



SCIENTIFIC BASIS OF INNOVATIVE ACTIVITY

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BREEDING TRITICALE WITH HIGH PRODUCTIVITY AND IMPROVED GRAIN QUALITY

Introduction. *Natural, climatic, ecological, and economic conditions make us think over the ways of the development of agrarian production. Along with other urgent measures, in the near future, it is expected to develop updated highly productive cultivars and hybrids, which correspond to the climate conditions and realize their genetic potential for 70–75%.*

Problem Statement. *The breeding of hexaploid triticale in the current conditions aims at increasing the crop capacity, ensuring its stability, improving grain quality, and keeping the adaptive properties.*

Purpose. *The purpose of this research is to analyze the development of triticale genotypes with a high productivity and an improved grain quality.*

Material and Methods. *Field, laboratory mathematical-statistical research techniques, samples of hybrid populations of hexaploid triticale of various ecological and geographical origin and type have been used.*

Results. *Twenty-six cultivars have been created by means of intra-specific triticale hybridization $2n = 42 \times 2n = 42$ with various types of the development. Lines with more resilient and elastic gluten have been singled out from the combinations that include the forms with weak but viscous and too tensile gluten. These lines have been used*

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as basis for creating *Amos*, *Markiian*, and *Nikanor* multilinear baking and universal purpose cultivars, which give an improved quality of bread. High productive 40–105 cm high triticale with very elastic gluten has been singled out from *Rarytet*/*KhAD 7* hybrid population. In dry conditions of 2014–2020, the grain yield capacity of the best short-stem cultivars *Tymofii*, *Pudik*, and *Yelan* reached 9.94–10.36 t/ha that exceeded that of *Rarytet* and *Baltikotriticale* cultivars and *Podolianka* soft wheat cultivar. The best quality of gluten, dough, and bread has been reported for *Pudik* and *Yelan* cultivars with a subunit of gliadin 2* – 7 + 8.

Conclusions. The use of the intra-specific triticale hybridization technique in breeding practice in combination with long-term trials of hybrid populations and lines in different ecological conditions makes it possible to create short-stem highly productive cultivars of winter triticale with improved grain quality and good baking properties, as well as with complex immunity to the main diseases.

Keywords: multi-linear cultivars, intra-specific hybridization, hexaploid triticale, breeding, and baking properties.

The recent natural, climatic, ecological, and economic realities have made us think about the ways of development of agricultural production. Along with other urgent measures, in the coming years, it has been planned to create modern high-yielding varieties and hybrids, which correspond to changes in the climate conditions and realize their genetic potential for 70–75%. They should become the basis of advanced bioadaptive technologies for the production of ecologically clean crop products. Given the need to reduce man-made and chemical loads and the growing need for food and feed raw materials, more attention should be paid to triticale that is a synthetic high-yielding crop. The long-term studies in different zones have confirmed the better adaptability of this new culture and economic benefits from its cultivation. The varieties created in Poland (*Lamberto*, *Moderato*, *Pavo*, and *Woltario*), the Russian Federation (*Cornet*, *Zimogor*, *Nemchynovsky 56*, and *Sotnyk*), the Republic of Belarus (*Mykhas*, *Dubrava*, and *Mara*), and in other countries are capable of providing stable yields, higher than wheat and rye by 20–35%. At the same time, the cost of growing grain is almost 30% lower. This result is achieved due to both a higher yield and a lower chemical load on the crops. The breeding of hexaploid triticale in modern conditions aims at increasing yield, ensuring its stability [1, 2], and improving grain quality [3–6] while keeping the adaptive properties [7]. However, in the arid conditions of the Steppe and Forest Steppe of Ukraine, they fall behind the local medium-stem varieties in terms of grain yield and quality.

Important problems of genetics and breeding of triticale have been studied at the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine. The breeding lines and varieties of triticale created in this institution have ensured the production of more than 9.0 t/ha grain, which matches or even exceeds the productivity of the best varieties of winter wheat [8, 9].

Also, in Ukraine, there have been introduced into agricultural production special triticale varieties that have different economically valuable characteristics. Forage-type triticale *Amphidiploid 256*, *Harne*, *Bouquet*, *Shalanda*, which have become widespread in all agro-ecological zones of the country, guarantee stably high harvests of grain (7.5–10.5 t/ha) and green mass (45–65 t/ha). Food and universal varieties *Amos*, *Nikanor*, *Rarytet*, *Plastun Volynskyyi*, and *Yaroslava* with a grain yield of 8.5–11.5 t/ha are characterized by good and excellent indicators of the quality of gluten, dough, and bread. These groups of varieties belong to the medium-stem type and are well adapted to the unfavorable factors of overwintering and vegetation. However, in abnormally wet years, they are still prone to lodging, which reduces yield, especially in high soil conditions. For such conditions, triticale varieties with a plant height of 85–100 cm have been created.

The purpose of the research is to analyze the creation of triticale genotypes with a high productivity and an improved grain quality.

The research has been carried out in the fields of the Yuryev Plant Production Institute of the National Academy of Agrarian Sciences of Ukraine.

ne, the Primorsky Research and Breeding Site, the Volhynian State Agricultural Research Station of the Institute of Potato Growing of the National Academy of Agrarian Sciences of Ukraine, the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine, and the Prykarpattia State Agricultural Research Station of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine.

The object of research is winter and spring triticale (*x Triticosecale Wittmack*), varieties and samples of soft and durum wheat and rye of various geographical and genetic origin; intergeneric, interspecific, and intraspecific hybrids; and breeding material created on their basis.

The field experiments have been carried out on chernozem and sandy soils after crop rotation, peas and perennial grasses. The culture cultivation technology is generally accepted for the respective zone. The trial variety samples are sown with a SSFK-7 seeder with 4–6 repetitions; the sowing rate is 4.5 million similar seeds per ha, the area is 10 m². The trial samples and the samples from the reference nursery are harvested with a *Sampo-130* harvester, the crops from other nurseries are harvested manually.

The hybrid populations are created by crossing hexaploid triticale of various ecological and geographical origin and type. To breed stable, phenotypically homogeneous lines, we have used the method developed by us [10]. The required adaptive and economically valuable characteristics are selected under contrasting conditions. In the arid steppe (Prymorsky RBS, southern part of Donetsk Oblast), the populations and lines have been evaluated in terms of drought and heat resistance, resistance to germination during long-term rest on the roots, and grain quality. In the conditions of the Western Polissia (the Rokyni village), Western (the Pyadyki village) and Eastern (Kharkiv) Forest Steppe, the hybrid and breeding material has been studied in terms of yield, quality, resistance to unfavorable factors of overwintering and vegetation.

The grain quality and baking properties have been assessed in the Plant Production Institute of the NAAS, according to the State Variety Testing Methodology, without the use of improvers and additives [11]. In F₃–F₄, the content of protein, starch, carotenoids, as well as sedimentation, hardness, and the falling number have been determined. The content of protein and starch in grain has been measured by the express method with the use of *Infra LUM FT-10* device, which is based on the measurement of grain sample optical density in the near-infrared range of the spectrum, which is determined according to a previously established calibration [13], and the subsequent calculation of the quality indicators. The content of carotenoids has been determined according to the Tsyrel modified method [14]: 20 ml acetone is added to a 4 g flour sample. The carotenoid pigments are extracted from flour during 16 hours, at a temperature of 20 °C. The optical density of the obtained filtered acetone solution of carotene is measured on a *FEK-60* photoelectrocolorimeter, at a wavelength of 440 nm. The sedimentation index is determined by the Pumpyanskyi method [15]. Grain hardness is determined by measuring the force with the use of a *YPD-300D* hardness tester, in newton (N) [16]. The falling number is determined according to Hagberg-Perten, with the use of *Falling Number* device (Sweden). The method is based on rapid pasteurization of a water suspension of flour in a boiling water bath, followed by the measurement of liquefaction of the starch gel under the action of alpha-amylase. The grain is ground on a laboratory mill of the hammer type *Perten 3100* (Sweden) [17]. The complete process analysis is made with F₄ in constant lines [12]. The electrophoresis of glutenins is made in *Wibex* laboratory (Poland).

The experimental data are processed by the methods of variation, correlation, and dispersion analysis [18]. The descriptive statistics (*Microsoft Excel 2010* package) have been used as well.

The selection and use of new genetic sources for the development of current breeding lines is of great importance in distant hybridization that

underlies the creation and improvement of triticale and influences quality improvement, stem height reduction, resistance to diseases, and adaptability. Therefore, since the end of the 1960s, primary attention has been paid to the synthesis of new triticale genotypes involving the diversity of wheat and rye from the world collections. For a long period, the main method for creating the source material was the biological method [19]. The genetic material of soft and durum winter and spring wheat, triticale, and rye into the genealogy of newly created varieties has been introduced through large-scale crossings (Table 1).

Labor intensity and complexity of intergeneric (wheat/rye) and interspecies hybridization (soft/durum wheat followed by F_1 – F_3 pollination with triticale, wheat, or rye pollen) are associated with low grain set and low germination of hybrid seeds and high sterility of the first generations of the plants. However, the use of these methods has enabled obtaining a unique, in terms of individual properties, source material that has been further improved by intraspecific hybridization with the use of paired, systemic, backcross, and convergent schemes. Inter-line crossings $2n = 42 \times 2n = 42$ have proved themselves the most effective in increasing grain size, fullness of ears, yield, and especially grain quality.

In 1980, high-grain spring triticale samples of USA and subsequently of Mexican and local ori-

gin, started being extensively involved in cross-breeding with winter triticale. The better predictability and effectiveness of hybridization of genotypes with a contrasting type of development have been confirmed in rapidly changing climatic conditions, when improving adaptability and varying the component ratios become very urgent. On the basis of winter-spring hybrid populations, many triticale varieties that combine optimal and high winter hardiness, endurance to drought, yield, quality, resistance to diseases and some other economically valuable properties have been created.

The development of plastic varieties has been facilitated by the long-term, more than 10 years, selection of the source material in various soil conditions. The scheme of the selection process is designed given the biological characteristics of the populations created by crossing forms with a contrasting type of development. The specificity of winter-spring triticale hybrids is complex interaction of non-identical genetic systems (Vrn, Ppd, etc.). As a result, there has been done a long-term splitting by the type and rates of development in combination with other morphobiological properties, the variability of which in certain combinations reliably exceeds the limits of the parents. The purposeful selection (winter, spring, alternative type of development of lines of diffe-

Table 1. Methods for the Creation of the Source Material and Their Efficiency (Plant production Institute of the NAAS, 1973–2020)

Type of crossing	Grain set, %	Field germination, %	Yield of valuable lines, %	Bred varieties
<i>T. aestivum</i> / <i>S. cereale</i>	5.1	42.7	—	AD1, AD15, AD18, AD42, AD52, AD60, AD201, AD206
<i>T. durum</i> / <i>S. cereale</i>	19.4	1.3	—	
F_1 (<i>Triticum</i> / <i>Secale</i>) // <i>Triticale</i>	1.3	50.2	15.8	
<i>Triticale</i> / <i>T. aestivum</i> $2n = 42$	16.5	62.4	11.9	<i>Ladne, Poverna</i>
<i>Triticale</i> / <i>Triticale</i> $2n = 42$	36.7	90.8	75.4	AD3/5, AD10, AD44, AD256, <i>Amos, Harne, Yelan, Nikanor, VolynskiyiPlastun, Pudik, Rarytet, Ratne, Tymofii, Kharroza</i>
Intravarietal selection <i>Triticale</i> , $2n = 42$	—	—	0.2	Amphidiploid 51

Note: * — soft wheat.

rent frost and winter resistance, duration of the growing season, biochemical composition) with the use of contrasting soil conditions for the development of F_1 – F_5 hybrids by the alternation of trials in contrasting zones (forest-steppe/very arid steppe) and sowing periods (autumn/spring) has enabled the separation of transgressive genotypes with high yields and corresponding adaptive properties.

In a short period, in the selection of a new crop, there have been solved several urgent problems, such as increasing the graininess of the ear and the fullness of the grains, harmonizing their linear parameters, improving the density of the productive stem, strengthening and balancing the adaptive properties, which in general has contributed to the improvement of the yield and its stability.

Along with the winter samples, a valuable triticale gene pool (1.2 thousand lines) with a grain yield of 5.5–9.5 t/ha, different duration of the growing season (spring sowing, 90–120 days; autumn sowing, 275–310 days) has been formed. Individual triticale dicotyledons (*Amphidiploid* 23–83, *Kharkivske Zolotyse*, etc.) have a relatively high level of frost resistance (7.0–7.5 points), at the level of the best varieties of winter wheat, which is unique for the genotypes capable of earing and ripening during spring sowing [20].

Hexaploid triticale is a unique crop, the grain of which is suitable for the production of various food products, including cereals, bread, cookies, biscuits, etc. The analysis of the correlations of grain, dough, and bread quality indicators in 1,300 samples of medium-stem and tall-stem triticale varieties for 1983–1995 has shown a significant influence of the correlations on the baking properties of only a few of varieties. The bread volume is positively influenced by the crumb porosity ($r = 0.42$), the glassiness ($r = 0.53$), and the gluten content ($r = 0.41$). The general baking quality is strongly negatively dependent on the gluten content ($r = -0.71$), the IDC index ($r = -0.77$) and, accordingly, and the gluten quality group ($r = -0.66$). A medium positive relationship has been established between the general baking quality

and the flour strength ($r = 0.40$), the dough elasticity ($r = 0.51$). To the greatest extent, the quality of bread is determined by the crumb porosity ($r = 0.90$). An important indicator of the quality of flour and gluten – the flour strength – has a significant positive effect on the porosity ($r = 0.43$) and the general baking quality ($r = 0.40$). There is a closer relationship between the flour strength and the gluten quality ($r = 0.51$), the dough elasticity ($r = 0.66$) and stretchability ($r = 0.67$).

The first varieties of winter triticale with a high gluten content (*Rosner*, AD1, AD3/5, AD201, ADM4, *Proryv*, *Soyuz*) were distinguished by weak quality, inelastic blurring dough. The bread made of the flour of these triticale had poor porosity and was characterized by a low general baking quality. Modern triticale genotypes are divided into “the complete” (*Avatar*, AD42, *Dar*, *Ladne*, *Navarra*, *Rozivska* 6, *Talva* 100, *Panteon*, TF–12) and “the substituted” (*Strateg*, *Vihren*) ones. The geneticists and biochemists from the USA, Poland, Australia, and the Russian Federation have proven that in some cases, the “substituted” triticale may have a high gluten quality, but no direct relationship between the genomic composition and the gluten quality at the current stage in triticale breeding has been established so far [21, 22].

In order to create triticale varieties with improved bread-baking qualities, the search for hybrid combinations with minimal negative influence of rye chromosomes has been expanded, and additionally, the offsprings with the complementary nature of the interaction of wheat-rye genetic systems have been selected among low-gluten forms that high indicators of elasticity and stretchability of the dough. 17,900 combinations were realized between 1980 and 2020, including 67.9% of intraspecific crosses. Based on the hybridization of triticale $2n = 42 \times 2n = 42$ with different types of development, 26 varieties have been created and submitted for state registration in Ukraine, out of which only two (*Yunga* and *Stepan*) failed to pass tests for individual indicators of the variety suitability for the distribution in Ukraine.

The next stage of the selection process aims at improving bread-making properties is the breeding of the Kharkiv winter triticale variety *Rarytet* from the hybrid combination *Amphidiploid* 547 / D8-192 / *Aist* (year of registration 2008). The stabilization of the quality of the gluten complex at a high level has been achieved in the created variety by combining appropriate complementary, constant and morphologically homogeneous lines [20]. The hybrid effect is enhanced due to the increased dough elasticity (*P*) of some lines and the unique stretchability (*L*) of other lines. The genetic basis of the *Rarytet* variety is formed by the lines with the contrasting indicators of dough quality: stretchability up to 86 mm and elasticity up to 79 mm, which contributes to the formation of a highly balanced gluten complex ($P/L = 82/77$), the growth of flour strength (up to 222 a. u.) and obtaining a high-quality bread without improvers (550–600 ml). The *Rarytet* triticale variety is characterized by increased productivity in all zones, immunity to leaf-stem and powdery mildew diseases, as well as by consistently high bread-making properties.

The widespread use of the *Rarytet* variety in intraspecific crossings has proven its good combining ability, including the quality of gluten, dough, and bread. There have appeared new opportunities for improving the baking properties of triticale, which were limited to the very strong but not sufficiently elastic gluten of the *Rarytet* variety. Numerous crossings have been realized. The most valuable combinations should be considered those with the use of samples with weak, but viscous, excessively extensible gluten: *Amphidiploid* 206 / *Rarytet*, *Rarytet* / *Valentyn* 90, and *Rarytet* / *KhAD* 7, out of which the lines with more elastic gluten have been selected. On their basis, the following new varieties for baking and universal purposes: *Amos* (registered since 2014), *Markian* (since 2015), and *Nikanor* (since 2016), have been formed. With the creation of these varieties, the quality of triticale bread has improved significantly. So, the volume has increased to 650 ml with a total baking quality index of 9.0 points. The

universal purpose triticale at the current stage of selection of this crop is characterized as a medium-stem variety with good and excellent baking qualities, increased plant foliage (*Nikanor*, *Yaroslava*, *Plastun Volynskiyi*). These varieties have been approved for distribution in Ukraine since 2016–2018, and can be successfully used both for green fodder, silage, forage, and for the production of bread by the rye or wheat technology.

In order to increase the competitiveness of triticale, it is necessary to combine in one variety the increased productivity of short-stem plants and high bread-making properties while maintaining complex resistance to adverse factors. The short-stem varieties from Poland, Romania, Slovakia, and the Russian Federation have a high potential yield, but weak gluten and are used mainly for fodder and technical purposes. During the long-term trials of the *Rarytet* / *KhAD* 7 population under the contrasting conditions, we have selected constant, highly productive lines of triticale with a plant height of 40–105 cm. The separation of short-stem offspring when crossing medium- and tall-stem components is not a unique phenomenon, since in the *Rarytet* pedigree there are short-straw varieties of triticale and wheat. The complementarity of the source genotypes in terms of technological qualities, high dough stretchability in *KhAD* 7, and high elasticity of the *Rarytet*gluten complex increase the probability of the appearance of a sufficiently large sample of short lines with excellent bread-baking properties that exceed those of the parental genotypes.

In the conditions of 2014–2017, the short-stem triticale lines (2.8 thousand samples) selected from the combination *Rarytet* / *KhAD* 7 are distinguished by good and excellent overwintering (8.2–9.0 points) and have 530–640 productive shoots per 1 m² with a plant height of 62–98 cm, which is at the level of the Polish short-stem variety *Baltiko*. As compared with the *Rarytet* variety, the plant height is reduced by 30–50% by shortening all internodes, mostly at the expense of the middle (l_4) and lower ones (l_5, l_6), which increases the lodging resistance (9 points). The

duration of the growing season of the short-stem lines corresponds to the source varieties (275–278 days). The new triticale inherits mostly high resistance to powdery mildew and leaf stem diseases. Passed through selections in a very arid steppe, these lines show high drought and heat resistance and form well-filled grain with a mass of 1000 pieces of 44.3–62.5 g. In arid conditions of 2014–2017, the grain yield of the best short-stem varieties *Tymofii*, *Pudyk*, and *Yelan* varies from 8.82 t/ha to 10.77 t/ha and averages 9.94–10.36 t/ha, which exceeds by 3.07–3.49 t/ha the grain yield of *Rarytet*, by 1.81–2.23 t/ha that of *Baltiko*, and by 3.69–4.11 t/ha that of *Podolianka* soft winter wheat (Table 2).

The analysis of the interrelationships of thirty morphobiological and technological properties of short-stem varieties and lines of triticale has shown

that all the studied indicators affect the formation of grain quality, but make significantly different contributions to these processes. The high volume of bread (650–880 ml) reliably depends on 15 characteristics, including the stability of the dough ($r = 0.58$), its resistance to kneading ($r = 0.63$) and the general valorimetric value ($r = 0.71$). The bread volume has inverse close relationships with the protein content ($r = -0.53$), the dough thinning ($r = -0.54$), IDC ($r = -0.63$) and the plant height ($r = -0.72$). Eighteen characteristics had a reliable influence on the general baking quality, out of which the most effective are the stability and resistance of the dough ($r = 0.69$; $r = 0.70$), the general valorimetric value ($r = 0.76$), the bread volume ($r = 0.76$), and especially the crumb elasticity ($r = 0.82$) and the bread porosity ($r = 0.87$). There is no significant ef-

Table 2. Morphological and Process Characteristics of Hexaploid Triticale (2014–2017, \bar{X})

Variety	Height, cm	Yield, t/ha	Protein content In grain, %	Gluten content in flour, %	IDC, un.	Falling number, s	Dough elasticity, mm	Dough stretchability, mm	Flour strength, o.a.	Bread volume, ml	General baking quality, points
Winter triticale											
<i>Amphidiploid 256</i> reference	136	5.61	12.30	16.7	82	206	39	37	57	473	6.6
<i>Rarytet</i> reference	125	6.87	11.52	17.4	55	254	71	74	194	627	9.0
<i>Amos</i>	123	7.33	11.48	16.9	58	246	75	79	203	640	9.0
<i>Tymofii</i>	92	9.94	11.67	17.0	54	152	84	81	210	698	8.7
<i>Pudik</i>	90	10.14	11.39	20.3	45	226	81	77	226	727	9.0
<i>Yelan</i>	94	10.36	11.87	19.0	50	199	72	77	229	800	9.0
Triticale of alternative development											
<i>Yaroslava</i> *	98	3.72	12.80	22.0	68	180	58	65	132	498	8.3
<i>Yaroslava</i> **	125	8.68	12.18	20.4	63	203	65	77	157	617	8.7
<i>Alexandra</i> *	102	4.10	12.69	21.8	65	178	84	62	156	600	8.5
<i>Alexandra</i> **	128	8.56	12.06	18.6	50	206	88	57	196	640	8.6
Soft winter wheat											
<i>Podolianka</i> reference	102	6.25	12.44	27.0	63	263	72	69	207	657	8.8
<i>HIP</i> ₀₅ **/significance level, 95%	−/12	0.38/−	−/0.22	−/1.0	−/13	−/19	−/10	−/9	−/40	−/72	−/0.6
<i>HIP</i> ₀₅ */significance, 95%	−/9	0.31/−	−/0.55	−/3.4	−/3	−/15	−/15	−/5	−/21	−/91	−/0.7

Note: * – spring sowing, ** – autumn sowing.

fect of the falling number on the volume of bread and the general baking quality. The largest number of reliable correlations has been recorded with the general baking quality (18), the dough thinning (20), and the bread porosity (21). The highly reliable predictability of the baking properties of short-stem triticale depending on the complex of morphobiological and technological indicators has been confirmed by the regression analysis and is 93%. The studied trends in the interdependence of the baking qualities form the basis for the creation of genotypes with a specific manifestation of the properties of the protein-gluten complex, which later have been used in the formation of new competitive varieties.

The physical properties of short-stem triticale grains are good and excellent (see Table 2). The bulk weight varies within 662–804 g/l, the glassiness 17–52%, the hardness ranges within 76.4–123.0 N. The sedimentation (33–40 ml) in the new lines are higher as compared with the forage-type triticale *Amphidiploid* 256 and *Pawo* (27–31 ml). Varying the falling number (73–230 s) does

not significantly affect the quality. The short-stem triticale is distinguished by a low protein content in the grain (9.8–11.9%), which corresponds to the level of the *Rarytet* variety. The gluten content in the flour of short-stem amphidiploids is different and ranges from 10.0% to 22.0%. The gluten content is 16.0–19.3%, in the *Rarytet* variety; and 20.0–27.9%, in wheat. The short-stem triticale has exceptionally elastic gluten: the IDC varies from 30 e. u. to 55 e. u.; many lines surpass both common wheat (63 e.u.) and the *Rarytet* triticale variety (55 e.u.) that is the best in terms of this characteristic.

New varieties of triticale differ significantly in terms of flour strength. The winter triticale for fodder purposes has a flour strength of 55–98 a. u., that of the spring triticale is 109–131 u. a. *Yaroslava* and *Alexandra* triticale of the alternative development type form stronger flour, especially in the case of autumn sowing (157–196 a. u.), as compared with the spring amphidiploids. In the first commercial variety of grain triticale *Amphidiploid* 206, the flour

Table 3. Characteristics of New Triticale Varieties According to the Results of State and Competitive Tests (X in 2018–2020)

Variety	Year of registration	Type	Period	Zone	Height, cm	Vegetation period, days	Over-wintering, points
<i>Tymofii</i>	2019	Winter	2018–2019	FS	86	279	9.0
				P	95	278	8.8
<i>Pudik</i>	2020	Winter	2019–2020	FS	88	277	8.4
				P	98	278	8.3
<i>Leontii</i>	2021	Winter	2019–2020	FS	109	277	9.0
				P	124	278	8.8
<i>Yelan</i> (autumn)	2021	Alternative	2019–2020	FS	97	277	8.3
				P	104	278	8.4
<i>Alexandra</i> (autumn)	2021	Alternative	2019–2020	FS	96	271	8.8
				P	109	282	8.8
<i>Alexandra</i> (spring)	2021	Alternative	2019–2020	FS	91	101	—
				P	92	104	—
<i>Ilona</i> (autumn)	DSV	Alternative	2020	FS	101	265	9.0
				P	111	279	8.8

Note: * no reference; FS – forest steppe; P – Polissia.

strength varies, depending on the conditions of the year and the predecessor crops, from 57 to 95 u. a. and averages 72 u. a., versus 4 times higher one (288 a.u.), in *Myronivska 808* wheat.

A consistently high value of flour strength has been established for the first time in the *Rarytet* triticale variety. On average for 10 years (2001–2011), this indicator reaches 193 u. a. for this variety, 121 u. a. for the spring variety *Aist Kharkivskyi*, 200 u. a. for soft spring wheat *Kharkivska 26*, 319 u. a. for soft winter wheat *Odeska 267* [12]. A similar flour strength for different varieties is observed in 2014–2017 (see Table 2).

At the current stage, an important indicator of the triticale baking qualities is well-balanced dough properties. For the triticale with weak gluten, the dough elasticity is very low (39–52 mm). The forage triticale is more diverse in terms of dough stretchability as it varies within 37–82 mm. Unlike the forage-type varieties, *Rarytet* has a well-balanced dough in terms of elasticity and stretchability. In 2001–2011, these parameters aver-

age 71 mm and 74 mm, respectively, with P/L being equal to one. In 2014–2017, *Rarytet* form the same elastic and elastic dough that allows making 627 ml bread without improvers, with a general baking quality of 9 points.

The *KhAD 7* line has an unbalanced dough with an elasticity of 50 mm and a stretchability of 88 mm. The short-stemtriticale lines selected from the combination *Rarytet/KhAD 7* give dough with elasticity of 72–96 mm and a stretchability of 68–89 mm. Varieties *Tymofii*, *Pudik*, and *Yelan* bred with the involvement of the best short-stem lines, the elasticity and stretchability are consistently high and, in 2014–2020, average 84 mm and 81 mm, 81 mm and 77 mm, 72 mm and 77 mm respectively. In the same years, *P* and *L* are 71 mm and 74 mm, for *Rarytet*, and 72 mm and 69 mm, for *Podolyanka* soft winter wheat.

According to the data of the Ukrainian Institute of Plant Varieties Assessment (2018–2020), the new triticale varieties of winter and alternative development type (Table 3) have a high re-

Resistance against powdery mildew, points	Mass of 1000 grains, g	Yield, t/ha			Protein content, %	Flour strength, a.u.	Bread volume, ml	General baking quality index, points
		X_{\max}	\bar{X}	\pm relative to the reference				
9.0	48.2	8.33	5.44	0.00	13.6	215	750	9.0
9.0	40.4		5.14	+0.60	14.2			
8.8	40.7	7.77	5.70	+0.12	11.6	230	820	9.0
8.6	35.4		5.23	+0.46	13.0			
8.8	44.9	8.92	6.47	+0.89	11.5	60	435	4.3
8.8	40.8		5.55	+0.78	13.1			
8.8	44.3	9.17	5.90	+0.32	11.6	180	710	9.0
8.8	37.7		5.29	+0.51	12.8			
8.7	45.0	8.38	6.28	+0.70	12.6	180	650	8.0
9.0	39.2		5.37	+0.60	10.8			
8.9	45.4	7.32	4.73	*	15.4	195	550	8.0
8.8	39.0		4.27		14.0			
9.0	40.5	9.33	6.32	+0.74	11.0	170	680	8.0
8.6	41.3		5.56	+0.64	13.1			

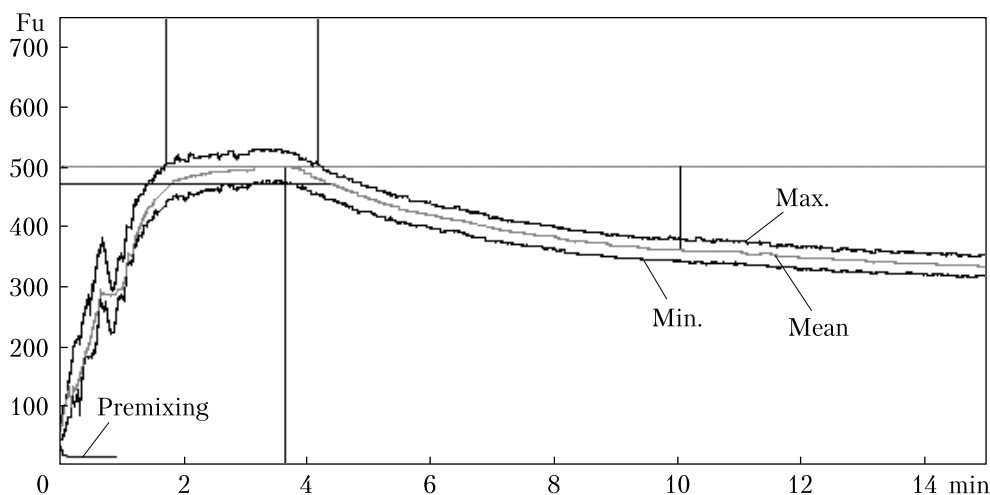


Fig. 1. Farinogram of the *Panteon* triticale variety, a representative of the forage triticale

sistance to adverse overwintering conditions (8.3–9.0 points) and to powdery mildew (8.6–9.0 points), form full wheat-type grain, with 1000 seeds weighing 35.4–44.9 g, and give a yield from 7.32 t/ha to 9.33 t/ha, which significantly exceeds the reference of 0.12–0.89 t/ha. At the same time, the protein content in grain ranges from 10.8% to 15.4%. In terms of bread-making qualities, both the winter varieties and the alternative ones have high indicators, except for *Leontii* variety that has a flour strength at the level of the forage-type triticale (60 a.u.).

For the purpose of studying the quality of the tightly bound wheat-rye gluten complex of the new triticale varieties, with using the advanced approaches, the seeds of the best short-stem forms have been sent to leading research laboratories: the USA (J. Dubcovsky, UC Davis), Australia (R. Trethowan, The University of Sydney), Poland (H. Woś), the Russian Federation (A. I. Grabovets, Donskoy Institute), Mexico (H. J. Braun, CIMMYT), and Germany (K. J. Mueller, Getreidezuechtungsforschung Darzau).

The forage-type triticale (*Amphidiploid* 256, *Pawo*, *Baltiko*, *Titan*, etc.) has rather poor physical properties of the dough: the formation time is 1.30–2.10 min, the formability is 0.50–3.00 min, the resistance to kneading (the time before the

start of thinning) 2.00–4.24 min, the stability 3.00–5.40 min, and the thinning vary from 156 f.u. up to 220 f.u. The dough of such triticale gets formed quickly, but its stability is five times and the calorimetric value is half as less as compared with the strong wheat and the baking-type triticale. Thus, the farinograms have indicated a weak, intensively thinned dough for the forage-type triticale varieties (Fig. 1). It is less elastic, excessively plastic, very sticky, more similar to a dough of rye or weak wheat flour or of sprouted, damaged and defective grain. The bread made of the triticale flour without improvers, with the use of the wheat technology, has a small volume (360–490 ml) and a dense sodden crumb. As a result, the general baking quality does not exceed 5.5–7.5 points.

The best short-stem lines and varieties of triticale give elastic, resistant to kneading and thinning, dough with a high gas-holding capacity (Fig. 2), which is as good as that made of valuable and strong wheat (Fig. 3). Thus, in the *KhAD* 69–189 lines, for the *Tymofii*, *Pudik*, and *Yelan* varieties, the dough formation time is 2.8–3.5 min, the formability is 10.5–12.5 min, the kneading resistance is 13.4–15.7 min, the stability is 10.5–17.2 min, the dough thinning is 55–98 f. u., and the total calorimetric value is 84–90 v. u. The volume of bread made by the wheat technology,

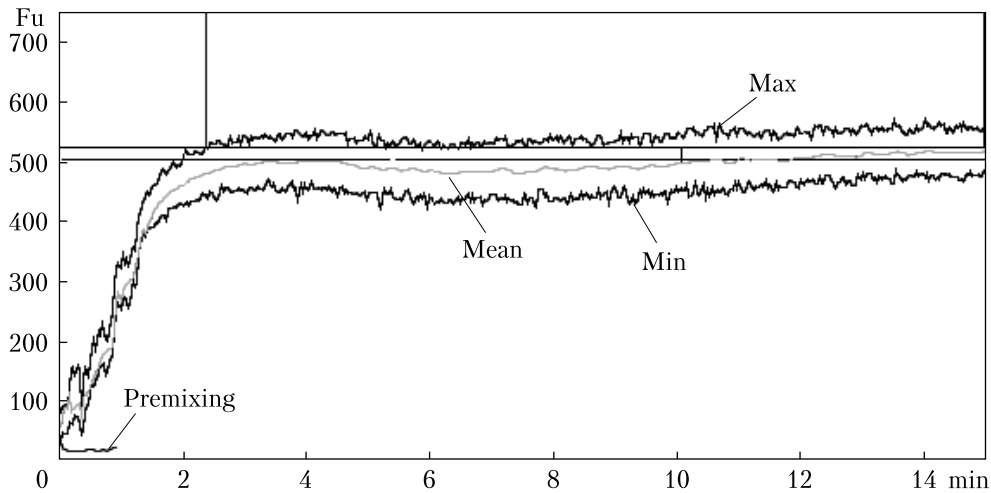


Fig. 2. Farinogram of *Pudik* triticale variety, which shows high quality indicators of flour for baking bread

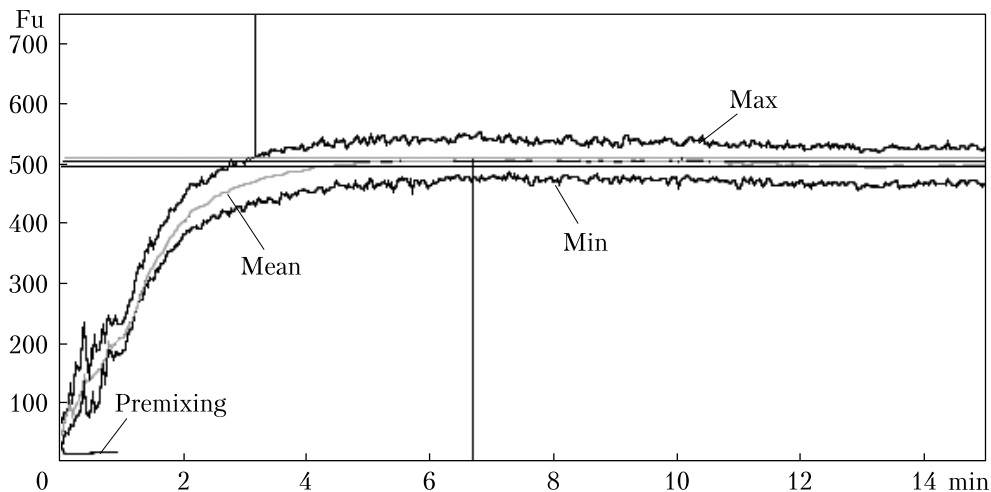


Fig. 3. Farinogram of *Sailor* soft wheat variety (for comparison)

without improvers, reaches 610–880 ml, the general baking quality index is 8.6–9.0 points. In terms of color and appearance, the bread made of the baking-type triticale flour is similar to the wheat one, but has better nutritional, taste, and aromatic qualities.

The glutenin analysis of the short-stem varieties *Tymofii* and *Pudik*, which was made in *Wibex* laboratory (Poland), has shown that unlike the fodder-type reference variety *Amphidiploid* 256, the parent varieties *Raritet* and *KhAD 7 (Plastun)* have different types of spectra. The *Amphidiploid*

256 has subunits $2^* - 7 + 9$ (75%) and $1 - 7 + 9$ (25%). The maternal component with high baking properties *Rarytet* is also represented by two types of spectra: $2^* - 7 + 8$ (75%) and $2^* - 7 + 9$ (25%). The parent variety *KhAD 7* that is characterized by average bread-making properties, has the subunit $2^* - 7 + 8$.

In the spectra of the *Tymofii* variety created from the two short-stem lines isolated by the combination *Rarytet/KhAD 7*, there are subunits $2^* - 7 + 9$ (80%) and $2^* - 7 + 8$ (20%). The highest quality of gluten, dough, and bread has been-

reported for *Pudik* and *Yelan* varieties with subunit $2^* - 7 + 8$.

As a result of the research, a high selection efficiency of intraspecific hybridization of triticale $2n = 42 \times 2n = 42$ with different types of development has been established as a method for creating the source material.

The highest quality of gluten, dough, and bread has been reported for the varieties with glutenin subunit $2^* - 7 + 8$.

The use of hexaploid triticale intraspecific hybridization of the varieties with a contrasting type of development and different quality of gluten during interzonal tests of populations, lines and varieties has enabled the creation of winter- and alternative-type triticale varieties with high

baking properties. The created medium-stem varieties *Rarytet*, *Amos*, and *Nikanor* and the short-stem varieties *Tymofii*, *Pudik*, and *Yelan* with a yield of 9.5–12.5 t/ha are resistant to major diseases, give abroad volume (without improvers) of 650–800 ml, and have a general baking quality index of 9.0 points.

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СЕЛЕКЦІЯ ТРИТИКАЛЕ З ВИСОКОЮ ПРОДУКТИВНІСТЮ ТА ПОЛІПШЕНОЮ ЯКІСТЮ ЗЕРНА

Вступ. Еколого-економічні реалії сьогодення змушують замислитися над шляхами розвитку аграрного виробництва. У найближчі роки передбачено створити сучасні високопродуктивні сорти та гібриди, які відповідають умовам клімату й реалізують свій генетичний потенціал на 70–75 %.

Проблематика. Селекція гексаплоїдних тритикале в сучасних умовах спрямована на підвищення врожайності, її стабільності, поліпшення якості зерна при збереженні комплексу адаптивних властивостей.

Мета. Аналіз створення генотипів тритикале з високою продуктивністю та поліпшеною якістю зерна.

Матеріали й методи. Використано польові, лабораторні та математично-статистичні методи дослідження зразків і гібридних популяцій гексаплоїдних тритикале різного еколого-географічного походження та типу розвитку.

Результати. Внутрішньовидовою гібридизацією тритикале $2n = 42 \times 2n = 42$ з різним типом розвитку було створено 26 сортів. З утворених комбінацій виділено низку ліній з більш пружною й одночасно еластичною клейковиною. Ці лінії стали основою для створення багатолінійних сортів хлібопекарського та універсального призначення з підвищеною якістю хліба 'Амос', 'Маркіян', 'Ніканор'. З гібридної популяції Раритет/НАД 7 виділено високопродуктивні тритикале заввишки 40–105 см та надзвичайно еластичною клейковиною. В посушливих умовах 2014–2020 рр. урожайність зерна кращих низькорослих сортів 'Тимофій', 'Пудік' та 'Єлань' становила в середньому 9,94–10,36 т/га, що перевищувало сорти тритикале 'Раритет' і 'Baltiko' та сорт пшениці м'якої 'Подольнка'. Найвищу якість клейковини, тіста та хліба виявлено в сортів 'Пудік' та 'Єлань' з субодиницею гліадіну $2^* - 7 + 8$.

Висновки. Застосування в селекційній практиці методу внутрішньовидової гібридизації в поєднанні з багаторічними випробуваннями гібридних популяцій та ліній у різних екологічних умовах дає змогу створювати короткостеблові високопродуктивні сорти тритикале озимого з поліпшеною якістю зерна, комплексним імунітетом до основних хвороб та високими хлібопекарськими властивостями.

Ключові слова: багатолінійні сорти, внутрішньовидова гібридизація, гексаплоїдні тритикале, селекція, хлібопекарські властивості.