УДК 631.524.83:631.524.85:633.112.1«324»

PRODUCTIVITY, ADAPTABILITY AND GRAIN QUALITY OF MODERN UKRAINIAN WINTER TRITICALE CULTIVARS*

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Поступила в редакцию 2 августа 2011 г. Принята к публикации 8 октября 2011 г.

Grain-type winter triticale cultivars were studied in comparative long-term (2000–2009) trials in two agroecological zones of Ukraine. Since 1977, 16 triticale cultivars have been enrolled into the register in Ukraine, and their potential productivity has increased by 1.52 t/ha. Specialized winter triticale cultivars with optimal combinations of productivity, adaptive properties and improved technological parameters of grain quality have been raised by intraspecific hybridization methods. High winter hardiness is observed in cultivars Amphidiploid 42, Amphidiploid 52, Amphidiploid 256, and Garne (scores 7.5–8.0), and improved drought tolerance, in Amphidiploid 44, Kapriz, Raritet, and Amphidiploid 256. New multi-line cultivars Garne and Raritet show relatively high baking quality and overpower standard cultivar Amphidiploid 256 by 79–192 % in flour strength, by 26–39 % in bread volume recovery, and by 180–190 % in the overall baking quality index.

Key words: triticale, breeding, adaptability, drought, winter hardiness, abiotic stress, tolerance, drought resistance index, baking quality.

Introduction

Significant achievement of modern genetics and plant breeding is the creation of triticale, cultivars of which successfully penetrate agricultural production. The increase of the sown area of the new grain and fodder crop is promoted by better compared to wheat (*Triticum aestivum* L.) adaptability, high and stable productivity, ample opportunities in grain use for food, technical and fodder purposes (Тритикале России, 2000).

Triticale cultivars are generally characterised by satisfactory baking properties (Борес, Раковська, 1990; Сокол и др., 2001; Tsvetkov, Stoeva, 2003; Сиволап и др., 2005). Winter cultivars, which at various times became widespread in Ukraine and Russia (Amphidiploid 206, Amphidiploid 3/5, Amphidiploid 60, Amphidiploid 42, Amphidiploid 256, ADM4, Papsuevske, Proryv, etc.) are distinguished by high amylolytic activity, thus form weak gluten. Bakers reluctantly use triticale flour, as to manufacture good quality bread it is necessary to employ a long fermentation process with use of leaven, or to improve baking technologies for the purpose of moderated amylase inactivation.

Poor baking properties of many hexaploid triticale cultivars are attributed to complete or partial absence of D-genome chromosomes. Some octoploid and R/D substituted 42-chromosomal forms show relatively better technological properties (Федорова и др., 1988; Anon., 1989). Such relationship is detected in individual samples and does not exclude participation of alternative genetic factors in the control of technological and baking qualities of triticale, which determine optimal composition and quality of polysaccharides and gluten proteins.

Demand for competitive triticale cultivars for food production in regions where sturdy and fine

* Работа была представлена на Международной научной конференции «Экология, генетика, селекция на службе человечества», Ульяновск, 2011.

wheat cultivars are grown is still considered as problematic (Комаров и др., 2008). However, necessity of improvement of baking properties of wheat-rye amphidiploids has no doubts and stipulates search for new approaches to breeding of new cultivars, which would form grain with stably improved quality characteristics, thus strengthen role of the new grain crop in national economy. Comparative analysis of productivity, adaptive properties, morpho-anatomic and technologic features of winter triticale cultivars of different breeding periods was the purpose of the present study.

Material and Methods

Cultivars of triticale (×*Triticosecale* Wittmack, 2n = 6x = 42) Amphidiploid 3/5, Amphidiploid 42,Amphidiploid 44, Amphidiploid 51, Amphidiploid 52, Amphidiploid 60, Amphidiploid 206, Amphidiploid 256, Garne, Ratne, Raritet, Yunga, Kapriz, Stephan, Russia, Ladne, Kharroza, Proryv, Valentin 90, Cornet, Lamberto, Moderato, and Aist; soft wheat (*Triticum aestivum* L.) Donetskaya 48, Odesskaya 267, Kharus, and Kharkovskaya 26; and rye (*Secale cereale* L.) Kharkovskaya 98, Khasto and Saratov, developed at the Yurjev Plant Production Institute of the Ukrainian Academy of Agrarian Sciences (YPPI) and other regions were studied in competitive field trials of the Department of Breeding and Genetics of Winter Triticale of the YPPI. Seeds were sowed using SSFK-7 seed drill on 10 m^2 plots in six repetitions with a rate of 4.5 million germinating seeds per hectare. Ecological cultivar trials in eastern forest-steppe (YPPI, Kharkov) and acute arid steppe (Seaside Experimental Breeding Station of the Laboratory of Agrochemistry, Ilyich Public Corporation, Mariupol) zones of Ukraine were sowed manually on 1 m^2 plots in triple repetitions with norm of seeding of 3 million per ha. Soil types were chernozem (forest-steppe) and sandy loam (steppe), fallow land as a forecrop; planting dates optimal for each zone (5–15 September in forest-steppe, 1–10 October in steppe). Frost resistance and winter hardiness were estimated in field conditions and in freezing chambers KNT-1 (Юрьев, 1938); drought tolerance – both in the field and in a 50 m^2 drought shelter (steppe) made from polyethylene film (Мусиенко и др., 1985). Winter hardiness was evaluated on a 9-point scale (9 = most resistant, 1 = most susceptible; Prášilová & Prášil, 2001). A drought resistance index (Dr) was calculated as the relation between the levels of a trait expression in the drought shelter to its expression on a natural background (Abdelmula *et al*., 1999), and homeostaticity according to Khangil'din (Хангильдин, 1978). Morpho-anatomic measurements and calculations were done on 20–100 plants of each cultivar using a microscope Biolam under × 18–96 lens magnification. Competitive field trials were harvested with Sampo-130 plot harvester and ecological trials manually, together with roots (extraction of roots was carried out from sandy soil using trenches, from depth up to 1.35 m). Grain quality parameters were determined as defined by the State Testing Methodology (Методи визначення показників ..., 2000).

Results and Discussion

All YPPI-bred triticale cultivars of the first and the second generation, except for Amphidiploid 256, are created by a stepwise intergeneric hybridisation using the scheme: bread wheat (2n = 42) / rye (2n = 14) // triticale (2n = 42). Cultivar Amphidiploid 256, as well as cultivars of the third generation registered during years 2004–2008, are created via intraspecific hybridisation at hexaploid level (2n = 42). New triticale cultivars in comparative trials have significantly exceeded yield potential of cultivars-predecessors. The greatest gain of grain yield (1.65 t/ha) was demonstrated by the third generation cultivar Garne (Table 1). Growth of triticale productivity has occurred due to change of different components of the crop yield structure, mainly due to increased stalk density and a number of grains per head and per plant (data not shown). Among cultivars of the second generation, the highest number of grains per head (71) and per spikelet (2.49) has cultivar Amphidiploid 256. In comparison with the first generation cultivar Amphidiploid 206, homeostaticity of a head of Amphidiploid 256 is higher by 37 % (spikelets) to 170 % (grain). Triticale of the third generation are characterised by significantly higher productive tilling capacity (+4.3 to 14.2 %), number of grains per head (+6.9 to 45.1 %), its homeostaticity (+36.7 to 48.7 %), and mass of grain per plant (+2.2 to 25.8 %).

The higher survival rate of triticale is stipulated by a better (compared to that of wheat) tolerance to adverse environmental factors. During breeding of

Table 1

Productivity of winter triticale of different cultivar changes (YPPI, competitive cultivar trials)

Cultivar change	Cultivar	Year of registration	Grain yield by years*, t/ha										Increase from the previous cultivar change	
			2000	2001	2002	2003	2004	2005	2007	2008	2009	mean	t/ha	%
I	Amphidiploid 206	1977	6.2	4.8	5.2	2.9	4.0	5.7	5.2	5.4	4.8	4.91		
	Amphidiploid 60	1988	6.4	5.1	5.3	2.0	4.4	5.7	4.9	5.7	4.6	4.90		
	mean	–	6.3	4.9	5.3	2.5	4.2	5.7	5.1	5.6	4.7	4.91	n.a.	n.a.
II	Amphidiploid 42	1996	6.3	6.7	6.5	3.2	4.7	6.2	5.2	7.2	5.9	5.77		
	Amphidiploid 52	2000	7.3	5.7	6.4	3.1	4.5	5.9	6.2	5.3	5.7	5.57		
	Amphidiploid 256	2001	7.3	5.6	6.9	3.7	5.2	5.8	6.0	5.8	6.1	5.82		
	mean	–	7.0	6.0	6.6	3.3	4.8	6.0	5.8	6.1	5.9	5.72	0.81	16.5
III	Garne	2004	8.5	7.1	6.9	3.7	5.4	6.9	6.9	7.1	6.5	6.56		
	Ratne	2007	8.5	7.2	6.8	3.1	5.4	6.7	6.1	7.3	6.6	6.41		
	Raritet	2008	7.9	6.5	6.8	3.2	6.1	6.1	5.7	7.4	7.1	6.31		
	mean	–	8.3	6.9	6.8	3.3	5.7	6.6	6.2	7.3	6.7	6.43	0.71	12.4
Wheat**			5.0	4.1	4.8	0.3	4.2	5.5	5.0	6.5	6.0	4.60	n.a.	
Rye***			6.1	6.6	5.8	1.6	5.1	5.6	5.7	6.0	6.3	5.42	n.a.	
$LSD_{0.05}$			0.31	0.48	0.40	0.52	0.39	0.28	0.41	0.49	0.44	0.41	n.a.	

* Results of the 2006 season trials are excluded due to crops damage by hail; ** 2000–2005 – Donetskaya 48; 2007–2009 – Odesskaya 267; *** 2000–2005 – Kharkovskaya 98; 2007–2009 – Khasto.

more productive genotypes triticale, it was possible to preserve their adaptive potential, including frost and winter hardiness. Under conditions of 2003 season (ice crust, lowest temperature at tillering node –17 °C), against the background of wheat winterkill, high winter hardiness (7.5–8.0 points) was demonstrated by cultivars Amphidiploid 42, Amphidiploid 52, Amphidiploid 256 and Garne. Cultivars Ratne and Raritet concede to these genotypes 0.5 points in their winter hardiness and 1.0–1.5 °C in frost resistance. It is remarkable that triticale created by hybridisation of winter forms with spring and facultative forms have high (Amphidiploid 256, Garne) and heightened (Amphidiploid 44, Ratne, Raritet) levels of frost and winter hardiness.

Among the complex of adaptive properties, that limit efficiency of triticale plants it is necessary to single out drought tolerance. Successful search for thermo-tolerant genotypes depends on many biotic and technological factors, e.g. presence of suitable provocative background, a method of creation and duration of study of an initial material, morpho-physiological features of components of created breeding populations.

In terms of ear emergence, the first-generation triticale cultivars are relatively early maturing (period from resumption of the spring growth to ear emergence 53–58 days), and in terms of the duration of vegetative period are mid-ripening (285–292 days). In the process of breeding and selection, there was a lengthening of the period of active photosynthetic activity of triticale plants. In ecological study (seasons 2006–2007) in the conditions of steppe on a natural background cultivars Amphidiploid 60 and Amphidiploid 206 eared on 17–18 of May, the rest of triticale cultivars 1–7 days later, and winter wheat on 19–21 of May.

In a drought shelter, air temperature from a booting phase onwards was higher than ambient by 7.5 °C to 15.0 °C, which has accelerated plants development, and has affected their productivity and crop harvest structure. The period from ear emergence to full ripeness was within 38–44 days (on the average 41 days for triticale and 38 days for wheat), which is 3–5 days shorter compared to a natural background.

Under the conditions of an artificial drought, accumulation of the aboveground biomass of plants has considerably decreased. Decrease in productive tilling capacity was 20.7 % for triticale, and 14.3 % for wheat. The height of triticale plants has decreased on average by 8.9 % with a variation from 3.3 % (Amphidiploid 60) to 16.7 % (Lamberto). Stalks shortening of wheat plants were between 4.0 % (Kharus) to 7.6 % (Odesskaya 267).

Ability of plants to develop vigorous root system in the lower layers of soil under water-deficit conditions is an important indicator of drought tolerance. Winter triticale are characterised by considerable differences in roots weight that influences the water status and plants productivity. Under natural conditions the weight of dried roots of one triticale plant (on the average for different cultivars) was 1.493 g. Corresponding value of the trait in the drought shelter was higher by 22.7 % and varied between 1.718 g (Amphidiploid 52) to 2.058 g (Raritet). Cultivars Amphidiploid 256, Raritet, Garne, Stephan, Kapriz and Odesskaya 267 had higher (by 29.9–38.4 %) roots weight. Cultivars Amphidiploid 42, Amphidiploid 52, Amphidiploid 60, Ratne and Yunga have increased underground weight by only 14.0–16.0 %. By the index of drought tolerance of root system stood out soft wheat Odesskaya 267 and triticale Raritet (Dr = 0.72–0.73). Drought sensitivity of the underground biomass of cultivars Amphidiploid 60 and Ratne was appreciably higher (Dr = 0.86–0.88).

Under drought-stressed conditions, thousand-kernel weight (TKW) of winter wheat has decreased by 5.4 % (Odesskaya 267) to 19.1 % (Kharus), while TKW of triticale has decreased on the average by 13.8 %. The TKW of triticale cultivars Amphidiploid 44, Amphidiploid 256, Raritet, Yunga and Kapriz has changed by only 4.0–7.5 % (Dr = 1.06–1.08). Shrivelled and lightweight grain was formed by cultivars Amphidiploid 51, Lamberto and Amphidiploid 52 (–24.3 % to –25.1 %, Dr = 1.32–1.34).

The grain yield of triticale in the drought shelter has averaged 315 g·m^{-2}, which is 18.1 % lower compared to a natural background. The drought-tolerant wheat cultivar Odesskaya 267 on a natural background had grain yield of 397 g·m^{-2} and has conceded to the best triticale Garne, Amphidiploid 256 and Kapriz accordingly by 11.8, 20.3 and 23.5 %. In the drought shelter differences have somewhat decreased (respectively 377 g·m^{-2} and 6.0, 14.1 and 18.4 %), which confirms high potential of drought and thermal tolerance (Dr = 1.05) of the wheat cultivar created by D.A. Dolgushin in the South of Ukraine. Improved drought tolerance of triticale Amphidiploid 44, Kapriz, Raritet and Amphidiploid 256 (Dr = 1.08–1.13) to a certain degree is stipulated by their origin: Kapriz was bred in a droughty zone of the Rostov region, Russia (Тритикале России, 2000), and the others are multi-linear cultivars, initial lines of which are selected in acute-droughty conditions of the Azov Sea region, Ukraine (Щипак, 2008).

In the drought shelter from action of high temperatures and water deficiency on sandy-loam soil have strongly suffered (especially during the period of grain setting and filling) cultivars Lamberto, Stephan, Amphidiploid 51, Ratne and Amphidiploid 206 (reduction of yield 24.5–28.8 %, Dr = 1.32–1.40). Decreased productivity of these cultivars is caused by insufficient water-retaining capacity of plants, vulnerability of their generative systems to extreme environmental conditions that has led to decreased number of grains per ear and to formation of shrivelled grain.

Investigated forms of triticale did not demonstrate close relationship of leaf size to productivity and adaptive properties. Flag leaf area of triticale cultivars averaged 24.1 cm^2, wheat 18.4 cm^2 (Kharus) and 18.7 cm^2 (Odesskaya 267), and winter rye (Khasto) 8.3 cm^2. With an exception of the another-region cultivar Kapriz with the flag leaf area of 17.3 cm^2, highly productive genotypes, irrespective of growth conditions had large, dark green leaves with a thick waxy layer: Amphidiploid 256 – 28.1 cm^2, Garne – 27.4 cm^2, and Raritet – 28.1 cm^2. Large flag leaf is also characteristic to the first grain triticale cultivar Amphidiploid 206 – 29.3 cm^2. Among the small-leaved forms were available both drought-tolerant (Yunga, Amphidiploid 44; 15.7–20.0 cm^2) and drought-sensitive (Amphidiploid 52, Lamberto; 15.0–18.6 cm^2) cultivars.

Breeding of winter triticale for higher yielding potential is inseparably linked to perfection of the plant organism as a whole, including its fibro-vascular system. Studied triticale cultivars are non-uniform regarding the quantity of large fibro-vascular bundles, and the range of variation for this trait is considerably wider than in its parental crops. Tall triticale Amphidiploid 3/5, Amphidiploid 44, Ladne, Stephan and middle-height highly productive cultivars Garne and Kharroza develop powerful conductive system comprising of 53–62 large bundles; cultivars Amphidiploid 60, Ratne, and Raritet have only 38–40 bundles. On average triticale have 49, winter wheat 45, rye Saratov 6 and Khasto between 48 to 56 bundles.

Bread-making qualities. Quality of triticale grain is studied at the YPPI for more than 35 years. To date was analysed about 7200 breeding lines and cultivars that were created mainly by methods of distant and intra-specific hybridisation. After intergeneric hybridisation and genetic «explosion» under the scheme [F_1(wheat/rye)] // triticale, it was not possible to select complex-valuable forms with heightened baking properties. Reduction of negative influence of the R genome and better harmonisation of wheat and rye proteins in triticale was achieved by a method of stepwise intraspecific hybridisation with the subsequent lasting selection assessment. That has given the chance to derive wheat-rye amphidiploids with an alternative type of development with improved and stable levels of expression of some quality characteristics of flour, dough, bread, and mixing ability (Щипак, 1998). Out of populations derived from hybridisation of facultative and winter forms during consequent long-term selections were created winter cultivars and breeding lines of triticale, that are close to wheat regarding proportion of protein fractions. However, selections of individual elite plants did not yet result in creation of triticale cultivars with the high-level balanced gluten quality. In the meantime, it was proved possible to improve technological properties of synthetic cultivars, which were created by aggregation of the suitable lines selected from the same or different hybrid combinations (Щипак и др., 2009).

Search for the optimal line mixtures has led to creation of two multi-line cultivars with improved baking properties: Garne, which is included into the Register of Plant Cultivars of Ukraine (since 2003) and Russia (since 2009), and Raritet that is registered in Ukraine since 2008.

Cultivar Garne is created by aggregation of 260 morphologically similar lines that have been selected from two related hybrid populations derived from crossing of winter and spring triticale of a different origin: Malno (Poland), Kubanets (Russia), 2059 p[11] (USA), and Amphidiploid 3/5 (Ukraine). Improvement of technological properties of the cultivar Garne is caused by elasticity of the gluten complex that has a higher gliadin and gluthelin content, moderate activity of α-amylase because of prevalence in the population of lines with a falling number of 250–350 s.

Cultivar Raritet has in its pedigree the following hexaploid triticale: winter Amphidiploid 3/5, Amphidiploid 206, Amphidiploid 547 (Ukraine); facultative Amphidiploid 77, Amphidiploid 77/75, Amphidiploid 8/192 (Ukraine); spring 6TA 418 (USA), Kharkovskiy 41, and Aist (Ukraine). During field trials in conditions of forest-steppe and acute arid steppe (seasons 1993–2003) from the created hybrid population were selected 51 highly-adaptive lines with contrasting quality parameters: gluten deformation index (GDI) 45–120 units, falling number 236–394 s, dough elasticity 40–95 mm, and tensile strength 30–110 mm. Modification of technological properties and positive mixing effect occurs as the result of interaction of contrasting protein complexes, characterised by improved gluten elasticity of some lines and unique tensile strength of the other, in this case derived from the same hybrid combination. Since 2002 the genetic basis of the cultivar Raritet is comprised by lines with parameters of dough tensile strength of up to 79–86 mm, which has promoted formation of a balanced gluten complex (77 mm elasticity, 83 mm tensile strength of dough), improved flour strength (222–275 alveograph units) and production of high-quality bread (9 points). During quality tests all technological parameters of the multi-line cultivar Raritet were the best among triticale assortment of the YPPI and other breeding establishments (Tables 2 and 3). Cultivars Garne and Raritet exceed standard Amphidiploid 256 in their flour strength by 79–192 %, in volumetric bread recovery by 26–39 %, and in general baking rating by 180–190 %.

Conclusions

Application of methods of intraspecific hybridisation has provided for creation of specialised cultivars of winter triticale with an optimal combination of productivity, adaptive properties and improved technological parameters of grain quality. Substantial improvement of baking qualities of the new triticale cultivars Garne and Raritet is reached on a multi-line genetic basis by aggregation of purposefully selected morphologically

Table 2

Grain quality of triticale and wheat (2001–2008 average)*

Cultivar	Grain protein content, %	Gluten		Dough			Flour strength, alveograph units	Bread	
		Content in flour, %	GDI units	Elasticity (P), mm	Tensile strength (L), mm	P/L		Volume, mL	Overall bread making rating, points
Winter triticale									
Amphidiploid 256**	10.7	15.8	77	44	39	1.1	62	358	4.8
Raritet	11.2	18.3	47	66	76	0.9	181	498	9.0
Garne	10.7	20.2	70	50	61	0.8	111	452	8.5
Spring triticale									
Aist**	13.4	20.8	58	49	68	0.7	108	385	6.0
Winter wheat									
Kharus**	11.8	27.0	57	83	80	1.0	269	570	7.2
Spring wheat									
Kharkovskaya 26**	13.4	32.2	90	60	101	0.6	172	483	4.8

* Results of the 2006 season trials are excluded due to crops damage by hail; ** the national standard of Ukraine.

Table 3

Grain quality characteristics of winter triticale cultivars
(competitive trial, average for 2008–2009 seasons)

Cultivar	Year of registration	Country	Grain-unit, g L^{-1}	Content, %		Gluten quality, GDI units	Dough, mm		Flour strength, alveograph units	Bread volume recovery, mL	Baking evaluation, points
				protein	crude gluten		elasticity	tensile strength			
Amphidiploid 206	1977	Ukraine	692	14.1	23.6	97.5	44.5	64.0	94.5	430	7.0
Amphidiploid 256	2001	Ukraine	672	12.7	20.6	77.5	49.5	67.5	111.0	360	6.0
Raritet	2008	Ukraine	776	11.6	16.4	49.0	76.5	83.0	275.0	595	9.0
Proryv	2004	Russia	732	11.9	20.8	62.5	43.0	77.0	107.5	460	8.1
Valentin 90	2007	Russia	724	12.1	23.2	60.0	52.0	115.0	190.0	470	8.6
Kornet	2006	Russia	712	11.2	22.4	82.5	39.5	75.5	101.5	425	7.7
Lamberto	2003	Poland	724	11.8	17.6	75.0	42.0	67.0	92.0	390	7.4
Moderato	2004	Poland	724	11.6	19.6	90.0	55.0	72.0	131.0	360	5.5
Odesskaya 267 (wheat)	1997	Ukraine	788	13.2	26.3	55.0	91.0	109.0	412.0	610	9.0

homogeneous lines with contrasting parameters of gluten and dough qualities. Multi-line cultivars, as complex genetic and coenotic systems, manifest greater buffering capacity to changing environmental conditions, which secures an opportunity of grain formation with stably high for triticale baking properties.

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ПРОДУКТИВНОСТЬ, АДАПТИВНОСТЬ И КАЧЕСТВО ЗЕРНА СОВРЕМЕННЫХ УКРАИНСКИХ СОРТОВ ОЗИМОЙ ТРИТИКАЛЕ

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Приведены результаты сравнительного изучения (2000–2009 гг.) в двух агроэкологических зонах сортов озимых зерновых тритикале, выведенных в Институте растениеводства им. В.Я. Юрьева. За период с 1977 г. в Украине зарегистрировано 16 сортов тритикале, урожайность возросла на 1,52 т/га. Новые многолинейные сорта Гарнэ и Раритет имеют высокие для пшенично-ржаных амфидиплоидов хлебопекарные свойства и превышают стандарт Амфидиплоид 256 по силе муки на 79–192 %, объемному выходу хлеба на 26–39 %, общей хлебопекарной оценке на 180–190 %.

Ключевые слова: тритикале, селекция, адаптивность, засуха, зимостойкость, абиотические стрессы, толерантность, индекс засухоустойчивости, хлебопекарные качества.