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Combining Ability and Heterosis in Maize (*Zea mays* L.)

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Abstract: Combining ability for growth parameter and yield components were evaluated in a 7×7 diallel fashion in maize at the research farm of Plant Breeding Division, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur during Rabi season 2013-14 to determine the general combining ability and specific combining ability of parents and the crosses. Significant general and specific combining ability variances were observed for some of the characters. The overall study of gca effects suggested that parent WL3 was significant for general combiner for yield, WL2 and WL3for earliness and WL1 for short stature. These parents could be used in future breeding programme to improve maize yield with desirable traits. The good combiner parents for different traits could be used in hybridization to improve yield as well as with desirable traits as donor parents for the accumulation of favorable genes. For yield improvement in maize both additive and non additive genes should be exploited through a suitable breeding method. However, the crosses WL1×WL6, WL1×WL7, WL4×WL5, WL6×WL7showed high sca effect for kernel yield. The significant positive sca of crosses could be used for commercial variety development after verifying them. The maximum heterosis was recorded in WL1×WL6 (15.60**%) when BHM 7 used as check and heterosis ranged from -56.59 to 15.60%. Only one hybrid WL2×WL7 recorded negative heterosis against BHM 7 for days to maturity.

Keywords: Combining Ability, GCA, SCA, Maize

1. Introduction

Maize (*Zea mays* L.) plays a significant role in human and livestock nutrition worldwide [1]. It is the world's most widely grown cereal and is the primary staple food in many developing countries [2]. It is a versatile crop with wider genetic variability and able to grow successfully throughout the world covering tropical, subtropical and temperate agro-climatic conditions.

Inbred lines are prerequisite for hybrid development in maize. Combining ability analysis is of special importance in cross-pollinated crops like maize as it helps in identifying potential parents that can be used for producing hybrids and synthetics [3].

Combining ability is an important aspect of hybrid breeding programme. Rojas and Sprague [4]. stated that the value of an inbred line in the commercial production of hybrid maize is determined by two factors, the characteristic of the line itself with respect to yielding ability, pollen shedding, disease resistance, etc. and the behavior of the line in hybrid combinations. Over the years, the combining ability concept has become increasingly important not only in maize but in other crops as well.

A sound breeding programme provides the opportunity to produce high yielding varieties of a crop. However, the development of meaningful breeding programme needs information on the nature of gene actions controlling the yield and yield contributing characters. Knowledge of genetic architecture of the characters is essential for adopting appropriate breeding procedure. Such knowledge leads the plant breeder to develop new commercial varieties of the crop. [5] stressed that information on variation attributable to genetic differences and also on the relationship among various quantitative traits is fundamentally significant in a crop improvement programme. Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of hybrid. It helps to get idea about the nature of gene action for a particular character. This information is also useful to breeder for selection of diverse parents and hybrid combinations. Diallel cross analysis provides the estimates of genetic parameters regarding combining ability and a picture of the dominance relationship of the parents studied using the first filial generation (F_1) with or without reciprocals.

The nature and magnitude of gene action is an important factor in developing an effective breeding programme, which can be understood through combining ability analysis. This information is helpful to plant breeders for formulating hybrid breeding programmes. The present investigation with 7 × 7 diallel cross was done with the following objectives:

i) to determine the general combining ability of parents for yield and its components
ii) to identify the best performing hybrids on the basis of specific combining ability and
iii) to estimate heterosis of F_1s over check variety for yield components.

2. Materials and Methods

Seven maize inbred lines were crossed in a diallel fashion excluding the reciprocals during the rabi season in 2012-2013. The resulting 21 F_1's and their parents were evaluated along with the check BARI hybrid maize 7 in a alpha lattice design with three replications at the Bangladesh Agricultural Research Institute, Gazipur in the following rabi season of 2013- 2014. The pedigree/designation of those parents used in the crosses were as follows: WL1=BIL20, WL2 =BML36, WL3= BIL77, WL4= BIL106, WL5 = CLQRCY44, WL6 = BIL79 and WL7 = BIL 31. The hybrids were designated as WL1×WL2, WL1×WL3, WL1×WL4, WL1×WL5, WL1×WL6, WL1×WL7, WL2×WL3, WL2×WL4, WL2×WL5, WL2×WL6, WL2×WL7, WL3×WL4, WL3×WL5, WL3×WL6, WL3×WL7, WL4×WL5, WL4×WL6, WL4×WL7, WL5×WL6, WL5×WL7, WL6×WL7.

Each entry planted in single row of *5* m long plot. The spacing between row to row was 75 cm and plant to plant was 20 cm. One plant per hill was maintained after proper thinning. The plants were harvested on 3rd May, 2014. Fertilizers were applied @ 250, 55, 110, 40, 5 and 1.5 kg/ha of N, P_2O_5, K_2O, S, Zn and B respectively. Standard agronomic practices were followed [6] and plant protection measures were taken as required. Observations were recorded on ten randomly selected plants from each plot for plant height (cm), ear height (cm), ear length (cm), and 100-kernel weight (g). Days to silking, days to maturity and kernel yield were recorded on whole plot basis and yield was converted to ton/ha. Data were analyzed for variance for all the characters studied. General combining ability (GCA) and specific combining ability (SCA) were estimated following Model II, Method IV of [7]. The mean squares for GCA and SCA were tested against error variance desired. ANOVA for combining ability analysis in Model I and Method 4 [8]

Percent heterosis was calculated by the formula as heterosis (%) = $[(F_1 - CV)/CV] \times 100$ where, F_1 and CV represented the mean performance of hybrid and standard check variety. The significance test for heterosis was done by using standard error of the value of check variety.

3. Results and Discussion

3.1. Analysis of Variance

The mean performances of all the crosses along with the check BHM 7 are presented in Table1. Significant differences were observed for all the characters except days to maturity. It indicated sufficient genetic variability present among the genotypes, parents, crosses and parent vs. crosses.

3.2. GCA and SCA Variance

The magnitude of mean squares for general and specific combining abilities for studied characters indicated significant differences among the gca as well as sca effects (Table 2). This suggested presence of notable genetic variability among the genotypes for the characters studied. Furthermore, the analysis of variance for combining abilities (gca and sca) showed significant variations for the maximum characters, which indicated significant differences among the gca as well as sca effects. Highly significant differences for most of the sources of variation were also reported [9]. The significant differences for gca and sca variances for different traits in maize have also been reported earlier [10]. This indicated an adequate amount of variability present in the materials for these traits.

Further, analysis of variance for combining ability showed that estimates of mean squares due to gca and sca were highly significant for days to silking, plant height, ear height, cob length TSW(g) and yield (t/ha). Insignificant variation was recorded in days to tasseling, ASI and cob diameter. This indicated importance of both additive and non additive components of genetic variance in controlling these traits. This was confirmed by [11], [12] who reported similar results for yield and yield components in maize. Similar findings also reported by [13].

Table 1. *Mean performance of hybrid maize for growth and yield contributing characters obtained from 7×7 diallel cross.*

Cross/ Hybrids	DT	DS	ASI	PH (cm)	EH (cm)	DM	CL (cm)	CD (cm)	1000 Grain wt. (g)	Yield (t/ha)
WL1×WL2	95.00	99.33	4.33	174.00	86.00	150.00	28.22	3.96	373.33	7.72
WL1×WL3	93.33	97.33	4.00	184.33	94.27	150.00	30.33	4.07	424.00	8.38
WL1×WL4	94.00	98.33	4.33	173.33	89.67	149.00	27.11	4.04	377.00	8.02
WL1×WL5	99.00	105.67	6.67	138.67	68.67	151.33	22.56	3.45	330.67	3.61
WL1×WL6	94.33	97.67	3.33	198.40	97.20	150.00	29.78	3.87	426.67	9.61
WL1×WL7	94.33	97.33	3.00	188.53	93.00	150.00	30.45	4.09	432.00	8.01
WL2×WL3	91.67	95.67	4.00	199.20	100.07	150.00	29.33	4.42	384.00	7.80
WL2×WL4	92.67	101.67	5.67	171.80	91.53	149.33	27.33	4.07	365.33	6.63
WL2×WL5	93.67	96.67	3.00	188.67	97.73	149.00	30.11	3.94	402.67	8.05
WL2×WL6	92.33	95.33	3.00	192.60	92.00	148.67	29.33	4.00	341.33	6.60
WL2×WL7	90.00	94.00	4.00	191.00	93.40	147.00	27.67	3.94	382.67	7.37
WL3×WL4	91.67	97.00	5.33	202.27	105.13	148.67	30.43	4.34	392.00	7.81
WL3×WL5	92.33	96.67	4.67	202.67	104.73	149.33	29.99	4.07	420.00	8.71
WL3×WL6	93.00	97.33	4.33	217.87	115.47	148.67	30.33	4.23	330.67	7.62
WL3×WL7	93.67	97.33	3.67	204.80	105.00	149.67	28.00	4.09	397.33	6.55
WL4×WL5	95.33	100.33	5.00	208.13	105.33	149.33	28.33	4.16	357.33	9.02
WL4×WL6	94.00	98.67	4.67	202.93	105.00	148.33	30.00	4.34	345.33	6.33
WL4×WL7	92.67	97.33	4.67	192.87	101.53	149.67	27.11	4.25	381.33	7.10
WL5×WL6	95.00	98.33	3.33	193.60	98.80	150.33	29.89	4.17	302.67	5.05
WL5×WL7	94.00	98.33	4.33	184.80	90.53	150.00	27.78	4.00	417.33	7.54
WL6×WL7	96.67	101.33	4.67	196.20	92.47	149.67	33.00	4.02	338.67	8.67
BHM-7	88.69	94.33	4.66	172.46	82.87	147.33	29.98	4.55	386.66	8.31
F-test	**	**	*	**	**	-	**	**	**	**
Mean	93.75	98.18	4.29	190.79	96.55	149.43	28.91	4.07	377.25	7.44
CV(%)	2.91	2.56	21.63	8.75	9.89	0.60	7.13	4.98	9.68	18.18
LSD(5%)	0.866	1.14	0.42	7.60	4.35	0.40	0.94	0.09	16.62	0.62

*, ** indicated at 5% and 1% level of significance, respectively.

Days to 50% tasseling (DT), Days to 50% silking (DS), Anthesis Silking Interval (ASI), Plant height (PH), Ear height (EH), Days to maturity (DM), Cob length (CL), Cob diameter (CD), Thousand seed weight (TSW) and Yield (t/ha).

The ratio of the components revealed that gca variance was higher than sca for days to tasseling days to silking, plant height, ear height, and kernel weight in Table 2. This indicated predominance of additive genetic variances for these traits. [14] reported predominant additive genetic variance in the inheritance of ear height in maize. [15] reported predominance of additive gene action for ear length and [16] reported high gca effects for yield components in the same crop. Sca for kernel yield (t/ha) recorded highly significant than gca which was predominantly controlled by non-additive gene action (dominance and epistasis). Predominant role of sca effect i.e. non-additive gene actions in the inheritance of kernel yield was also reported [17], [18], [19], [20]. The genetic control of different yield contributing characters is finally projected through kernel yield. Therefore, non-additive gene action for kernel yield is expected.

Table 2. *Mean squares due to general and specific combining ability (GCA and SCA) for growth and yield components in a7×7 diallel cross of maize.*

Sources of variation	df	Mean of squares									
		DT(cm)	DS	ASI	PH (cm)	EH (cm)	DM	CL	CD	TSW (g)	Yield (t/ha)
GCA	6	18.576	17.222*	0.247	1119.493**	368.095**	2.179	6.645*	0.1306	3313.985*	2.0867
SCA	21	6.285	11.710*	1.078	1070.430**	283.183**	3.158	9.819**	0.0943	1551.034ns	4.2955**
Error	54	1.972	5.270	1.336	155.9871	60.213	3.697	2.223	0.0351	1107.414	0.9784
GCA: SCA		2.955	1.470	0.229	1.045	1.299	0.689	0.676	1.384	2.136	0.485

*, ** indicated at 5% and 1% level of significance, respectively

Days to 50% tasseling (DT), Days to 50% silking (DS), Anthesis Silking Interval (ASI), Plant height (PH), Ear height (EH), Days to maturity (DM), Cob length (CL), Cob diameter (CD), Thousand seed weight (TSW) and Yield (t/ha).

3.3. General Combining Ability (GCA) Effects

The estimates of general combining ability effects of the parents are presented in Table 3.

Significant negative variation was observed in WL2 (-1.534**) and WL3 (-1.571**) but positive variation in WL1 and WL5. For days to tasseling, negative estimates are considered desirable as those were observed to be associated with earliness. WL4, WL7 showed negative gca. For days to silking, negative estimates are considered desirable as those were observed to be associated with earliness. The entry WL2 (-1.556*), WL_3 (-1.629*), WL4 and WL7 showed negative value. According to Singh and Singh (1979), generally earliness is associated with days to silk and the shorter plants. The parents WL2 (-0.296) and WL6 (-0.148) had negative ASI which is desirable for earliness. But none of the genotypes recorded significant variation. Negative gca for plant height was observed in WL1 (-17.089**), WL2 (-4.837), WL5, (-6.919), WL7 (-0.733). Among them highly significant but negative gca was in WL1 indicating dwarfness. According to [21], generally earliness is associated with days to silk and the shorter plants with low ear height are associated with resistance to lodging. Negative gca for ear height was observed in WL1(-8.571**), WL2 (-2.771), WL5 (-3.497), WL7(-2.979). Significant positive variation was identified in WL3 and WL4. Among them highly significant but negative gca exhibited in WL1(-8.571**) indicating dwarfness. The shorter plants with low ear height are associated with resistance to lodging. The genotypes WL3 (-0.153), WL4(-0.376), WL6(-0.524) and WL7 (-0.265) showed negative estimates of gca value but not significant which is associated with earliness. Significant positive gca recorded only in WL3 (1.244*). Undesirable negative gca identified in WL1(-1.061*), WL5(-0.618) and WL7(-0.766).

Significant positive gca recorded in WL3 (0.156*), WL4(0.169*). Undesirable negative gca identified in WL1 (-0.155*) WL2 (-0.007), WL5 (-0.085), WL6(-0.039) and WL7(-0.038). Positive but insignificant value of gca recorded in three genotypes out of seven such as WL1 (10.449), WL3 (18.191) and WL4(7.635). Highly significant and negative value identified in WL6 (-37.958**). The entry WL3 (0.798*) and WL4 (0.542) showed desirable positive value. The rest of the genotypes identified undesirable negative value. Parent W_3 seemed to be the best general combiner for kernel yield and also possessed significant positive gca effects for other yield components like cob length and cob diameter and TSW. This was supported by [22], [23].

The overall study of gca effects suggests that parent WL3 was significant for general combiner for yield, WL2 and WL3for earliness and WL1 for short stature. These parents could be used in future breeding programme to improve maize yield with desirable traits.

Table 3. *General combining ability (GCA) effects for growth and yield components in a 7×7diallel cross of maize.*

Parents	DT	DS	ASI	PH	EH	DM	CL	CD	TSW	Yield
WL1	2.021**	2.037**	0.111	-17.089**	-8.571**	0.884	-1.061*	-0.155*	10.449	-0.268
WL2	-1.534**	-1.556*	-0.296	-4.837	-2.771	0.032	0.198	-0.007	-1.365	-0.038
WL3	-1.571**	-1.629*	0.074	17.637**	10.673**	-0.153	1.244*	0.156*	18.191	0.798*
WL4	-0.979	-0.519	0.185	5.704	4.932*	-0.376	0.149	0.169*	7.634	0.542
WL5	1.429**	1.333	0.037	-6.919	-3.497	0.402	-0.618	-0.085	-9.958	-0.244
WL6	0.688	0.444	-0.148	6.237	2.214	-0.524	0.853	-0.039	-37.958**	-0.487
WL7	-0.053	-0.111	0.037	-0.733	-2.979	-0.265	-0.766	-0.038	13.005	-0.302
SE	0.348	0.573	0.286	3.090	1.920	0.476	0.369	0.046	8.234	0.245
SE(sij)	0.863	1.434	0.710	7.674	4.769	1.181	0.916	0.115	20.448	0.608

*, ** indicated at 5% and 1% level of significance, respectively.

Days to 50% tasseling (DT), Days to 50% silking (DS), Anthesis Silking Interval (ASI), Plant height (PH), Ear height (EH), Days to maturity (DM), Cob length (CL), Cob diameter (CD), Thousand seed weight (TSW) and Yield (t/ha).

3.4. Specific Combining Ability (SCA) Effects

The estimates of general combining ability effects of the parents are presented in Table 4.

For days to tasseling eight cross combination showed significant negative value such as WL1×WL3(-1.926*), WL1×WL4 (-1.852*), WL1×WL6(-3.185**), WL1×WL7(-2.444**), WL2×WL7 (-3.222**), WL3×WL5 (-2.333*), WL5×WL6 (-1.926*) and WL5×WL7 (-2.185*) indicating earliness of the hybrids. Significant negative sca identified in four crosses such as WL1×WL6 (-4.231**), WL1×WL7(-4.009*), WL2×WL6(-2.972*), WL2×WL7 (-3.750*). The rest of the crosses showed negative but insignificant combination. Only three crosses found positive value such as WL2×WL4, WL4×WL5 and WL6×WL7. Negative significant sca for ASI was found only in WL1×WL7 (-1.648*) indicating earliness and positive sca in WL1×WL5 (2.019**) which represented late maturing variety. None of the hybrids showed significant negative sca except WL1×WL5 (-12.909) and WL2×WL4 (-4.650) which exhibited negative value. Highly significant positive sca recorded in four crosses WL1×WL6 (33.669**), WL1×WL7(30.772**), WL2×WL5 (24.839**) and WL4×WL5 (33.765**). The hybrid WL1×WL5 (-8.007) had desirable negative value but not significant. Highly significant positive sca recorded in four crosses WL1×WL6 (14.815**), WL1×WL7 (15.807**), WL2×WL5 (15.259**) and WL4×WL5 (15.156**). Among the 21 hybrids, all showed negative sca except the hybrids WL4×WL7 (0.093), WL5×WL6 (0.241) and WL6×WL7 (0.241) which showed positive sca for days to maturity. Highly significant positive sca was identified in WL1×WL7 (4.580**), WL2×WL5 (2.836**), WL6×WL7 (5.220**), WL1×WL6 (2.291*) and WL5×WL6 (1.958*). Significant negative value was recorded only in WL1×WL5 (-3.458**) which is undesirable. Highly significant positive sca was exhibited in WL1×WL7 (0.344**), WL2×WL3 (0.339**) and WL5×WL6 (0.358**) and in WL4×WL6 (0.271*). The rest hybrids showed positive sca except WL1×WL5(-0.027), WL2×WL4(-0.246*). Significant positive sca was recorded in the crosses WL1×WL6 (89.472**), WL1×WL7 (43.843*), WL2×WL5 (49.287*), WL3×WL5(47.065*) and WL5×WL7(49.583*). Another seven hybrids showed positive but insignificant combination. The rest nine hybrids recorded negative combination. Highly significant positive sca identified in WL1×WL6 (3.666**), WL1×WL7(1.888**), WL4×WL5 (2.030**), WL6×WL7 (2.763**). Significant sca value was also observed in WL_1×WL2 (1.327*), WL2×WL5 (1.633*), WL3×WL5 (1.457*) and WL5×WL7(1.390*). Highly significant negative sca was recorded in WL1×WL5 (-2.577**).

Estimates of significant positive sca effects for cob length, cob diameter and TSW are more frequently associated with significant estimates of sca effect of kernel yield. Positive relationship between sca effect of kernel yield and yield contributory characters were reported [24]. The significant estimates of gca and sca variances suggested the importance of both additive and non-additive gene actions for the expression of all the characters except ear diameter. Therefore, for yield improvement in maize both additive and non additive genes should be exploited through a suitable breeding method. However, the crosses WL1×WL6, WL1×WL7, WL4×WL5, WL6×WL7showed high sca effect for kernel yield could be used in hybrid development after further evaluation.

The studied results showed that both gca and sca effects were significant for TSW inWL1×WL7, cob length, cob diameter, TSW and yield (t/ha) in WL3×WL5 indicating that both additive and non additive genetic actions were important combining hybrids from the diallel crosses which was supported [25]. Two factors are considered important for the evaluation of inbred lines in hybrid maize production - the characteristics of the line itself and the behaviour of the line in a particular hybrid combination [26]. As a basic principle [27]. emphasized that sca is more important than gca among selected inbred lines.

Gca and sca effects were significant for cob length, cob diameter, TSW and yield (t/ha) in the crosses WL1×WL6, WL1×WL7 though it had negative gca. Positive sca indicated that desirable lines were in opposite heterotic groups, while negative sca effects indicated lines were in the same heterotic group [28].

In general, the gca effects of the parents were reflected in the sca effects of the crosses in most of the studied traits. This is corroborated with the results of [29]. [22]. [30]. Besides, [31] reported good general combining parent does not show high sca effects in their hybrid combinations. On the contrary, [32] obtained high estimates of sca from high gca parents in their study.

Table 4. *Specific combining ability (SCA) effects for growth and yield contributing characters in a 7×7 diallel cross inmaize.*

Cross/Hybrids	DT	DS	ASI	PH	EH	DM	CL	CD	TSW	Yield
WL1×WL2	-0.296	-0.565	0.019	20.343*	8.600	-1.130	1.392	0.190	-0.454	1.327*
WL1×WL3	-1.926*	-2.491	-0.685	8.202	3.422	-0.944	2.456*	0.133	30.657	1.159
WL1×WL4	-1.852*	-2.602	-0.463	9.135	4.563	-1.722	0.331	0.087	-5.787	1.054
WL1×WL5	0.741	2.880	2.019**	-12.909	-8.007	-0.167	-3.458**	-0.246*	-34.528	-2.577**
WL1×WL6	-3.185**	-4.231**	-1.130	33.669**	14.815**	-0.574	2.291*	0.129	89.472**	3.666**
WL1×WL7	-2.444**	-4.009*	-1.648*	30.772**	15.807**	-0.833	4.580**	0.344**	43.843*	1.888**
WL2×WL3	-0.037	-0.565	-0.278	10.817	3.422	-0.093	0.197	0.339**	2.472	0.341
WL2×WL4	0.370	4.324**	1.278	-4.650	0.630	-0.537	-0.708	-0.027	-5.639	-0.566
WL2×WL5	-1.037	-2.528	-1.241	24.839**	15.259**	-1.648	2.836**	0.100	49.287*	1.633*
WL2×WL6	-1.630	-2.972*	-1.056	15.617	3.815	-1.056	0.589	0.107	15.954	0.426
WL2×WL7	-3.222**	-3.750*	-0.241	20.987*	10.407*	-2.981	0.541	0.053	6.324	1.018
WL3×WL4	-0.593	-0.269	0.574	3.343	0.785	-1.019	1.346	0.076	1.472	-0.225
WL3×WL5	-2.333*	-2.454	0.056	16.365*	8.815	-1.130	1.670	0.063	47.065*	1.457*
WL3×WL6	-0.926	-0.898	-0.093	18.409*	13.837**	-0.870	0.543	0.177	-14.269	0.610
WL3×WL7	0.481	-0.343	-0.944	12.313	8.563	-0.130	-0.171	0.033	1.435	-0.641
WL4×WL5	0.074	0.102	0.278	33.765**	15.156**	-0.907	1.108	0.137	-5.046	2.030**
WL4×WL6	-0.519	-0.676	0.130	15.409	9.111	-0.981	1.304	0.271*	10.954	-0.424
WL4×WL7	-1.111	-1.454	-0.056	12.313	10.837*	0.093	0.037	0.181	-4.009	0.164
WL5×WL6	-1.926*	-2.861	-1.056	18.698*	11.341*	0.241	1.958*	0.358**	-14.120	-0.918
WL5×WL7	-2.185*	-2.306	-0.241	16.869*	8.267	-0.352	1.468	0.187	49.583*	1.390*
WL6×WL7	1.222	1.583	0.278	15.113	4.489	0.241	5.220**	0.159	-1.083	2.763**
SE(gi)	0.345	0.573	0.286	3.090	1.920	0.476	0.369	0.046	8.234	0.245
SE(sij)	0.863	1.424	0.710	7.674	4.769	1.181	0.916	0.115	20.448	0.608

*, ** indicated at 5% and 1% level of significance, respectively.

Days to 50% tasseling (DT), Days to 50% silking (DS), Anthesis Silking Interval (ASI), Plant height (PH), Ear height (EH), Days to maturity (DM), Cob length (CL), Cob diameter (CD), Thousand seed weight (TSW) and Yield (t/ha).

3.5. Heterosis

The standard heterosis expressed by the F_1 hybrids over the the standard checks namely, BHM 7 (BARI hybrid maize 7) for different characters are presented in Table 5. The percent of heterosis in F_1 hybrids varied from character to character or from cross to cross.

Considering commercial hybrid BHM7 as a check, all the crosses showed significantly positive heterosis for days to tasseling and that ranged from 1.48 to 11.62%. For days to silking, none of the crosses showed significantly negative heterosis except WL2×WL7 (-0.35) which exhibited negative but insignificant value. Negative heterosis is expected for ASI. Heterosis for ASI ranged from -35.62 to 43.06. Only one cross WL1×WL5 (-19.59**) exhibited significant negative heterosis for plant height indicated dwarfness of the hybrids (Table 5). The hybrid WL2×WL4 (-0.38%) identified as negative heterosis. For ear height, heterosis varied from -17.14 to 39.33% where only one cross WL1×WL5 (-17.14**%) showed significant negative heterosis and all others are positive. Highly significant positive heterosis was identified in all the hybrids and it ranged from -0.22 to 2.72%. Only one hybrid, WL2×WL7 (-0.22) recoded negative heterosis. Negative heterosis is also desirable for days to maturity which helps for adjusting cropping pattern. Among the studied hybrids eight hybrids showed significant negative heterosis. Only one hybrid WL6×WL7 (10.07**%) exhibited highly significant positive heterosis. Positive heterosis expected for this trait. But only five hybrids such as WL1×WL3 (9.66**), WL1×WL6(10.34**), WL1×WL7 (11.73**), WL3×WL5 (8.62**)and WL5×WL7 (7.93**) showed significant positive heterosis. Positive heterosis expected for this yield. Heterosis ranged from -56.59 to 15.60% which indicated sufficient variability among the studied hybrids. The maximum heterosis recorded in WL1×WL6 (15.60**%). Standard heterosis in cob length, cob diameter, TSW and grain yield were identified with wide range of variability (negative to positive) [33], [34], [35].

Table 5. *Percent heterosis over the hybrid variety BHM7 for yield and yield contributing characters in 7×7 diallel cross.*

Cross/ Hybrids	DT	DS	ASI	PH (cm)	EH (cm)	DM	CL (cm)	CD (cm)	TSW (g)	Yield (t/h)
WL1×WL2	7.12**	5.30**	-7.01	0.89	3.78	1.812**	-5.86**	-12.89**	-3.45	-7.14
WL1×WL3	5.24**	3.18**	-14.16**	6.89**	13.75**	1.812**	1.18	-10.55**	9.66**	0.88
WL1×WL4	5.99**	4.24**	-7.01	0.51	8.20**	1.13**	-9.56**	-11.28**	-2.49	-3.40
WL1×WL5	11.63**	12.02**	43.06**	-19.59**	-17.14**	2.72**	-24.76**	-24.18**	-14.48**	-56.59**
WL1×WL6	6.36**	3.54**	-28.47**	15.04**	17.29**	1.81**	-0.68	-14.95**	10.35**	15.60**
WL1×WL7	6.36**	3.18**	-35.62**	9.32**	12.22**	1.81**	1.56	-10.18**	11.73**	-3.57
WL2×WL3	3.36**	1.42*	-14.16**	15.51**	20.75**	1.81**	-2.16	-2.78**	-0.69	-6.18
WL2×WL4	4.48**	7.78**	21.60**	-0.38	10.45**	1.36**	-8.83**	-10.55**	-5.52*	-20.18**
WL2×WL5	5.61**	2.48**	-35.62**	9.39**	17.94**	1.13**	0.43	-13.33**	4.14*	-3.17
WL2×WL6	4.11**	1.06	-35.622**	11.68**	11.02**	0.91**	-2.16	-12.16**	-11.72**	-20.62**
WL2×WL7	1.48**	-0.35	-14.16**	10.75**	12.71**	-0.22	-7.72**	-13.33**	-1.03	-11.27**
WL3×WL4	3.36**	2.83**	14.45**	17.28**	26.87**	0.91**	1.51	-4.69**	1.38	-6.02
WL3×WL5	4.11**	2.48**	0.14	17.52**	26.38**	1.36**	0.03	-10.55**	8.62**	4.77
WL3×WL6	4.86**	3.18**	-7.01	26.33**	39.33**	0.91**	1.18	-7.03**	-14.48**	-8.34*
WL3×WL7	5.61**	3.18**	-21.32**	18.75**	26.70**	1.59**	-6.60**	-10.18**	2.76	-21.18**
WL4×WL5	7.49**	6.36**	7.29	20.69**	27.11**	1.36**	-5.49	-8.65**	-7.59**	8.58*
WL4×WL6	5.99**	4.59**	0.14	17.67**	26.70**	0.68**	0.07	-4.69**	-10.69**	-23.87**
WL4×WL7	4.48**	3.18**	0.14	11.83**	22.52**	1.59**	-9.56**	-6.67**	-1.38	-14.56**
WL5×WL6	7.12**	4.24**	-28.47**	12.26**	19.22**	2.04**	-0.31	-8.35**	-21.72**	-39.27**
WL5×WL7	5.99**	4.24**	-7.01	7.16**	9.25**	1.81**	-7.35**	-12.09**	7.93**	-9.27*
WL6×WL7	8.99**	7.42**	0.14	13.77**	11.58**	1.59**	10.07**	-11.72**	-12.41**	4.33
Min	1.48	-0.35	-35.62	-19.59	-17.14	-0.22	-24.76	-24.18	-21.72	-56.59
Max	11.62	12.02	43.06	26.33	39.33	2.72	10.07	-2.78	11.73	15.60
$CD_{(0.05)}$	0.98	1.21	9.05	4.41	5.25	0.28	3.13	2.03	4.29	7.41
$CD_{(0.01)}$	1.33	1.65	12.35	6.01	7.16	0.37	4.27	2.77	5.86	10.10

Days to 50% tasseling (DT), Days to 50% silking (DS), Anthesis Silking Interval (ASI), Plant height (PH), Ear height (EH), Days to maturity (DM), Cob length (CL), Cob diameter (CD), Thousand seed weight (TSW) and Yield (t/ha).

4. Conclusion

Gca effects suggested that the parent WL3 (BIL 77) was significant for general combiner for yield and WL2 (BML 36) and WL3 (BIL77) for earliness WL1 (BIL 20) for short statured plant. The crosses WL1×WL6, WL1×WL7, WL4×WL5, WL6×WL7showed high sca effect for kernel yield could be used in hybrid development after further evaluation. The cross WL1 ×WL6 (15.60) showed the maximum positive heterosis for yield over the check BHM 7. The cross WL2×WL7 exhibited highly negative heterosis against either of the check variety in case of days to maturity.

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