REALIZATION OF PRODUCTIVITY POTENTIAL AND COMPETITIVENESS OF WINTER WHEAT VARIETIES IN MIXTURES

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INTRODUCTION

Winter wheat breeding has made recent progress in improving the individual productivity of plants by applying various methods for selecting genotypes in hybrid populations. As a result, the vast majority of modern wheat varieties are pure lines in comparison to the old multi-line varieties[1]. The advantages of one-genotype variety are obvious: high productivity of the plants in favorable environments for the genotype, total resistance of plants to certain pathogens, genetically determined resistance to certain abiotic factors, simultaneous passage of organogenesis phases. Nevertheless, the successful implementation of the genotype into high yield results is possible only under sufficiently favorable growing conditions for its growth and development, which may limit the cultivation area of this variety[2]. Farmers in regions with unsustainable farming conditions often mix two or more different varieties to ensure future crop stability[3]. This practice is being successfully developed and applied in various climatic conditions[4,5] around the world. Among the advantages of varietal mixtures, their ability to withstand the spread of diseases due to the combination of varieties with resistance to various races of the pathogen comes to the first place[6,7,8,9]. Also,

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there is an increase in the competitive ability of mixed varieties to weeds[10,11]. In some studies, a 10−20% of increase in the yield of mixtures in comparison with their pure varietal counterparts is noted, especially under stressful environmental conditions, while in favorable years there are no significant differences[12].

Currently, there are three different points of view on the relationship between the competitiveness of a genotype in mixture and its productivity in pure line: 1) the productivity of a variety is negatively related to its competitive ability, therefore, in breeding, preference should be given to slightly competitive varieties tolerant to high density growing[13,14,15,16,17] in these cases, aggressive genotypes suppress others which are high productive in pure line and effective selection from the mixture in the presence of competition is impossible; 2) some researchers note that there is no connection between the productivity of a genotype in pure line and its competitive ability in a mixture[18]; 3) others note this relationship is positive[19].

The effects of intraspecific genotype competition between plants in agrocenosis sometimes play a key role, but, unfortunately, are not taken into account in breeding practice, which significantly reduces and sometimes

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nullifies the selection efficiency in the early breeding stages[20]. With growing winter wheat plants in a selection nursery with generally accepted density, the variability will be mainly determined by the genotype variance of competitive ability, which suppresses genotype expression[21,22]. With low density plant growing the competition between plants for soil and air nutrition and moisture is reducing or completely eliminating, which is actually practiced in breeding. In this case, one of the reasons of low efficiency of individual selection is ignoring the coenotic component of the productivity of agrophytocenosis, because selection is carried out at organism level, and the final assessment of breeding material in variety testing is carried out on coenotic level[23]. So, it was shown that plants with high potential productivity are not sources of highly productive populations[24,25].

Thus, in increasing the efficiency of selection, the main problem is the identification of the genotype by phenotype, to solve which it is most important to remove the "noise" of environmental and genotypic competition. "Noise" usually means the variability that prevents extrapolating the productivity of an individual plant in population to the productivity of a unit area of cenosis[26,27,28.]

1. Productivity of wheat plants
under intraspecific genotypic competition

The objective of this study was to investigate the possibility of realization of productivity by wheat plants in conditions of intraspecific

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genotypic competition. In this study, we assessed the competitiveness of four varieties of winter wheat on the basis of our own experiments and theoretical developments, we set the following goals: to describe the competitiveness of the varieties of winter wheat and the relationship of competitiveness with yield and some agronomic parameters and indices used in breeding; c) to search for simple traits and more complex indices that could play the role of markers of plant productivity for the selection both in the presence and absence of competition; d) to study the possibility of using component mixtures of low-competitive varieties with different levels of quality in the technology of growing winter wheat in order to increase productivity.

The experiment was carried out at the research field of Plant Breeding Centre of Poltava State Agrarian Academy in Poltava region of Ukraine in 2017−2018. This region is situated in Forest-Steppe climatic zone of Ukraine with 562 mm of annual rainfall, characterized by continental climate with frost winters, spring delays and summer droughts and in whole by very unstable environmental conditions.

As a material for research, four winter wheat varieties were taken: Levada, Redut, Dolya and Venera. The seeds of each variety were sown: (i) in mixtures according to the diallelic scheme; (ii) in mixture of four varieties in equal quantities and (iii) in pure variety. The plot size was 16.5 m^2, four replications.

Before harvesting, 50 plants of each variety from mixture plots and 50 plants from pure varieties plots were randomly selected for measuring agronomic parameters: productive tillering (PT), plant height (H), grain weight per ear (GW), dry stem weight (SW). The some indices were used for plant productivity study: linear ear density (LED) = number of grains per ear / ear length, Poltavskii index (PI) = grain weight per ear / last internode length[29].

The competitiveness of winter wheat varieties was determined, on the one hand, as the change of trait value of variety in mixture in comparison with trait value of pure variety (ΔXi), and on the other hand, as the change of trait value in mixture of varieties in comparison with the value of this trait in pure varieties (ΔXj). In this experiment, trait values were calculated as follows for each variety:

$$\Delta XiL = (XL(D) + XL(R) + XL(V))/ 3XL(L) \cdot 100\text{-}100, \qquad (1)$$

$$\Delta Xj = (XD(L) + XR(L) + XV(L))/ (XD(D) + XR(R) + XV(V)) \cdot 100 – 100, \quad (2)$$

where, ΔXiL is the deviation of trait of variety L in mixture from pure line; XL (D) ... XL (V) − variety L in mixtures with other varieties; XL (L) − pure variety L; ΔXjL − deviation of varieties in mixtures with variety L from

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pure lines; XD (L) ... XV (L) − varieties in mixtures with variety L; XD (D) ... XV (V) − pure varieties.

Coefficient of competitiveness (CC) of varieties in four-component mixture was calculated by the formula:

CC = Xmix / Xmono, (3)

where Xmix is the trait value for each variety in the mixture, Xmono is the trait value in pure line. To determine the effects of + or - compensation the plant productivity of variety mixtures was compared with the plant productivity of pure varieties.

Table 1 shows the characteristics of the varieties used in the experiment by yield and the most important quantitative characteristics and indices. By yield, the varieties in descending order were as follows: Levada, Venera, Redut, Dolya. According to other characteristics and indices, the arrangement of varieties was somewhat different (Table 1). Levada was superior to other varieties also in such a valuable traits as productive tillering winter hardiness.

Table 1

Characteristics of winter wheat varieties involved in the study

Traits and indices	Varieties			
	Levada	Dolya	Redut	Venera
Type	Erithrospermum	Ferrugineum	Erithrospermum	Lutescens
Yield, t/ha	6,18	4,12	5,45	5,94
Vegetation period	middle-ripening	early-ripening	middle-ripening	middle-ripening
Productive tillering (PT)	5,1	4,3	4,3	4,1
Plant height (PH), cm	95	89	90	99
Grain weight /ear (GW), g	1,6	1,2	1,6	1,6
Stem weight (SW), g	1,2	1,2	1,3	1,6
Linear ear density (LED)	4,3	3,9	4,4	3,9
Poltavskii index (PI)	5,1	4,6	3,0	5,1
Winter hardiness, score from 1 to 9	9	8	8	7

Table 2 presents results of study of competitiveness of winter wheat varieties in mixtures and pure line by some agronomic parameters and indices.

Grain weight/ear (GW). According to estimation the difference of GW in mixture and pure variety, the lowest-yielding variety Dolya had the highest competitiveness ΔXi, and the highest-yielding Levada variety had the least negative competitiveness. Venera's competitiveness ranked second and had a significant excess in GW in mixture compared to pure variety, and Redut showed zero competitiveness, i.e. there was no difference between mixture and pure variety. This result is confirmed by the analysis of ΔXj.

The highest increase in GW of varieties was observed in a mixture with Levada, and the lowest − in mixture with Venera and Dolya.

Competitiveness of winter wheat varieties
by agronomic parameters and indices

Variety	Levada	Dolya	Redut	Venera	ΔXi	ΔXj
Grain weight/ear (GW), g						
Levada	1,6	1,6	1,4	1,6	- 4,167	20,455
Dolya	1,5	1,2	1,5	1,4	22,222	4,167
Redut	1,8	1,6	1,6	1,4	0,000	11,364
Venera	2,0	1,8	1,8	1,6	16,667	0,000
Stem weight (SW), g						
Levada	1,2	1,2	1,0	1,2	- 5,556	19,512
Dolya	1,4	1,2	1,4	1,2	11,111	0,454
Redut	1,6	1,4	1,3	1,2	7,672	7,500
Venera	1,9	1,7	1,9	1,6	14,583	2,703
Linear ear density (LED)						
Levada	4,3	4,3	4,6	4,6	4,651	8,197
Dolya	4,4	3,9	4,3	4,7	14,513	- 0,794
Redut	4,4	4,2	4,4	4,0	- 4,545	7,438
Venera	4,4	4,0	4,1	3,9	6,838	5,263
Poltavskii index (PI)						
Levada	51	55	49	48	- 0,654	40,945
Dolya	61	46	59	55	26,812	26,515
Redut	57	55	30	43	72,222	10,135
Venera	61	57	55	51	13,072	19,685
Productive tillering, pc.						
Levada	5,1	5,0	4,2	4,4	- 11,111	7,087
Dolya	4,2	4,3	3,8	3,6	- 10,078	0,000
Redut	4,7	4,5	4,3	3,7	0,000	- 15,556
Venera	4,7	4,0	3,6	4,1	0,000	- 14,599

Coefficient of competitiveness (CC) had shown that genotypes with CC > 1 had increased trait parameters in mixtures in comparison with pure varieties. Genotypes with CC < 1, respectively, had reduced trait parameters in mixture compared to pure varieties (Table 3). Thus, varieties Venera and Dolya had a positive competitiveness (> 1), and varieties Redut and Levada – negative (< 1), that confirmed results from ΔXi and ΔXj.

Stem weight (SW). According to estimation the ΔXi and ΔXj values, the highest competitiveness ΔXi was observed in Venera variety; Dolya and Redut varieties also had positive competitiveness. High-yielding variety Levada had as negative competitiveness as in GW. These results are fully confirmed by the results of CC in 4-components mixture.

Table 3

Coefficient of competitiveness (CC) of winter wheat varieties in 4-components mixture by agronomic parameters and indices

Variety	GW			SW			LED			PI			PT		
	Mix	Pure	CC	Mix	Pure	CC	Mix	Pure	CC	Mix	Pure	CC	Mix	Pure	CC
L*	1,4	1,6	0,88	1,0	1,2	0,83	4,1	4,3	0,95	4,7	5,1	0,92	3,8	5,1	0,75
D*	1,3	1,2	1,08	1,2	1,2	1,0	4,0	3,9	1,03	5,1	4,6	1,11	4,1	4,3	0,95
R*	1,5	1,6	0,94	1,3	1,3	1,0	4,2	4,4	0,96	4,7	3,0	1,57	3,6	4,3	0,84
V*	2,0	1,6	1,25	1,9	1,9	1,19	4,3	3,9	1,10	6,2	5,1	1,22	3,5	4,1	0,85
Av	1,55	1,5	1,03	1,35	1,35	1,02	4,15	4,13	1,01	5,18	4,45	1,16	3,75	4,45	0,84

* L– Levada, D – Dolya, R – Redut, V – Venera

Linear ear density (LED). The highest positive competitiveness ΔXi in linear spike density (LED) was in Dolya variety, then Venera and Levada, and the lowest negative competitiveness was in Redut variety. According to the 4-components mixture, the positive CC had varieties Dolya and Venera, and Levada and Redut had negative CC, although the difference between all varieties in mixture and pure varieties was small. In other words, LED has reacted weakly to the presence or absence of genotype competition.

Poltavskii index (PI). A detailed description of this new index is given by, which was successfully used for selection of winter wheat genotypes at early breeding stages. Variety Redut has showed high competitiveness ΔXi by PI in mixture, but in pure variety PI was low (3.0) compared to 4.6 ... 5.1 in other varieties. A negative low ΔXi and high positive ΔXj of PI of Levada variety has indicated the extremely low competitiveness of Levada by this valuable selection index. Varieties Dolya and Venera had a positive average competitiveness ΔXi of PI. This distribution of varieties in diallelic mixtures completely coincides with their assessment in 4-component mixture. On average, the value of PI in mixtures had significantly exceeded pure varieties on 14%. It should be noted that the differences between the varieties by

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competitiveness of Poltavskii index (PI) are more significant than by the parameters discussed above.

Productive tillering (PT). This valuable selection trait was characterized by the fact that all varieties in two-component mixtures turned out to be uncompetitive. A similar and even clearer result was obtained in a 4-component mixture - all 4 varieties had CC < 1. On average, the value of PT in mixtures was less than in pure varieties by 18,7%.

Among the 4 winter wheat varieties studied, significant differences were noted in competitiveness. The effect of competition on five traits and indices related to grain productivity was studied. By such parameters as, grain weight / ear (GW), stem weight (SW) and breeding indices (Poltavskii index (PI) and index of linear ear density (LED)), significant differences were noted between varieties competitiveness. According to GW and LED, the most plus-competitiveness was possessed by the lowest-yielding, early-ripening, short-stem variety Dolya; the plus-competitiveness on these traits was shown by the relatively high-yielding variety Venera; the lowest negative competitiveness was observed in the high-yielding variety Levada and medium-yielding variety Redut. Blending of varieties adversely affected the productive tillering of all varieties in which negative competitiveness was observed on this trait.

Overcompensation (+ ; -). The effects of overcompensation were determined by the deviation of the actual yield of mixtures from the theoretical yield, calculated by the average yield of pure varieties. If the actual yield exceeded the theoretical one, it was interpreted as plus-overcompensation, and if the actual yield was lower than the theoretical one, then it was attributed to minus-overcompensation. As can be seen from Table 4, in most combinations of mixtures an overcompensation effect was observed, and Levada+Venera mixture had highest yield that was exceeded any pure variety. In comparing the actual yield of mixture with the yield of the best component in mixture, either the absence of reliable over-compensation or the presence of negative over-compensation was recorded.

When comparing actual and theoretical productivity, the positive over-compensation was noted in five combinations of mixtures, and the negative over-compensation was noted only in two combinations. The mutual inhibition of the components was especially strong in the Levada+Redut mixture (- 81.3%). For practical purposes, only the Levada+Venera combination can be present of certain interest.

It is known that plants with high potential productivity are not sources of highly productive populations, which is due to the effects of intraspecific genotype competition between plants in agrocenosis, which sometimes play a decisive role, but, unfortunately, are often not taken into account in breeding practice, which significantly reduces, and sometimes reduces to zero, the selection efficiency in the early breeding stage. For increasing the efficiency of selection, the main problem is the identification of the genotype

by phenotype, to solve which it is important to remove the "noise" of environmental and genotypic competition. "Noises" usually mean the variability that prevents extrapolating the productivity of an individual plant in population to the productivity of a unit area of cenosis[30].

Overcompensation effects defined by comparing the yield of varieties in pure line and mixture

№	Mixture of varieties	Yield of mixture, t/ha	± to the best variety		± to the average of varieties	
			t/ha	%	t/ha	%
1	Levada + Dolya	5,58	- 0,60	- 10,8	+ 0,43	+ 7,7
2	Levada + Venera	6,66	+ 0,48	+ 7,2	+ 0,60	+ 9,0
3	Levada + Redut	3,21	- 2,97	- 92,5	- 2,61	- 81,3
4	Dolya + Redut	4,24	- 1,21	- 28,5	- 0,55	- 13,0
5	Dolya + Venera	5,94	0,0	0,0	+ 0,91	+ 15,3
6	Redut + Venera	5,88	- 0,06	- 1,0	+ 0,46	+ 7,8

2. Variability of quantitative traits of winter wheat varieties in mixture and in pure-lines

This report presents the results of studies of 4 varieties of winter wheat in its pure form and in diallelic mixtures with respect to the average yield of "pure components" and shows the formation of grain quality in component mixtures, which is very important in the milling and baking industries.

In the experiment of this report in pure and competitive mixtures, the yield of varieties was calculated. The highest yield in pure-lines was noted in the variety Radyvonivka, which amounted to 5.93 t/ha. The lowest yield in pure-lines in the experiment was in the variety Sharada, the level of which was 4.37 t/ha, that is, 1.56 t/ha less than the variety whose yield was maximum.

Yield of winter wheat varieties in pure-lines and mixture (t/ha)

Variety	Sharada	Ariivka	Karmelyuk	Radyvonivka	Mixture of 4 varieties
Sharada	*4,37*	4,60	4,33	4,70	6,37
Ariivka	4,60	*4,37*	4,80	4,97	6,37
Karmelyuk	4,33	4,80	*5,67*	5,10	6,37
Radyvonivka	4,70	4,97	5,10	*5,93*	6,37

A high level of productivity was noted in mixtures (Radyvonivka + Karmelyuk) − 5.10 t/ha; (Radyvonivka + Ariivka) − 4.97 t/ha; (Karmelyuk + Ariivka) − 4.80 t/ha; (Sharada + Ariivka) − 4.60 t/ha; (Sharada + Radyvonivka) − 4.70 t/ha. In the experiment, such a feature was noted that

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30 Essah S.Y.C., Stoskopf N.C. Mixture performance of phenotypically contrasting barley cultivars. Can. *J. Plant Sci.* 2001. № 82. P. 1−6.

some varieties in mixtures increased the yield by experience, and in some they decreased. So, the varieties Sharada, Ariivka in mixtures: Sharada + Ariivka; Sharada + Radyvonivka; Ariivka + Karmelyuk; Ariivka + Radyvonivka increased productivity according to the pure-lines, and in mixtures Karmelyuk + Sharada; Karmelyuk + Ariivka; Karmelyuk + Radyvonivka, on the contrary, yield according to the pure-lines decreased.

Plus compensation in relation to the average yield of "pure components" was observed in four mixes, with an excess of 0.44 to 2.00 t/ha. The results of plus compensation can be used both in the practical cultivation of varieties-mixtures (Sharada; Ariivka; Karmelyuk; Radyvonivka), and to create multi-linear varieties. We believe that with the involvement of a wider range of varieties and breeding lines of winter wheat in the study, it is possible to select components for mixtures that provide increased yield, crop stability and higher grain quality.

One of the main traits of the yield potential is the grain weight per ear. In the experiment, the level of formation of this trait ranged from 1.18 g (Charada + Ariivka) to 1.26 (Sharada + Karmelyuk) (Table 6). Only 2 cases were noted when a decrease in grain weight was observed in 2 component mixtures (Sharada + Ariivka) and 4 component mixtures (Sharada + Ariivka + Radyvonivka + Karmelyuk) by 0.9 ± 0.4 g, and in other cases it increased in relation to pure-lines.

Table 6

Variability of productivity parameters of winter wheat variety Sharada in pure-line and in mixtures

Parameters	Sharada pure-line	Sharada + Ariivka	Sharada + Karmelyuk	Sharada + Radyvonivka	4-varieties mixture
Y(t/ha)*	4,37	4,33	4,80	5,10	6,37
H (sm)	74,8 ± 1,4	72,5 ± 0,8	66,9 ± 1,6	69,4 ± 1,1	72,2 ± 1,2
TSI	3,4 ± 0,1	3,5 ± 0,1	3,4 ± 0,1	3,4 ± 0,1	3,2 ±0,1
EL	4,9 ± 0,1	4,9 ± 0,1	4,9 ± 0,1	4,9 ± 0,1	4,6 ± 0,1
SE	16,3 ±0,3	17,1 ± 0,3	17,5 ± 0,2	17,2 ± 0,3	16,3 ± 0,3
GW	1,21 ± 0,1	1,18 ± 0,01	1,26 ± 0,03	1,24 ± 0,01	0,90 ± 0,04
GE	37,4 ± 1,6	39,8 ± 1,6	39,5 ± 1,0	39,6 ± 1,1	30,6 ± 1,3
TGW	32,2 ± 0.6	29,8 ±0,8	31,8 ± 0,6	31,6 ± 0,8	29,5 ± 1,2

Y – , t/ha; H – plant height, sm; TSI – thickness of the second internode, mm; EL – ear length, sm; SE – number of spikelets per ear, pc.; GW – grains weight per ear, g; GE – grain number per ear, pc.; TGW – thousand grains weight, g

For the Ariivka variety, a decrease in this trait was noted in almost all component mixtures provided for in the experiment by grain weight. If in pure-line it was 2.6 ± 0.1 g, then in other component mixtures, a tendency to decrease was noted (Table 7).

According to Karmelyuk variety, the level of grain weight formation per ear in pure-line was 1.5 ± 0.1 g, and in 2-component mixtures (Karmelyuk + Sharada) this indicator increased to the level of 1.7 ± 0.1 g (Table 8).

In 2-component mixtures (Karmelyuk + Radyvonivka) the value of this trait decreased by a small percentage. We explain the increase in grain weight in the 2-component mixture (Karmelyuk + Sharada) by the difference in plant height, that is, in this mixture, obviously, there was more lighting for Karmelyuk and it formed a high level of stem weight.

Table 7

Variability of productivity parameters of winter wheat variety Ariivka in pure-line and in mixtures

Parameters	Ariivka pure-line	Ariivka +Sharada	Ariivka + Karmelyuk	Ariivka + Radyvonivka	4-varieties mixture
Y(t/ha)*	4,37	4,60	4,80	4,97	6,37
H (sm)	77,9 ± 1,1	83,7 ± 0,8	80,8 ± 1,2	84,2 ± 1,9	80,4 ± 1,2
TSI	4,2 ± 0,1	4,0 ± 0,1	4,1 ± 0,1	3,9 ± 0,1	3,5 ±0,1
EL	8,6 ± 0,1	8,4 ± 0,1	8,3 ± 0,1	8,6 ±0,2	8,4 ± 0,2
SE	20,3 ± 0,2	20,4 ± 0,3	19,6 ± 0,3	19,2 ± 0,3	18,1 ± 0,4
GW	2,6 ± 0,1	2,4 ± 0,1	2,3 ±0,1	2,2 ±0,1	2,02 ± 0,1
GE	62,5 ± 1,6	58,7 ± 1,3	56,7 ± 1,6	55,9 ±2,1	51,8 ± 2,1
TGW	41,1 ±0,8	40,9 ±0,9	40,01 ±0,8	39,9 ± 0,9	38,7 ± 1,01

Table 8

Variability of productivity parameters of winter wheat variety Karmelyuk in pure-line and in mixtures

Parameters	Karmelyuk pure-line	Karmelyuk +Sharada	Karmelyuk + Ariivka	Karmelyuk + Radyvonivka	4-varieties mixture
Y(t/ha)*	5,67	4,33	4,80	5,10	6,37
H (sm)	80,02 ± 2,8	86,0 ± 1,0	93,3 ± 1,0	95,2 ±1,6	91 ± 1,5
TSI	3,4 ± 0,1	3,3 ± 0,1	3,4 ± 0,1	3,4 ±0,1	3,5 ±0,1
EL	7,9 ± 0,1	7,7 ± 0,1	7,6 ± 0,1	7,3 ±0,1	7,7 ± 0,1
SE	16,9 ± 0,3	17,2 ± 0,2	17,0 ± 0,3	16,2 ±0,3	17,2 ± 0,2
GW	1,5 ±0,1	1,7 ± 0,1	1,5 ±0,1	1,3 ±0,1	1,6 ± 0,06
GE	40,6 ±1,5	42,7 ± 1,1	39,6 ± 1,3	34,3 ± 1,5	40,6 ± 1,3
TGW	37,7 ± 1,1	40,7 ± 0,9	38,3 ±0,8	37,9 ± 0,9	39,3 ± 0,6

The level of formation of the trait "grain weight per ear" in a pure-line Radyvonivka was 2.2 ± 0.1 g and in mixtures in only one case (Radyvonivka + Sharada) the level of grain weight per ear increased, and in other cases, this indicator decreased in relation to pure-line (Table 9).

The number of grains per ear is one of the main traits of the formation of the yield potential of winter wheat varieties. In the experiment, the level of formation of this trait in Sharada was 37.4 ± 0.6 g relative to pure-line, and in 2-component mixtures this indicator increased to the level of 39.8 ± 1.6 g. It should be noted that in the 4-component mixture, there was a sharp decrease in the number of grains per ear to 30.6 ± 1.3 g.

Table 9

**Variability of productivity parameters of winter wheat variety
Radyvonivka in pure-line and in mixtures**

Parameters	Radyvonivka pure-line	Radyvonivka +Sharada	Radyvonivka + Ariivka	Radyvonivka + Karmelyuk	4-varieties mixture
Y(t/ha)*	5,93	4,70	4,97	5,10	6,37
H (sm)	94,4 ±1,0	96,3 ± 0,7	97,0 ± 1,0	104,8 ±0,9	101 ± 1,4
TSI	3,8 ±0,1	4,01 ± 0,1	3,7 ± 0,1	3,8 ± 0,1	3,8 ±0,04
EL	9,1 ±0,2	9,04 ± 0,1	8,2 ±0,2	8,2 ±0,2	8,0 ± 0,1
SE	18,8 ± 0,3	19,2 ± 0,3	17,8 ± 0,3	17,5 ±0,3	17,5 ± 0,2
GW	2,2 ±0,1	2,3 ± 0,1	1,9 ±0,1	1,8 ±0,1	1,7 ± 0,05
GE	49,4 ± 1,6	52,2 ± 1,8	46,1 ±1,7	42,5 ± 1,9	41,3 ± 1,3
TGW	45,5 ± 0,8	44,8 ± 0,8	40,7 ± 0,8	42,9 ± 0,7	42,0 ± 0,5

In 4-component mixtures, the number of grains per ear in Karmelyuk variety in relation to pure-line was stable and amounted to 40.6 ± 1.5 g, and in 2-component mixtures (Karmelyuk + Sharada) we observed an increase in the trait to 42.7 ± 1.1 g., in 2 other cases, a decrease in the trait was observed in relation to pure-line − 34.3 ± 1.5 g.

For Radyvonivka variety, the number of grains per ear decreases in relation to pure-line from 49.4 ± 1.6 g to 41.3 ± 1.3 g, except for 2-component mixtures (Radyvonivka + Sharada) where the trait was 52 , 2 ± 1.8.

Grain quality of winter wheat varieties in competitive mixtures

Grain quality of winter wheat is the main criterion for evaluating the variety and therefore has a direct relationship with the traits of grain productivity.

In the CIS countries, three groups of soft wheat are distinguished by the technological properties of grain: strong, valuable and weak. Strong wheat contains the maximum amount of protein (at least 14%) and high-quality gluten (28% with Index of gluten deformation = 45−75), forms a dough that can withstand intensive kneading and prolonged fermentation, provides a high volume of bread.

Valuable wheat gives good quality bread, but they can not be improvers. The three quality groups of winter wheat varieties − strong, valuable and filler − since 2003 added a group of superstrong wheat with specific physical and technological parameters of grain quality, the first of which was the Panna variety, obtained by crossing the highly winter-resistant Odom variety with the high-quality Odesska chervonokolosa variety.

Such high grain quality parameters as Panna have only Canadian spring wheat variety Glen Lea. Panna differs from all other varieties of strong wheat in the presence of four new for Ukraine alleles of the storage proteins Gld 1A10, Gld 1B15, Gld 6B4 and Glt 1B5 and a sufficiently high resistance to grain germination in ear at the final stage of maturation.

The objective of the experiment was also to investigate the level of grain quality formation of the studied varieties of winter wheat. We included two parameters in the grain quality: the protein content (%) and gluten content

(%). According to the analysis data (Table 10), in terms of protein content, the Sharada variety in the experiment with 2-component mixtures formed an increased protein content from 15.2 to 16.2 in relation to pure-line, and a decrease in protein content by a slight percentage in relation to pure-line.

Table 10

Protein content of winter wheat varieties in mixture, %

Variety	Sharada	Ariivka	Karmelyuk	Radyvonivka	4-varieties mixture
Sharada	*16,1*	15,2	16,2	16,0	15,5
Ariivka	13,6	*13,7*	14,3	13,6	14,7
Karmelyuk	12,2	12,4	*12,3*	12,7	13,3
Radyvonivka	13,7	13,0	12,0	*14,6*	12,1
Mean					13,9

In the experiment, in relation to pure-line in 2-component mixtures, the Ariivka variety reduced the protein content to 13.6, and only in the Karmelyuk + Ariyevka mixture did it increase from 13.7 to 14.3. Karmelyuk in the experiment in 2-component mixtures increased the protein content in relation to pure-line, and in the mixture (Sharada + Karmelyuk) there was a decrease to 12.2. It should be noted that in the 4-component mixture, the Karmelyuk variety formed the highest protein content, and the Radyvonivka variety in the experiment on the protein content in all mixtures reduced the protein content in relation to pure-line from 14.6 to 12.0%.

In the experiment on gluten content (Table 11), pure-line varieties had a high gluten content, and in mixtures this parameter decreased. So, for Sharada, the gluten content in pure-line was 35.0% and in 2-component mixtures (Ariivka + Sharada) − 33.3%, in 4-components mixture − 33.7%.

Table 11

Gluten content of winter wheat varieties in mixtures, %

Variety	Sharada	Ariivka	Karmelyuk	Radyvonivka	4-varieties mixture
Sharada	*35,0*	33,3	37,0	35,7	33,7
Ariivka	30,0	*29,0*	30,5	29,1	31,8
Karmelyuk	24,6	25,3	*25,8*	26,9	28,3
Radyvonivka	28,9	27,2	24,3	*31,3*	25,2
Mean					29,7

It should be noted that in Ariivka variety, in the experiment on the gluten content in all mixtures, an increase in this parameter with respect to pure-line from 29.0 to 31.8% was observed. And in the varieties Karmelyuk and Radyvonivka, on the contrary, a decrease in this parameter was observed in relation to pure-line.

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3. Indirect methods for estimation of winter wheat lines and varieties

The left-bank forest-steppe Ukraine is major producer of winter wheat. It is characterized by continental climate with frost winters, spring delays, and summer droughts and in whole by very unstable environmental conditions. Therefore the winter wheat grain production varies by years. The main causes of this are low resistance to frost and others abiotic and biotic factors. In Poltava region the modern commercial cultivars of Ukrainian and Russian breeding are cultivated and characterized by high productivity but low frost resistance. The creation of new intensive cultivars, with adaptation to the forest-steppe climate varying, demands special approaches to winter wheat breeding programs. A new program of selection and genetic research has been developed in our centre since 1999 based on ecological and genetic approach. It is aimed at creating cultivars with improved parameters of yield, quality, adaptability and other useful characteristics. For the purpose of improvement of breeding process the method of indirect estimation of accessions is applied. The traits and indexes that have close genetic correlations with productivity traits are used for selection of accessions at early stages of breeding. The selection of accessions by desirable parameters is provided by cluster analysis. The application of indirect selection on the early winter wheat breeding by optimal combinations of useful traits in one genotype will provide effective breeding for high spike productivity.

Winter wheat is characterized by autumn-winter-spring environment factors that influence on productivity: frost resistance, presence of genes of sensibility to photoperiod, necessity of definite duration of vernalization, "per se" genes and others. The level of adaptation of wheat plant to limited environment factors is defined by photoperiodic sensibility and duration of vernalization period. The new estimation procedure of photoperiodic sensibility with the using of three autumn sowing dates: early, optimal and late has been implemented in our breeding practice.

For detection of necessity definite duration of vernalization period for different lines and cultivars the method of artificial delay of spring vegetation (Medinetz method) is actively used. Genotype differences between lines generally are reflected in the number of plants which survived and on productivity accordingly. This method allows choosing genotypes and selecting accessions by the level of photoperiodic sensitivity and duration of vernalization period for specific environmental conditions. The technology of individual and family selection under limiting environmental factors became promising way of plant breeding.

The elaboration and application these new approaches in winter wheat breeding allow the little team of our breeding centre during a short time to create unique breeding material, 14 cultivars which are in National Catalogue and characterized by high adaptive properties, grain quality and productivity.

Every year 300−350 accessions of winter wheat and others crops are multiplied and studied. In our collections the main place is held by the donors and sources of special useful characteristics such as resistance to pathogen race, morphological traits, resistance to unfavorable environmental factors (frost and drought resistance of winter wheat cultivars) and others. Some of cultivars, that are cultivated now, were created using the accessions of world genetic collection in hybridizations. For example, winter wheat Levada was created by step hybridization of Ukrainian cultivar Mironovskaya 808 with Bulgarian Pliska and the obtained line 140 was crossed with modern Ukrainian cultivar Albatros odesskiy.

Global climate changes exert influence on winter wheat cultivation, main cereal of left-bank forest-steppe Ukraine. This region is characterized by instability of weather conditions, especially in autumn-winter-spring period. Thus to get the stable yield each year independently of winter conditions it is necessary to use winter wheat varieties which are characterized by high level of adaptation. With this aim in our Research Plant Breeding Centre the breeding program of the creation of productivity winter wheat cultivars with great winter resistance is developed.

First in Poltava region conditions the methods of winter hardiness estimation of winter wheat varieties and lines have been elaborated and implemented. It has been proposed that the main components in winter hardiness are photoperiodic sensibility and vernalization period. One of the methods is the using different sowing term and the analysis of photoperiodic sensibility of plants. Another is the analysis of vernalization period duration in conditions of hand-made delay of vegetation in spring time. Genotype differences between lines generally are reflected in the number of plants which survived and on productivity accordingly.

The researches according to indirect methods of winter hardiness estimation have been carried out at Poltava State Agrarian Academy during last 20 years. The method of indirect estimation of photoperiodic sensibility (PPS) and duration of vernalization period (DVP) were developed. The basis of PS estimation is sowing terms and the basis of DVP estimation is the time of renewal spring vegetation.

Winter wheat varieties significantly are different according to duration of vernalization period from 15 to 60 days and more. It is known that demand in DVP is controlled by genes *Vrd1* and *Vrd2* and less demand in DVP predominates (20−30 days) (Fayt, 2003). On the other hand photoperiodic sensibility is controlled by genes *Ppd1…3*, dominant alleles of these genes determine neutral and weak PPS, and recessive alleles determine strong PPS (long-day varieties).

PPS and DVP define significantly the level of plant adaptation to growing conditions and especially to wintering. The differences between genotypes by these signs (PPS and DVP) appear at early developmental stages of plant. Thus, the strong PPS and long DVP delay development of

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rudiments of reproductive organs during autumn period and increase the resistance level to stress environment factors in wintering. The weak PPS and short DVP, vice versa accelerate development but in this case plants perish from the frost although these plants are characterized by rapid spring aftergrowing.

The method of photoperiodic reaction testing winter wheat cultivars is rather complicated under laboratory conditions and expensive. We use simpler method of reaction testing by means of yield according to different sowing terms.

One of the main methods of our breeding is ***index method***. Besides, the registration of main quality and quantity traits the accessions are estimating by the values of relative traits, or indexes. The index is a complex notion where the numerator is often some component of productivity and the denominator is the component of vegetative part. Our investigations showed that harvest index (HI), attraction index (AI), microdistribution (MDI), Poltavskiy index (our elaboration) (PI) are the most suitable for using on early breeding of winter wheat. These indexes have a high genetic correlation coefficient with yield per unit of area as compared with grain weight per plant and high heritability coefficient (74−76% beside 42% by grain weight per spike).

The varieties of Research Plant Breeding Centre of Poltava State Agrarian Academy (RPBC PSAA) and some others Ukrainian cultivars, in general 17 varieties were involved in this experiment. The experimental fields located in Poltava region, Forest-Steppe zone of Ukraine.

Two sowing terms were used for studying the photoperiodic sensibility of given varieties: the 1st term is early term – September1; the 2nd term is late term –October1. The optimal sowing term for winter wheat in this region is from September15 till September 25.

For studying the necessity of vernalization period duration of different varieties, Medinetz's method has been used. According to this method hand-made snow cover is created which delay the renewal time of spring vegetation.

Hand-made snow cover was removed for two times: 17 April and 25 April. Then the number of survived plants on the 15th and the 30th day after the beginning of vegetation was calculated. Optimal term of the beginning of spring vegetation in this region is from 15 March till 25 March.

Investigated varieties according to different sowing terms are divided to three groups (Table 12). Varieties of group 1 showed high yield in both sowing terms and it means that these varieties are very sensitive to photoperiod. Kryzhynka variety is characterized by high sensitiveness in our experiment. These varieties don't overgrow under early sowing terms. This feature is very important for producers especially under conditions of moisture lack during autumn period.

Varieties of the group 2 showed a low yield under the early sowing term and a high yield under the late sowing term and these varieties are genotypes with weak or neutral PPS. These varieties also overgrow during autumn period, accumulate less sugar in leaves, thin out during winter thaw and low temperatures in spring. Under such weather conditions varieties of group 2 lose winter-hardiness and correspondingly have low yield.

Varieties of the group 3 showed a high yield under the early sowing term however under late sowing term can show as well high or lowered yield. These varieties are sensitive to PPS and middle DVP. Winter wheat varieties of this group (early sowing term) attract attention for climatic zones with very instable weather conditions. These varieties intensive grow in spring, it is very important under insufficient moisture during the period "the beginning of spring vegetation – ear formation". During autumn period these varieties are characterized with intensive root system growth on the background weak development of aboveground part. These varieties are winter-hardy and actively use winter moisture through well-developed root system and that is why are able to form high yield.

Winter wheat varieties of Research Plant Breeding Centre of Poltava State Agrarian Academy (RPBC PSAA) according to the results are varieties which have middle and heightened sensibility to PPS. The yield of given varieties don't depend on sowing terms.

Table 12

Yield of winter wheat cultivars subject to sowing terms

Varieties	Yield, c/ha		Photoperiodic sensibility
	I sowing term (September1)	II sowing term (October1)	
Vdala	31,7	43,3	neutral
Dovira	38,3	56,7	neutral
Vita	41,7	53,3	neutral
Elegia	41,7	60,0	neutral
Ermak	41,7	63,3	neutral
Odeska 267	51,7	55,0	mid-sensitive
Albatros odeskiy	50,0	58,3	mid-sensitive
Mironivska 68	63,3	61,7	mid-sensitive
Kryzhynka	68,3	70,0	high-sensitive
Cultivars of RPBC PSAA breeding			
Kolomak 5	46,7	65,0	mid-sensitive
Ukrainka poltavska	55,0	65,0	mid-sensitive
Levada	55,0	71,7	mid-sensitive
Dykanka	53,3	76,7	mid-sensitive
Govtva	60,0	66,7	mid-sensitive
Sidor Kovpak	50,0	76,7	mid-sensitive
Vilshana	48,3	58,3	mid-sensitive
Sagaydak	63,3	76,7	mid-sensitive

The determination of demand in DVP in winter wheat varieties was carried out according to V. Medinezt's method of keeping hand-made snow cover.

It has been established that varieties which showed high percentage survived plants on the 30th day after removing snow cover are characterized elongated DVP. Those varieties which showed total plant loss on the 30th day is characterized by short DVP. The cultivars which showed 50% of survived plants are characterized by middle period of vernalization. The table 12 demonstrates that varieties with neutral PPS demand the short vernalization period. Whereas sensitive PPS varieties demand middle and elongated vernalization period.

To confirm the conclusions about demands in DVP we calculate additionally the number of full ears. Such indirect method of estimation of demand in DVP presents a view of influence of vernalization period on productivity (table 13).

Table 13

**Indirect estimation of DVP by full ear number
after forced delay of spring vegetation**

Varieties	The number of ears		
	Natural condition	Delay of vegetation	
		Till 17 April	Till 25 April
Albatros odeskiy	283,8	217,8 (76,7)	178,2
Kolomak 3	330,0	323,4 (98,0)	224,4
Kolomak 5	360,0	330,8 (91,9)	204,6
Ukrainka poltavska	363,0	290,4 (80,0)	145,2
Levada	343,2	250,8 (73,0)	138,6
Dykanka	448,8	369,6 (82,4)	171,8
Manjelia	330,0	217,8 (66,0)	151,8
Govtva	448,8	277,2 (61,8)	151,8
Sidor Kovpak	440,0	270,2 (61,4)	160,8
Vilshana	290,4	264,0 (90,9)	151,8
Sagaydak	310,2	297,0 (95,7)	231,0

All given varieties showed the high percentage of survived plants after delay vegetation till 17 April (from 61% to 98%). Thus these varieties need the middle or elongated vernalization period.

Because of unfavourable climatic conditions during autumn-winter-spring period the special method of determination of winter hardiness of winter wheat varieties and lines is used in our Centre. The sign of winter hardiness was divided into such components as PPS and DVP.

The yield estimation of varieties according to different sowing terms and forced delay of spring vegetation give possibilities to select genotypes and estimate lines and varieties using the level of PPS and DVP for special weather conditions. The estimation of winter hardiness for winter wheat varieties of PSAA breeding is given. It has been established that Poltava

winter wheat varieties (Levada, Dykanka, Ukrainka poltavska, Manjelia, Sagaidak, Govtva, Vilshana, Sidor Kovpak) have long vernalization period and strict photoperiodic sensibility. It allow to solve the problem of winter wheat plant outgrowing in autumn and save plants under ice crust and in the period of thaw in winter and in low temperature in early spring. In years with unfavorable weather conditions for winter wheat growing and development (low temperatures and long-term ice crust) these varieties showed sufficiently high level of winter resistance.

CONCLUSIONS

Among the 4 winter wheat varieties studied, significant differences were noted in competitiveness. The effect of competition on five traits and indices related to grain productivity was studied. By such parameters as, grain weight / ear (GW), stem weight (SW) and breeding indices (Poltavskii index (PI) and index of linear ear density (LED)), significant differences were noted between varieties competitiveness. According to GW and LED, the most plus-competitiveness was possessed by the lowest-yielding, early-ripening, short-stem variety Dolya; the plus-competitiveness on these traits was shown by the relatively high-yielding variety Venera; the lowest negative competitiveness was observed in the high-yielding variety Levada and medium-yielding variety Redut. Blending of varieties adversely affected the productive tillering of all varieties in which negative competitiveness was observed on this trait.

Overcompensation, or excess of actual productivity over theoretical, i.e. over the average yield of pure varieties, it demonstrated itself differently depending on mixtures of certain varieties. According to the best-yielding variety, in only one case out of six (Levada x Venera) the plus-overcompensation was noted; according to the average yield of pure varieties plus-compensation in four variants of mixtures was observed.

The data on variety competitive interaction in winter wheat with certain assumptions, due to the limited set of genotypes in this experiment, can be used to increase the selection efficiency in the early stages of breeding, because a mixture of varieties imitates a hybrid nursery with a wide range of genotypes represented in it. The obtained results do not make it possible to make reliable conclusions about the negative or positive relationship between competitiveness and productivity or trait value.

The phenomenon of overcompensation can be used both in the practical cultivation of mixtures of varieties, and to create multi-line varieties. With the involvement of a wider range of varieties and lines of winter wheat into the study, it is possible to select components for mixtures that provide increased productivity and yield stability.

The application of indirect estimation methods in plant breeding has given us opportunity to select genotypes according the level of photoperiodic sensibility and duration of vernalization period for special weather

conditions. It has been established that Poltava winter wheat varieties (Levada, Dykanka, Ukrainka poltavska, Manjelia, Sagaidak, Govtva, Vilshana, Sidor Kovpak) have long vernalization period and strict photoperiodic sensibility. It allow to solve the problem of winter wheat plant outgrowing in autumn and save plants under ice crust and in the period of thaw in winter and in low temperature in early spring. In years with unfavorable weather conditions for winter wheat growing and development (low temperatures and long-term ice crust) these cultivars showed sufficiently high level of winter resistance.

SUMMARY

This study was aimed to investigate the possibility of realization of productivity by wheat plants in conditions of intraspecific genotypic competition. Four winter wheat varieties were studied in two- and four-component mixtures for effect of competition on yield, some agronomic traits and indices. Significant differences were noted between varieties competitiveness by such parameters as, grain weight per ear, stem weight and breeding Poltavskii index and index of linear ear density.

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