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Combining ability, Heterosis and maternal effects for yield and attributing traits in yellow sarson (*Brassica rapa* L. var. *yellow* sarson)

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Abstract

Rapeseed-Mustard is one of the most important oilseed crops in India. Yellow sarson (*Brassica rapa* L. var. *yellow sarson*), an important ecotype of rapeseed has higher oil content due to thin seed coat. The present investigation was conducted to analyze combining ability, heterosis and maternal effects for the yield traits in three Yellow sarson varieties (B9, YSH 401 and NRCYS 05-03) crossed in Complete diallel design (Griffing, 1956). Significant differences were observed for all the thirteen characters from the analysis of variance. ANOVA for Combining ability revealed that variation due to GCA, SCA and reciprocals were significant for various characters. Analysis made on the Hayman's (1954) model exhibited maternal effects, which mainly accounted for the significant reciprocal effects for many characters. YSH 401 was the best general combiner while YSH401 x B9 was the earliest and best cross showing good mean performance for various yield traits showing high heterosis.

Keywords: Yellow sarson, combining ability, heterosis, maternal effects

Introduction

The oilseed brassicas commonly known as rapeseed-mustard are one of the most important groups of edible oil-bearing crops belonging to *Brassicaceae* family. Rapeseed-mustard crops in India include toria (*Brassica campestris* L. var. toria), brown sarson (*B. campestris* L. brown sarson), yellow sarson (*B. campestris* L. var. yellow sarson), Indian mustard (*B. juncea* L. Czernj and cosson), black mustard (*B. nigra*) and taramira (*Eruca sativa/vesicara* Mill.) species [1]. Being the second most important oilseed crop in India after soybean, its share is about one fourth of total area and one-third of total oil production in the country [2]. Rapeseed-mustard is the major source of income especially for the marginal-and small-farmers in rainfed areas, which are about 25% of the total cultivated area. Yellow *sarson* (*Brassica rapa* var. yellow *sarson*), an important ecotype of rapeseed is gaining preference due to its higher oil quality which can be attributed to its thin seed coat.

Information on the relative importance of the additive (GCA) and non-additive (SCA) gene actions in a breeding population guides the breeder for effective breeding procedure to follow [3]. Most previous studies on combining abilities have shown significant GCA and SCA effects for yield and its component characters. These results indicate that both additive and non-additive gene action are important in the inheritance of these traits [4, 5, 6]. Information on heterosis can provide basis for the exploitation of valuable cross combinations in breeding program [7] and for this reason, the achievement of heterosis has become a major objective for the breeders of canola [8] and the related species because exploitation of heterosis contributes to increasing seed yield. Maternal effects may be important in the inheritance of some rapeseed characters.

Yellow sarson is an important oilseed brassica. Development of superior early maturing varieties is an important breeding objective of this crop. With this background in mind, the present experiment was undertaken to study combining ability, heterosis and maternal effects for yield traits in yellow sarson.

Materials and Methods

Plant material and field experimentation

The present study was carried out in the experimental farm of the Department of Plant Breeding and Genetics, Assam Agricultural University, Jorhat, located at 26°44´ north latitude and 94°12´ east longitude, at an elevation of 91 m above the mean sea level (www.aau.ac.in).The experiments were conducted during Rabi season 2016-17 and 2017-18.

Three yellow sarson varieties, namely YSH 401, B9 and NRCYS 05-03 were crossed in complete diallel design including reciprocals during 2016-17 in a crossing block.
The 3 parents and the 6 F_1s were evaluated during the Rabi season 2017-18. During Rabi 2016-17 the parents were grown in a crossing block. During Rabi 2017-18, the 9 entries comprising of 3 yellow sarson varieties and their F_1s and reciprocal F_1s were grown in randomized block design with 3 replications. The experimental plots were thoroughly prepared and recommended package of practices for rapeseed were followed.

Trait evaluation
Observations were recorded on 10 random plants in each plot for plant height (PH) in cm, number of primary branches/plant (PB), number of secondary branches/plant (SB), main shoot length (MSL) in cm, number of siliquae on main shoot (SMS), seeds/siliqua(SSQ), thousand seed weight (TSW) in g, maximum root length (MRL) in cm, biological yield per plant (BYP) in g, seed yield per plant (SYP) in g and harvest index (HI) in %. Days to flowering (DF) and maturity (DM) were observed on plot basis. Observations on yield and various yield attributing parameters were recorded by using standard procedures.

Statistical analyses
The plot mean values for each character were subjected to the following statistical and biometrical analyses.

Analysis of variance
The plot mean data were subjected to analysis of variance for each character following standard statistical procedure in the fixed model. Genotypic means were compared by computing least significant difference [9] in the experiment conducted during 2017-18.

Combining ability analysis
Combining ability analysis of the complete diallel population was done following model I, method 1 of Griffing,1956 [10]. General combining ability and specific combining ability effects were estimated from the analysis.

Estimation of heterosis
The extent of heterosis was determined in relation to the better parent (BP) as
Heterosis = (F_1 mean – BP mean)/BP mean
and then expressed as percentage of better parent.

Estimation of maternal effects
The Diallel analysis of Griffing, Model I, Method I, was used for the estimation of reciprocal effects. Presence of maternal effects was determined following Hayman [11] and Roy [12].

Results and Discussion
Analysis of Variance
Analysis of variance of the diallel populations (Table 1), indicated that the mean sum of squares due to genotypes were highly significant for all the 13 characters studied, indicating the existence of sufficient amount of variability for all the traits.

Combining ability analysis
Analysis of variance for combining ability (Table 2) revealed that mean squares due to GCA were significant for DM, SSQ, TSW, SYP, HI, DF and BYP. The mean squares due to SCA were significant for all the characters except DM in direct crosses whereas non-significant for DM, PH, PB, MSL, SMS, SSQ and MRL in reciprocal crosses. Both additive and non-additive gene effects were important in the inheritance of these characters. The results are in agreement with [13, 14, 15] and [16].

Table 1: Analysis of variance of a diallel cross in Yellow sarson

Source	df	DF	DM	PH	PB	SB	MSL	SMS	SSQ	MRL	TSW	SYP	BYP	HI
Replications	2	0.26	8.48	96.62 **	2.70 *	0.26 *	17.23	34.26	8.11 *	0.65	0.212 **	3.20 **	121.16 **	0.006 *
Genotypes	8	3.73 **	42.50 **	164.48 **	6.59 **	10.34 **	120.60 **	126.62 **	12.67 **	7.71 **	0.299 **	39.21 **	90.48 **	0.030 **
Error	16	0.67	4.14	7.80	0.70	0.47	13.90	12.88	1.53	1.67	0.027	0.34	7.29	0.001
CV%		1.23	1.85	2.38	10.30	19.64	6.41	6.38	6.18	5.01	4.674	5.33	8.83	8.771

* Significant at P=0.05; ** Significant at P=0.01

Table 2: Analysis of variance for combining ability in diallel cross of Yellow sarson (Griffing, 1956) [10].

Item	df	DF	DM	PH	MRL	PB	SB	MSL	SMS	SSQ	TSW	BYP	SYP	HI
GCA	2	1.34 *	47.26 **	19.91 **	0.87	0.27	0.13	8.25	10.82	3.85 **	0.068 **	10.11 *	19.27 **	0.0268 **
SCA	3	1.05 *	4.83	123.78 **	4.48 **	4.76 **	2.69 **	100.03 **	103.37 **	8.64 **	0.139 **	42.22 **	6.67 **	0.0044 **
Reciprocal	3	1.37 **	1.44	9.14 **	1.80	0.92 *	0.48 **	1.66	1.96	0.05	0.080 **	31.46 **	15.33 **	0.0045 **
Error	16	0.23	1.72	2.60	0.56	0.24	0.07	4.63	4.30	0.51	0.009	2.43	0.11	0.0004

* Significant at P=0.05; ** Significant at P=0.01

Gupta *et al*. [17], reported additive genetic effects for DF while, Parmar *et al*. [18], Gupta *et al*. [17] and Gupta *et al*. [19] reported the effectiveness of additive genetic effects for DM in rapeseed.

Combining ability gives useful information for the choice of parents in terms of expected performance of their crosses and progenies [20]. The GCA effect is controlled by fixable additive gene and the cross-involving parents with high GCA will give better transgressive segregants in later generations. Therefore, selection of parents based on GCA effects would have an impact on breeding program.

Reference to Table 3, shows that YSH 401 was the best parent having significant positive GCA effects for SYP and HI. It was also a good parent for early flowering and short growing habit. B9 was the best general combiner for early maturity and SYP while, NRCYS 05-03 was a good general combiner for tall PH, SSQ and TSW. Highly significant effects for DF and DM were observed, which were not desirable.

Table 3: General combining ability effects of the parental genotypes in Yellow sarson

Parent	DF	DM	PH	SSQ	TSW	SYP	BYP	HI
YSH 401	-0.481**	0.093	-2.047**	0.222	-0.117**	1.300**	0.369	0.069**
NRCYS 05-03	0.463**	2.759**	1.443*	0.667*	0.089*	-2.044**	-1.443*	-0.065**
B 9	0.019	-2.852**	0.604	-0.889**	0.028	0.744**	1.074	-0.004
SE (gi)	0.158	0.437	0.538	0.238	0.031	0.112	0.520	0.006
SE (gi-gj)	0.274	0.757	0.931	0.412	0.054	0.194	0.900	0.011

* Significant at P=0.05; ** Significant at P=0.01

Specific combining ability effects of the crosses with heterosis expression In the present investigation, crosses were evaluated on the basis of SCA, reciprocal effects and better parent heterosis and mean performance as presented in table 4, 5 and 6.1 – 6.2.

Table 4: Specific combining ability effects of diallel crosses in Yellow sarson

Cross	DF	PH	PB	SB	MSL	SMS	SSQ	MRL	TSW	SYP	BYP	HI
YSH 401 x NRCYS 05-03	0.26	7.72 **	1.26 *	0.55 **	4.36 **	4.30 **	-1.38	0.80	0.02	0.07	-0.80	-0.02 **
YSH401 x B9	0.37	2.68 **	0.92	0.77 **	3.93 **	4.30 **	0.50	1.21 **	0.18	2.18 **	5.83 **	-0.04 **
NRCYS 05-03 x B9	0.60 *	2.14 *	0.37	0.66 **	3.94 **	3.85 **	-1.94 **	0.50	0.22	-1.23 **	-0.29	-0.02 **
SE (sij)	0.25	0.84	0.25	0.14	1.13	1.09	0.38	0.39	3.54	0.18	0.82	0.004
SE (sij-sik)	0.38	1.32	0.40	0.22	1.76	1.46	0.50	0.52	0.06	0.24	1.10	0.013

* Significant at P=0.05; ** Significant at P=0.01

Table 5: Reciprocal effects in a diallel cross of Yellow sarson

Cross	DF	PH	PB	SB	TSW	SYP	BYP	HI
YSH 401 X NRCYS 05-03	-0.500	0.772	0.500	-0.500*	-0.110	1.867**	1.150	0.051**
YSH401 X B9	1.167**	-3.522**	-0.833*	-0.167	0.017	-4.367**	-5.233**	-0.064**
NRCYS05-03 X B9	0.667	-0.842	-0.667	0.667**	0.330**	-0.667*	-4.300**	0.014
$SE(r_{ij})$	0.336	1.140	0.342	0.186	0.067	0.237	1.102	0.013

* Significant at P=0.05; ** Significant at P=0.01

YSH401 X B9 was the best cross out of the three crosses evaluated having highest SCA effects for PH, SB, MSL, SMS, MRL, SYP and BYP. PH, SYP, BYP and HI expressed significant negative reciprocal effects and highly significant positive reciprocal effects for DF, which is not desired. Significant heterosis was observed for early maturity, SB, MSL, SMS, MRL, TSW and BYP with highest mean value for SSQ and BYP.

YSH 401 X NRCYS 05-03 showed highest SCA effects for PH, SB, MSL and SMS. Besides significant SCA effect was observed for PB, while SYP and HI showed significant reciprocal differences. It had significantly high heterosis for SB, MSL, SMS and MRL and highest mean for DM, PH, PB, MSL, SMS, MRL, SYP and HI.

NRCYS05-03 X B9 had significant SCA effects for PH, SB, MSL, SMS, and DF (late). Significant positive reciprocal effects were observed for SB and TSW, while significant negative reciprocal effects were observed for SYP and BYP. Significant and high heterosis was observed for DF, SB, MSL, SMS and TSW and highest mean for DF, SB and TSW.

Table 6: Better parent heterosis in diallel crosses in Yellow sarson

Cross	DF		DM		PH		PB		SB		MSL		SMS	
	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean
YSH 401 x NRCYS 05-03	-0.70	47.00	0.29	120.66	13.46	125.18	42.85*	10	75.18 *	2.33	21.02 **	62.93	19.60 **	61
YSH401 x B9	3.57 *	48.33	-3.32 *	113.66	11.78	115.01	20.12	8	303.03 **	2.66	18.94 **	59.83	21.82 **	57.66
NRCYS05-03 x B9	3.52 *	49.00	-1.76	118.33	6.13	120.64	14.28	8	175.18 **	3.66	19.92 **	62.36	18.29 **	60.33

* Significant at P=0.05; ** Significant at P=0.01

Table 6a: Better parent heterosis in diallel crosses in Yellow sarson

Cross	SSQ		MRL		TSW		SYP		BYP		HI	
	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis	Mean
YSH 401 x NRCYS 05-03	-21.61 **	19.33	11.6**	28.36	-1.75	3.36	7.74	12.10	3.68	29.86	-29.82 **	0.40
YSH401 x B9	-7.82	19.66	11.14 *	26.53	14.64 **	3.60	-5.86	10.76	19.96 *	32.63	-42.10 **	0.33
NRCYS05-03 x B9	- 27.00 **	18	3.46	26.28	21.64 **	4.16	-32.63 **	7.70	-11.00	25.63	-28.57 **	0.30

* Significant at P=0.05; ** Significant at P=0.01

Heterosis (Table 6 and 6a) was expressed as the deviation of F_1 mean from the better parent. Estimation of heterosis for the crosses revealed that among the three direct crosses, YSH 401 x B9 exhibited high heterosis for DM (-3.32%), SB (303.03%), MSL (18.94%), SMS(21.82%), MRL (11.14%), TSW (14.64%) and BYP (19.96%).YSH 401 x NRCYS 05-03 exhibited high heterosis for PB (42.85%), SB (75.18%), MSL (21.02%), SMS (19.6%) and MRL (11.6%) while, NRCYS 05-03 x B9 expressed relatively high heterosis for SB (175.18%), MSL(19.92%), SMS (18.29%) and TSW (21.64%). Negative heterosis for harvest index was found in all the crosses. The crosses giving high SCA effects also showed high heterosis suggesting that SCA effects and heterosis responses are interrelated. In brown sarson genotypes, significant better parent heterosis for TSW, PB and SB, SMS and DM were observed [21]. Negative heterosis for HI and siliqua characters were reported in toria, brown sarson and yellow sarson crosses [13]. Significant heterosis for PH, pods on main receme and TSW, while low and negative heterosis for number of pods per plant were reported by [15]. Shehzad *et al.* [22] reported high to low degree of heterosis over better parent for various yield attributing characters in *B napus*.

Maternal effects

The Diallel analysis of Griffing, Model I, Method I, accounts the estimation of reciprocal effects (Table 7). The reciprocal effects were produced due to presence of maternal effects or cytoplasmic inheritance, whereas in the diallel analysis of Hayman, presented in Table 8, direct estimates of maternal effects are made. Results from these two methods are compared. With refence to Table 7, highly significant reciprocal differences were observed for DF, SB, TSW, BYP, SYP and HI in the Griffing's method. These differences were may be due to the presence of maternal effects. Though, cytoplasmic interactions may also be responsible for the same.

In the Hayman's method (Table 8), maternal differences were highly significant for DF, SB, TSW, BYP and SYP and significant for PH, MRL, PB and HI. Hence, maternal effects were predominantly responsible in the inheritance of these characters. Highly significant reciprocal differences were observed for the same characters for which highly significant maternal effects were obtained, except for HI for which significant maternal effects were observed.

Table 7: Maternal effects of the parental genotypes in Yellow sarson

Parent	DF	MRL	PH	PB	SB	TSW	SYP	BYP	HI
YSH 401	0.444	1.002*	-1.833	-0.222	-0.444**	-0.062	-1.667**	-2.722**	-0.008
NRCYS 05-03	0.778*	-1.307**	-1.076	-0.778*	0.778**	0.294**	-1.689**	-3.633**	-0.025*
B 9	-1.222**	0.304	2.909**	1.000**	-0.333*	-0.231**	3.356**	6.356**	0.033**
SE (gi)	0.274	0.431	0.931	0.280	0.152	0.054	0.194	0.900	0.011

* Significant at P=0.05; ** Significant at P=0.01

Table 8: Analysis of variance for maternal and reciprocal effects in a diallel cross of Yellow sarson (Hayman, 1954)

Item	df	DF	DM	PH	MRL	PB	SB	MSL	SMS	SSQ	TSW	BYP	SYP	HI
Parents	2	1.34 *	47.27 **	19.91 **	0.87	0.27	0.13	8.25	10.82	3.85 **	0.068 **	10.11 *	19.27 **	0.0268* *
Genetic interaction	3	1.05 *	4.83	123.79 **	4.48 **	4.76 **	2.69 **	100.03 **	103.37* *	8.64 **	0.139 **	42.22 **	6.67 **	0.0044* *
Av. maternal effect	2	1.72 **	2.02	9.73 *	2.10 *	1.24 *	0.69 **	2.30	2.80	0.07	0.108 **	45.75 **	12.67 **	0.0013*
Reciprocal effect	3	0.67	0.30	7.94	1.19	0.30	0.07	0.40	0.30	0.02	0.028	2.89	20.66 **	0.0111* *
Error	16	0.23	1.72	2.60	0.56	0.24	0.07	4.63	4.29	0.51	0.009	2.43	0.11	0.0004

* Significant at P=0.05; ** Significant at P=0.01

Thus, it can be inferred that the reciprocal differences observed in Griffing's method were due to the predominance of maternal effects (residual reciprocal differences arenon-significant). While for harvest index non-maternal reciprocal differences (residual effects) were highly significant which may be due to predominance of cytoplasmic interaction. For SYP, both maternal and non- maternal reciprocal differences were highly significant both of which, and their interaction may be responsible for the inheritance of this character.

Among the parental genotypes (Table 7), B9 was highly influenced by maternal effects as it showed positive maternal effects for PH, PB, BYP, SYP, HI and for early flowering, while the other two parents YSH 401 and NRCYS 05-03 were much less effected. NRCYS 05-03 showed positive maternal effects for SB and TSW, whereas YSH 401 exhibited positive maternal effect for MRL. Sharma *et al.*, [14] found highly significant reciprocal differences for DF, DM, PB, SB, TSW, BYP, SYP and HI.

Sincik *et al.* [15] observed that reciprocal effects were highly significant for PH and number of pods per main raceme. Highly significant reciprocal effects were reported for number of pods/plants, pod length, SSQ, TSW and SYP [23]. Presence of highly significant maternal effects and non-maternal reciprocal effects were observed for PH, siliqua length, SSQ and SYP, while only non-maternal reciprocal effects were highly significant for TSW [24] and Naheed *et al.* [25] reported significant reciprocal effects at $p \leq 0.01$ for pods per main raceme, SSQ and SYP.

Conclusion

The diallel populations possessed significant variation showing prospects for success of selection. Variability studies revealed that selection would be effective. The yellow sarson parents B9 and YSH 401 were found to be superior general combiners with respect to yield attributing characters. These parents could be utilized successfully for subsequent breeding programme. The crosses YSH 401 x B9 was the earliest and best performing cross for various yield traits having high heterosis, while the other two crosses were also good for particular yield attributes. These crosses could be good material for heterosis breeding and recurrent selection schemes in this crop.

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