60.37 ± 2.72

Table 2 – Chemical and technological properties of wheat (n=3, P≥0.95)

Sample name	Ash content, %	Protein content, %	Wet gluten content, %	Gluten deformation index, units	Test Zeleny, ml	Test Zeleny 120, ml	Falling Number, seconds
Strong Wheat	1.69 ± 0.03	13.51 ± 0.19	26.1 ± 1.37	78 ± 7.97	58 ± 4.96	76 ± 8.59	472 ± 14.53
Hard Wheat	1.59 ± 0.03	12.40 ± 0.09	23.8 ± 2.25	82 ± 6.24	51 ± 7.58	64 ± 4.30	453 ± 27.32
Waxy Wheat	1.64 ± 0.05	12.28 ± 0.21	22.5 ± 1.52	68 ± 7.16	44 ± 5.16	56 ± 6.24	70 ± 2.48
Soft Wheat	1.61 ± 0.05	12.65 ± 0.08	21.8 ± 0.87	60 ± 6.24	36 ± 1.43	46 ± 5.16	230 ± 16.88

Table 3 – Milling properties of wheat (n=3, P≥0.95)

Sample name	Straight flour yield, %	Long patent flour yield, %	Flour ratio	Bran ratio	Milling Score 1	Milling Score 2	Milling Score 3
Strong Wheat	72.67 ± 2.38	59.57 ± 1.27	3.78 ± 0.31	3.01 ± 0.27	69.70 ± 2.98	50.73 ± 1.59	4528 ± 68
Hard Wheat	72.88 ± 2.62	61.40 ± 1.55	3.32 ± 0.22	3.37 ± 0.25	70.40 ± 0.99	49.50 ± 1.24	4493 ± 87
Waxy Wheat	69.60 ± 2.52	55.63 ± 2.25	3.21 ± 0.27	2.58 ± 0.39	65.33 ± 3.79	50.13 ± 2.74	4399 ± 120
Soft Wheat	67.17 ± 2.25	54.67 ± 2.07	1.78 ± 0.26	4.07 ± 0.36	61.23 ± 3.39	49.57 ± 1.37	4743 ± 202

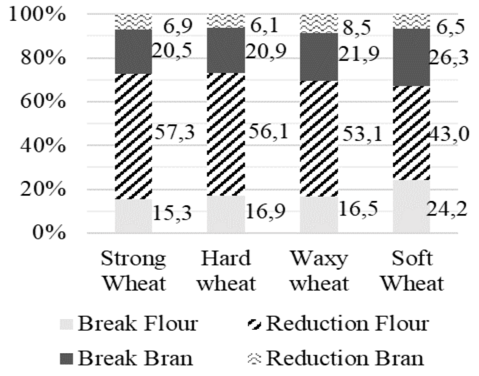


Fig. 1. Flour and bran yield

Wheat grain of high milling quality should be characterized by high 1000 kernel weight, test weight, vitreousness and uniformity (average size and sieve test) [42]. Test weight of wheat grains mainly depends on environmental conditions during growth period and on the variety. The presented samples had relatively low-test weight and 1000 kernel weight, which are unusual for these wheat varieties, which is associated with their growing conditions. In the Odesa region, the 2019–2020 marketing year was characterized by a combination of all unfavorable factors for plant development: lack of moisture in autumn and winter, cold spring with a large amplitude of daily temperature fluctuations and hot summer. This affected the reduction in grain size, reduction in its thickness, poor performance and the formation of a wrinkled surface. This was especially evident in waxy wheat, which had the smallest 1000 kernel weight and the smallest weighted average particle size.

At the same time, this species of wheat had the highest vitreousness, belonging to group I (high) – more than 60%. Strong and hard wheat had group II (medium), while soft wheat had group III (low), less than 40%. Therefore, before grinding, strong, hard and waxy wheat were moistened to 16.0% within 24 hours (waxy wheat) or 20 hours (hard wheat with GPC-B1 gene and common hard wheat), but soft wheat was tempered within 16 hours to 15.0% tempering moisture. Tempering of the grain was carried out in one stage due to the same grain moisture content of all samples (> 12.0%).

Ash content is the inorganic residue remaining on complete combustion of all organic matter from a measured mass of grain [43]. The ash content of the studied samples was from 1.59 (hard wheat) to 1.69% (strong wheat), which is typical for Ukrainian wheat grown today [35]. Because all wheats were grown under the same conditions, the higher ash content in strong is explained by its ability to extract minerals from the stem and accumulate minerals in the grain at the last stage of plant maturation due to the presence of the wild-type gene GPC-B1. The same effect is observed for protein content. Strong wheat thanks to the wild-type gene GPC-B1 (grain protein concentration), which significantly increases the protein content in grain, showed the highest protein content (13.51%), which in 1.07–1.10 times more than other wheats.

It is known that flour for conventional baking would generally be milled from a hard-grained wheat with a protein content of over 12% [43]. Although all the studied grain samples had a protein content of more than 12.0%, attention should be paid to the gluten content and the ratio between the gluten content and the protein content. The highest gluten content was in strong wheat (26.1%) and hard wheat (23.8%) at a ratio of 1.93. In waxy wheat, this ratio has decreased to 1.83. Soft had the smallest ratio. The same trend is also characteristic of the gluten deformation index (GDI), which may indicate a higher proportion of the gliadin fraction of proteins in strong and hard wheat samples, since gliadins, due to more active physicochemical centers of the molecule with free energy, bind much more water compared to glutenin's [44]. The Zeleny test confirmed that, according to the properties of the protein-protease complex, strong, hard and waxy wheat samples can be attributed to high bread-baking strength wheat (test Zeleny more than 40 ml), and soft wheat can be attributed to medium-strength wheat.

Strong and hard wheat samples have low alpha-amylase activity with high Falling Number (>350 seconds), which in recent years is typical for grain of Ukrainian wheat. The waxy wheat sample showed the expected value of Falling Number (70 seconds), which is due to the peculiarity of its carbohydrate-amylase complex. Although for wheat with conventional starch, consisting of 20–25% amylose and 75–80% amylopectin, a Falling Number of less than 150 seconds indicates a high activity of alpha-amylase due to grain germination [45,46], when for waxy wheat, with such low values of this indicator, it associated with high starch damage and low viscosity of the flour paste from amylopectin-type starch [47,48]. Soft wheat has a normally Falling Number value between 200 and 250 seconds.

During laboratory milling, the total yield of flour from wheat grain line with the GPC-B1 locus was 72.67%, and the yield of flour and bran at the stages of the technological process is similar to the same indicators for grain of ordinary baking wheat, in which the total yield of laboratory flour was 72.88 %. The yield of flour from this wheat during milling is above 70%, which is consistent with [24] and indicates the economic feasibility of their processing into flour. At the same time, there is no difference in the lower yield of 1% for GPS-B1, which is explained by the larger size and weight of 1000 grains in wheat with GPC-B1 compared to the sample of ordinary wheat of the Kuyalnik variety taken for the study.

When grinding waxy wheat, there is a noticeable decrease in the total yield of flour to 69.60% due to a decrease in the yield of reduction flour and an increase in the total yield of bran. This is due to the larger particle size of the flour due to the greater hardness of the endosperm of waxy wheat [49], which is more difficult to grind in a short laboratory grinding scheme, so part of the endosperm gets into the bran.

A more noticeable difference in the yield of laboratory milling products can be seen for the soft wheat variety Bilyava. First, when it is ground, the total yield of flour is less – 67.17%. Secondly, when milling this wheat variety, the yield of break flour increases, and the yield of reduction flour – decreases, i.e. there is a redistribution of flour yield by stages of the technological process. These trends are due to the fact that the starch grains in soft wheat are larger, the intermediate protein is smaller, resulting in less hardness, so they are initially easier to mill, with more flour in the break process [50].

Bran ratio of wheat with locus GPC-B1 (3.01) is similar to the bran ratio of hard wheat, in which it is 3.37. For waxy wheat this indicator was the lowest (2.58), which is due to getting more reduction bran, and opposite for soft wheat the bran ratio was the highest (4.07), which is due to getting more break bran. This can be explained by the fact that the bran layer of hard wheat is usually more susceptible to grinding than the bran layer of soft wheat. Soft wheat brans are more pliable and less grindable, which indicates a much higher amount of break bran – 26.3% despite 20.5–20.9% for hard-grained wheats (wheat with Gpc-B1 gene and common wheat) and 21.9% for waxy wheat.

Flour ratio according to milling systems for strong, hard and waxy wheat samples, was almost the same with a noticeable decrease in the flour yield on the reduction systems. For waxy wheat this is due to the larger flour particles and the ingress of flour parts into reduction bran. During milling yield of reduction bran for Sofiika wheat was 8.5% versus 6.1–6.9% for other wheats. In soft wheat, there was a significant redistribution of the flour yield towards an increase in the yield of break flour in 1.43–1.58 times compared to the other wheats.

When evaluating the efficiency of milling according to the milling score, determined by different formulas, no significant differences were found between strong and hard wheat. They showed the best milling efficiency compared to waxy and soft wheat, which is confirmed by the Milling Score 1 criteria data – 69.70 and 70.40 for strong and hard wheat, respectively. For waxy wheat, this indicator was significantly lower than 65.33, and the lowest for soft wheat was 61.23.

Milling Score 2 showed no significant differences in the milling properties of different types of wheat, since when determining this criterion, the ash content of grain and flour is used, which depends on the ash content of the grain endosperm, which, in turn, varies over a wide range – from 0.35 to 0.53% [51].

According to Milling Score 3, soft wheat had the best milling efficiency. When calculating this criterion, the flour whiteness index is significant important, which is much higher for soft flour than the others (Table 5). The rest of the wheat samples are arranged in the same order: strong, hard, waxy.

The quality of the milling products was evaluated as follows: ash content and protein content were determined in bran (Table 4); flour was evaluated by whiteness, SRC test indicators (Table 5), flour chemical and technological properties: ash content, protein content, gluten content, gluten deformation index, Falling Number and test Zeleny (Table 6), rheological properties of the dough on the alveograph (Table 7, Figure 2), indicators of dough mixing on the Mixolab according to the Chopin S protocol (Table 8, Figure 3).

Table 4 – Bran quality characteristics (n=3, P≥0.95)

Sample name	Break bran			Reduction bran		
	Moisture content, %	Ash content, %	Protein content, %	Moisture, %	Ash content, %	Protein content, %
Strong Wheat	15.61 ± 0.44	5.15 ± 0.37	15.87 ± 0.38	14.83 ± 0.38	3.77 ± 0.14	15.30 ± 0.25
Hard Wheat	15.59 ± 0.21	4.77 ± 0.26	15.26 ± 0.45	14.73 ± 0.38	3.70 ± 0.33	14.83 ± 0.21
Waxy Wheat	15.48 ± 0.47	4.70 ± 0.25	15.01 ± 0.53	13.98 ± 0.36	3.42 ± 0.31	13.37 ± 0.14
Soft Wheat	14.39 ± 0.22	4.17 ± 0.30	15.97 ± 0.52	13.74 ± 0.41	3.44 ± 0.10	14.35 ± 0.21

Table 5 – Physical and technological and SRC properties of flour obtained during experimental milling (n=3, P≥0.95)

Sample name	Moisture content, %	Whiteness, units	GPI	SRC (water), %	SRC (sucrose), %	SRC (sodium carbonate), %	SRC (lactic acid), %
Strong Wheat Total Flour	15.69 ± 0.12	62.33 ± 1.89	0.80 ± 0.05	68 ± 3.79	110 ± 12.48	90 ± 4.96	160 ± 10.02
Hard Wheat Total Flour	15.42 ± 0.16	61.53 ± 1.25	0.76 ± 0.04	65 ± 1.43	102 ± 6.24	84 ± 1.43	143 ± 5.16
Waxy Wheat Total Flour	15.01 ± 0.27	63.27 ± 1.86	0.61 ± 0.02	69 ± 5.73	113 ± 6.56	108 ± 2.86	134 ± 5.73
Soft Wheat Total Flour	14.53 ± 0.29	70.70 ± 1.74	0.70 ± 0	55 ± 2.86	96 ± 4.30	71 ± 5.16	117 ± 7.16

The bran is a by-product during grain milling process, it consists predominantly of the grain periphery, the aleurone layer and some endosperm that could not be separated during milling. Since the peripheral parts of the grain, especially the aleurone layer, have a higher protein and ash content [52], these indicators can be used to judge efficiently the milling process.

If we compare the data of ash content (Table 4) of bran obtained from laboratory milling and bran obtained under industrial conditions, then the ash content of break bran will be approximately higher on 1.0–1.5%, and reduction bran – on 0.7–1.2% [53, 54], which is explained by the lower yield of flour in laboratory conditions. Both indicators of ash and protein content of break bran higher (in 1.21–1.37 times – for ash content, 1.04–1.12 times – for protein content) compared to reduction bran for all wheat samples.

Wheat varieties of different classes exhibited large differences in composition of bran. This is due to the initial indicators of ash content and protein content in the grain. According to ash content in total bran all wheat samples ranked in the following order: strong wheat > hard wheat > waxy wheat > soft wheat. According to protein content in total bran all wheat samples ranked in the following order: strong wheat > hard wheat > soft wheat > waxy wheat.

Another indicator that is related to ash content is whiteness (Table 5). All samples in this indicator exceed the value for patent flour (>54 units), which is associated with a lower flour yield and the use of 132 µm sieves than with the commercial milling process. As expected, the best result was shown by the soft wheat sample – 70.7 units. To determine the end use, baking quality and hydration performance during mixing of obtained flours were used the SRC test. The SRC (solvent retention capacity) method is designed to determine the solution retention capacity simultaneously in four solvents: deionized water (to determine WAC), 5% lactic acid solution (to measure the effects of glutenin), 5% sodium carbonate solution (to measure the effects of starch damage) and 50% sucrose solution (to measure the effect of pentosans) [55,56]. The level of all indicators is higher in waxy flour, which is explained by the influence of flour size and the indicator of damaged starch on water absorption capacity in all solutions, similar to phenomenon in the study [57].

According to [55] GPI describes the overall performance of the gluten. As can be seen from Table 5, the GPI values of strong wheat flour, with highest value of gluten content, show highest gluten performance index (0.80).

The water SRC value indicates the water absorption capacity contributed by gluten protein, damaged starch, and arabinoxylans. In general, the higher the water SRC value is, the more added water require to make a dough. These values are confirmed by the results of Mixolab Chopin S protocol test (Table 7), where the highest WAC have waxy wheat flour and the lowest – soft wheat flour. Flour with a low water holding capacity is preferred for low moisture crackers and cookies. High flour absorption can be detrimental, lead to cookie spread, longer baking time and increased production costs.

Sodium carbonate solvent extracts damaged starch from the flour sample; therefore, strong and hard flour samples with average values of sodium carbonate SRC (90% for strong wheat flour and 84% for hard wheat flour) most likely have average level of damaged starch contents. Waxy wheat flour had the highest value (108%), which corresponded with its highest damaged starch content.

Table 6 – Chemical and technological properties of flour obtained during experimental milling

Sample name	Ash content, %	Protein content, %	Gluten content, %	Gluten deformation index, units	Test Zeleny, ml	Test Zeleny 120, ml	Falling Number, seconds
Strong Wheat Total Flour	0.52 ± 0.01	12.70 ± 0.30	30.1 ± 1.89	68 ± 7.97	53 ± 1.43	65 ± 4.96	473 ± 18.94
Hard Wheat Total Flour	0.51 ± 0.04	11.37 ± 0.19	27.7 ± 1.59	76 ± 5.16	45 ± 3.79	57 ± 4.30	434 ± 34.75
Waxy Wheat Total Flour	0.53 ± 0.04	11.16 ± 0.10	25.0 ± 1.12	63 ± 6.56	40 ± 6.24	53 ± 6.24	76 ± 5.16
Soft Wheat Total Flour	0.47 ± 0.01	10.79 ± 0.20	24.0 ± 1.83	55 ± 1.43	32 ± 6.24	38 ± 2.86	232 ± 21.67

Lactic acid SRC is an indicator for predicting gluten strength and it has good correlation with Test Zeleny and protein content (Table 6). Lactic acid SRC values of the samples were in the range 117–160%. Therefore, the expected highest result was shown by flour from strong wheat.

The ash content of strong, hard and waxy flours is comparable (0.51–0.53%), although the ash content of strong wheat grain was higher. Apparently, this is due to the fact that the mineral elements concentrated in the peripheral layers are gone with the bran.

The trend in protein content is similar to the protein content in grains. Strong wheat has the highest value (12.70%). Protein content of hard and waxy wheat flours is comparable and was in the range of 11.16–11.37%, while soft wheat flour showed the lowest result – 10.79%. Moreover, the higher the protein content in the flour is, the more gluten it contains.

The quantity and quality of gluten largely determine the technological properties of flour and the range of using it to manufacture bakery and pastry product. Wheat flour with a high gluten content can be used in bread baking on its own or as an improver for weaker varieties of wheat. An analysis of laboratory studies showed that strong wheat flour contains more gluten (on 2.4%) than hard wheat flour. Gluten deformation index (GDI) is one of the important quality indicators that affect the baking properties of flour. The quality of gluten depends on its ability to resist compression and stretching. The optimal result of measuring the gluten deformation index is in the range from 55 to 75 units. GDI of hard wheat flour (76 units) can be attributed to a very good group. Soft wheat flour typically has less gluten content (24.0%) and forms less elastic gluten (GDI 55 units) that tears easily.

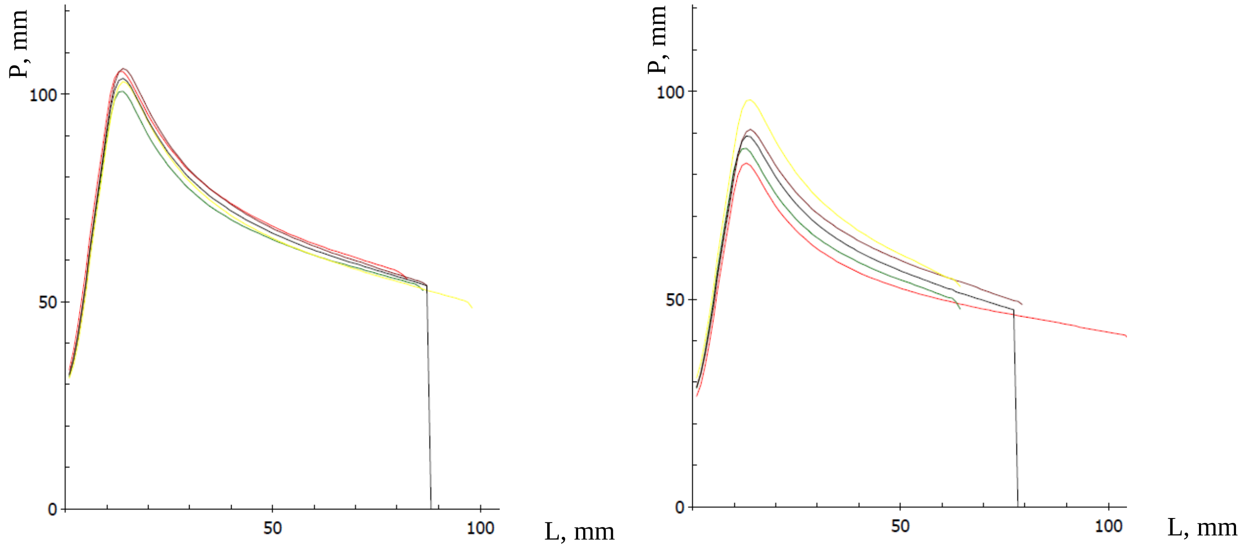
Test Zeleny is the quality indicator, which similar to protein content, gluten content and GDI – characterizes the protein-proteinase complex of flour [58]. A variation of this method with resting for 120 minutes additionally characterizes the quality of gluten proteins. The value of standard test Zeleny more than 60 ml and the difference between standard test Zeleny and test Zeleny 120 more than 20 ml in grain indicates superior baking strength and is suitable for mixing with weaker wheat for the production of bread flour, or for milling very strong flour. Typically, such indicators have hard wheat with high protein content, usually over 14% and superior gluten quality. When test Zeleny value is more than 40 ml and the difference between tests Zeleny is 15–20 ml, the grain allows to obtain flour, which is characterized as high bread-baking strength. Exactly to this group refereed flour from strong, hard and waxy wheats. Flour from soft wheat belonged to the 3rd group – medium bread-baking strength.

The FN value in flour varied in the same way as in grain, from high values for strong and hard wheat flours to low values for soft wheat flour.

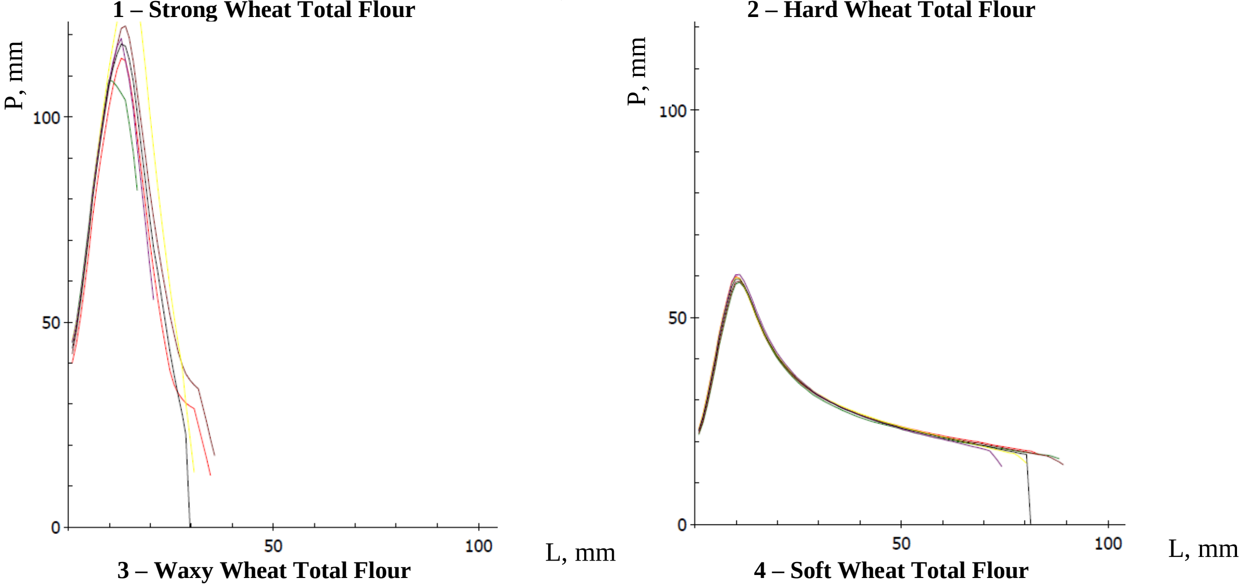
But in order to be able to talk about the baking value and end use of flour, it is necessary to know its rheological properties (Table 7), which will show its behavior during kneading and proofing processes.

Table 7 – Rheological properties of the dough from flour obtained during experimental milling on alveograph (n=3, P≥0.95)

Sample name	W, $\cdot 10^{-4}$ J	P, mm	L, mm	P/L	G	Ie
Strong Wheat Total Flour	396 ± 15.75	114 ± 13.12	86 ± 6.24	1.32 ± 0.20	20.7 ± 1.89	69.2 ± 1.89
Hard Wheat Total Flour	307 ± 37.88	99 ± 5.73	76 ± 5.73	1.29 ± 0.08	19.4 ± 0.94	68.5 ± 2.15
Waxy Wheat Total Flour	140 ± 21.48	130 ± 10.02	28 ± 1.43	4.71 ± 0.32	11.8 ± 0.62	—
Soft Wheat Total Flour	153 ± 14.32	65 ± 3.79	79 ± 7.58	0.83 ± 0.10	20.0 ± 1.25	44.3 ± 5.16



1 – Strong Wheat Total Flour **2 – Hard Wheat Total Flour**



3 – Waxy Wheat Total Flour **4 – Soft Wheat Total Flour**

Fig. 2. Alveograph curves from flour obtained during experimental milling

Rheological properties of the dough are a complex indicator that describe the state and behavior of the dough during kneading and throughout the process. Alveograph allows to compare, select and classify the different varieties of wheat available on the market according to their future use. According to their classification flours with good baking properties makes elastic dough with high pressure (P), extensibility (L) and has good breadmaking potential (0.8<P/L<0.9, W >$250 \cdot 10^{-4}$ J).

From many literary resources it can be concluded that the strength of wheat flour is based on the gluten content and gluten quality. An increase in amount of gluten in strong wheat results in a stronger dough, associated with an increase of alveograph deformation energy (W>1.3 times), tenacity (P>1.15 times) and extensibility (L>1.13 times), compared to hard wheat flour. But insufficient elasticity of the dough affects the increase in P/L, while the elasticity indicator Ie slightly exceeds the hard wheat Ie indicator (69.2 – for strong flour, 68.5 – for hard flour). Such wheat due to a high strength (W=$396 \cdot 10^{-4}$ J) can be referred to extra-strong wheats and can be used in production of flour which is used in low-temperature technologies for the manufacture of frozen convenience foods.

Good bread-making properties is generally associated with high resistance to extension and good extensibility with a large curve area. Hard wheat shown standard rheological properties of all Ukrainian common bakery wheats with good indicator of strength (W=$307 \cdot 10^{-4}$ J), but slightly increased pressure (P=99 mm) which leads to sub-optimal P/L 1.29 for breadmaking.

Table 8 – Rheological properties of the dough from flour obtained during experimental milling on Mixolab (Chopin S protocol) (n=3, P≥0.95)

Sample name	WAC on b14%, %	DDT, min	Stability, min	Degree of softening, UF / Nm
Strong Wheat Total Flour	60.3 ± 1.43	2.4 ± 0.38	37.0 ± 7.44	43 / 0.095
Hard Wheat Total Flour	58.1 ± 1.27	1.5 ± 0.14	12.0 ± 2.48	53 / 0.117
Waxy Wheat Total Flour	67.3 ± 2.86	2.5 ± 0.25	13.2 ± 2.58	32 / 0.070
Soft Wheat Total Flour	52.7 ± 1.59	1.0 ± 0	3.0 ± 0.62	95 / 0.209

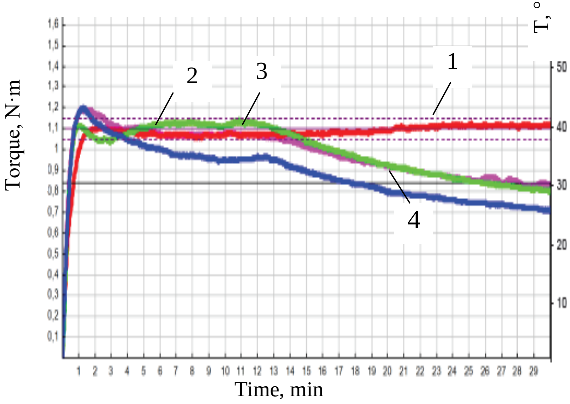
Flour from soft wheat is expected to have average baking properties ($W=153\cdot10^{-4}$ J) with low resistance to extension (P<1.5 times despite hard wheat), but good extensibility (L=79 mm) at the level with hard wheat flour (L=76 mm). Based on worldwide experience, such flour can be used as a biscuit dough, which should have a lower P and a greater L to facilitate leavening and bubble growth or recommended for making cookies. Soft wheat flour can also add to special types of bread to give a lighter color to the crumb and relax the dough, but in a small amount.

In waxy wheat flour, the absence of elasticity (Ie) and low indicator of strength ($W = 140\cdot10^{-4}$ J), explained by high resistance to extension – P indicator in 1.3 times more than hard wheat and very low extensibility (L<3.07 times). It is known that with the indicator L less than 40 mm elasticity cannot be determined. This is all due to a very high WAC (67.3%) – in 1.2 times more than strong and hard wheat (Table 8), when the alveograph standard test is carried out approximately at 53% dough absorption [59]. A high WAC value waxy wheat results from high damage of starch granules during milling process and this could be owing to greater susceptibility of this variety to mechanical damage during milling.Mixolab device determines a comprehensive qualitative profile of the wheat flour and plots, in real time, rheological properties and changes of the dough by increasing or decreasing the temperature values of the flour during dough formation [60]. The Mixolab Chopin S protocol allows to get the complete characterization of the flours in terms of proteins quality by determining their water absorption (WAC), dough development time (DDT), stability and softening properties (Degree of softening); starch behavior is during gelatinization and retrogradation and enzymatic activity of the proteases, amylases.

WAC – the ability of particles of flour to absorb water. It is dependent on the flour composition (protein, starch, fiber, etc.), but to a greater extent this indicator is affected by the degree of damage to starch grains. Flour from soft wheat had a lowest WAC indicator 52.7%, and from non-amylose wheat, a highest water-absorbing capacity (WAC=67.3%) compared to hard wheat. The high value of WAC for waxy wheat is explained by the technological features of the grain during grinding. Flour from strong wheat have higher WAC on 2% despite hard wheat, but both of these values lead to high water absorption.

Dough development time (DDT) is the time from the start of water addition to the point on the curve just before the first signs of consistency loss appear. Stability of flour is calculated as a time difference with an accuracy of 0.5 min between the point where the upper border of the farinogram first crosses the line 500 EF (equivalent to 1.1N·m on Mixolab) and the point where the upper border of the farinogram again crosses the line 500 EF (Figure 3). This value characterizes the resistance of flour to kneading.

The degree of softening of the dough is calculated as the difference between the value of the center of the farinogram at the end of the dough development time and the value of the center of the farinogram 12 minutes after passing this point.



1 – Strong Wheat Flour; 2 – Hard Wheat Flour;
3 – Waxy Wheat Flour; 4 – Soft Wheat Flour

Figure 3 – Mixolab curves (Chopin S protocol) of flour obtained during experimental milling

The strength of each wheat variety could be adjudged from the Mixolab data on the basis of dough development time (DDT) and dough stability. According to the data obtained from Mixolab simulator, strong wheat flour shown significantly different results compared to hard wheat. Lines of wheat with introgression of the GPC-B1 gene exhibited the characteristics of extra strong wheat varieties with longer DDT (2.4 min), higher dough stability

(>30 min) [24]. It also showed low degree of softening of the dough (43 UF).

By the nature of the curve waxy and hard wheat shown similarly results. Stability of the dough from waxy flour (12 min.) was at the same level as for hard flour – 13.2 min. Dough from waxy flour significantly differed in degree of softening – 32 UF despite 53 UF in hard wheat, which is associated with higher average size of flour particles and water absorption capacity.

High dough stability values are usually related to the strength of flours. Soft wheat was weak as it developed quickly, with low dough stability (3.0 min), indicating that these doughs were less tolerant to mixing as compared to the other wheat varieties. As can be seen from the above data, flour from grain of soft variety was characterized by a shorter DDT (1.0 min), as well as a greater degree of softening, which indicates worse baking properties compared to hard wheat.

Conclusion

A comparative study of grain quality indicators, its milling properties and flour quality indicators of 4 varieties of grain of different species, grown in the same agro-climatic conditions, showed significant differences between them. Compared to common baking wheat (Kuyalnik), the main differences are as follows:

Hard Wheat with GPC-B1 gene (breeding line). This wheat has a superior baking strength due to the GPC-B1 locus (grain protein concentration), which significantly increases not only the protein content in grain and increasing iron and zinc, shown highest results for all quality indicators. During laboratory milling, the total yield of flour from wheat grain line with the GPC-B1 locus is above 70%, which indicates the economic feasibility of their processing into flour. At the same time, there is no difference in the lower yield of 1% for GPS-B1, which is explained by the larger size and weight of 1000 grains in wheat with GPC-B1 compared to the sample of common wheat of the Kuyalnik variety taken for the study. Hard wheat flour with GPC-B1 gene, due to the high values of strength ($W=396\cdot10^{-4}$ J), gluten content (30.1%) and gluten performance index (0.80) can be used in production of flour which is used in low-temperature technologies for the manufacture of frozen convenience foods. Wheat with the GPC-B1 gene can used as improver for increase the rheological properties of the dough or for pasta-making properties.

Waxy wheat (Sofiika variety). According to the obtained data waxy wheat consimilar with common baking wheat, but in the same time it significantly differs in the alpha-amylase activity. Low indicator of Falling Number (70 seconds) in this case is associated with high starch damage and low viscosity of the flour paste from amylopectin-type starch. During milling of Waxy wheat, there is a noticeable decrease in the total yield of flour to 69.60% due to a decrease in the yield of grinding flour and an increase in the total yield of bran. This is lead to the larger particle size of the flour due to the greater hardness of the endosperm of waxy wheat, which is more difficult to grind in a short laboratory milling diagram, so part of the endosperm gets into the bran. When determining on the alveograph, the dough is very tight (L<40 mm) due to high water absorption capacity (WAC=67.3%), so independent use of waxy wheat can be recommended in the production of pasta products. Although Sofiika wheat can be used as regulator in flour blending for correcting indicators of Falling Number and water absorption capacity of common baking wheat. In composition with wheat grain line with the GPC-B1 locus, it is ideal for making frozen products, as the absence of amylose causes a higher viscosity and slows down its decrease during storage, which requires further research.

Soft wheat (Bilyava variety) differs significantly from common hard wheat. In terms of wheat quality indicators, it can be attributed to medium bread-baking strength. During milling process the total yield of soft flour is less – 67.17% and the yield of break flour increases, but the yield of reduction flour – decreases, i.e. there is a redistribution of flour yield by stages of the technological process. This is due to the fact that the starch granules in soft wheat are larger, the intermediate protein is smaller and resulting in less hardness, so they are initially easier to mill, with more flour in the break process. Such flour characterized by less ash content and protein content. Soft wheat flour has less elasticity, but greater extensibility, resulting in a lower P/L ratio. Soft wheat flour can be added in a small amount to special types of bread to give a lighter color to the crumb due higher whiteness (70.7 units). Soft flour with a low water absorption capacity (52.7%), small particles, low protein content (10.79%), so is preferred for low moisture crackers and cookies.

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ПОРІВНЯННЯ ТЕХНОЛОГІЧНИХ ВЛАСТИВОСТЕЙ РІЗНИХ ТИПІВ ПШЕНИЦІ

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Анотація. Досліджено технологічні властивості зерна чотирьох видів пшениці та одержаного з них борошна лабо-раторного помелу. Встановлено, що за показниками якості зерна, борошномельними властивостями та показниками якості борошна, 4 типи пшениці, вирощені в однакових агрокліматичних умовах, мають суттєві відмінності. Твердозерна пшениця з геном GPC-B1 (селекційна лінія) має кращу хлібопекарську міцність завдяки гену GPC-B1, який значно підвищує вміст білка в зерні (13,51%), вміст клейковини (26,1%), тест Зелені (58 мл) та зольність (1,69%) у порівнянні зі звичайною твердозерною пшеницею (сорт Куяльник). У результаті борошно характеризується високою силою (W=396·10^{-4} J), високим значенням SRC-тесту (розчиноутримаючої спромож-ності) в молочній кислоті (160%), високою стабільністю тіста (>30 хвилин), низьким ступенем розрідження тіста (43 UF). За отриманими даними, ваксі пшениця (сорт «Софійка») схожа на звичайну хлібопекарську пшеницю, за винятком низького значення показника Число Падіння (FN=70 секунд). При визначенні на альвеографі тісто дуже туге (L<40 мм) через високу здатність поглинання води (WAC=67,3%). Результати SRC-тесту у карбонаті натрію (108%) свідчать про високий ступінь пошкодження крохмалю. Борошно з м'якозерної пшениці (сорт Білява) суттєво відрізняється від звичайного хлібопекарського борошна та характеризується меншим вмістом золи (0,47%), меншим вмістом білка (10,79%), більшою білістю (70,7 од.), меншою еластичністю (Ie=44,3), але більшою розтяжністю, що приводить до нижчого коефіцієнта P/L (0,83) та низької водопоглинальної здатності (WAC=52,7%). За борошномельними властивостями встановлено, що твердозерна пшениця з локусом GPC-B1 та зви-чайна твердозерна пшениця сорту Куяльник мають схожі показники якості. Загальний вихід борошна з цих пшениць при помелі становить понад 70%, що свідчить про економічну доцільність їхньої переробки на боро-шно. При подрібненні ваксі пшениці спостерігається зниження виходу розмелювального борошна і збільшення виходу розмелювальних висівок, а при подрібненні м'якозерної пшениці, навпаки, вихід драного борошна збільшується, а вихід розмельного борошна зменшується.

Ключові слова: пшениця, типи пшениці, GPC-B1, твердозерна, м'якозерна, ваксі, помел, показники якості, Альвеограф, Міксолаб, водопоглинальна здатність, реологічні властивості.