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ОРИГИНАЛЬНАЯ СТАТЬЯ

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ИСПОЛЬЗОВАНИЕ *AVENA MACROSTACHYA* ДЛЯ УЛУЧШЕНИЯ ЗИМОСТОЙКОСТИ ОВСА В ПОЛЬШЕ

Актуальность. Эксперименты с возделыванием сортов зимующего овса в Польше в конце XX века, особенно в засушливые годы, показали увеличение потенциала урожайности иностранных в два раза по сравнению с местными стандартными яровыми сортами овса. Тем не менее, в этом случае мягкие зимы были залогом успеха таких сортов, т. к. их зимостойкость была достаточной при данных погодных условиях. Польская же программа по улучшению зимостойкости овса началась только в 2002 г.

Материалы и методы. Иностранные зимующие сорта и линии овса были скрещены с выделенными образцами тетраплоидного многолетнего дико-го вида *Avena macrostachya* Bal. ex Coss et Dur. Гибриды F₁ были клонированы, обработаны колхицином и выращены вместе с зимующими сортами овса, которые являлись спонтанными опылителями для данных гибридов.

Результаты и обсуждение. Были получены три гибрида, из которых по двум были получены семена. Большие различия были замечены в уровне фертильности и структуре хромосом в потомстве двух гибридов. Следующее поколение (B₁F₁ или F₂) состояло из растений с числом хромосом от 40 до 49, октоплоидов (2n = 56) и растений, несущих в своем геноме от 60 до 70 хромосом. Растения из первой группы мнимых гексаплоидов, как правило, обладали мужской стерильностью, но после дополнительного бекроссирования пыльцой *A. sativa* L. они становились фертильными. В засушливые годы 2009 и 2013 гг. они имели почти на 100% выше урожайность, чем стандартные яровые сорта овса. Натура зерна зимующего овса была также на 4 кг/л выше, чем у ярового овса. Две выделенные пленчатые линии показали уровень зимостойкости лучше, чем родительская популяция *A. sativa*, находящаяся в Польском государственном сортоиспытании. Эти линии могут быть рекомендованы для возделывания в регионах с устойчивым снежным покровом, потому что растения этих линий погибали в бесснежные зимы при температуре поверхности почвы ниже –14°C, такие зимы были дважды в течение последних 8 лет в районе г. Радзикова. Погодные условия прошлой зимы (2015/2016 гг.) были особенно экстремальными, даже для линий октоплоидов, которые ранее считались наиболее зимостойкими. Октоплоиды не болеют, формируют большое количество зеленой массы и очень крупное зерно, богатое белком, однако их зерновая продуктивность не велика (в настоящее время она составляет только 50–67% от урожайности лучших зимующих сортов овса) и вегетационный период удлинен. Последний суровый зимний сезон был полезным для отбора нескольких новых гексаплоидных линий из комбинаций скрещиваний 6x × 8x, которые были сделаны для трансгрессии морозостойкости от октоплоидного родителя. Аллоплоиды *sativa-macrostachya* с уровнем плоидности 8x или 10x оказались эффективными источниками зимостойкости для гексаплоидного овса.

Ключевые слова:

аллоплоид, *Avena macrostachya*, *Avena sativa*, скрещивание, зимостойкость, зимующий овес, урожай

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USING *AVENA MACROSTACHYA* FOR IMPROVEMENT OF OAT WINTERHARDINESS IN POLAND

Background: The experiments with winter oat cultivation in Poland at the end of 20th century indicated potential of high yielding, especially in dry seasons, when foreign winter strains or cultivars doubled yields of local spring standards. However, a mild preceding winter season was condition for the success; winterhardiness of foreign oats was sufficient only in some years. The Polish program of winterhardiness improvement in oat began in 2002. **Materials and methods:** Foreign winter oat cultivars and lines were crossed with accessions of tetraploid perennial wild species *Avena macrostachya* Bal. ex Coss et Dur. The F₁ hybrids were intensely cloned, treated with colchicine and grown in vicinity of winter oat pollinators. **Results and conclusions:** Three F₁ hybrids were obtained, two of them set seed. Large differences were noticed in fertility level and chromosome constitution of progeny of the two hybrids. The next generation (B₁F₁ or F₂) consisted of plants with chromosome numbers between 40 and 49, octoploids (2n = 56) and plants carrying 60 to 70 chromosomes. The quasi-hexaploids of the first group were generally male sterile, but after additional back-cross to *A. sativa* L. valuable hexaploid breeding strains were produced. In the dry seasons 2009 and 2013 they yielded nearly 100% higher than the spring cultivar standard. Test weight of the winter oat was also ca. 4 kg/hl higher than in the spring oat. Two of the husked strains, showing winterhardiness level better than the starting *A. sativa* population, are in the Polish state variety trials. They could be recommended for the regions with stable snow cover, because they were not able to survive naked ground surface temperatures below -14°C, which happened twice in Radzików in the last 8 years. Especially the last winter (2015/2016) was destructive, even for the octoploids, which were earlier considered the most winter-hardy oats. The octoploids produce healthy green mass and very large plump grain, rich in protein, however they require a breeding effort to increase yield (now 50-67% of the best winter hexaploids) and to make ripening uniform. The last severe winter season was helpful for selection of several new hexaploid strains from the 6x x 8x cross combinations, which were transgressive in frost resistance to their octoploid parents. The 8x or 10x *sativa-macrostachya* allopoloids proved to be effective sources of winterhardiness for hexaploid oat.

Introduction

Preliminary experiments with winter oat in Poland at the end of the 20 century indicated its potential of high yielding especially in dry seasons, when foreign winter strains or cultivars doubled yields of local spring standards (Zygmynt Nita, personal comm.). However, a mild preceding winter season was condition for the success; winterhardiness of the oat lines from western countries was generally insufficient.

A stagnation was recorded in oat winterhardiness in the second half of the last century until a progress was reported in North Carolina, USA, first as a result of crossing the winterhardy cultivars 'Wintok' and 'Norline' (Livingston, Elwinger, 1995; Livingston et al., 2004), and later after application of the wild species *Avena macrostachya* Bal. ex Coss et Dur. as a cross component to the cultivar Brooks (Santos et al., 2002). A cross with an alien species may introduce new and useful genetic variation when intraspecific variation of a crop is insufficient; there is also possible advantage of whole genome incorporation through allopolyploidy. It is relevant particularly for the quantitative traits including abiotic stress responses. Wide crossing of *Avena sativa* L. with *A. macrostachya* was the starting point for winter oat acclimation in Poland. Initiation of the work in IHAR-Radzików was encouraged by the acceptable level of winter survival in the Uniform Oat Winter Hardiness Nursery (UOWHN) grown in the location since 1993, as well as by presence of a relatively large *A. macrostachya* collection in the IHAR gene bank. The accessions were collected during expedition in the Atlas mountains elevated sites, next sown in Gubalówka, Poland, on foothills of the Tatra mountains, where clones of this perennial species survived nearly 10 years. Attractiveness of the variation source was strengthened by high resistance of *A. macrostachya* to biotic stresses. Herrmann (2006) reported introgression of powdery mildew resistance to *A. sativa*. Loskutov (2007) listed other resistances potentially useful for breeders: to crown and stem rust, septoria blotch, helminthosporium blotch, myrothecium blotch, frit fly; Weibull (1988) announced resistance to aphid *Rhopalosiphum padi* L.

Breaking the interspecific isolation barriers

The crossing between foreign winter oats and *A. macrostachya* was performed in

Radzików in 2002. Single hybrid seeds were obtained only in three of 51 cross combinations, when common oat was used as a mother plant. Only two of the F₁ plants recovered (after *in vitro* embryo culture) were sufficiently vigorous and produced abundantly tillers in greenhouse, which enabled establishment of large clonal populations. The clones were treated with colchicine and planted in field in early spring, among a winter and spring sown mixture of winter oats, which were the additional pollen donors for the F₁ plants. The clone derived from the cross involving winterhardy oat cv. 'Wintok' (W-F₁) consisted of finally 969 plants and produced ca. 2050 panicles and 3 germinable seeds. The other clone of 2073 plants based on a German (Lochow-Petkus) non-winterhardy 'Mirabel/Pendragon' recombinant line (MP-F₁), produced ca. 9890 panicles and 54 germinable seeds. The earlier publications of Lapinski et al. (2012, 2013) contain more detailed description of overcoming the interspecific reproductive barriers.

The results strongly confirmed the idea of starting from a broad variety of genotypes in a difficult interspecific cross. In addition to the known and expected differences in crossability, F₁ viability and sterility, a substantial difference occurred in toleration of aneuploidy between the successful W- and MP- cross combinations, which greatly determined the direction of further evolution of the progenies. The F₁ generation had 35-chromosomes, 21 from *A. sativa* mother and 14 from *A. macrostachya* (autotetraploid, 4n = 28). Progeny of the W-F₁ hybrid consisted of three euploids: two octoploids (8x = 56) and one decaploid (10x = 70). Aneuploids prevailed in progeny of the MP-F₁: there were 32 plants with chromosome numbers between 40 and 49, one octoploid and 28 hypo-decaploids, with 60 to 69 chromosomes (table 1). The quasi-hexaploids of the first group showed various level of weakness and sterility, but in the following generations most of the progenies quickly regulated their chromosome complement and restored fertility, usually with help of additional spontaneous back-cross to *A. sativa*. Eleven of these cytogenetically unbalanced progenies produced valuable and stable hexaploid (6x = 42) breeding strains. The octoploids, less frequent than expected, gave also rise to cytogenetically stable stocks. The descendants of the hypo-decaploid primary synthetics were less vigorous than the octoploids or hexaploids and their propagation required verification of ploidy level at reproduction, as

there was a tendency to spontaneous decrease of number of chromosomes.

Таблица 1. Распределение числа хромосом в проростках гибридов B_1F_1 и F_2 от скрещивания *Avena sativa* × *A. macrostachya*
Table 1. Distribution of chromosome numbers in the B_1F_1 and F_2 generation seedlings of the *Avena sativa* × *A. macrostachya* hybrids

F ₁ mother parent	Number of chromosomes																															
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	
W-F ₁																	2															1
MP-F ₁	2	3	4	3	4	4	1	3	1	1							1	1	1					3	5	5	3	5	2	2		
dead MP*			1		2	1	1	1																	1							

*plants which produced seminal roots for chromosome counting but died at germination (from Lapinski, Podyma, 2007)

The octoploids as a new species comparable to primary triticales

An abiotic stress response is usually determined by numerous interacting genes, thus, recombination itself, usually restricted by reduced meiotic pairing, may not be effective in transfer of all necessary genes. Creation of allopolyploids makes it possible to transfer a whole genetic system (set of chromosomes) controlling a trait(s) of interest. Triticale is a convenient reference species to compare results of transfer of abiotic stress tolerance through whole genome transfer; it exceeds wheat and its introgressive interspecific recombinants in resistance to drought, soil salinity and acidity (Hede, 2001). It requires less nitrogen and water than wheat to produce a similar yield. Triticale winterhardiness was a more difficult breeding objective but a few decades were sufficient to restore expression to the level of parental species. No such incompatibility of winterhardiness genetic systems occurred in our *sativa-macrostachya* allopolyploids; first generations of the obtained octoploids exceeded their hexaploid common oat parents in winter hardiness. The 8x line PR-4H8 had the best survival scores in UOWHN 2010. However, we did not observe in the octoploids any further progress in the trait expression compared to that recorded recently in the hexaploid wide hybrids. Probably, lack of appropriate variation is the cause. As yet, our attempts to produce secondary winter octoploids through crossing hexaploids with decaploids are unsuccessful: in 24 crosses of this type progenies shifted to the 6x ploidy level. Variation in our octoploids comes mainly from recombination initiated by the

back-cross of interspecific F₁ to *A. sativa*. The most interesting lines, including the PR-4H8, came from the cross of the W-F₁ ('Wintok' based) with Welsh line 95-43Cn4 (the only line among the pollen parents which had a black hull marker enabling parentage control). The *sativa-macrostachya* octoploids produce large, elongated seed (in nurseries TKW up to 70 g), plump and rich in protein (up to 20%) but with poor beta-glucan content (ca. 2,7%). The seed quality in these octoploids was much better than shrivelled and frequently sprouted seed of early wheat-rye allopolyploids. Yield of grain of the oat octoploids approximated to 50–67% of the good hexaploid winter forms and its average value in the years with winter survival is similar to that of common spring oat. Yield potential of the octoploids is probably underestimated, because of an uncontrolled negative effect of wild animals selectively grazing on the trial plots, which occurs regularly in early spring at our location. Leaf diseases resistance is high and green mass abundance is suggesting usefulness for green forage or silage. In cultivation of the octoploids for grain, late and non-uniform ripening may be problematic in some years (the wild component is a perennial plant with prolonged tillering phase). Care must be taken regarding the disappearance of resistance to diseases in single 8x lines. We noticed loose smut, which was never recorded before in the location, on a few of the W-F₁ lines. The loss of some genes (or a loss of their function) may be attributed to recombination of heterologously translocated chromosomes or rapid sequence elimination and epigenetic modifications (Ma and Gustafson 2008) which occur in early generations

of new allopolyploids. Continuing the comparison with first wheat-rye hybrids, grain yield potential of early triticales from CIMMYT was reported as ca. 2.4 t/ha. After three decades of breeding (nearly 60 generations) it reached 10 t/ha (Hede, 2001). The 2/3 of common oat yield in our raw octopolyploids makes for a much better starting point. Considering the most dis-

tant systematic position of *A. macrostachya* in relation to *A. sativa* and other oat species in the genus, the relatively high performance of the octopolyploids could not only justify their breeding as a separate crop, but should also encourage the use of other *Avena* species in oat improvement through whole genome addition or substitution

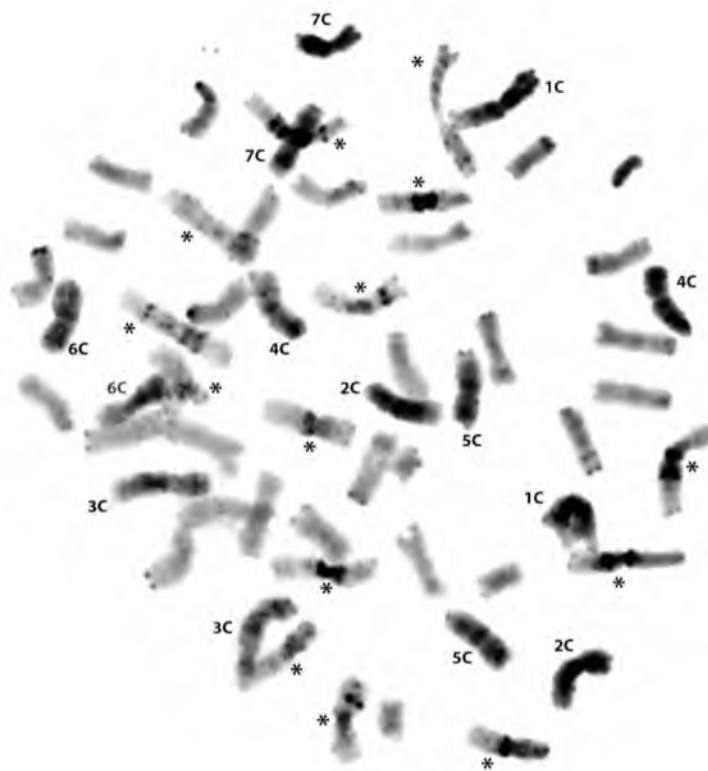


Рисунок. Хромосомный набор, окрашенный по Гимза, 56-хромосомного стабильного аллоплоида PR-4H8, полученного при В-кроссировании *A. sativa* (cv. Wintok') × *A. macrostachya* × *A. sativa* (95-43Cn4).

Хромосомы '*macrostachya*' помечены звездочкой.

Хромосомы С-генома *A. sativa* помечены цифрами

(преп. Е. Jellen, приведено из работы Lapinski et al., 2013).

Figure. The Giemsa C-banded chromosome complement of the stable 56-chromosome allopolyploid PR-4H8 from an interspecific back-cross of *A. sativa* (cv. Wintok') × *A. macrostachya* × *A. sativa* (95-43Cn4).

The '*macrostachya*' chromosomes marked with asterisks.

C-genome *A. sativa* chromosomes are numbered

(prep. by E. Jellen, from Lapinski et al., 2013).

Hexaploid progeny of the wide crosses

The unexpected 40-49 chromosome plants of the MP-F₁ progeny resulted most probably from irregularly reduced female gametes fertilized with normal 21-chromosomal male gam-

etes of common oat. Such back-crosses should facilitate homeologous recombination and produce more unique genotypes than the products of 'academic' back-crosses of hexaploids with octopolyploids, aimed at promoting introgression. Conjugation of *A. macrostachya* chromosomes

with those of *A. sativa* is possible but poor (Leggett, 1985), thus, in the 6x x 8x F₁, they are expected to remain unpaired, particularly when the *sativa* chromosomes form competitive bivalents. Finally, the most probable result should be a loss of the alien chromosomes without any introgression. Forcing of homeologous recombination and better chances for maintenance of alien germplasm may occur in progeny created from a selection of gametes with random chromosome composition. Therefore, high numbers of independent recombinant lines were derived from the MP-F₁ quasi-hexaploids in the next generations. Their selection and stabilization was accompanied with division into winter or spring types, according to response to the occurring low winter temperatures. After four years in nurseries, the first winter hardy strains were directed to field trials. Some of them showed winterhardiness levels higher than the lines from the foreign oat collection or the UOWHN nursery objects. Two husked lines were sent to the international UOWHN nurseries in 2011 and 2012, where they reached top scores of winter survival. Moreover, investigation of the 2011 UOWHN nursery objects with the winterhardiness DNA markers set, developed in the University of North Carolina (Wooten et al., 2008), revealed the lowest number of the frost resistance markers in our 5Q5.2 line, in spite of the highest phenotypic winterhardiness record (Lapinski et al. 2013). It confirmed uniqueness of the resistance source. Yields of the both UOWHN studied lines were satisfactory in two-locations field trials, thus they were directed to the Polish state variety trials in 2014 and 2015. The line 5Q5.2 (proposed cultivar name 'Radzikus') is of medium height, yielding grain with relatively high test weight (in Radzików ca. 60 kg/hl, 2–3 kg/hl more than the average for winter oat and ca. 4 kg/hl better than the spring standard) and relatively high oil content (see table 4). The other line 5T8.A is 10–20 cm taller (but not less resistant to lodging), has a larger grain and shows resistance to mildew. In the Polish weather conditions, both lines are of facultative type, however late sowing in some environments may cause problems with delayed heading. Yielding of these lines is shown in tables 2 and 3, in relation to winter barley and spring oat standards. In Radzików, the average yield of 5Q5.2 in five seasons with good winter survival reached 90,4% of the winter barley standard ('Carola') and was much better (141,2%) than average yield of the spring oat standard ('Kre-

zus'). Two years with winter killing (2012 and 2016) resulted in lower values at 64,6% and 100,8%, respectively. However, considering the ca. 7 dt/ha yield equivalent necessary to pay for re-sowing of a winter killed plantation, the winter oat remains economically still very competitive to spring one. In Radzików, in a season with winter survival, average advantage of winter oat yield over the spring one is 20,1 dt/ha, which compensates almost for three years of winter killing losses. In the sub-mountainous station Grodkowice, where the 5Q5.2 oat died only in 2016, the results are even more attractive. The average yield reached 91,3% of the average barley yield. Considering only the period 2012–2015 with good winter survival of oat, the line overyielded the winter barley check (114,3%).

On less fertile sandy soils, winter killing risk is much higher and yield compensation, in relation to spring form, is smaller, thus carefulness and local trials are recommended before large scale planting. The year 2011 was conducive for oat growth in Radzików and the potential for yield quantity and quality was well expressed for both winter and spring forms. The basic quality parameters for some bulks and advanced lines, shown in table 4, confirmed good quality of hexaploid winter oats derived from the interspecific crosses, in comparison with the spring oat standard and the 'mix W' protein rich bulk from a spring x winter *A. sativa* intraspecific cross.

Relevance of the allopolyploids in winterhardiness improvement

The last winter 2015/2016 was the most destructive in Poland since last 25 years, in spite of relatively high average winter temperatures. In Radzików the first significant frost of -14°C suddenly attacked, without snow cover, in January 2–6 and totally killed more than 1/3 of winter oats in nurseries and in field trials. The lines which survived the first attack of winter showed a wide scope of damage level. However, during the following two months with temperatures oscillating near 0°C the surviving plants lost green colour and were not able to grow and regenerate. Finally, all oats died, while the winter barley standard stayed alive. Oat survival in Poland in 2016 was only possible in the south-western part of the country, where snow cover supplied sufficient protection against frost (and, probably, solarization).

Variation in frost resistance scores (collected shortly after the January frost) is presented

in Table 5. for various groups of crosses involving hexaploids, octoploids and decaploids. The results are based on 147 lines from Radzików field trials, derived from 45 cross combinations, classified into 8 groups.

Таблица 2. Урожайность (ц/га) некоторых озимых межвидовых гибридов и стандартных яровых овсов. Радзиков, 2009–2016 гг.

Минимальная температура (°C) дана на поверхности почвы)
Table 2. Yields (dt/ha) of some winter oat interspecific hybrids together with winter barley and spring oat standards. Radzików, 2009-2016.
The minimal temperatures (°C) are given for ground surface

Year°C Line	2009	2010	2011	2012 -	2013	2014	2015	2016 -	\bar{x} , all years	\bar{x} , surv. years
	-8,0	-5,2	-9,5	14,3	-5,8	-5,7	-8,7	14,0		
Carola winter bar- ley	79,8	66,9	82,2	not studied	57,2	90,0	81,3	not studied	76,2	76,2
Krezus spring oat	33,8	50,4	76,0	not studied	33,8	56,0	43,0	not studied	48,8	48,8
5Q5.2	-	76,8	80,0	dead	57,8	73,0	56,9	dead	49,2	68,9
5T8.A	-	-	75,7	dead	65,5	83,7	44,7	dead	44,9	67,4
best 6x w. oat	62,8	81,8	79,3	dead	65,7	99,8	64,0	dead	56,8	75,7
best 8x w. oat	36,3	56,3	53,2	dead	45,7	65,0	38,0	dead	36,8	49,1

Таблица 3. Урожайность (кг/м²) некоторых межвидовых озимых гибридов овса и стандартов ячменя. Гродкович, 2012–2016 гг.

Table 3. Yields (kg/10m²) of some winter oat interspecific hybrids and winter barley standard. Grodkowice, 2012–2016

Year Line	2012	2013	2014	2015	2016	\bar{x} , all years	\bar{x} , survival years
Carola winter bar- ley	(133,7) border effect	42,5	68,2	82,9	not studied	64,5	64,5
5Q5.2	81,8	66,7	64,3	81,8	dead	58,9	73,7
5T8.A	67,2	47,1	64,8	76,6	dead	51,1	63,9
best 6x w. oat	81,8	66,7	82,2	86,4	dead	63,4	79,3

Each cross combination is represented in the table by only one line with the best frost resistance. The group 1. of hexaploid lines or bulks derived from spontaneous pollinations of the interspecific MP-F₁, containing the 5T8.A and 5Q5.2 cultivar candidates, showed no more the best winterhardiness. The octoploids (group 2) maintained their resistance level, but the most hardy four oat lines, with scores higher than 6, were hexaploid. They had the W-F₁ derived octoploid parent or grandparent (best score 6) as a source of the resistance. The other octoploid (MP-F₁) showed lower level of resistance (score 4), related to distinctly lower

winterhardiness of its MP (Mirabel/Pendragon) initial wide cross parent. The difference attributable to these two grand-parental 6x forms is maintained, however less distinct in the groups of 6x x 10x crosses. Considering the 9 best cross combinations with top scores higher than 5, presence of an allopolyploid (8x or 10x) in a line parentage seems essential for high expression of frost resistance, while the resistance level of the other (hexaploid) parent was less important. It suggests a low number of 'strong' genetic loci involved. An oat object with the score 8 has the spring cultivar ('Buggy') as mother cross component. Another

spring line (from 'Strzelce' Breeding Co.) brought also, as a grandparent, a remarkable contribution to the other two transgressive genotypes with scores 9 and 7. The high proportion of spring oat genes in the elite winter type materials is surprising, however, in general, their influence on winterhardiness is neg-

ative, as shown for other spring parents in comparisons between groups 4 and 5 or 7 and 8. Winterhardiness alleles in spring oat were reported earlier by Amirshahi and Patterson (1956), Murphy (1958) and Wooten et al. (2008).

Таблица 4. Параметры качества урожая озимого овса (голозерного типа) в Радзиков (2010/2011 гг.). Буквами а-г обозначены турецкие группы результатов урожайности
Table 4. Winter oat (husked type) yield quality parameters from the 2010/2011 field trial in Radzików. The a-g designations are for Tukey's grouping of yield results

Line	yield kg/10m ²	protein %	fibre %	oil %	TKW g	% of husk
Krezus (spring oat check)	7,60 ab	14,6	7,2	5,2	37,4	21,8
5Q5.2 ('Radzikus') 6x	8,00 a	16,3	5,1	7,0	36,5	23,6
mix M (hybrid bulk) 6x	7,92 ab	15,1	8,5	6,3	43,1	22,7
5T8.A 6x	7,57 abc	17,1	5,4	5,1	53,3	26,3
mix W ('sativa' bulk) 6x	7,22 abc	19,2	5,3	3,7	46,6	24,6
5P8.31 6x	6,97 abcd	17,1	6,6	6,8	51,5	24,4
5O8.aa 6x	6,17 defg	15,5	7,9	4,8	52,8	24,0
4H8 (bulk) 8x	5,45 efg	18,6	6,4	6,3	61,0	24,9
4H8.8 8x	5,32 fgh	19,8	5,8	5,9	61,5	25,0

(from Lapinski et al., 2012)

Таблица 5. Распределение по морозостойкости различных скрещиваний озимого овса. Радзиков, 2016 г. Шкала 1 – гибель, 2-9 – уровень устойчивости. Каждое скрещивание представлено наиболее зимостойкой линией.

Table 5. Distributions of frost resistance scores for various groups of winter oat crosses. Radzików, 2016. Score 1 means total killing, 2 to 9 describe ascending levels of resistance. Each cross is represented by its most winterhardy line.

Group Nr	Parents and prog- eny ploidy levels	Winter or spring	Resistance scores									No. of crosses	Mean score
			1	2	3	4	5	6	7	8	9		
1.	MP-F ₁ 5x * 6x > 6x	w * w	3	6	1							10	1,8
2.	F ₁ 5x * 6x > 8x	w * w				1		1				2	5
3.	6x * 6x > 6x	w * w	2	1	2		1					6	2,5
4.	6x * W8x > 6x	w * w	2		1			1	1		2	7	5,1
5.		s * w	4		1	2				1		8	2,9
6.	6x * W10x > 6x	w * w			1		2	1				4	4,8
7.	6x * MP10x > 6x	w * w	2			1		2				5	3,6
8.		s * w	3									3	1
Total			16	7	6	4	3	5	1	1	2	45	3,2

Effectiveness of the 6x × 8x allopolyploid backcrosses was unexpectedly high, considering the expected low level of meiotic homoeologous conjugation and the resulting elimination of

alien chromosomes. Finally, there is still no certainty about contribution of *A. macrostachya* genes in the recorded progress, sole intraspecific recombination effects cannot

be excluded until molecular verification of the alien source hypothesis is produced. Even when the interspecific gene exchange may not be a major factor, allopolyploid back-cross seems still attractive as a prospective version of 'incorporation' breeding strategy (Simmonds, 1993), which is usually based on secondary intercrossing among independently introgressed lines of a distant cross, aimed at restoration of a trait genetic architecture disrupted by interspecific recombination. The most frustrating restriction in breeding for winterhardiness is a decrease of yielding potential associated with increase of resistance to winter stress. The physiological basis of this link, related to deepness and duration of dormancy period in winter, is also known in crops other than oat. The only way to keep yield high is breeding for cultivars with the lowest acceptable level of winterkill resistance in the targeted area (Reynolds et al., 2001).

A year ago the 'Radzikus' 5Q5.2 cultivar candidate seemed to have the most optimal combination of winterhardiness and yielding capacity, reaching in 2015 70,0% and 98,7% of the barley check yield in Radzików and Grodkowice, respectively. Three new lines were identified which were more productive than 5Q5.2 in 2015 while being also more winterhardy in the current season. The best of these lines combined 84,2% of the barley check yield (in Radzików, 2015) with the highest possible frost resistance score 9. The

corresponding 2016 score for 5Q5.2 was only 2. It opens new prospects to rise level of the yield-resistance compromise in oat. The elite includes also one line of naked oat with winterhardiness score 6. Hulless forms from earlier crosses were generally classified as insufficiently resistant to winter killing. The elite resistant line comes from a cross involving a winter naked common oat and the 'Wintok' derived octoploid. Its yield in Radzików in 2015 was very low (3 dt/ha, 39,8% of the winter barley standard). Better result recorded for that line in Grodkowice (56,2 % of the barley check) could make it more competitive to spring naked oat.

Conclusions

1. Relatively high performance of the *sativa-macrostachya* octoploids underline the potential for use of allopolyploidy in improvement of oat.
2. Crosses of common oat with 8x or 10x *sativa-macrostachya* allopolyploids proved to be effective in transgressive improvement of winterhardiness.
3. Some spring oats confirmed their value as good cross components for winterhardiness improvement.
4. In spite of the risk of winter killing, cultivation of the hexaploid oat wide hybrids in Poland is economically feasible on sufficiently fertile soils in regions with stable snow cover.

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