Sel'skokhozyaistvennaya Biologiya [Agricultural Biology], 2013, № 1, p. 15-25

UDK 633.11:631.524

A COMPARISON OF GRAIN QUALITY IN SPRING AND WINTER WHEATS ASSOCIATED WITH MARKET CLASSES (review)

O.V. Krupnova
Research and Development Institute of Agriculture of the South-East, RAAS, Saratov 410010, Russia
e-mail: raiser@mail.saratov.ru

Received October 17, 2011

Summary

In Russia, as one of the biggest grain manufacturer and exporter, the wheat is cultivated from west regions to the Far East, and the differences between market classes of wheat grain are of a special interest. In many countries one of the principles for dividing wheat grain on market classes is the type of cultivation in spring and winter wheat. The analysis of accessible publications has shown discrepancy of the conclusions about distinctions between these classes on test weight of a grain, grain protein and gluten content and composition, a gliadin/glutenin ratio, a falling number, dough rheology, parameters of alveogramms, farinogramms, mixogramms, and also on baking properties. As a result of weather conjuncture, the spring wheat cultivars succeed in some regions, but the winter wheat cultivars — in other ones.

Keywords: spring wheat, winter wheat, grain protein content, gliadin, glutenin, dough rheology, baking properties.

Wheat is one of major components of daily human diet. It is rich in protein containing all essential amino acids, as well as starch and many other valuable nutrients important for complete healthy nutrition, and it is suitable for long-term storage (1). In the twentieth century, the population growth was accompanied by rapid increase in production of wheat, which in recent years has exceeded 600 million tons and the crop area over 210-220 million hectares (2). Wheat is the most common cereal crop in the World. It has been cultivated from 67º N in Russia and Norway up to 45º S in Argentina. Winter wheat is the main cereal crop grown in southern and western regions of the European Russia, while in Siberia and the Altai this role belongs to spring wheat, and they both are cultivated in the Volga region. Over the last decade, the acreage of winter wheat in the Volga region has greatly expanded due to its higher yield associated with seasonal vegetation cycle, improved cultivation techniques, and global warming. In normally overwintered winter wheat, a yield of grain usually 2-3 times exceeds that of spring wheat. However, extreme drought is harmful for both spring and winter wheats, which was dramatically evident in 2010. Soft wheat (*Triticum aestivum* L.) is the most economically important species, while durum wheat (*T. durum* Desf) is grown on less than 10% acreage in many countries including Russia.

There are several market classes of wheat adopted with respect to its main criteria – botanical species, planting season, grain texture, and color. For example, in the United States there are following market classes of wheat : I – durum (*T. durum* Desf), II - HRS (hard red spring), III – HRW (hard red winter), IV – SRW (soft red winter), V – HW (hard white), VI – SW (soft white) (www.plainsgrains.org). A similar classification of wheat types is used in Russia : I - soft red spring, II – hard spring, III – soft white spring, IV – soft red winter, V – soft white winter, VI - hard winter (GOST R 52554-2006). In the USA standards, wheat class I is represented by the botanical species *T. durum* Desf, which corresponds to the Russian standard of durum wheat class II ; USA wheat classes II, III, and V classes include *T. aestivum* L., while soft wheats belong to separate classes IV and VI .

Cultivation technique affects peculiarities of plant growth, yield formation, and grain quality; growing season of winter wheat is 200-300 days or more, and in spring what it can reduce to 70-80 days.

The knowledge of relations between different adopted market classifications of wheat is quite important today due to the increasing world demand for grain and the expansion of international trade (3-9). This is most relevant for Russia – the main producer and exporter of wheat, which is grown from the western boundary of the country to the Far East. In the available domestic literature there are only few special reports and no reviews on this issue that now is of an increasing interest (8-11).

The main genetic difference between summer and winter soft wheat is allelic state of *Vrn*-loci determining plants' response to vernalization. In a typical winter wheat all *Vrn*-loci include recessive alleles, and in spring wheat – dominant ones, especially in the strongest locus *Vrn1*. *Vrn A1* was identified on chromosome 5A, *Vrn B1* – on 5B, *Vrn D1* – on 5D, and chromosome 7B contains the loci *Vrn4*, *Vrn5,* and *Eps* (earliness per se, ripening locus) (12).

Along with it, in the direction away from the equator to the north or to the south, wheat varieties show the replacement of dominant alleles in *Ppd*-loci (response to photoperiod) by recessive ones: *Ppd A1* was identified on chromosome 2A, *Ppd B1* – on 2B, *Ppd D1* – on 2D chromosome (12). The analysis of SNP-polymorphism (single nucleotide polymorphisms, SNPs) in 479 varieties of spring and winter wheat from the USA and CIMMYT (International Maize and Wheat Improvement Center, Mexico) showed the most significant differences between spring and winter varieties in alleles of genes localized on chromosomes 5A, 2A, 2B, 6B, and 7B (13), which are associated with adaptation and cultivation technique.

Grain quality is determined, on the one hand, by genes encoding composition of proteins, starch, lipids, lipoproteins, enzymes, and other substances, and on the other – by interactions of genes and environment (1, 14, 15). Formation and maturation of grain in spring and winter wheat varieties occurs in different periods that usually differ in amount of water, heat, soil nitrogen, epiphytoties, and pest infestation. This all greatly complicates studying the influence of a growing season on grain quality (3, 7, 8).

Natural grain weight (NGW) ranges from 600 to 850 g/l. The higher is NGW the less number of containers for storage and transfer are required, and the higher is yield of flour and middling it provides, as well as the less ash content (16-18). NGW also determines the price of wheat grain (19). NGW value depends on morphology and internal structure of grains (length, diameter, grove depth, powdery, endosperm vitreousity, grain size), growth conditions and peculiarities of sampling. In some cases, winter wheat varieties are at advantage (10), in others - spring wheats, but commonly they have no significant difference especially at comparison of large lots and samples (9).

The yield of flour depends on many characteristics including NGW. Some studies indicate the advantage of HRS in flour yield against HRW (9, 20), as well as the absence of any difference between these groups (21). Comparison of wheat classes with approximately equal protein content in grain (PCG) (73 HRW and 75 HRS samples) revealed no differences in flour yield (9).

The color of flour and middling is an important trait in milling industry as a whole and product use. White-grained varieties usually provide the flour colored lighter than red wheats whose flour at grinding gets an admixture of bran (pericarp) pigmented due to dominant alleles of *R*-genes (*Red grain color*). At high pH (e.g. , in some kinds of noodles) these pigments enhance browning of products. White grained varieties are preferable for non-yeast products.

Color of endosperm (flour, semolina, and a final product) is associated with xanthophylls, carotenoids, and flavonoids; they commonly provide yellow color and present in *T. aestivum* at less contents than in *T. durum* varieties.

The amount and composition of pigments are generally different in various wheat classes (9, 22). The color of flour is determined by L* value; it is significantly higher in HRW than in HRS, so HRW flour has a lighter color than HRS, and the flour from winter wheat has higher proportion of green and yellow components than that of spring wheat (9). Lipoxygenase and peroxidase can bleach flour and greatly reduce its yellowness (23). Darkening of wheat products also depends on the activity of polyphenol oxidase and other enzymes (24).

The content of crude fiber and ash content in wheat are closely related to the number of bran particles present in wheat, which is in inverse proportion to flour yield. Small and undersized grain usually contains more bran and, therefore, it gives higher yield of crude fiber and ash, and lower yield of flour. Grain ash includes 1,5-3,0 % minerals. This rate also depends on natural grain weight (25). Some facts show that ash content is higher in HRS wheat varieties than in HRW ones (3, 9, 21).

Protein content in grain (PCG) ranges from 6-7 to 18-20 % and above (26); gliadin and glutenin are the main grain proteins that define unique baking properties of gluten (27). Bread-making industry uses wheat grain with protein content of 10,5-14,0 %, the production of noodles – 8-15 %. Low-protein grain is widely used in confectionery (14). Grain with 15% and more of high-quality protein is an important improver of a low quality wheat (14, 28-30) .

Protein content is one of the most important quality factors in the world grain market (31, 32). PCG of spring wheat usually exceeds that of winter wheat (3, 8-10, 20, 21, 28), probably, due to lower yields of spring varieties and better nitrogen supply of developing grains.

Along with PCG, the quality of grain also depends on composition of proteins, particularly, gliadin and glutenin. Total grain protein contains about 30 % gliadin and 5-10% glutenin found as a mixture of heterologous proteins (15). Gliadins are divided to four groups (α-, β-, γ-, and ω-gliadin), glutenins – into two groups (high- and low-molecular weight, or HMW and LMW glutenins). Subunits of glutenin have intra- and intermolecular disulfide bonds that play an important role in formation of gluten macropolymers. Even early studies of spring and winter wheats showed their difference in gliadin content and composition (33, 34).

The comparison of grain from 100 samples of HRW and 98 HRS showed that the average content of both insoluble and soluble polymeric proteins, as well as gliadin was significantly higher in HRS wheats (9). The analysis of 282 spring and 323 winter varieties from Russia and Ukraine revealed their differences in the frequency of alleles in glutenin loci. In particular, in spring wheats the most frequent alleles were *Glu-A1b*, *Glu-B1c*, and *Glu-D1a*, in winter wheats – *Glu-A1a*, *Glu-B1c*, and *Glu-D1d*. Distribution of alleles in *Glu-1* loci depends on the place of origin. In spring wheat, drought resistance is associated with *Glu-D1a* allele, in winter wheat – with *Glu-B1b*. There are identified sources of *Glu-1* alleles in spring and winter varieties (35).

Gluten is a continuous protein matrix mainly formed by gliadin and glutenin in cells of a mature grain (27). Gluten content in grain is positively though incompletely correlated with PCG. Gluten proteins represent about 75% grain protein calculated per dry substance, and they provide the unique position of wheat among other cereal crops. Flexibility and extensibility of wheat gluten make it possible to use wheat flour in bakery and other products.

In our country, a market price of grain is determined considering wet gluten rather than protein content. However, both these criteria not linked by close connection are important for final estimate of grain quality (36).

The analysis of 100 HRW and 98 HRS samples with significant differences in PCG showed that HRS reliably exceeded HRW in the average content of gluten. In comparison of wheats with PCG ranging from 11,4 to 15,8 % (73 HRW and 75 HRS samples), various wheat classes showed no differences in this parameter, as well as in average value of gluten index (9).

Usually, spring wheat is sown in spring and harvested in late summer, while winter wheat is sown in late summer or fall and harvested after over-wintering in the next year. In order to eliminate the differences in growing conditions, 12 HRS varieties and 12 HRW ones (11 red and 1 white-grained) were grown in California contemporaneously for 3 years (8). The experimental group of HRS varieties developed higher contents of protein and gluten, as well as higher index of kernel hardness and loaf volume, but the lower gluten index than HRW (8).

Three market classes of wheat are distinguished for grain texture: soft hexaploid, hard hexaploid, and durum. Durum grain is the result of unique substitutions in amino acid sequence of puroindolin proteins that include a and b components responsible for this trait (37). The molecular basis of durum trait is *Pina* and *Pinb* genes (*PinA* and *PinB*), as well as *Ha*-locus with *Grain Softness Protein-1* (*Gsp-1*). Grain hardness is determined by polymorphic genes. Homologs of puroindolin genes were found in rye and barley (38). Except grain hardness, vitreousity is another criteria most commonly used in our country as somewhat characteristic of grain hardness. Grain hardness is associated grit-forming capacity of grain (39).

Particle size index (PSI) in milled grain varies in a wide range depending on species and varieties of wheat. This index is used to separate grain shipments into categories. HRW has lower index of grain hardness than HRS (8, 9). Flour particle geometric mean diameter (GMD) is higher in HRS (89,2 um) than in HRW (83,8 um), i.e. HRW flour contains finer particles. This may result from the smaller index of grain hardness of HRW compared with HRS (9).

In Kazakhstan, it was observed a higher variation in grain hardness of winter wheat compared with spring wheat against the protein content of 14-16% and gluten content of 21-40 % (40). Kazakhstan varieties were inferior by gluten strength and gluten properties to Australian varieties (40).

Lipids of wheat grain is a group of substances with different physical and chemical properties, and biological value. Total lipid content in wheat grain varies within 2,0-4,0 % of dry matter and 0,7-8,0 % of gluten (3). It was established a difference in lipid content of various wheat cultivars. For example, in the set of 100 HRW samples and 98 HRS, the content of free polar lipids was higher in HRW, while the content of free non-polar lipids was almost similar in both classes (9). The data about the influence of lipids on breadmaking quality of grain is inconsistent (9 , 41, 42).

Starch in wheat grain is represented by amylose and amylopectin. According to the research of N.P. Kozmina (3), winter wheat has higher amylose content in starch than spring wheat. There are three types of starch granules: large A-type (> 15 um), fine B-type (5-15 um), and finest C-type (≤5 um). In the USA, the average content of B-type granules in HRW wheat varieties amounts to 39,9 % (from 28,5 to 49,1 %), while in HRS varieties – 47,3% (from 37,7 to 56,2 %) (11). The size of starch granules and their ratio affect baking properties of flour and its milling yield (43).

In some types of products, B-type starch granules are undesirable because they can reduce loaf volume and increase baking time (44). The best baking quality has the flour with a definite ratio of large and small-granule starch fractions (while other properties are equal). It was established a reliable correlation between the number of B-type granules and many parameters of flour quality (mixograms, farinograms, loaf volume, and porosity). There is a negative correlation between the proportion of B-granules and PCG. The highest quality can be obtained with a certain proportion of starch A- and B-type granules. The ratio of starch fractions in flour depends on the variety and growing conditions. Flour color (L*) is positively correlated with content of B-granules (possibly, due to the inverse correlation between color of flour and protein content: $r = -0,56$ at P <0,0001). In this case, the darker was flour, the higher was PCG, however, it was reported about the trend to reduce in amount of B-granules in wheat grain with high PCG (11).

Polyphenol oxidase (PPO) is the enzyme associated with discoloration of Asian noodles. Genes (*Ppo*) that control the activity of this enzyme were mapped on chromosomes of the 2nd homologous group (2A, 2B, 2D). According to some reports, PPO activity is correlated with delayed earing (45). PPO content in flour samples of HRW and HRS wheats wasn't significantly different, as well as in compared HRS and HRW groups with almost equal PCG (9).

SDS-sedimentation volume (sodium dodecyl sulfate sedimentation value) is widely used in evaluation of a breeding material: as a rule, the higher is SDS value, the better is grain quality (46). Average SDS-volume of HRW flour was significantly lower than that of HRS (9). Comparison of HRS and HRW samples with equal PCG revealed higher SDS-value in HRS wheats (9).

Falling number (FN) reflects the activity of α-amylase, which is an indicator of pre-harvest sprouting. The research performed in Kansas (USA) on 100 HRW and 98 HRS samples showed a significant difference between FN in HRW and HRS (9). Among the compared samples with equal PCG, FN was reliably lower in HRS than in HRW (9). At the same time, during the 4-year study conducted in Estonia (2004-2007) on winter and spring wheats, there were observed, respectively, on average 50 and 40 samples with no significant difference in FN (10).

Pre-harvest sprouting caused by high activity of α-amylase is a problem of both spring and winter wheats. However, if a variety has "defective" genes, such activity may not be accompanied by visible germination of grain (47). Pre-harvest sprouting is promoted by dirty rainy weather in the period of grain maturation and harvesting, which in some regions coincides with ripening and harvesting of winter wheat, and in others - spring wheat (48-50).

Rheological properties of dough include water absorption, resilience, viscosity, elasticity, extensibility, resistance to deformation, gas-retaining capacity. These features are determined on farinograph, mixograph, alveolograph, and other devices, which allows predicting the quality of bread, noodles, and other products.

In the test on farinograph, a group of 98 HRS samples showed higher values of water absorption (WA), dough resistance and breakdown, as well as dough development time compared with 100 HRW samples. In this experiment, the analysis of dough properties on mixograph revealed the reliably higher WA and mixing time in HRS while a similar dough resistance in both studied classes (9). Along with it, a comparison of farinograms of wheat groups with almost equal PCG showed the advantage of HRS only in resistance to kneading. Dough mixing time measured on mixograph was higher in HRS than in HRW (9). All characteristics of flour determined on alveograph were reliably higher in HRS except P/L ratio that was superior in HRW (9).

There were observed similar correlations between parameters of mixograms, farinograms, PCG and distribution of starch granules by size. In contrast to HRW, HRS exhibited a closer negative correlation between a differential volume, diameter of starch granules, and the parameters determined on mixograph (WA, dough mixing time, and resistance) and farinograph (dough development time, stability, and breakdown) (11).

In the view of Australian scientists (51), no rheological test can reliably predict the quality of baked bread. One of major reasons why rheological tests are not efficient for selection of desired genotypes is the complexity of genetic control over the quality of a final product (bread, noodles, pasta, etc.). It is caused by interaction of genes that control various metabolic pathways – synthesis of gluten (high- and low-molecular weight glutenins and gliadins in a certain ratio), starch, polysaccharides, lipids, and pigments in endosperm (51). Direct assessment of the final product quality is the most reliable criterion for selection of desirable genotypes (51).

K.F. Finney and M.A. Barmore (52) were the first who established a positive correlation between the protein content in flour and bread loaf volume. In this regard, HRS varieties exceed HRW ones, as they have an average protein content 2,3 % higher than HRW (28). Some authors have noted a better baking quality of spring wheat compared with winter wheat (7, 9, 21). A group of 98 HRS samples exhibited higher mean values of loaf volume and porosity compared with a group of 100 HRW samples (9).

After milling, the flour contains only starchy endosperm (about 70% grain weight), while the bran and germs (grain shell and aleurone layer) are removed. However, whole grain is more useful for good nutrition and healthy digestion. It is rich in lignin, phenolic compounds, alkyl resorcinol, phytosterols, folates, tocopherol and other vitamins, as well as macro- and micronutrients (zinc, iron, magnesium, selenium, etc.). A diet with whole wheat grains is efficient for prevention and protection from obesity, diabetes, cardiovascular diseases, and cancer (53, 54). Wheat species and cultivars differ in content and composition of dietary fiber, bioactive substances, macro- and micronutrients (55, 56). For many of these traits, it was established the difference between winter and spring wheat varieties – eg., the content of folates (57), phytosterols (58), tocopherols, and tocotrienols (59). As a rule, small-sized grain has higher content of physiologically active substances vs. large grain, and their content is rather affected by the environment than by the genotype (57-59) .

The second half of the twentieth century gave a start to improvement of wheat productivity and pest resistance through the introgression of genes from different relative species – spelt, goatgrass (*Aegilops*), wheatgrass (*Agropyron elongatum* Host., *Agropyron intermedium* Host.), etc. (12, 60). All these species carry potentially useful polymorphic alleles for gliadin, glutenin, many other proteins, enzymes, and other components including starch (44, 61-63). It is known that 1B.1RS translocation of rye (*Secale cereale* L.) causes a significant effect on grain texture (hardness), protein composition and dough rheology (64). In China, India, Australia, the USA, Ukraine, and many other countries, wheat varieties with 1B.1RS translocation (*S. cereale* L.) are already grown on more than 40% total acreage of this crop (65, 66). Another promising way of modern research is creation of wheat varieties that carry multiple different translocations introduced from relative species (67, 68). This all brings a question about the impact of these foreign genes, particularly, their products, on human health. It becomes important to study wheat as one of the "big eight" food allergens and the effector of celiac disease, because it affects about 1 % population in many countries (1, 69-74).

Thus, the main genetic distinction of summer and winter soft wheats is the state of alleles in *Vrn*-loci that determine plants' response to vernalization. There are complex interactions between the genes that control adaptation of plants to growing conditions and the genetic system of grain quality traits – composition of proteins, starch, lipids, enzymes, and many other substances. Differences in growing conditions of spring and winter wheats affect grain quality. In plants, gluten proteins are accumulated slower than starch. The shorter is maturation period, the greater changes the ratio for structural/metabolic and storage proteins, endosperm and bran, gliadins and glutenin (75). Protein content in grain and flour yield depend on grain size: the smaller it is, the higher is yield of bran, as well as the content of protein, biologically active substances, macro- and micronutrients in whole grains. The sum of all conditions provides the advantage in some regions for spring wheat varieties, and in others – for winter ones. Even in one enterprise, in different years the advantage in grain quality may vary between spring and winter wheats.

So, the author have reviewed contradictory conclusions about different market classes of wheat grain in respect to natural grain weight, protein content and composition, gluten, gliadin/glutenin ratio, falling number, alveograms, farinograms, mixograms, and other rheological parameters of dough measured by instruments, as well as the quality of bread and non-yeast products. These facts suggest the need in further comprehensive study of differences in grain quality of spring and winter wheat as a major food product of a daily diet.

REFERENCES

1. Shewry P.R. Wheat. *J. Exp. Bot*., 2009, 60: 1537-1553.
2. Altenbach S.B., Tanaka Charlene K., Hurkman W.J., Vensel W.H. Expression of globulin-2, a member of the cupin superfamily of proteins with similarity to known food allergens, is increased under high temperature regimens during wheat grain development. *J. Cereal Sci*., 2009, 49: 47-54.
3. Koz'mina N.P. *Biokhimiya zerna i produktov ego pererabotki* [Biochemistry of Cereal Grain and Its Derivatives]. Moskva, 1976.
4. Stadnik G.I. *Selektsiya polevykh kul'tur na Yugo-Vostoke* [Breeding Field Crops in the South-East]. Saratov, 1982: 73-79.
5. Marushev A.I., Stadnik G.I. *Nauchnyetrudy NIISKH Yugo-Vostoka*, 1978, 37: 107-108.
6. Polityko P.M., Parygina M.N., Vol'pe A.A., Magurova A.M., Kalanchina A.S., Nikiforov V.M., Berkutova N.S. *Sel'skokhozyaistvennaya Biologiya* [*Agricultural Biology*], 2010, 3: 71-76.
7. Larmour R.K. *A comparison of hard red winter and hard red spring wheats. Agricultural Experiment Station*. Kansas State College of Agriculture and Applied Science, Manhattan, KS, 1940, Bull. № 289: 1-57.
8. Chung O.K., Ohm J.B., Lookhart G.L., Bruns R.F. Quality characteristics of hard winter and spring wheats grown under an overwintering condition. *J. Cereal Sci*., 2003, 37: 91-99.
9. Maghirang E.B., Lookhart G.L., Bean S.R., Pierce R.O., Xie F., Caley M.S., Wilson J.D., Seabourn B.W., Ram M.S., Park S.H., Chung O.K., Dowell F.E. Comparison of quality characteristics and breadmaking functionality of hard red winter and hard red spring wheat. *Cereal Chemistry*, 2006, 83: 520-528.
10. Koppel R., Ingver A. A comparison of the yield and quality traits of winter and spring wheat. *Agronomijas vestis (Latvian Journal of Agronomy)*, 2008, 11: 83-89.
11. Park S.-H., Wilson J.D., Seabourn B.W. Starch granule size distribution of hard red winter and hard red spring wheat: Its effects on mixing and breadmaking quality. *J. Cereal Sci*., 2009, 40: 98-105.
12. McIntosh R.A., Yamazak Y., Dubcovsky J., Rogers J., Morris C., Somers D.J., Appels R., Devos K.M. *Catalogue of gene symbols for wheat. 2008*. http://www.grs.nig.ac.jp/wheat/komugi/genes/.
13. Chao S., Dubcovsky J., Dvorak J., Luo M.-C., Baenziger S.P., Matnyazov R., Clark D.R., Talbert L.E., Anderson J.A., Dreisigacker S., Glover K., Chen J., Campbell K., Bruckner P.L., Rudd J.C., Haley S., Carver B.F., Perry S., Sorrells M.E., Akhunov E.D. Population- and genome-specific patterns of linkage disequilibrium and SNP variation in spring and winter wheat (Triticum aestivum L.). *BMC Genomics*, 2010, 11: 727 (doi: 10.1186/1471-2164-11-727).
14. Bushuk W. Wheat breeding for end-product use. *Proc. 5th Inter. Wheat Conference «Wheat: Prospects for global improvement»*. Ankara, Turkey, 1996: 203-211.
15. Payne P.I. Genetics of wheat storage protein and the effect of allelic variation on breadmaking quality. *Ann. Rev. Plant Physiol*., 1987, 38: 141-153.
16. Yamazaki W.T., Briggle L.W. Components of test weight in soft wheat. *Crop Sci*., 1969, 9: 457-459.
17. Schuler S.F., Bacon R.K., Finney P., Gbur E.E. Relationship of test weight and kernel properties to milling and baking quality in soft red winter wheat. *Crop Sci*., 1995, 35: 949-953.
18. Guttieri M.J., Stark J.C., O'Brien K., Souza E. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. *Crop Sci*., 2001, 41: 327-335.
19. Farrer D., Weisz R., Heiniger R., Murphy J.P., Pate M.H. Delayed harvest effect on soft red winter wheat in the southeastern USA. *Agron. J*., 2006, 98: 588-595.
20. Endo S., Okada K., Nagao S., D'Appolonia B.L. Quality characteristics of hard red spring and winter wheats. I. Differentiation by reversed-phase high performance liquid chromatography and milling properties. *Cereal Chem*., 1990, 67: 480-485.
21. McGuire C.F., Blackwood L.G. End-use quality of Montana-grown hard red spring compared to hard red winter wheats. *Can. J. Plant Sci*., 1990, 70: 629-637.
22. *Pshenitsa i otsenka ee kachestva* /Pod redaktsiei N.P. Koz'minoi, L.N. Lyubarskogo [Wheat and Evaluation of Its Quality. N.P. Koz'mina, L.N. Lyubarskii (eds.)]. Moskva, 1968.
23. Carrera A., Echenique V., Zhang W., Helguera M., Manthey F., Schrager A., Picca A., Cervigni G., Dubcovsky J.A deletion at the Lpx-B1 locus is associated with low lipoxygenase activity and improved pasta color in durum wheat (Triticum turgidum ssp. durum). *J. Cereal Sci*., 2007, 45: 67-77.
24. Demeke T., Morris C.F., Campbell K.G., King G.E., Anderson J.A., Chang H.-G. Wheatpolyphenol oxidase: distribution and genetic mapping in three inbred line populations. *Crop Sci*., 2001, 41: 1750-1757.
25. Koz'mina N.P., Kretovich V.L. *Biokhimiya zerna i produktov ego pererabotki* [Biochemistry of Cereal Grain and Its Derivatives]. Moskva, 1950.
26. Krupnova O.V. *Sel'skokhozyaistvennaya Biologiya* [*Agricultural Biology*], 2009, 3: 13-23.
27. Shewry P.R., Halford N.G. Cereal seed storage proteins: structures, properties and role in grain utilization. *J. Exp. Bot*., 2002, 53: 947-958.
28. *Pshenitsa i ee uluchshenie* /Pod redaktsiei M.M. Yakubtsinera, N.P. Koz'minoi, L.N. Lyubarskogo [Wheat and Its Improvement. M.M. Yakubtsiner, N.P. Koz'mina, L.N. Lyubarskii (eds.)]. Moskva, 1970.
29. Bebyakin V.M., Vinokurova L.T. *Doklady RASKHN*, 2003, 4: 3-5.
30. Marushev A.I. *Kachestvo zerna pshenits Povolzh'ya* [Grain Quality in Wheats of Volga Region]. Saratov, 1968.
31. Otteson B.N., Mergoum M., Ransom J.K. Seeding rate and nitrogen management on milling and baking quality of hard red spring wheat genotypes. *Crop Sci*., 2008, 48: 749-755.
32. Souza E.J., Martin J.M., Guttieri M.J., O'Brien K., Habernicht D.K., Lanning S.P., Carlson G.R., Talbert L.E.. Influence of genotype, environment, and nitrogen management on spring wheat quality. *Crop Sci*., 2004, 44: 425-432.
33. Lookhart G.L., Cox T.S., Chung O.K. Statistical analyses of gliadin reversed-phase high-performance liquid chromatography patterns of hard red spring and hard red winter wheat cultivars grown in a common environment: Classification indices. *Cereal Chem*., 1993, 70: 430-434.
34. Huebner F.R., Nelsen T.C., Bietz J.A. Differences among gliadins from spring and winter wheat cultivars. *Cereal Chem*., 1995, 72: 341-343.
35. Dobrotvorskaya T.V., Martynov S.P. *Genetika*, 2011, 47(7): 905-919.
36. Krupnova O.V. *Vestnik RASKHN*, 2009, 5: 46-48.
37. Chen F., He Z., Chen D., Zhang C., Zhang Y., Xia X. Influence of puroindoline alleles on milling performance and qualities of Chinese noodles, steamed bread and pan bread in spring wheats. *J. Cereal Sci*., 2007, 45: 59-66.
28. Bhave M., Morris C.F. Molecular genetics of puroindolines and related genes: allelic diversity in wheat and other grasses. *Plant Mol. Biol*., 2008, 66: 205-219.
39. Greffeuille V., Abecassis J., Rousset M., Oury F.-X., Faye A., Helgouac'h C.B.L., Lullien-Pellerin V.Grain characterization and milling behaviour of near-isogenic lines differing by hardness. *Theor. Appl. Genet*., 2006, 114: 1-12.
40. Abugalieva A., Peña R. Grain quality of spring and winter wheat of Kazakhstan. *The Asian and Australasian Journal of Plant Science and Biotechnology*, 2010, 4: 87-90.

41. Chung O.K., Pomeranz Y., Finney K.F. Relation of polar lipid content to mixing requirement and loaf volume potential of hard red winter wheat flour. *Cereal Chem*., 1982, 59: 14-20.
42. Pomeranz Y. Composition and functionality of wheat flour components. In: *Wheat chemistry and technology. Vol. II* /Y. Pomeranz (ed.). AACC International, St Paul, MN, 1988: 219-370 (цит. по ссылке 9).
43. Edwards M.A., Osborn B.G., Henry R.J. Effect of endosperm starch granule size distribution on milling yield in hard wheat. *J. Cereal Sci*., 2008, 48: 180-192.
44. Stoddard F.L. Survey of starch particle-size distribution in wheat and related species. *Cereal Chem*., 1999, 76: 145-149.
45. Martin J.M., Berg J.E., Fischer A.M., Jukanti A.K., Kephart K.D., Kushnak G.D., Nash D., Bruckner P.L. Divergent selection for polyphenol oxidase and its influence on agronomic, milling, bread, and chinese raw noodle quality traits. *Crop Sci*., 2005, 45: 85-91.
46. Axford D.W.E., McDermott E.E., Redman D.G. Note on the sodium dodecyl sulfate test of breadmaking quality: Comparison with Pelshenke and Zeleny tests. *Cereal Chem*., 1979, 56: 582-583.
47. Mares D., Mrva K. Late-maturity α-amylase: low falling number in wheat in the absence of preharvest sprouting. *J. Cereal Sci.,* 2008, 4: 6-17.
48. Krupnova O.V., Sibikeev S.N., Krupnov V.A., Sovtsova A.V, Antonov G.Yu. *Sbornik nauchnykh trudov GNU NIISKH Yugo-Vostoka Rossel'khozakademii* [Compilation of Sci. Works of the Research and Development Institute of Agriculture of the South-East of RAAS]. Saratov, 2009, 113-119.
49. Krupnov V.A., Sibikeev S.N., Krupnova O.V. *Sel'skokhozyaistvennaya Biologiya* [*Agricultural Biology*], 2010, 3: 3-16.
50. Mares D., Rathjen J., Mrva K., Cheong J. Genetic and environmental control of dormancy in white-grained wheat (Triticum aestivum L.). *Euphytica*, 2009, 168: 311-318.
51. Mann G., Diffey S., Cullis B., Azanza F., Martin D., Kelly A., McIntyre L., Schmidt A., Ma W., Nath Z., Kutty I., Leyne P.E., Rampling L., Quail K.J., Morell M.K. Genetic control of wheat quality: interactions between chromosomal regions determining protein content and composition, dough rheology, and sponge and dough baking properties. *Theor. Appl. Genet*., 2009, 118: 1519-1537.
52. Finney K.F., Barmore M.A. Loaf volume and protein content of hard winter and spring wheats. *Cereal Chem*., 1948, 25: 291-312.
53. Fardet A. New hypotheses for the health-protective mechanisms of whole-grain cereals: what is beyond fibre? *Nutrition Research Reviews*, 2010, 23: 65-134.
54. Slavin J. Whole grains and digestive health. *Cereal Chem*., 2010, 87: 292-296.
55. Zhao F.J., Su Y.H., Dunham S.J., Rakszegi M., Bedo Z., McGrath S.P., Shewry P.R. Variation in mineral micronutrient concentrations in grain of wheat lines of diverse origin. *J. Cereal Sci*., 2009, 49: 290-295.
56. Jonnala R.S., Irmak S., MacRitchie F., Bean S.R. Phenolics in the bran of waxy wheat and triticale lines. *J. Cereal Sci*., 2010, 52: 509-515.
57. Kariluoto S., Edelmann M., Piironen V. Effects of environment and genotype on folate contents in wheat in the HEALTHGRAIN diversity screen. *J. Agric. Food Chem*., 2010, 58: 9324-9331.
58. Nurmi T., Lampi A., Nystrom L., Piironen V. Effects of environment and genotype on phytosterols in wheat in the HEALTHGRAIN diversity screen. *J. Agric. Food Chem*., 2010, 58: 9314-9323.
59. Lampi A.M., Nurmi T., Piironen V. Effects of the environment and genotype on tocopherols and tocotrienols in wheat in the HEALTHGRAIN diversity screen. *Agric. Food Chem*., 2010, 58: 9306-9313.
60. Krupnova O.V. *Kachestvo zerna yarovoi myagkoi pshenitsy s translokatsiyami ot sorodichei. Avtoreferat doktorskoi dissertatsii* [Grain Quality in Spring Soft Wheat with Translocations from Related Species, Extended Abstract of Doctoral Sci. Dissertation]. Saratov, 2010.
61. Qi P.F., Wei Y.M., Ouellet T., Chen Q., Tan X., Zheng Y.L. The g-gliadin multigene family in common wheat (Triticum aestivum) and its closely related species. *BMC Genomics*, 2009, 10: 168 (doi: 10.1186/1471-2164-10-168).
62. Stoddard F.L., Sarker R. Characterization of starch in Aegilops species. *Cereal Chem*., 2000, 77: 445-447.
63. Howard T., Rejab N.A., Griffiths S., Leigh F., Leverington-Waite M., Simmonds J., Uauy C., Trafford K. Identification of a major QTL controlling the content of B-type starch granules in Aegilops. *J. Exp. Bot*., 2011, 62(6): 2217-2228.
64. Weightman R.M., Millar S., Alava J., Foulkes M.J., Fish L., Snape J.W. Effects of drought and the presence of the 1BL/1RS translocation on grain vitreosity, hardness and protein content in winter wheat. *J. Cereal Sci*., 2008, 47: 457-468.
65. Huang X.-Q., Wolf M., Ganal M.W., Orford S.R., Koebner M.D, Röder M.S. Did modern plant breeding lead to genetic erosion in European winter wheat varieties? *Crop Sci*., 2007, 47: 343-349.
66. Kozub N.A., Sozinov I.A., Sobko T.A., Sozinov A.A.Variation at storage protein loci in winter common wheat cultivars of the Central Forest-Steppe of Ukraine. *Cyt. Genetics*, 2009, 43: 69-77.
67. Krupnova O.V., Druzhin A.E., Voronina S.A., Krupnov V.A. *Vestnik VOGiS*, 2010, 14(4): 641-646.
68. Krupnov V.A., Sibikeev S.N., Krupnova O.V., Voronina S.A., Druzhin A.E. *Agrarnyi vestnik Yugo-Vostoka*, 2010, 1(4): 11-14.
69. Inomata N. Wheat allergy. *Curr. Opin. Allergy Clin. Immunol*., 2009, 9: 238-244.
70. Morita E., Matsuo H., Chinuki Y., Takahashi H., Dahlström J., Tanaka A. Food-dependent exercise-induced anaphylaxis — importance of omega-5 gliadin and HMW-glutenin as causative antigens for wheat-dependent exercise-induced anaphylaxis. *Allergol Int*., 2009, 58: 493-498.
71. Caputo I., Lepretti M., Martucciello S., Esposito C. Enzymatic strategies to detoxify gluten: implications for celiac disease. *Enzyme Res*., 2010, Article ID 174354, 9 pages (doi: 10.4061/2010/174354).
72. Van Herpen T.W.J.M., Goryunova S.V., Van der Schoot J., Mitreva M., Salentijn E., Vorst O., Schenk M.F., Van Veelen P.A., Koning F., Van Soes t L.J.M., Vosman B., Bosch D., Hamer R.J., Gilissen L.J.W.J., Smulders M.J.M. Alpha-gliadin genes from the A, B, and D genomes of wheat contain different sets of celiac disease epitopes. *BMC Genomics*, 2006, 7: 1-13.
73. Stepniak D., Wiesner M., Ru A.H., Moustakas A.K., Drijfhout J.W., Papadopoulos G.K., Veelen P.A., Koning F. Large-scale characterization of natural ligands explains the unique gluten-binding properties of HLA-DQ2. *J. Immunol*., 2008, 180: 3268-3278.
74. Van den Broeck H.C., De Jong H.C., Salentijn E.M., Dekking L., Bosch D., Hamer R.J., Gilissen L.J., van der Meer I.M., Smulders M.J. Presence of celiac disease epitopes in modern and old hexaploid wheat varieties: wheat breeding may have contributed to increased prevalence of celiac disease. *Theor. Appl. Genet*., 2010, 121: 1527-1539.
75. Dupont F.M., Hurkman W.J., Vensel W.H., Tanaka C., Kothari K.M., Chung O.K., Altenbach S.B. Protein accumulation and composition in wheat grains: effects of mineral nutrients and high temperature. *Eur. J. Agron*., 2006, 25: 96-107.