UDK 577.2:631.526.3:581+351.777.6 **doi: 10.15407/biotech9.01.079**

NEW GENOTYPES AND TECHNOLOGICAL INDICATORS OF WINTER TRITICALE

T. Z. Moskalets[1]
S. P. Vasylkivskyi[1]
B. V. Morgun[2]
V. I. Moskalets[3]
V. V. Moskalets[1]
V. K. Rybalchenko[4]

[1]Bila Tserkva National Agrarian University, Ukraine
[2]Institute of Cell Biology and Genetic Engineering of the National Academy of Sciences of Ukraine, Kyiv
[3]Nosivka Breeding and Research Station of Remeslo Myronivka Institute of Wheat of the National Agrarian Academy of Sciences of Ukraine
[4]Taras Shevchenko National University of Kyiv, Ukraine

E-mail: shunyascience@ukr.net

Received 19.02.2016

The aim of the research was to conduct basic screening of new lines and cultivars of winter hexaploid triticale by the technological and molecular genetics indicators. Molecular and genetic research conducted by polymerase chain reaction allelic variants of gene loci *Wx-A1*, *Wx-B1*, and quality parameters of grain, flour and bread — on technological markers. The new cultivars and lines of winter hexaploid triticale of Nosivka Breeding and Research Station of Remeslo Myronivka Institute of Wheat by technological indicators of grain, flour and bread quality were studied. According to representative criteria's the most promising genotypes, which are the main products in terms Forest-Steppe ecotypes' and a high-quality raw materials for bakeries and bioethanol were identified. Molecular and genetic identifications of allelic variants of genes loci *Wx-A1, Wx-B1* triticale, which in the early stages of ontogenesis to predict targeted uses genotypes were conducted. The first among a series of triticale cultivars and lines Forest-Steppe ecotypes and biotypes with nonfunctional "*b*" gene allele *WxA1*, which defines a high content of amylopectin of starch, an important release for more ethanol was identified. It was found that technological characteristics of grain, flour and bread of new cultivars and lines of winter triticale meet the modern requirements production dietetic food and bioenergy products is important and relevant in the context of food security of Ukraine.

Key words: winter triticale, molecular and genetic markers.

Triticale is a promising culture for expanding the resource base of baking industry and bioethanol production. This is a separate plant genus x *Triticosecale* created by artificial selection (from *Triticum* — the wheat genus, and *Secale* — the rye genus) [1–3]. This artificial plant is of interest due to its nutritional value which largely surpasses in many aspects those of wheat and rye. Nutritional value of triticale grain is caused by high content of protein, essential amino acids, minerals, vitamins B, PP, E, and carotenoids. It should also be noted that the triticale culture is not very discriminative of growing conditions and is the most capable among other crops in the area of weak implementation of biological potentials. Currently, there is a number of winter and spring triticale sorts with high productivity, grain quality, and stable expression of economic characters [4–6]. Not all of the sorts present the valued economic characteristics that meet the requirements of baking and alcohol-distilling use [7, 8]. Thus expansion of gene pool of triticale with such properties is important for national nutritional safety.

The aim of the work was to screen new lines and sorts of hexaploid winter triticale by technologic features and molecular genetic markers.

Materials and Methods

In 2008–2015, we bred new lines and sorts of winter triticale (Pshenychne, Slavetne, Chaian, Д-5_2010, ПС_2-12, ПС_1-12) and studied their genotypic and phenotypic characters in the conditions of Polissia and Forest-Steppe ecotopes (Nosivska selection and research station of Remeslo Myronivka Institute of Wheat of NAAS of Ukraine).

Evaluation of triticale grain and flour by the cereal, protein-proteinase, and carbohydrate-amylase complexes, and of the triticale bread was done in collaboration with Yuriev Plant Production Institute of NAAS of Ukraine in the grain quality laboratory. Extraction of total DNA from triticale grain was conducted according to [9–11], with certain modifications. Gene polymorphism analysis was performed using uniplex and multiplex PCR with specific primers by pre-designed and optimized programs [16]. Reaction solutions were: specific primers, 2 mcl of buffer for PCR *10xDreamTaq™ Green Buffer (Thermo Scientific)*, 0,2 мМ of skin deoxyribonucleotide-3-phosphate (*Scientific*), 0,5 unites of polymerase *DreamTaq™ DNA Polymerase (Thermo Scientific)*, 30 ng of total plant DNA, de-ionized water *Milli-Q* till the end volume of 20 mcl. Selecting valuable genotypes with zero alleles of *Wx*-genes was done amplifying DNA with primers according to Vanzetti et al., (2009) and Saito et al., (2004) [10, 11], allowing for detection of *Wx-A1b, Wx-B1b* alleles. The characteristics of *Wx* genes and alleles of triticale are given in Table 1.

Mathematical and statistical analysis was conducted according to Dospekhov [12] using *Ecxel* 2007 and *Statistica* 6.0. software.

Results and Discussion

As determined by long-term studies, some of the triticale genotypes such as АД 256 (national standard), Pshenychne, Slavetne, Chaian, Д-5_2010, ПС_2-12, ПС_1-12 can in Polissia and Forest-Steppe conditions produce high stable harvests of quality grain if grown using scientifically based technologies. It was shown that the abovementioned genotypes have high bakery performance, for example, the grain nature is 690–720 g/l and 35–44% vitrescence (flour quality indicators) (Table 2). Analysis of technological indicators of grain revealed that the new genotypes lead to the development of grain consisting of 12.1–15.5% protein, 22.6–29.3% gluten (Table 3). In particular, the flour of all studied new genotypes of winter triticale is first-class due to > 18% gluten content. The minimum indicator values of protein complex are in the Д_5-2010 line.

Quality baking industry depends on the dough elasticity. It is determined that the aforementioned genotypes (namely, АД 256, Slavetne, Д_5-2010, and Chaian), are characterized by dough elasticity of 52–65 mm, which eventually positively reflects on the total baking assessment of 6.5–8.6 points (Table 3, Fig. 1–4).

Experimentally it was shown that the content of “raw” protein for all studied grain genotypes varies insignificantly (except for Slavetne sort where this indicator is only 12.1% although this is within the error relative to АД 256 control).

Among the important characteristics of quality of triticale grain is the quality of gluten as a combination of physical properties: elasticity, flexibility and extensibility. The resistance to compression deformation of gluten of these triticale varieties and lines (85–106 cond. u.) is much higher than that of the common wheat of Yuvivata sort (60–72 cond. u.). Although the grain of all studied genotypes by the resistance to compression deformation of gluten belongs to the II quality group and is characterized as “satisfactorily weak”, it can be improved with oxidizing supplements that change gluten.

It should be noted that weak gluten has high extensibility, minimum elasticity, and flows quickly [3, 5, 7].

Triticale grain quality depends not only on the content and quality of gluten, but also on the grain carbohydrate-amylase complex (Table 4). Studying the sort peculiarities of starch content in grain and the carbohydrate-

Table 1. **Localization of Wx genes and alleles in the genome of hexaploid triticale [9–11]**

Gene	Allele	Amplicon size, n. p.	Chromosome
Wx-A1	*Wx-A1a*	495	7AS
	Wx-A1b	652	
	Wx-A1e	176	
Wx-B1	*Wx-B1a*	778	4AL
	Wx-B1e	934	
	Wx-B1b	668	

Table 2. **Performance cereal properties of grain of winter triticale and common wheat**

Sort or line	Grain performance indicators			
	moisture content,%	weight of 1000 grains, g	bulk density, g/l	vitrescence,%
ПС_1-12	14	58 ± 1.8* ″	715 ± 4.1″	35 ± 0.6″
ПС_2-12	14	64 ± 2.2* ″	720 ± 2.4″	40 ± 0.7* ″
Slavetne	14	52 ± 3.9	716 ± 3.0″	13 ± 0.8* ″
Chaian	14	49 ± 2.0	695 ± 5.2* ″	44 ± 1.0* ″
Д-5_2010	14	48 ± 2.3	690 ± 2.7* ″	29 ± 0.8* ″
Pshenychne	14	55 ± 2.5* ″	712 ± 3.3* ″	38 ± 0.9* ″
АД 256 (control)	14	48 ± 3.9	718 ± 2.0	35 ± 1.1
Yuvivata 60 (wheat)	14	50 ± 2.4	786 ± 1.6	50 ± 0.7

Note: hereafter * — $P < 0.05$ versus control (АД 256); ″ — $P < 0.05$ versus wheat.

Table 3. **Special (technological) indicators of grain quality of winter triticale and common wheat by protein-proteinase complex**

Sort, line	"Raw" protein content,%	Raw gluten content,%	Dough extensibility, mm	Dough elasticity, mm	Resistance to compression deformation (H^{MDG}_{def}, c.u.))	Flour strengh, u. a.
ПС_1-12	14.9 ± 0.8*	27.7 ± 0.5*″	53 ± 2.2* ″	92 ± 3.2* ″	90 ± 4.5* ″	127 ± 3.0* ″
ПС_2-12	13.7 ± 0.5	29.3 ± 1.0*	41 ± 2.7* ″	78 ± 2.8* ″	88 ± 3.0* ″	119 ± 2.1* ″
Slavetne	12.1 ± 0.6″	24.0 ± 0.6″	34 ± 3.4* ″	65 ± 2.0* ″	95 ± 3.6* ″	72 ± 2.6″
Chaian	14.5 ± 0.5*	26.4 ± 0.4*″	25 ± 1.1″	52 ± 2.1*	95 ± 2.8* ″	94 ± 3.4* ″
Д-5_2010	12.7 ± 0.5″	22.6 ± 0.7″	27 ± 2.7″	55 ± 2.5*	97 ± 2.1″	70 ± 1.8* ″
Pshenychne	15.5 ± 0.7*″	28.6 ± 0.5*	48 ± 2.8* ″	90 ± 2.5* ″	85 ± 2.7* ″	121 ± 2.6* ″
АД 256 (st)	12.8 ± 0.4	23.8 ± 0.4	28 ± 2.4	59 ± 3.3	101 ± 2.5	75 ± 2.2
Yuvivata 60	14.2 ± 0.5	29.6 + 0.5	82 ± 2.5	53 ± 2.7	102 ± 2.0	272 ± 3.4

Table 4. **Winter triticale and and common wheat grain characteristics by the carbohydrate-amylase complex**

Sort, line of triticale	Starch content,%	Amilose content in starch,%	Fermentability of starch,%	Autolytic activity,%, per dry matter	Temperature of maximum viscosity of starch gel, Tmaxvic, °C	Falling number, c
ПС_1-12	68.5 ± 0.6*	22.2 ± 0.7	28.5 ± 0.5	35.5 ± 0.9	83.5 ± 0.7*	178 ± 14.4
ПС_2-12	64.7 ± 1.1″	22.6 ± 0.6	29.2 ± 0.8	33.2 ± 1.4	83.0 ± 0.6*	181 ± 13.0
Slavetne	65.8 ± 0.8″	21.4 ± 0.8	27.2 ± 0.8″	35.0 ± 1.2	84.9 ± 0.4*	176 ± 8.2
Chaian	64.0 ± 0.5″	26.2 ± 0.9* ″	35.5 ± 0.7* ″	41.8 ± 1.0* ″	80.4 ± 0.8	172 ± 9.6
Д-5_2010	65.6 ± 0.9″	18.8 ± 0.6* ″	23.2 ± 0.7* ″	45.6 ± 0.8* ″	86.2 ± 0.3*	199 ± 11.7
Pshenychne	67.6 ± 0.5*	23.4 ± 1.3	30.5 ± 1.0	34.7 ± 1.5	80.7 ± 0.4	170 ± 9.6
АД 256 (st)	65.2 ± 0.8	21.9 ± 0.7	28.0 ± 0.8	36.6 ± 1.4	84.1 ± 0.3	181 ± 8.0
Yuvivata 60	67.8 ± 0.6	–	–	–	–	–

Fig. 1. **Ear, grain and bread of Pshenychne line of winter triticale**

Fig. 2. **Ear and bread of Chaian line of winter triticale**

Fig. 3. **Ear, grain and bread of Slavetne of winter triticale**

Fig. 4. **Ear and bread of Д-5-2010 line of winter triticale**

amylase complex allowed to determine that the starch content in the grain of aforementioned sorts and lines of triticale is quite high and ranges 64.0–68.5%. The starch is the main grain component, which is why its content, state and properties always impact the rheological properties of dough and therefore the quality of the final products. It should be noted that triticale grain contains a significant total amount of sugars and has a lower temperature of starch gelatinization, and highly active α-amylase [13].

Lately the Ukrainian baking industry practices the method of estimation of falling number index by viscosity, as is widely referred to in other countries [5, 14] as як "Hagberg falling number" (*HFN*). This index reflects the activity of special enzymes, mostly α-amylases that that break down starch molecules into sugars with intense release of CO_2, influencing the porosity and bread structure. The preferable α–amylase level is low [3, 7] because otherwise there is active re-synthesis of starch and the dough becomes viscose and sticky.

High falling number is an important indicator of baking quality of triticale grain, caused by low autolytic activity of α-amylase enzymes that convert starch amylose into glucose and maltose [5, 7] resulting in high protein content.

Our experiments reveal that the least autolytic activity of the studied sorts and lines of triticale grain is in lines ПС_1-12 and Pshenychne (33.2 and 34.7% respectively) and the maximum is in Д-5_2010 (Table 4) which is characterized by the highest activity of amylases and α-amylase in particular and therefore is the least suitable for the production of bakery products.

High amylase content in the grain of studied triticale genotypes is confirmed by identification, in all sorts and lines, of wild type alleles coding isoforms of *GBSS 1* enzyme (*granulebound starch synthase = ADP glucose starch glycosyl transferase*, EC2.4 1.21 = *GBSS 1*). The relevant genes are located in 4AL chromosome shoulders [12–14, 19]. In particular,, the alleles "*a*" (amplification size 495 n. p.) and "*e*" (176 n. p.) in the *Wx*-A1 gene locus, and alleles "*a*" (778 n. p.) and "*e*" (934 n. p.) of *Wx-B1* gene locus (Fig. 5, 6) were found.

Molecular genetic screening for winter triticale grain by alleles of Wx-genes confirmed the physical and chemical composition of starch. Particularly, in the Д-5_2010 the not-functioning null allele "*b*" of *Wx-A1* gene was found, 652 n. p. in size, with the 5′-CGGCGTCGGG TCCATAGATC-3′ sequence (Fig. 6), chich does not influence the expression of synthesis of granulebound starch synthase. The 668 n.p. amplicon — product of *Wx-B1b* gene — was not found in any of studied samples of winter triticale.

Amylopectin, which is part of the starch granules, is hydrolyzed by amylase enzymes better than the amylose [15–19]. Starch granules of amylopectin are physically unstable against mechanical stress during grain grinding, so they are easily broken and thus the total surface of the starch granules that are attacked by amilases increases significantly [13, 20]. This causes the acceleration of starch hydrolysis by amylase, which is important in shaping the raw material for alcohol- distillate and bakery production [2, 16]. Temperature of maximum viscosity of starch gel shows the ratio of amylose and amylopectin polysaccharides in starch granules. The results of our studies on reciprocal interdependence of temperature values of maximum viscosity of starch gel and amylose content and fermentability are consistent with data of some other authors [17, 18]. By temperature values of maximum viscosity of starch gel (T_{max}), the grains of new winter triticale genotypes are variable, as confirmed by different amylose contents in studied samples (Table 5). The only exception is the triticale line Д-5_2010 with T_{max} higher approximately 7.2% than in others, and with the highest amilopectin level in starch

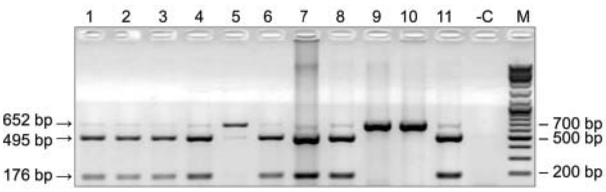

Fig. 5. **Electrophoregram of Wx-A1 gene amplification products:**

1 — ПС_1-12;
2 — ПС_2-12;
3 — Slavetne;
4 — Chaian;
5 — D-5_2010;
6 — Pshenychne;
7 — АД 256;
8 — control sample of triticale with wild type allele (*Wx-A1a*);
9 — control sample of triticale with null allele of *Wx-A1b* gene;
10 — control sample of wheat with null allele of *Wx-A1b* gene;
11 — control sample of wheat with wild type allele (*Wx-A1a*), the Gardemarin sort;
-C — negative control (without DNA);
M — molecular weight marker GeneRuler™ DNA Ladder Mix

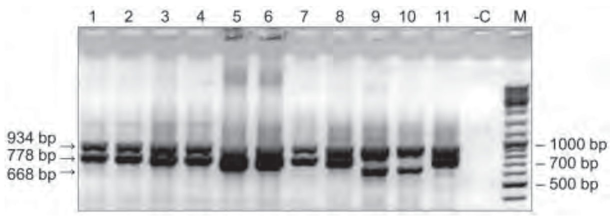

Fig. 6. **Electrophoregram of Wx-B1 gene amplification products:**

1 — ПС_1-12;
2 — ПС_2-12;
3 — Slavetne;
4 — Chaian;
5 — Д-5_2010;
6 — Pshenychne;
7 — АД 256;
8 — control sample of triticale with wild type allele (*Wx-A1a*);
9 — control sample of triticale with null allele of *Wx-B1b* gene;
10 — control sample of wheat with null allele of *Wx-B1b* gene;
11 — control sample of wheat with wild type allele (*Wx-A1a*), the Gardemarin sort;
-C — negative control (without DNA);
M — molecular weight marker GeneRuler™ DNA Ladder Mix

Table 5. **Average indicators of quality of winter triticale and winter soft wheat bread**

Sort, line	Moisture content,%	Acidity, pH	Porosity,%	Volumetric bread outut of 100 g of dough, cm^3	Total baking rating, points	Specific volume, cm^3/ 100 g
ПС_1-12	54.0 ± 0.2* ″	5.1 ± 0.1″	41.1 ± 1.3″	490 ± 5.2* ″	9.0 ± 0.3*	1.37 ± 0.1″
ПС_2-12	53.7 ± 0.1* ″	5.0 ± 0.2″	39.6 ± 1.7″	470 ± 4.4* ″	8.5 ± 0.4	1.35 ± 0.1″
Slavetne	55.6 ± 0.4″	5.6 ± 0.1″	40.5 ± 1.4″	460 ± 3.8* ″	8.6 ± 0.6	1.34 ± 0.2″
Chaian	52.2 ± 0.2* ″	4.8 ± 0.2″	39.3 ± 2.6″	430 ± 3.0* ″	8.2 ± 0.6	1.31 ± 0.1″
Д-5_2010	56.8 ± 0.3* ″	6.1 ± 0.3* ″	25.8 ± 1.1*″	390 ± 6.6* ″	6.5 ± 0.3* ″	1.20 ± 0.1″
Pshenychne	53.0 ± 0.3* ″	5.2 ± 0.1 ″	40.4 ± 2.0″	480 ± 6.1* ″	9.0 ± 0.5	1.34 ± 0.1″
АД 256	55.1 ± 0.2	5.3 ± 0.4	40.2 ± 1.6	440 ± 5.3	8.0 ± 0.4	1.33 ± 0.2
Yuvivata 60	50.2 ± 0.3	3.5 ± 0.3	64.8 ± 2.4	590 ± 6.5	8.7 ± 0.6	3.24 ± 0.2

granules (81.2%), which is indicative of valuable raw material for bioethanol industry.

Analysis of quality indicators of products made it possible to identify the best bakery triticale genotypes: ПС_1-12, ПС_1-12, Chaian, Pshenychne, АД 256. Bread, made from grain of triticale line Д-5_2010 was of worse quality. This is due to low content of raw gluten and increased amylase activity. In addition, low gluten content in grain triticale lines indicated poor porosity makes bread. In addition, low gluten content in grain of that triticale line causes poor bread porosity. The biggest porosity of 39.3-41.1% characterized the bread made of triticale grain of ПС_1-12, Slavetne, Pshenychne lines. The bread with highest specific volume (1.37 cm^3/g) was made from triticale flour of ПС_1-12 line, characterizing it as the most promising for baking. Pshenychne and ПС_2-12 triticale lines, characterized by high levels of protein-proteinase and carbohydrate-amylase complex, perform well in bakery products and are also noteworthy.

Hence, here molecular and genetic markers and technological indicators of grain, flour and bread of new sorts and lines of hexaploid winter triticale were studied at Nosivka Breeding and Research Station of Remeslo Myronivka Institute of Wheat of the National Agrarian Academy of Sciences of Ukraine. Of the triticale genotypes grown in Polissia and forest-steppe ecotope conditions, the most promising genotypes were chosen by relevant criteria in order to determine producers of quality raw material for baking and bioethanol industry. Identification of allelic variants of genes Wx-A1, Wx-B1 allows to determine the targeting use of genotypes at the early stages of ontogeny. For the first time, among a number of triticale varieties and lines grown in Polissia and Forest-Steppe ecotopes, biotypes with nonfunctional (*A1b*) allele of *Wx* gene which defines the high content of amylopectin in starch of the grain was identified, which is important for increasing the output of bioethanol.

It is found that high-performance protein-proteinase and carbohydrate-amylase complexes, and qualitative assessment of bakery products as well as of new varieties of winter triticale lines meet modern requirements for effective processing and production of important dietary food products, which is important and a priority in the context of food security of Ukraine.

REFERENCES

1. *Moskalets T. Z., Moskalets V. V.* Autekolohichni ta demekolohichni proiavy modyfikatsiinoi zdatnosti henotypiv tryby *Triticeae* lisostepovoho ta poliskoho ekotypiv [Population ecology and autecology manifestations of modificational variability of genotypes tribe *Triticeae* in forest-steppe and polissya ecotypes]. *Ecology and noospherology*. 2015, 26 (1–2), 41–52. doi: 10.15421/031505. (In Ukrainian).
2. *Rybalka A.* Tritikale and energetic. *Grain*. 2012, 9 (78), 34–37. (In Ukrainian).
3. *Drobot V. I., Fedorova T. O.* Research baking properties wholemeal flour of triticale flour and bread manufacturing technology of from this flour. *Proceedings of the All-Ukrainian scientific-practic Conference*. Poltava, 2003. (In Ukrainian).
4. *Moskalets T. Z., Hrynyk I. V., Tarasiuk S. I., Moskalets V. V., Buniak N. M., Moskalets V. I., Rybalchenko V. K.* Modification changeability of new caltivare of wheat-rye amphidiploid for ecological, economic valuable and molecular genetic indicators. *J. Problems of Environmental Biotechnology* Available at http://ecobio.nau.edu.ua/ index.php/ ecobiotech. (In Ukrainian).
5. *Riabchun V. K., Shatohin V. I., Panchenko I. A.* The baking quality of grain of new lines of spring hexaploid triticale. *Abstracts of the "Scientific bases stabilization of crop production"*, Kharkiv, Ukraine. 1999. (In Ukrainian).
6. *Shhipak G. V., Ignatenko A. I.* Highly productive cultivar of winter triticale Garne with good baking properties. *The Plant Production Institute nd. a. V.Ya. Yuryev of NAAS*. 2010, V. 7, P. 141–147. (In Ukrainian).
7. *Korjachkina S. Ja., Kuznecova E. A., Cherepnina L. V.* The Technology of Bread From Whole Grain Triticale. *Orel: FGBOU VPO "Gosuniversitet — UNPK"*. 2012, 177 p. (In Russian).
8. *Zahra M., Arash F.* Molecular diversity and detection of Waxy genes in the Iranian wheat populations by multiplex PCR. *Biotechnol. Biotechnol. Equip*. 2015, 29 (5), 869–875. doi:10.1080/13102818. 2015.1045940.
9. *Ma J., Stiller J., Zheng Z., Liu Y., Wei Y., Zheng Y., Liu C.* A high-throughput pipeline for detecting locus-specific polymorphism in hexaploid wheat (*Triticum aestivum* L.). *Plant Meth*. 2015, 11 (39), 14. doi: 10.1186/s13007-015-0082-6.
10. *Vanzetti L. S., Pflüger L. A., Rodríguez -Quijano M.* Genetic variability for waxy genes in Argentinean bread wheat germplasm. *J. Biotechnol. Available* at http://www. ejbiotechnology.info/index. php/ejbiotechnology/article/viewFile/ v12n1-2/682. (accessed, August 7, 2008). doi: 10.2225/vol12-issue1-fulltext-2.
11. *Saito M., Konda M., Vrinten P., Nakamura K., Nakamura T., Saito M.* Molecular comparison of waxy null alleles in common wheat and identification of a unique null allele. *Theor. Appl. Genet*. 2004, 108 (7), 1205–1216. PMID: 14689187.
12. *Dospehov B. A.* Methodology of field experiences. *Moskva: Agropromizdat*. 1985, P. 78–143. (In Russian).
13. *Guzmán C., Caballero L., Alvarez J., Yamamori M.* Amylose content and starch properties in emmer and durum wheat lines with different waxy proteins composition. *Sci. Food Agric*. 2011, 91 (9), 32–38. doi: 10.1002/jsfa.4358.
14. *Yamanaka S., Nakamura I., Watanabe K., Sato Y.* Identification of SNPs in the waxy gene among glutinous rice cultivars and their evolutionary significance during the domestication process of rice. *Theor. Appl. Genet*. 2004, 108 (7), 179–184. PMID: 14740088.
15. *Saito M., Vrinten P., Ishikawa G., Graybosch R., Nakamura T.* A novel codominant marker for selection of the null *Wx*-B1 allele in wheat breeding programs. *Mol. Breed*. 2009, V. 23, P. 209–217. doi:10.1007/s11032-008-9226-y.
16. *Morhun B. V., Stepanenko O. V., Stepanenko A. I., Rybalka O. I.* Molecular genetics identification of polymorphisms of *Wx* genes in hybrid common wheat by using multiplex polymerase chain reaction. *Plant Physiology and Genetics*. 2015, 47 (1), 25–35. (In Ukrainian).
17. *Ortega R., Alvarez J. B., Guzman C.* Characterization of the *Wx* gene in diploid Aegilops species and its potential use in wheat breeding. *Genet. Resources Crop Evol*. 2014, 7 (43). doi: 10.1007/s10722-013-0040-y.
18. *Klimushina M. V. Gladkih N. I., Divashuk M. G.* The distribution of alleles of genes Wx collection of common wheat Krasnodar Agricultural Research Institute nd. a. P. P. Lukianenko. *Vavilov Journal of Genetics and Breeding*. 2012, 16 (1), 187–192. (In Russian).
19. *Van K., Onoda S., Kim M. Y., Kim K. D., Lee S.-H.* Allelic variation of the *Waxy* gene in foxtail millet [Setaria italica (L.) P. Beauv.] by single nucleotide polymorphisms. *Mol. Genet. Genomics*. 2008, V. 279, P. 255–266. doi:10.1007/ s00438-007-0310-5.
20. *Delwiche S., Graybosch R., St Amand P., Bai G.* Starch waxiness in hexaploid wheat (*Triticum aestivum* L.) by NIR reflectance spectroscopy. *Agric. Food Chem*. 2011, 59 (8), 141. doi: 10.1021/jf104528x.

НОВІ ГЕНОТИПИ ТА ТЕХНОЛОГІЧНІ ПОКАЗНИКИ ТРИТИКАЛЕ ОЗИМОГО

Т. З. Москалець[1], *С. П. Васильківський*[1], *Б. В. Моргун*[2], *В. І. Москалець*[3], *В. В. Москалець*[1], *В. К. Рибальченко*[4]

[1]Білоцерківський національний аграрний університет, Україна
[2]Інститут клітинної біології та генетичної інженерії НАН України, Київ
[3]Носівська селекційно-дослідна станція Миронівського інституту пшениці ім. В. М. Ремесла НААН України
[4]Київський національний університет імені Тараса Шевченка, Україна

Метою роботи було вивчення нових ліній та сортів гексаплоїдного тритикале озимого за технологічними показниками та молекулярно-генетичними маркерами. Молекулярно-генетичні дослідження проведено за допомогою полімеразної ланцюгової реакції алельних варіантів локусів генів *Wx-A1*, *Wx-B1*, а якісні параметри зерна, борошна й хліба — за технологічними показниками. Вивчено нові сорти та лінії гексаплоїдного тритикале озимого Носівської селекційно-дослідної станції Миронівського інституту пшениці ім. В. М. Ремесла НААН України за технологічними показниками якості зерна, борошна й хліба. Ідентифіковано найбільш перспективні генотипи тритикале, основна продукція яких в умовах полісько-лісостепового екотопу є якісною сировиною для виготовлення хлібопродуктів і біоетанолу. Проведено молекулярно-генетичну ідентифікацію алельних варіантів локусів генів *Wx-A1*, *Wx-B1* тритикале, яка дає змогу на ранніх етапах онтогенезу спрогнозувати цільове використання генотипів. Уперше серед низки сортів і ліній тритикале поліського і лісостепового екотипів ідентифіковано біотипи з нефункціональним алелем «*b*» гена *WxA1*, який визначає високий вміст амілопектину в крохмалі, що є важливим для більшого виходу біоетанолу. З'ясовано, що технологічні показники зерна, борошна та хліба нових сортів і ліній тритикале озимого відповідають сучасним вимогам виробництва дієтично-харчових і біоенергетичних продуктів, що є актуальним та пріоритетним у контексті продовольчої безпеки України.

Ключові слова: тритикале озиме, молекулярно-генетичні маркери.

НОВЫЕ ГЕНОТИПЫ И ТЕХНОЛОГИЧЕСКИЕ ПОКАЗАТЕЛИ ТРИТИКАЛЕ ОЗИМОГО

Т. З. Москалец[1], *С. П. Васильковский*[1], *Б. В. Моргун*[2], *В. И. Москалец*[3], *В. В. Москалец*[1], *В. К. Рыбальченко*[4]

[1]Белоцерковский национальный аграрный университет, Украина
[2]Институт клеточной биологии и генетической инженерии НАН Украины, Киев
[3]Носовская селекционно-опытная станция Мироновского института пшеницы имени В. М. Ремесло НААН Украины
[4]Киевский национальный университет имени Тараса Шевченко, Украина

Целью работы было изучить новые линии и сорта гексаплоидного тритикале озимого по технологическим показателям и молекулярно-генетическим маркерам. Молекулярно-генетические исследования проведены с помощью полимеразной цепной реакции аллельных вариантов локусов генов *Wx-A1*, *Wx-B1*, а качественные параметры зерна, муки и хлеба — по технологическим показателям. Изучены новые сорта и линии гексаплоидного тритикале озимого Носовской селекционно-опытной станции Мироновского института пшеницы имени В. М. Ремесло НААН Украины по технологическим показателям качества зерна, муки и хлеба. Идентифицированы наиболее перспективные генотипы, основная продукция которых в условиях полесско-лесостепного экотопа является качественным сырьем для изготовления хлебопродуктов и биоэтанола. Проведена молекулярно-генетическая идентификация аллельных вариантов локусов генов *Wx-A1*, *Wx-B1* тритикале, что позволяет на ранних этапах онтогенеза спрогнозировать целевое использование генотипов. Впервые среди ряда сортов и линий тритикале полесского и лесостепного экотипов идентифицированы биотипы с нефункциональным аллелем «*b*» гена *Wx A1*, который определяет высокое содержание амилопектина в крахмале, что важно для более высокого выхода биоэтанола. Установлено, что технологические показатели зерна, муки и хлеба новых сортов и линий тритикале озимого соответствуют современным требованиям производства диетически-пищевых и биоэнергетических продуктов, что является актуальным и приоритетным в контексте продовольственной безопасности Украины.

Ключевые слова: тритикале озимое, молекулярно-генетические маркеры.