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COMBINING ABILITY OF THE PARENTAL FORMS OF THE NAKED-GRAIN OATS (*AVENA SATIVA* L.. VAR. NUDA) BASED ON EVALUATION OF SEVERAL TRAITS

ABSTRACT

Combining ability of the varieties and strains of the naked-grain oat was evaluated on the basis of the following traits: number of days to first heading, plant height and grain yield per plot. Six hundred and thirty nine strains of naked-grain oats were included involving F_4-F_8 generations over 5 years. Those strains were the progeny of 25 crossbreeding combinations of 9 testers with 13 varieties. The analysis of the variance in a hierarchic scheme showed highly significant values of the mean squares for years, testers, varieties and combinations for all the traits. The values of combining ability for testers, varieties and combinations of naked-grain oat were calculated. The results enabled to distinguish a group of naked-grain oat varieties, which effectively transferred the desirable traits to progeny: heading, shorter straw and high yield. The promising combinations for early heading were: Konradin × (Fl. nova × Swan mutant), and Caesar × (Płatek × Swan mutant), and for a higher grain yield Adam × Maro.

Key words: naked-grain oat, combining ability, heading, plant height, grain yield

INTRODUCTION

The program of naked-oat breeding (Nita and Orłowska-Job-1996) initiated at The Experimental Station of Plant Breeding Acclimatization Institute in Strzelce was successful and, as a result, the first Polish variety of naked oat named Akt (Nita 1997) has been registered. The breeding research program was focused on lines and forms of naked oat characterised, by low percentage of husk in the grain, high grain yield, and also high grain fat and protein content.

An important problem is still early heading and lodging resistance of new varieties of naked-grain oats. A further advance in breeding of the naked-grain oat depends on the recognition and estimation of combining ability of derived lines and their use in cross breeding with the forms obtained from other countries. Earlier, Muehlbauer et al. (1971) investigated the combining ability of early heading, growth rate, and plant height in generations F_2 and F_3 of 27 hybrids, obtained by crossing of 9 strains of winter oats with spring oats. In 1985 Cox crossed 10 forms of wild oats and 6 cultivars to estimate the combining ability for biomass,

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plant height and grain yield in F_2 and F_3 generations, while Kalasznik et al. (1985) investigated the combining ability of 7 oat cultivars in later generations F_3 to F_5.

In Poland evaluation of combing ability of white-grain oats (Śmiałowski, et al.1999) has been carried out in F_5 - F_7 generations and it has been demonstrated that for improving varieties of naked oat consideration of the number of days to first heading, plant height and grain yield per plot is useful.

A great interest in naked-grain oats in recent years in Poland, and also intensification of breeding programs, were the main reason to undertake studies on evaluation of the combining ability of the local naked oats lines and forms, and also of naked-grain oat cultivars from other countries.

MATERIALS AND METHODS

The studied material consisted of 644 hybrids of oats, obtained as a result of simple (also reciprocal) cross-breeding between various varieties, strains and lines (homogeneous) of oat: white-grain, yellow-grain and naked-grain botany groups of oats *(Avena sativa L. var. aristata, aurea and nuda).*

From the progeny which was obtained for cross-breeding, only naked-grain hybrids were selected. The population from F_4 (22 combinations), F_5 (9 combinations), F_6 (8 combinations), F_7 (7 combinations) to F_8 (2 combinations) (Table 1) were tested in the field within the years 1993-1998. The seeds were sown in the 10 m^2-test fields by the check-parcel method of each five plot in replication at the Experimental Station Strzelce of Plant Breeding and Acclimatisation Institute.

Out of this material, 639 forms were selected for the statistical-genetic analysis. They were the progeny of 13 forms and varieties of oats (including 6 as testers naked-grain: Terra, Rhea, Konradin, Adam, Ago and STH 1715, and the husky-grain yellow oats: Swan mutant and white-grain; Adamo). Those varieties were crossed in 25 combinations (Table 1), also reciprocally, in which some testers were male (paternal) and female (maternal) parent. The number of strains within each combination varied from 3 to 87, and within the testers from 11 to 126 (Table 2). The statistical-genetic analysis was based on 3 traits: number of days to first heading, plant height and grain yield. The testers and combinations were repeated each year, the total evaluation included 5 years, from 1993 to 1998, (excluding 1997).

The analysis of variance in hierarchic scheme previously described (Węgrzyn et al. 1979.1993, 1996) was used to estimate the combining ability. The total variation in the analysis was divided into 3 components: years, combinations and errors (Table 2). The sums of squares for combinations were partitioned in sums of squares for testers and varieties. The values of sum of the squares for geno-

Tabele 1

The combinations (F_4 to F_8) obtained from cross- breeding between of the 3 botany forms oats

No.	Combinations	Years				
		1993	1994	1995	1996	1998
1	*Terra × ** (Gambo × Alfred)	+				
2	*Terra × ** (Płatek × Swan mutant)	+				
3	*Terra × ** (Płatek × Swan)	+				
4	*Caesar × (Płatek × Swan mutant)	+				
5	*Caesar × (Płatek × Swan)	+				
6	**Swan mut. ×* Rhea	+				
7	**Swan mut. × *Adam	+				
8	*Rhea × Swan mutant	+				
9	*Rhea × ** (STH 1746 × Swan mutant)	+				
10	*Konradin × **Fl. nova × Swan mutant)	+	+			
11	*Konradin × ** (Mustang × Swan mutant)	+				
12	*Konradin × ***Boruta		+			
13	*Adam × ***Adamo	+	+	+	+	
14	*Adam × Swan mutant	+	+			
15	*Adam × ***Maro	+	+	+	+	
16	***Adamo × Adam	+	+	+	+	
17	***Adamo × Ago	+	+	+	+	
18	*Ago × Adamo	+	+	+	+	+
19	*Ago × **Ramiro	+	+	+	+	+
20	*Ago × (Fl. nova × Swan mutant)	+				
21	*Ago × (Mustang × Swan mutant)	+				
22	*Ago × ***Fl. Vita			+		
23	*Ago × **Semu			+	+	
24	*STH 1715 × *Nave	+				
25	*STH 1715 × * S.16906/76	+				

* - naked – grain *(Avena sativa L. var. nuda),* ** - yellow - grain *(Avena sativa L. var. aurea),*
*** - white – grain *(Avena sativa L. var aristata).*

type-environment interaction, i.e. the interaction between years and genotypes, were included in the sum of squares of error (Table 2). The significance of mean squares calculated from the analysis of variance was tested with the "F" test, and the significance of deviations from zero for the testers, varieties and combinations were tested with "t" test.

RESULTS AND DISCUSSIONS

The analysis of variance for 3 traits: number of days to first heading, plant height and yield grain per plot, showed high significance of mean squares for all components, that is: environment (years), combinations, testers and varieties in combinations (Table 2). This proves a highly genetically variable material. This holds especially, a particular group of 9 testers, which was evaluated for 3 traits: number of days to first heading, plant height and grain yield, showed relatively high values of mean squares.

Table 2

Analysis of variance of the three traits of naked-grain oat

Source of variation	Date of heading		Plant height		Grain yield	
	df	MS	df	MS	df	MS
Years	3	880.84*	4	5765.55*	4	15470.12**
Combination in	24	112.94**	24	1241.29*	24	254.33**
Testers	8	236.80**	8	1955.47*	8	484.33**
Cultivars	16	51.01**	16	884.19**	16	139.34**
Error	475	2.81	612	65.31	610	39.74

Significance at: P=0.05 (*) and P=0.01 (**)

The results were of high importance since they confirmed differences in the analysed traits of the testers and demonstrated a possibility for crossing different varieties and testers of the naked-grain oat. As shown in Table 2 the testers showed significant variability. Their combining ability was evaluated by the calculating of the mean values for each trait, and effects of the combinations (cross breeding) of hybrids and varieties. Cox et al. (1984) confirmed high significance of mean squares for combining ability estimated for *A. sativa* and *A. sterlis* for three traits: grain yield, biomass and the vegetative growth index. The results with negative values were considered as advantageous for earlier growth and plant height, which means a shorter period to first heading and a lower height of plant, thus resulted in better grain yield mean and higher fertility (productivity).

It was found that the best testers for early heading were the following naked-grain oat varieties: Caesar, Konradin, Rhea and Terra (with negative values of combination effect: -4.04**, -3.44**, -1.76** and -0.82** respectively), (Table 3), and the unfavourable, delay in the heading date in progeny populations were demonstrated by 2 testers: STH 1715 and Adam (positive combination effects: 1.76** and 1.69**respectively), (Table 3). The ability for early heading of tnaked-grain oats Caesar and Konradin, was detected in the progeny of the following combinations: Caesar × (Płatek x Swan mutant), Płatek × Swan, Konradin × (Fl. nova × Swan mutant), Konradin × Boruta and Konradin × (Fl. nova × Swan mutant).

Two out of the combinations listed above deserved special attention: Konradin × (Fl. nova x Swan mutant) and Konradin × (Mustang × Swan

Table 3

Number of the investigated strains, means and effects of testers, varieties and combinations

Date of heading				
Combinations/Testers	Number of strains	Mean [days]	Effects of combinations	Effect of strains
Terra × Gambo × Alfred	11	50,1	3,49**	4,31**
Terra × Płatek × Swan	16	44,3	-2,32**	-1,50**
Terra × Płatek × Swan mutant	15	44,2	-2,38**	-1,56**
Terra	42	45,8	-0,82**	
Caesar × Płatek × Swan mutant	10	41,8	-4,81**	-0,76**
Caesar × Płatek × Swan	16	43,0	-3,57**	0,48
Caesar	26	42,5	-4,04**	
Swan mutant × Rhea	7	43,9	-2,65**	-1,89**
Swan mutant × Adam	5	48,5	1,89**	2,65**
Swan mutant	12	45,8	-0,76**	
Rhea × Swan mutant	7	43,9	-2,65**	-0,89**
Rhea × STH 1746 × Swan mutant	5	46,1	-0,51**	1,25**
Rhea	12	44,8	-1,76**	
Konradin × Fl. Nova × Swan mutant	87	42,8	-3,75**	-0,31
Konradin × Boruta	4	50,7	4,08**	7,52**
Konradin × Mustang × Swan mutant	3	42,1	-4,51**	-1,07**
Konradin	94	43,1	-3,44**	
Adam × Maro	20	48,7	2,15**	0,46
Adam × Adamo	48	48,1	1,55**	-0,15**
Adam × Swan mutant	8	48,0	1,43**	-0,27
Adam	76	48,3	1,69**	
Adamo × Ago	56	48,5	1,95**	0,19
Adamo × Adam	48	48,1	1,55**	-0,22
Adamo	104	48,4	1,77**	
Ago × Mustang × Swan mutant	3	48,7	2,16**	0,88*
Ago × Adamo	65	48,5	1,96**	0,68
Ago × Fl. nova × Swan mutant	6	48,2	1,66**	0,38
Ago × Ramiro	47	47,6	1,04**	-0,24
Ago × Fl. vita	4	44,4	-2,17**	-3,44**
Ago × Semu	4	42,4	-4,17**	-5,44**
Ago	126	47,9	1,28**	
STH 1715 × S. 16906/76	4	47,3	0,74*	-1,02**
STH 1715 × Nave	7	48,9	2,35**	0,58
STH 1715	11	48,3	1,76**	
Mean (x)		46,6		
CV [%]		6,1		

Significant at:P=0,05 (*) and P=0,01 (*); Means from 5 years (4 years for heading)

Table 3

Continued

Combination/Testers	Plant height			
	Number of strains	Mean [cm]	Effects of combinations	Effect of strains
Terra × Gambo × Alfred	11	109,2	13,57**	14,96**
Terra × Płatek × Swan	16	85,6	-10,05**	-8,65**
Terra × Płatek × Swan mutant	15	92,5	-3,13	-1,74
Terra	42	94,2	-1,39	
Caesar × Płatek × Swan mutant	10	85,1	-10,49**	-6,08**
Caesar × Płatek × Swan	16	95,0	-0,61	3,80*
Caesar	26	91,2	-4,41**	
Swan mutant × Rhea	7	91,9	-3,65*	-11,19**
Swan mutant × Adam	5	118,8	23,20**	15,67**
Swan mutant	12	103,1	7,53**	
Rhea × Swan mutant	7	91,9	-3,65*	-1,44
Rhea × STH 1746 × Swan mutant	5	95,4	-0,19	2,02
Rhea	12	93,4	-2,21**	
Konradin × Fl. Nova × Swan mutant	87	84,9	-10,65**	-0,94
Konradin × Boruta	4	93,5	-2,14	7,57**
Konradin × Mustang × Swan mutant	3	103,1	7,53**	17,25**
Konradin	94	85,9	-9,71**	
Adam × Maro	23	107,8	12,14**	8,49**
Adam × Adamo	76	95,2	-0,42	-4,07*
Adam × Swan mutant	8	113,5	17,92**	14,27**
Adam	107	99,3	3,65**	
Adamo × Ago	79	96,3	0,68	0,54
Adamo × Adam	76	95,2	-0,42	-0,56
Adamo	155	95,8	0,14	
Ago × Mustang × Swan mutant	3	111,8	16,20**	14,00**
Ago × Adamo	85	96,2	0,58	-1,63
Ago × Fl. nova × Swan mutant	6	105,3	9,70**	7,50**
Ago × Ramiro	77	98,1	2,54	0,34
Ago × Fl. vita	4	107,8	12,22**	10,02**
Ago × Semu	7	95,7	0,10	-2,09
Ago	182	97,8	2,20*	
STH 1715 × S. 16906/76	4	112,8	17,20**	-1,73
STH 1715 × Nave	7	115,5	19,92**	0,99
STH 1715	11	114,5	18,93**	
Mean (x)		95,6		
CV [%]		10,9		

Significant at:P=0,05 (*) and P=0,01 (*); Means from 5 years (4 years for heading)

Table 3

Continued

Combination/Testers	Number of strains	Mean [dt/ha]	Effects of combinations	Effect of strains
	Grain yield			
Terra × Gambo × Alfred	11	32,3	-6,78**	2,19
Terra × Płatek × Swan	16	31,1	-7,89**	1,07
Terra × Płatek × Swan mutant	15	27,3	-11,72**	-2,75*
Terra	42	30,1	-8,97**	
Caesar × Płatek × Swan mutant	10	36,4	-2,65**	0,05
Caesar × Płatek × Swan	16	36,3	-2,74**	-0,03
Caesar	26	36,3	-2,70**	
Swan mutant × Rhea	7	39,5	0,42	1,48
Swan mutant × Adam	5	35,9	-3,13**	-2,07
Swan mutant	12	37,9	-1,05	
Rhea × Swan mutant	7	39,5	0,42	0,17
Rhea × STH 1746 × Swan mutant	5	39,1	0,02	-0,24
Rhea	12	39,3	0,26	
Konradin × Fl. Nova × Swan mutant	87	39,9	0,82	0,02
Konradin × Boruta	4	39,6	0,53	-0,27
Konradin × Mustang × Swan mutant	2	39,5	0,47	-0,33
Konradin	94	39,8	0,79	
Adam × Maro	13	43,3	4,24**	2,47
Adam × Adamo	75	40,5	1,47	-0,29
Adam × Swan mutant	8	36,5	-2,58*	-4,35**
Adam	106	40,8	1,76**	
Adamo × Ago	79	41,1	2,02	0,26
Adamo × Adam	75	40,5	1,47	-0,28
Adamo	154	40,8	1,75**	
Ago × Mustang × Swan mutant	3	42,6	3,61**	3,69**
Ago × Adamo	85	40,6	1,59	1,68
Ago × Fl. nova × Swan mutant	6	39,1	0,02	0,12
Ago × Ramiro	77	38,2	-0,86	-0,77
Ago × Fl. vita	4	38,1	-0,97	-0,88
Ago × Semu	7	25,8	-13,26**	-13,17**
Ago	182	38,9	-0,09	
STH 1715 × S. 16906/76	4	37,7	-1,36	3,89**
STH 1715 × Nave	7	31,6	-7,48**	-2,23
STH 1715	11	33,8	-5,25**	
Mean (x)		39,0		
CV [%]		17,1		

Significant at:P=0,05 (*) and P=0,01 (*); Means from 5 years (4 years for heading)

mutant) (Table 3), because of early heading resultating from a variety and a tester (Table 3).

An important problem in breeding oats is the lodging resistance. The components characterised by shorter and stiffer straw, and, therefore, potentially resistant to lodging were included in the cross-breeding program. The testers: Konradin, Caesar and Rhea with the respective negative effects: - 9.71**, -4.41** and -2.21** (Table 3), appeared to be the best components for transmitting short straw to their progeny. The effectiveness of those testers in stem shortening was particularly revealed in the combination: Konradin x (Fl. nova x Swan mutant), with the combinations effect -10.65** (Table 3) and in Caesar x (Płatek x Swan mutant), with combination effect (-10.49**). The testers for naked oat - varieties: Ago (2.20*), Adam (3.65**) and strains: STH 1715 (18.93**) characterised by positive values and lengthen straw in the progeny (Table 3). The valuable variety, Swan mutant (yellow-grained, husky-oat), used in many cross-breedings, in this case appeared to be undiserable tester and can not be recommended for shortening of straw in naked-grain forms of oat.

At present, the naked-grain oat breeding programs, concentrate mainly on high yield, besides the expression of naked-oats characteristics. The components, testers and varieties used in our cross-breeding program were characterised by low variability values and were generally unsatisfactory for transferring high yield to progeny. Of the naked-grain testers studied, only one variety - Adam, which showed positive combining ability (1.76**) significantly increased grain yield in its progeny (Table 3). However, a promising combination could be a hybrid obtained by crossing of the naked-grain variety Adam with white-grain Maro, characterised by a positive combination value (4.24**), (Table 3). The evaluation of different varieties and strains for their suitability in breeding revealed that it is possible to develop combinations including the components which were omitted in the previous cross-breeding programs.

In planning of new prospective combinations, it would be possible to take adventage of the results of our analysis of combining ability (Table 3).

It was found that Caesar × Fl. nova (husky-grain yellow oat form) or Caesar x Semu (white-grained, husky-oat) represent the best combinations for early heading . In the next generations of progeny there appeared early heading forms, but with both husky and naked-grain, as a result of genetic segregation. In order to avoid this phenomenon, it may be possible to use for crossing only early forms of naked-grain oats: Konradin, Caesar, Rhea or Terra, although the yield could be considerably diminished.

The most successful combination for straw shortening is a combination of a short, naked-oat cultivar Konradin with a short naked-grain form of oat (Płatek x Swan mutant). In this case, it is also necessary to select naked-grain forms out of naked-grain and husked-grain forms resulted from genetic segregation. Another valuable naked-grain oat variety, Rhea, showed negative combining ability for favourable characters (Table 3) but it is a tall form and should not be recommended as a component for straw shortening.

In planning of the increased grain yield of naked-grained oat, the most successful combination seems to be cross-breeding of naked-grain variety Adam with white-grain, husky-varieties Adamo or Maro (Table 3), which are characterised by a high grain yield per plot as well as positive effect of combination (Table 3). However, in both cases, morphological dissimilarities of these forms would make selection difficult in achieving a high yielding cultivar of naked-grain oat. When designing a cross-breeding program it would be advisable to consider the risk that the oat varieties, successfully tested in previous combinations, may not perform in new pairs earlier heading, reduction in straw length and high grain yield per plot in progeny. One of the reasons for failure could be a significant influence of the environment (years of study) on the combining ability. This influence, as demonstrated by significantly high values of the mean squares for years in this study (Table 2), can markedly modify the results of combining ability in varieties and testers and of the resulting hybrids (combinations).

This problem has been studied by Muelbauer et al. (1971) who described a significant influence of various environments (locations and years) on the combing ability of oats, especially for such traits as earlier first heading.

Our results demonstrated the insignificance of maternal influence on the combining ability for the following reciprocal combinations: Rhea x Swan mutant and Swan mutant x Rhea also Adam x Adamo and Adamo x Adam (Table 3).

The effect of variety Rhea in combination: Swan mutant × Rhea for heading was -1.89**, and for varieties Swan mutant in reciprocal combination: Rhea x Swan mutant was also significant at -0.89** (Table 3). Similarly, the effect of Rhea for plant height in the first combination: Swan mutant × Rhea, appeared to be significantly: high and negative: -11.19** and in the second, reciprocal combination, this effect of Swan mutant was also negative: -1.44 (Table 3). These results do not confirm the hypothesis of maternal influence on the combining ability in reciprocal crossing. A similar result was observed in the progeny of the hybrids between the oat-white varieties (Śmiałowski et al. 1999). The reciprocal effects, important only in some cases for maturity and yield were obtained by Muehlbauer et al. 1971).

Despite the fact that the maternal effect has not been observed in our research, it would be advisable to include in future programs, in order to utilise fully genetic diversity of oat varieties.

CONCLUSION

1. The statistic-genetical analysis of 644 strains of naked-grain oat allowed to identify a group of the varieties successfully transmitting to progeny the following traits: early heading, short stem and the high grain yield. The most beneficial parents for heading, are: Caesar, Konradin, Rhea and Terra, for short stem: Konradin, Caesar and Rhea and for high grain yield Adam.

2. The best, promising combinations in the naked-grain oat breeding programs for early heading and short stem are; Konradin x (Fl. nova x Swan mutant) and Caesar x (Płatek x Swan mutant) while high grain yield could be expected in the progeny of Adam x Maro.

3. This study confirmed that there was no significant influence of mothers i. e. the effect of crossing direction on combining ability in the progeny.

RFERENCES

Kalasznik N. A., Portjanko W. A., Bogaczkow W. J.1985. Selekcjonno-gienieticzeskij analiz produktiwnosti gibridow owsa. Jun. Ginietika: 1722-1730.

Cox D. J, Frey K. J.1984. Combining ability and the selection of parents for inter specific oat matings. Crop. Sci. 24: 963-967.

Muehlbauer F. J., Marshall H. G., Hill R. R Jr. 1971. Combining ability, heritability, and cytoplasmic effects in oats. Crop Sci. 11: 376-378.

Nita Z., Orłowska-Job W. 1996. Hodowla owsa nagoziarnistego w Zakładzie Doświadczalnym HAR w Strzelcach. Biul. IHAR, 197: 141-145.

Nita Z. 1997. Sprawozdanie z realizacji hodowli owsa w Zakładzie Doświadczalnym Instytutu Hodowli i Aklimatyzacji Roślin w Strzelcach. Dział Organizacji i Planowania badań.

Śmiałowski T., Węgrzyn S. Nita Z. 1999. Zdolność kombinacyjna rodów i odmian owsa na podstawie oceny kilku cech. Część I. Owies białoziarnisty, (Avena sativa L. var aristata). Biul. IHAR 210: 53-59.

Węgrzyn S., Nalepa S., Pochaba L. 1979. Ogólna i swoista wartość kombinacyjna dla plonu i jego komponentów u pszenicy ozimej. Hod. Rośl. Aklim. 23: 61-72.

Węgrzyn S., Pochaba L., Cygankiewicz A., Witkowski E. 1993. Zdolność kombinacyjna form rodzicielskich na podstawie oceny kilku cech rodów hodowlanych pszenicy ozimej. Biul. IHAR, 187: 19-28.

Węgrzyn S., Pochaba L., Choma K. 1996. Zdolność kombinacyjna form rodzicielskich na podstawie oceny kilku cech rodów hodowlanych pszenicy ozimej. Biul. IHAR, 200: 227-235.