UDC 575:633.15
DOI: 10.2298/GENSR1203595T
Original scientific paper

COMBINING ABILITY AND HETEROSIS EFFECT IN HEXAPLOID WHEAT GROUP

Primož TITAN[1], Vladimir MEGLIČ [2], and Jernej ISKRA[3]

[1]SEMENARNA Ljubljana, d.d., Ljubljana, Slovenia
[2]Agricultural Institute of Slovenia, Ljubljana, Slovenia
[3] "Jožef Stefan" Institute, Ljubljana, Slovenia

Titan P., V. Meglič, and J. Iskra (2012): *Combining ability and heterosis effect in hexaploid wheat group.* - Genetika, Vol 44, No. 3,595 - 609.

The main goal of hybrid wheat breeding is the identification of parents with high specific combining ability for grain yield and other agronomic traits. This kind of data facilitate the development of hybrid combinations with high level of heterosis in first filial generation (F_1 generation). The use of species from the hexaploid wheat group (e.g. *Triticum spelta* L. *Triticum compactum* HOST...) is representing an opportunity for the increase of heterosis level in the germplasm of common wheat (*Triticum aestivum* L.).

The study of combining ability and heterosis effect in hexaploid wheat group was carried out using crosses between thirteen inbred lines of common wheat (6 lines x 7 testers) and inter-species crosses (*T. aestivum* L. × *T. spelta* L., *T. aestivum* L. × *T. compactum* HOST, *T. aestivum* L. × *T.*

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Corresponding author: Vladimir Meglič, Agricultural Institute of Slovenia, Hacquetova ulica 17, 1000 Ljubljana, Slovenia, Phone: 00386 1 28 05 180. Fax: 00386 1 28 05 255.E-mail: vladimir.meglic@kis.si.

sphaerococcum PERCIV., *T. aestivum* L. × *T. macha* DEKAPR. et MENABDE, *T. aestivum* L. × *T. petropavlovskyi* UDACZ. et MIGUSCH, *T. aestivum* L. × *T. vavilovii* (THUM.) JAKUBZ.). The 42 common wheat F_1 hybrids were tested during two seasons (2010/11 and 2011/12) on the Selection center Ptuj. The experiment was carried out in a randomized block design with four replications. The 43 interspecies F_1 hybrids were tested on the same location in the season 2011/12 and the experiment was designed as an randomized block with three replications. The results were analyzed using statistical package AGROBASE generation II and STATGRAPHICS Centurion XVI.

The analysis of variance was significant for both, GCA and SCA variances ($P < 0,01$). Generally, SCA variances were lower than GCA variances. We could state, that the improvement of heterosis level in the common wheat germplasm through the use of relatives with the same genome (genome BAD) is possible. As an example we can point out the interspecies F_1 hybrid between common wheat variety Garcia and an accession of the *Triticum sphaerococcum* PERCIV. species (accession number 01C0201227).

Key words: combining ability, heterosis effect, hexaploid wheat group, hybrid wheat

INTRODUCTION

Exploitation of heterosis with hybrid varieties offers an oppurtunity for overcoming the stagnating yield plateau of common wheat (*Triticum aestivum* L.) (CHAKRABORTY and DEVAKUMAR, 2005). Heterosis or the gene expression of the beneficial effects of hybridization can be explained by effects of intra and inter loci gene action (dominance, over-dominance, epistasis) (JORDAAN *et al*., 1999). The limiting factor for the successful exploitation of heterosis represents the effective system for male sterility induction and the "gene pool" representing selected germplasm. In the past several approaches on the genetic level (e.g. cytoplasmic-genetic male sterility) transgenic level (e.g. RNA interference, the expression of cytotoxic and cytostatic polypeptides) and chemical level (the use of CHA) were proposed for the induction of male sterility in the common wheat (TITAN and MEGLIČ, 2011a; TITAN *et al*. 2012a). All wheat hybrids in Europe are currently produced with chemical hybridizing agents. The development of contemporary commercial chemical hybridizing agents continues, particularly towards achieving better selectivity of gametocidal activity and lesser impact on the environment (TITAN and MEGLIČ, 2011b; ISKRA *et al.*, 2012; TITAN *et al*. 2012b).

The level of heterosis can be expressed as a mid-parent heterosis (F_1 hybrid vs. mid parent value), better-parent heterosis or heterobeltiozis (F_1 hybrid vs. better parent value) and as a standard heterosis (F_1 hybrid vs. standard cultivar). Within the chosen germplasm, the highest level of heterosis could be achieved only with testing of general (additive mode of gene astion) and specific combining ability (non-aditive or dominant mode of gene action) (KRYSTKOWIAK *et al*., 2009). According to

SHORAN *et al*. (2003) the Line × Tester analysis is the basis model for the GCA and SCA testing. Such analysis facilitate the selection of parental genotypes with a high probability of heterosis in their F_1 progeny. The hybrid combinations with the highest SCA value express the highest hybrid performance. Despite the intensive GCA and SCA testing in the germplasm of common wheat, on average less than 10 % of mid-parent heterosis is observed in F_1 hybrids, while the hybrid combinations with the value over 20 % occur very rarely. This could be related to the relative high degree of genetic similarity among the parental lines (CISAR and COOPER, 2002). One of the options for the increase of heterosis level in the common wheat germplasm could represent the use of relatives within the hexaploid wheat group (QIXIN *et al*., 1997). The aim of this study is to identify genotype pairs in the hexaploid wheat group having the BAD genome (WGGRC, 2012) which could be expressed with higher combining ability and heterosis level in comparison with the F_1 hybrids of common wheat (*Triticum aestivum* L.).

MATERIALS AND METHODS

Plant materials

To study combining ability and heterosis effect in hexaploid wheat group we made crosses between thirteen french inbred lines of common wheat (*T. aestivum* L. × *T. aestivum* L.) and 43 inter-species crosses (*T. aestivum* L. × *T. spelta* L., *T. aestivum* L. × *T. compactum* HOST, *T. aestivum* L. × *T. sphaerococcum* PERCIV., *T. aestivum* L. × *T. macha* DEKAPR. et MENABDE, *T. aestivum* L. × *T. petropavlovskyi* UDACZ. et MIGUSCH, *T. aestivum* L. × *T. vavilovii* (THUM.) JAKUBZ.). All parental components and their F_1 hybrids are summarized in tables 1 and 2. Parental components for the interspecies crosses were determined on the basis of Wheat Genetic and Genomic Resources Center wheat taxonomy (WGGRC, 2012) and obtained from the gene bank of Plant Production Research Center – Piestany (PPRC, 2012).

Table 1. Thirteen inbred lines of common wheat and relatives of common wheat

Accession name and number	Species	Source
Garcia	*Triticum aestivum* L.	SECOBRA[1]
Alixan	*Triticum aestivum* L.	Limagrain[2]
Inoui	*Triticum aestivum* L.	Syngenta[3]
Azimut	*Triticum aestivum* L.	Limagrain[2]
Bologna	*Triticum aestivum* L.	Syngenta[3]
Guarni	*Triticum aestivum* L.	F. Desprez[4]
Aldric	*Triticum aestivum* L.	F. Desprez[4]
FD05152	*Triticum aestivum* L.	F. Desprez[4]
Racine	*Triticum aestivum* L.	SECOBRA[1]
Sailor	*Triticum aestivum* L.	SECOBRA[1]
Incisif	*Triticum aestivum* L.	Syngenta[3]

Euclide	*Triticum aestivum* L.	F. Desprez[4]
Illico	*Triticum aestivum* L.	Syngenta[3]
Orvantis	*Triticum spelta* L.	Syngenta[3]
Epeautre Nain (01C0106129)	*Triticum spelta* L.	PPRC[5]
Schwabenspelz (01C0106267)	*Triticum spelta* L.	PPRC[5]
Steiners tiroler dinkel (01C0100730)	*Triticum spelta* L.	PPRC[5]
Ostar (01C0106321)	*Triticum spelta* L.	PPRC[5]
Zeiners weisser dinkel (01C0100744)	*Triticum spelta* L.	PPRC[5]
Rouquin (01C0104432)	*Triticum spelta* L.	PPRC[5]
Desyanthum-Tabor (01C0106105)	*Triticum spelta* L.	PPRC[5]
Blauer kolbendinkel (01C0100922	*Triticum spelta* L.	PPRC[5]
Tmava (01C0100921)	*Triticum spelta* L.	PPRC[5]
Gentile-Tabor (01C0106107)	*Triticum spelta* L.	PPRC[5]
Redoute (01C0105692)	*Triticum spelta* L.	PPRC[5]
Baettig-Niederwill (01C0105446)	*Triticum spelta* L.	PPRC[5]
Harrisson barbee (01C0200657)	*Triticum compactum* HOST	PPRC[5]
Tiroler frueher binkel (01C0201147)	*Triticum compactum* HOST	PPRC[5]
Blauroter binkel (01C0105447)	*Triticum compactum* HOST	PPRC[5]
Little club (01C0201011)	*Triticum compactum* HOST	PPRC[5]
Shloucena (01C0200978)	*Triticum compactum* HOST	PPRC[5]
T. sphaerococcum (01C0201227)	*Triticum sphaerococcum* PERCIV.	PPRC[5]
Ruzyne (01C0200979)	*Triticum sphaerococcum* PERCIV.	PPRC[5]
Kolandi (01C0201097)	*Triticum sphaerococcum* PERCIV.	PPRC[5]
Triticum petropavlov. (01C0204140)	*Triticum petropavlovskyi* UDACZ. et MIGUSCH.	PPRC[5]
T. macha (01C0101087)	*Triticum macha* DEKAPR. et MENABDE	PPRC[5]
T. macha (01C0105518)	*Triticum macha* DEKAPR. et MENABDE	PPRC[5]
T. vavilovii (01C0105083)	*Triticum vavilovii* (THUM.) JAKUBZ.	PPRC[5]

[1]SECOBRA Recherches, Centre de Bois-Henry 78580 MAULE, France ,[2]Limagrain, Rue Limagrain, 63720 Chappes, France,[3]Syngenta Seeds SAS, 12 chemin de l'Hobit BP 27, 31790 Saint-Sauveur, France [4]Florimond Desprez Veuve et Fils, 59242 Capelle en Pévèle, France,[5]Plant Production Research Center – PPRC, Bratislavská cesta 122, 921 68 Piešťany, Slovakia

Field experiments

The 42 common wheat F_1 hybrids were tested in two seasons (2010/11 and 2011/12) on Selection center Ptuj (latitude: 46°24'45,84"N, longitude: 15°52'23,67"E; soil type: cambisol soil). The experiment was conducted in a randomized block design with four replications. The 43 interspecies F_1 hybrids were tested in the season 2011/12 on the same location where the experiment was laid out in a randomized block design with three replications.

Table 2. Common wheat and interspecies F_1 hybrids

***T. aestivum* L. × *T. aestivum* L. F_1 hybrids**
Alixan × Aldric, Alixan × FD05152, Alixan × Racine, Alixan × Sailor, Alixan × Incisif, Alixan × Euclide, Alixan × Orvantis, Guarni × Aldric, Guarni × FD05152, Guarni × Racine, Guarni × Incisif, Guarni × Euclide, Guarni × Orvantis, Inoui ×Aldric, Inoui × FD05152, Inoui × Racine, Inoui × Sailor, Inoui × Incisif, Inoui × Euclide, Inoui × Illico, Inoui × Orvantis, Azimut × Aldric, Azimut × FD05152, Azimut × Racine, Azimut × Incisif, Azimut × Euclide, Azimut × Orvantis, Bologna × Aldric, Bologna × FD05152, Bologna × Racine, Bologna × Sailor, Bologna × Incisif, Bologna × Euclide, Bologna × Illico, Bologna × Orvantis, Garcia × Aldric, Garcia × FD05152, Garcia × Racine, Garcia × Sailor, Garcia × Incisif, Garcia × Euclide, Garcia × Orvantis
Interspecies F_1 hybrids
Garcia × KM 93-2000, Garcia × Epeautre Nain, Garcia × Schwabenspelz, Inoui × Steiners tiroler dinkel, Inoui × Epeautre Nain, Inoui × Ostar, Inoui × Zeiners weisser dinkel, Bologna × Rouquin, Bologna × Desyanthum-Tabor, Bologna × Blauer kolbendinkel, Azimut × Tmava, Azimut × Gentile-tabor, Azimut × Redoute, Azimut × Rouquin, Guarni × Baettig-Niederwill, Guarni × Ostar, Garcia × Harrisson barbee, Garcia × Tiroler frueher binkel, Alixan × Blauroter binkel, Alixan × Little club, Alixan × Harrisson barbee, Inoui × Tiroler frueher binkel, Inoui × Blauroter binkel, Bologna × Shloucena, Azimut × Blauroter binkel, Azimut × Harrisson barbee, Guarni × Tiroler frueher binkel, Garcia × T. sphaerococcum (acc. num. (01C0201227), Garcia × Ruzyne, Inoui × T. sphaerococcum (acc. num. (01C0201227), Inoui × Ruzyne, Guarni × Kolandi, Guarni × Ruzyne, Alixan × T. macha (acc. num. 01C0101087), Bologna × T. macha (acc. num. 01C0101087), Azimut × T. macha (acc. num. 01C0101087), Azimut × T. macha (acc. num. 01C0105518), Alixan × T. vavilovii, Inoui × T. vavilovii, Garcia × Triticum petropavlovskyi, Alixan × Triticum petropavlovskyi, Bologna × Triticum petropavlovskyi, Guarni × Triticum petropavlovskyi

Statistical analyses

For three plants in each replication following parameters were recorded: number of spikes per plant, plant height and grain yield per plant. Due to the hybrid necrosis in the cross *T. aestivum* L. × *T. petropavlovskyi* UDACZ. et MIGUSCH data were collected for only 39 interspecies F_1 hybrids. Data were processed by the univariate analysis of variance (ANOVA) using the statistical package STATGRAPHICS Centurion XVI® (STATGRAPHICS®, 2012). GCA and SCA effects were analyzed using statistical package AGROBASE Generation II® (AGRONOMIX®, 2012). Heterosis effect for a given parameter was evaluated as a difference between F_1 hybrid performance and mid-parent or best-parent value. The results from the field experiments are represented on the basis of significance at 5 and 1 % levels (P = 0.05 and 0.01).

RESULTS AND DISCUSSION

The first step in the hybrid wheat breeding is made, when the combinations with high SCA value are determined. For the further F_1 hybrid development is also important to assess modes of the gene action (additive or non-additive) that have the highest impact on the given trait. The analysis of variance in our study showed both GCA and SCA variances (P < 0,01). Generally, SCA variances were lower than GCA variances. The biggest difference between GCA and SCA values has been observed for the grain yield per plant. In this case the additive allele effects were also more than twenty times greater than non-aditive allele effects (Table 3). Similar results were presented by CUKADAR and GINKEL (2001). They studied 148 F_1 hybrids of common wheat, which were produced using chemical hybridizing agent Genesis® (also MON 21200). They observed that overall general combining ability effects were also more important for grain yield than specific combining ability effects.

Table 3. Analysis of variance for traits related to grain yield

Source of variation	df	Mean square		
		Number of spikes per plant	**Plant height**	**Grain yield per plant**
2010/11				
Blocks	3	0,78^{ns}	8,46^{ns}	1,51^{ns}
Hybrids	41	7,44**	100,73**	45,84**
Parents	13	2,94**	377,46**	20,46**
Par. vs. Hybrids	1	137,61**	2140,47**	802,84**
GCA lines	5	29,52**	324,84**	264,49**
GCA testers	7	5,87**	56,59**	22,62**
SCA	29	4,01**	73,21**	13,85**
Residual	165	0,77	3,61	1,83
2011/12				
Blocks	3	0,93^{ns}	4,01^{ns}	1,16^{ns}
Hybrids	41	5,83**	85,54**	34,38**
Parents	13	4,80**	322,57**	22,81**
Par. vs. Hybrids	1	78,06**	1712,96**	361,92**
GCA lines	5	24,78**	293,87**	214,46**
GCA testers	7	4,55**	41,10**	18,52**
SCA	29	3,21**	62,40**	10,19**
Residual	165	0,08	3,37	1,604

* P < 0,05; ** P < 0,01

Before we proceeded to the analysis of the hybrid advantage distribution for F_1 hybrids of common wheat we evaluated correlations between SCA values and mid-parent heterosis values (SCA vs. MPH) and between mid-parent values and mid-parent heterosis values (x̄ vs. MPH). We confirmed the positive linear correlation betwen SCA values and mid-parent heterosis values for all traits and for both seasons (Table 4 and 5). The correlation coeficient values ranged from 0,683 to 0,727. The highest correlation coefficient was observed for grain yield (r_{xy} = 0,706 – 0,727).

Table 4a. Mid-parent value, SCA and MPH value for three traits in the season 2010/11

***T. aestivum* L. × *T. aestivum* L. – 2010/11**	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	x̄	SCA	MPH	x̄	SCA	MPH	x̄	SCA	MPH
Alixan × Aldric	5,17	0,17	48,39	87,44	0,91	4,79	9,74	1,11	43,53
Alixan × FD05152	5,90	-0,50	13,07	85,85	0,36	3,32	9,51	0,70	34,39
Alixan × Racine	5,90	-0,70	22,26	87,21	1,00	6,14	10,94	-0,92	25,78
Alixan × Sailor	5,65	-0,18	29,15	84,17	-1,45	6,39	9,97	-0,33	28,69
Alixan × Incisif	5,25	0,71	50,81	83,17	2,00	8,77	9,61	0,13	32,97
Alixan × Euclide	5,38	-0,11	19,38	82,23	-2,06	9,3	10,05	-0,58	13,73
Alixan × Orvantis	5,52	0,31	41,89	83,17	-0,15	9,77	10,14	0,64	45,17
Guarni × Aldric	6,25	-0,51	22,67	84,42	2,91	12,44	11,60	-0,31	30,42
Guarni × FD05152	6,98	0,86	18,21	82,83	-0,60	7,49	11,37	2,63	48,83
Guarni × Racine	6,98	-0,00	22,99	84,19	3,57	14,53	12,80	-0,86	28,04
Guarni × Incisif	6,33	1,36	46,06	80,15	-7,00	3,25	11,47	1,35	44,38
Guarni × Euclide	6,46	0,84	24,52	79,21	3,74	22,41	11,91	2,48	43,20
Guarni × Orvantis	6,60	-2,32	-11,0	80,15	-1,90	13,34	12,00	-4,16	4,12
Inoui ×Aldric	6,67	-1,59	9,37	87,38	-3,50	5,53	13,89	-0,90	20,87
Inoui × FD05152	7,40	0,95	22,25	85,79	5,11	14,76	13,65	2,12	39,29
Inoui × Racine	7,40	0,84	36,90	87,15	-0,39	10,35	15,08	2,05	42,81
Inoui × Sailor	7,15	-0,72	13,70	84,10	-2,90	10,68	14,11	-0,80	21,71
Inoui × Incisif	6,75	0,29	31,49	83,10	4,50	17,07	13,76	0,65	31,67
Inoui × Euclide	6,88	0,43	21,21	82,17	-1,63	15,97	14,19	-0,17	17,26
Inoui × Illico	6,46	-1,21	29,68	82,08	6,00	19,65	12,93	-3,04	25,41
Inoui × Orvantis	7,02	0,56	34,72	83,10	-4,44	10,70	14,28	0,02	32,38

x̄ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

The correlation between mid-parent value and mid-parent heterosis (x̄ vs. MPH) was positive only for grain yield (r_{xy} = 0,163 – 0,169). This means, that the advantageous effect of a given parental genotype is not associated with an improvement of the performance in hybrid progeny. Results confirm also a well-known fact that the occurrence of the heterosis effect in relation to one of the traits does not have to be equivalent to the occurrence of the heterosis in relation to other traits (KRYSTKOWIAK *et al.*, 2009). Similar results were obtained for interspecies F_1

progenies where we could not confirm positive correlations between different parameters (Table 6).

Table 4b. Mid-parent value, SCA and MPH value for three traits in the season 2010/11

***T. aestivum* L. × *T. aestivum* L. – 2010/11**	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	$\bar{x}$	SCA	MPH	$\bar{x}$	SCA	MPH	$\bar{x}$	SCA	MPH
Azimut × Aldric	6,15	2,19	50,51	90,48	3,68	1,31	10,23	1,15	20,49
Azimut × FD05152	6,88	-0,94	-22,4	88,90	-11,6	-16,7	10,00	-1,71	-13,2
Azimut × Racine	6,88	-0,18	6,06	90,25	-0,42	-2,03	11,43	-0,57	8,64
Azimut × Incisif	6,23	-0,81	-4,34	86,21	3,52	3,53	10,10	0,48	13,16
Azimut × Euclide	6,35	-0,41	-10,8	85,27	-0,21	4,37	10,54	-0,67	-8,48
Azimut × Orvantis	6,50	0,38	14,74	86,21	5,78	9,62	10,83	2,08	36,13
Bologna × Aldric	6,10	-0,47	22,18	86,04	-0,24	3,73	10,64	-0,62	27,72
Bologna × FD05152	6,83	-0,93	-9,15	84,46	3,84	7,70	10,40	-1,11	18,41
Bologna × Racine	6,83	-0,38	16,46	85,81	-2,08	2,84	11,83	-0,34	32,42
Bologna × Sailor	6,58	0,77	31,65	82,77	2,24	11,15	10,86	1,10	43,59
Bologna × Incisif	6,19	-0,92	8,42	81,77	-0,40	6,19	10,51	-1,99	14,14
Bologna × Euclide	6,31	0,01	10,23	80,83	0,63	12,99	10,94	1,26	33,47
Bologna × Illico	5,90	1,04	63,96	80,75	-5,49	-0,31	9,68	2,88	92,85
Bologna × Orvantis	6,46	0,43	29,68	81,77	4,24	15,52	11,03	-1,25	28,44
Garcia × Aldric	6,75	0,25	51,23	84,83	-2,53	10,71	13,53	0,12	46,02
Garcia × FD05152	7,48	0,16	24,79	83,25	4,13	17,97	13,30	-1,70	29,03
Garcia × Racine	7,48	0,46	44,85	84,60	-0,46	14,45	14,73	1,19	53,71
Garcia × Sailor	7,23	-0,10	36,02	81,56	2,40	21,53	13,76	-0,26	43,01
Garcia × Incisif	6,83	-0,58	32,93	80,56	-1,40	15,18	13,41	-0,07	44,41
Garcia × Euclide	6,96	-0,73	18,56	79,63	0,75	23,60	13,84	-1,77	22,91
Garcia × Orvantis	7,10	0,69	50,15	80,56	-2,30	17,77	13,93	3,23	72,93

$\bar{x}$ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

According to CORBELLINI *et al.* (2002) the distribution of hybrid yields approximates a normal distribution. The probability of identifying one or more hybrids that exceed a given economic threshold appears to be largely a function of testing adequate numbers of hybrid combinations (CISAR and COOPER, 2002). Results of our study do not confirm the distribution of hybrid yield performance in the form of a normal distribution. In both seasons the MPH value for grain yield per plant reach from - 13,3 % to 92,85 %. The reason for non-normal distribution lies in the small number of tested hybrids (42) and the preselection of parental components.

Table 5a. Mid-parent value, SCA and MPH value for three traits in the season 2011/12

***T. aestivum* L. × *T. aestivum* L. – 2011/12**	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	x̄	SCA	MPH	x̄	SCA	MPH	x̄	SCA	MPH
Alixan × Aldric	4,58	-0,07	44,81	82,97	0,70	4,85	8,76	0,96	43,59
Alixan × FD05152	5,24	-0,03	14,56	81,49	0,26	3,33	8,52	0,61	34,86
Alixan × Racine	5,31	-0,64	22,26	82,77	0,92	6,17	9,84	-0,90	24,75
Alixan × Sailor	5,08	-0,07	29,31	79,94	-0,99	5,98	8,94	-0,15	28,65
Alixan × Incisif	4,73	0,63	50,59	79,25	1,74	8,41	8,71	-0,11	30,02
Alixan × Euclide	4,84	-0,15	18,86	78,21	-2,14	8,88	9,04	-0,59	13,36
Alixan × Orvantis	4,97	0,32	43,90	79,00	-0,39	9,33	9,34	0,38	39,57
Guarni × Aldric	5,51	-0,30	25,31	80,10	3,68	13,66	10,40	-0,22	30,73
Guarni × FD05152	6,17	0,90	20,57	78,61	-0,50	7,49	10,16	2,12	49,66
Guarni × Racine	6,24	0,10	23,85	79,84	3,57	14,63	11,48	-0,65	28,24
Guarni × Incisif	5,66	1,32	47,02	76,37	-6,15	3,56	10,35	1,36	44,88
Guarni × Euclide	5,77	0,84	25,46	75,33	3,33	21,70	10,68	2,28	43,48
Guarni × Orvantis	5,9	-2,04	-10,4	76,13	-1,53	13,35	10,98	-3,61	2,38
Inoui ×Aldric	5,95	-1,53	7,56	82,85	-3,66	5,47	12,47	-0,82	20,94
Inoui × FD05152	6,61	0,85	16,07	81,37	4,75	11,24	12,23	1,69	27,87
Inoui × Racine	6,68	0,78	36,76	82,65	-0,61	10,22	13,55	1,72	41,54
Inoui × Sailor	6,45	-0,56	13,37	79,82	-2,52	10,18	12,65	-0,54	21,78
Inoui × Incisif	6,11	0,25	30,81	79,13	4,13	17,6	12,42	0,68	32,03
Inoui × Euclide	6,21	0,36	20,72	78,09	-1,49	15,96	12,75	-0,15	17,48
Inoui × Illico	5,84	-0,77	29,76	77,90	4,13	19,85	11,61	-2,71	25,00
Inoui × Orvantis	6,34	0,45	34,19	78,88	-4,16	10,73	13,05	0,06	30,32

x̄ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

The average MPH value for forty two *T. aestivum* L. × *T. aestivum* L. F_1 hybrids in terms of grain yield per plant ranged during both seasons from 30,33 % to 31,30 %. These values are within the interval of known values for mid-parent heterosis. Different authors reported about MPH values measured on single wheat plants that are higher than 30 % (JORDAN *et al*., 1999; CISAR and COOPER, 2002; CORBELLINI et al., 2002). The interspecies crosses between common wheat (*Triticum aestivum* L.) and its relatives with the same genome (BAD) (e.g. *T. macha* DEKAPR. et MENABDE., *T. spelta* L., *T. sphaerococcum* PERCIV., *T. compactum* HOST, *T. petropavlovskyi* UDACZ. et MIGUSCH, *T. vavilovii* (THUM.) JAKUBZ.)) also did not lead to new patterns related to the exploitation of heterosis. The average MPH value for thirty nine interpsecies F_1 hybrids was only 2,52 %. On the other hand, we can see a very promising interspecies F_1 hybrid (Garcia × T. sphaerococcum (accession number 01C0201227)) for the traits related to grain yield. Taking into account the MPH value and the mid-parent value for grain yield per plant, the performance of this interspecies F_1 hybrid exceeds the performance of many common wheat F_1 hybrids (Table 6).

Table 5b. Mid-parent value, SCA and MPH value for three traits in the season 2011/12

***T. aestivum* L. × *T. aestivum* L. – 2011/12**	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	x□	SCA	MPH	x□	SCA	MPH	x□	SCA	MPH
Azimut × Aldric	5,41	2,01	53,81	85,86	3,13	1,42	9,2	0,69	20,00
Azimut × FD05152	6,08	-1,09	-24,7	84,38	-11,5	-17,0	8,96	-1,84	-13,3
Azimut × Racine	6,14	-0,19	6,82	85,66	-0,62	-1,95	10,28	-0,78	8,19
Azimut × Incisif	5,57	-1,10	-9,76	82,13	2,58	2,76	9,16	0,06	11,75
Azimut × Euclide	5,68	-0,43	-10,1	81,09	-0,58	4,02	9,48	-0,94	-8,91
Azimut × Orvantis	5,81	0,30	16,25	81,89	-4,59	8,68	9,78	1,51	31,85
Bologna × Aldric	5,44	-0,47	21,84	81,52	-0,70	3,50	9,55	-0,60	27,79
Bologna × FD05152	6,1	-0,86	-8,61	80,03	3,54	7,77	9,32	-0,97	19,30
Bologna × Racine	6,17	-0,38	15,91	81,32	-2,11	2,84	10,64	-0,29	32,35
Bologna × Sailor	5,94	0,74	30,95	78,49	2,51	10,84	9,73	0,98	42,03
Bologna × Incisif	5,59	-0,65	11,73	77,79	-0,57	5,89	9,51	-1,84	13,53
Bologna × Euclide	5,7	-0,01	10,31	76,75	0,59	12,9	9,83	1,08	33,36
Bologna × Illico	5,33	1,17	62,91	76,56	-6,86	-0,21	8,7	2,66	92,96
Bologna × Orvantis	5,83	0,31	29,26	77,55	4,20	15,71	10,14	-1,10	25,76
Garcia × Aldric	6,00	0,26	52,92	80,33	-2,84	10,58	12,17	-0,00	45,66
Garcia × FD05152	6,66	0,15	26,08	78,84	3,82	18,11	11,93	-1,60	29,11
Garcia × Racine	6,73	0,25	42,62	80,13	-0,82	14,20	13,25	0,91	52,44
Garcia × Sailor	6,50	-0,01	36,15	77,30	3,08	21,82	12,35	-0,07	43,32
Garcia × Incisif	6,16	-0,54	32,79	76,60	-1,40	15,07	12,13	-0,14	43,65
Garcia × Euclide	6,26	-0,70	18,56	75,56	0,62	23,44	12,45	-1,68	22,70
Garcia × Orvantis	6,39	0,58	50,54	76,36	-2,38	17,54	12,75	2,78	68,99

x□ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

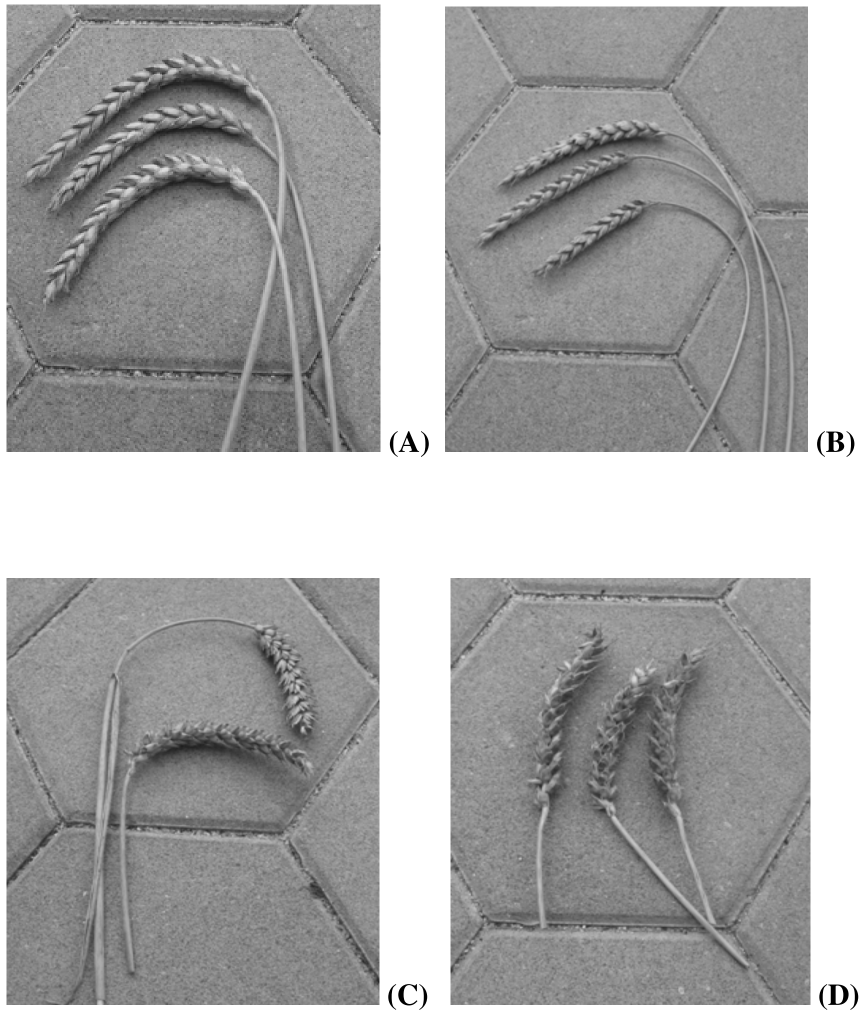

Figure 1. **(A)** Bologna × T. macha (acc. num. 01C0101087), **(B)** Alixan × T. vavilovii, **(C)** Alixan × Blauroter binkel, **(D)** Garcia × KM 93-2000

Table 6a. Performance of interspecies F_1 hybrids

Inter-species F_1 hybrid	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	$\bar{x}$	MPH	BPH	$\bar{x}$	MPH	BPH	$\bar{x}$	MPH	BPH
Garcia × KM 93-2000	6,8	-11,4	-17,1	90,4	8,0	-8,8	13,5	28,4	-10,4
Garcia × Epeautre Nain	8,1	-2,5	-14,7	92,3	9,0	-8,6	13,9	19,5	-7,8
Garcia × Schwabenspelz	9,7	7,5	-11,0	98,4	3,6	-19,1	12,1	4,3	-19,7
Inoui × Steiners tiroler dinkel	7,1	-12,6	-21,0	101,7	5,5	-15,2	9,6	-9,2	-35,3
Inoui × Epeautre Nain	8	-4,2	-16,1	95,6	9,9	-5,4	10,1	-12,8	-32,4
Inoui × Ostar	10,0	-0,3	-22,6	102,4	-1,3	-23,9	11,3	-5,7	-24,1
Inoui × Zeiners weisser dinkel	7,4	-12,8	-24,5	81,2	-1,3	-11,4	8,7	-16,3	-41,9
Bologna × Rouquin	10,1	12,3	-15,2	93,2	3,5	-14,9	12,2	15,8	15,3
Bologna × Desyanthum-Tabor	8,6	18,9	2,4	92,7	1,4	-17,4	8	-11,8	-23,7
Bologna × Blauer kolbendinkel	10,3	21,2	-5,8	103,2	11,3	-10,1	10,8	6,0	3,0
Azimut × Tmava	8,7	3,2	-14,2	96,6	10,3	1,4	11,4	18,2	16,9
Azimut × Gentile-tabor	9,8	8,8	-13,4	99,9	11,4	0,4	12,1	23,4	23,2
Azimut × Redoute	7,6	0,1	-10,2	101,9	2,5	-14,4	8,1	2,4	-17,5
Azimut × Rouquin	11,4	22,5	-4,2	95,4	0,8	-12,9	10,9	7,3	3,3
Guarni × Baettig-Niederwill	11,0	4,2	-25,1	98,2	15,4	-1,8	13,3	20,9	15,5
Guarni × Ostar	7,2	-25,5	-44,3	99,1	-3,1	-26,3	8,9	-8,8	-15,0
Garcia × Harrisson barbee	5,4	-6,6	-23,9	80,2	8,0	0,1	8,9	-13,6	-41,3
Garcia × Tiroler frueher binkel	6,0	-9,8	-15,9	84,6	8,4	-3,5	9,1	-17,1	-39,9
Alixan × Blauroter binkel	8,5	56,3	25,4	94,4	10,7	-3,3	14,3	43,4	36,1
Alixan × Little club	6,1	39,6	31,9	75,2	0,5	-1,9	11,4	15,3	10,4
Alixan × Harrisson barbee	4,3	0,7	-3,8	79,0	3,1	-1,5	7,7	3,7	-18,5

$\bar{x}$ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

In contrast to the study of QIXIN *et al*. (1997) we could not confirm that spelt (*Triticum spelta* L.) could be used as divergent heterotic group for the improvement of heterosis level in common wheat germplasm. On the other hand the improvement of heterosis level in the germplasm of common wheat through the use of relatives having the BAD genome constitution is possible. As an example we could point out the interspecies F_1 hybrid between common wheat variety Garcia and an accession of the *Triticum sphaerococcum* PERCIV. (accession number 01C0201227).

Table 6b. Performance of interspecies F_1 hybrids

Inter-species F_1 hybrid	**Number of spikes per plant [n, %]**			**Plant height [cm, %]**			**Grain yield per plant [g, %]**		
	$\bar{x}$	MPH	BPH	$\bar{x}$	MPH	BPH	$\bar{x}$	MPH	BPH
Inoui × Tiroler frueher binkel	7,7	15,9	7,8	85,3	6,2	-2,7	10,2	-5,7	-31,3
Inoui × Blauroter binkel	7,6	8,5	5,6	90,3	5,9	-7,5	16,5	29,6	10,6
Bologna × Shloucena	5,2	9,1	-14,0	88,4	1,8	-14,3	6,9	-9,5	-34,4
Azimut × Blauroter binkel	7,7	14,7	14,0	96,9	9,2	-0,8	12,8	26,0	21,6
Azimut × Harrisson barbee	5,9	4,5	-12,7	83,9	4,9	4,7	8,5	11,5	-13,5
Guarni × Tiroler frueher binkel	5,6	-11,9	-13,7	80,2	1,6	-8,5	8,1	-6,0	-22,6
Garcia × T. sphaerococcum...	12,3	36,7	13,2	90,0	10,4	-4,9	17,1	60,5	13,2
Garcia × Ruzyne	10,1	7	-14,1	95,8	12,1	-6,6	11,0	9,7	-27,0
Inoui × T. sphaerococcum...	11,7	29,9	7,7	91,0	8,6	-3,9	16,5	56,2	10,6
Inoui × Ruzyne	9,9	4,6	-15,9	92,6	5,5	-9,7	9,4	-5,2	-36,7
Guarni × Kolandi	7,6	-9,8	-27,1	89,8	7,2	-7,8	6,8	-14,5	-35,4
Guarni × Ruzyne	8,8	-3,6	-25,5	92,7	7,4	-9,6	7,1	-7,4	-31,7
Alixan × T. macha..(IPK)	6,2	2,0	-23,2	107,3	14,9	-5,7	5,9	-7,9	-38,0
Bologna × T. macha..(IPK)	8,4	19,1	4,2	103,3	12,1	-9,2	5,1	-25,4	-51,0
Azimut × T. macha..(IPK)	7,9	7,2	-2,1	106,6	10,2	-6,2	6,2	-5,3	-36,8
Azimut × T. macha..(St Peter.)	8,7	-3,0	-22,4	100,7	7,2	-6,7	4,9	-25,6	-49,6
Alixan × T. vavilovii..(Leningrad)	6,6	-17,4	-44,3	111,1	9,2	-14,8	3,5	-44,7	-63,3
Inoui × T. vavilovii..(Leningrad)	9,3	-2	-21,1	109,3	7,5	-16,2	4,4	-51,4	-70,7

$\bar{x}$ – mid parent value, MPH – mid-parent heterosis value, BPH – best-parent heterosis value

ACKNOWLEDGEMENTS

This study was funded by the European Union, European Social Fund. Operation implemented in the framework of the Operational Programme for Human Resources Development for the Period 2007-2013.

Received October 15th, 2012

Accepted November 30th, 2012

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KOMBINACIJSKA SPOSOBNOST I UČINAK HETEROZISA U GRUPI HEKSAPLOIDNIH PŠENICA

Primož TITAN[1], Vladimir MEGLIČ [2], and Jernej ISKRA[3]

[1] SEMENARNA Ljubljana, d.d., Ljubljana, Slovenia
[2] Agricultural Institute of Slovenia, Ljubljana, Slovenia
[3]"Jožef Stefan" Institute, , Slovenia

Glavni cilj uzgoja hibridne pšenice je identifikacija roditelja sa visokom specifičnom kombinacionom sposobnošću radi prinosa i drugim agronomskim osobinama. Ovi podaci pojednostavljuju razvoj hibridnih kombinacija sa visokim nivoom heterozisa u prvoj filijalnoj generaciji (F_1 generacija). Mogućnost povećanja nivoa heterozisa u germplazmi obične pšenice (*Triticum aestivum* L.) predstavlja i tako upotreba materijala iz heksaploidne grupe pšenica (npr. *Triticum spelta* L. *Triticum compactum* HOST).

Studija kombinacione sposobnosti i efekta heterozisa u heksaploidnoj grupi pšenica je sprovedena sa ukrštanjem između trinajstih inbred linija obične pšenice (6 linija x 7 testera) i međuvrstnih hibrida (*T. aestivum* L. × *T. spelta* L., *T. aestivum* L. × *T. compactum* HOST, *T. aestivum* L. × *T. sphaerococcum* PERCIV., *T. aestivum* L. × *T. macha* DEKAPR. et MENABDE, *T. aestivum* L. × *T. vavilovii* (THUM.) JAKUBZ.). 42 F_1 hibrida obične pšenice su testirana tokom dve sezone (2010/11 and 2011/12) u Selekcionom centru Ptuj. Ogled je sproveden po slučajnom blok sistemu sa četiri ponavljanja. 43 međuvrstnih F_1 hibrida je testirano tokom sezone 2011/12 na istoj lokaciji a ogled je sproveden po slučajnom blok sistemu sa tri ponavljanja. Rezultati su analizirani uz pomoć statističkog paketa AGROBASE generation II i STATGRAPHICS Centurion XVI.

Analiza varijanse je pokazala značajne varijanse i OKS i PKS ($P < 0{,}01$). Uopšteno, varijanse PKS su bile niže od varijansi OKS. Primetili smo da je poboljšanje nivoa heterozisa u germplazmi pšenice putem upotrebe srodnika sa istim genomom (BAD) moguća. Primer toga je međuvrstni F_1 hibrid između pšenice sorte Garcia i akcesije vrste *Triticum sphaerococcum* PERCIV.

Primljeno 15. X. 2012.
Odobreno 30. XI. 2012.