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Single-cross maize hybrids with mid and better parent heterosis in growth and yield attributing traits

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ABSTRACT

From October 6, 2015, to March 5, 2016, in research field of the National Maize Research Program, Rampur, Chitwan, Nepal, an experiment was conducted to assess mid parent and better parent heterosis in growth and yield traits among single-cross maize hybrids. In a randomized complete block design with three replications, eleven maize hybrids were evaluated. The results showed that mid parent and better parent heterosis were considerably greater for yield traits viz cob length (67.1, 49.6%), cob diameter (113, 93.6%), number of kernel rows per cob (40, 27.6%), number of kernels per row (134.5, 98%), and test weight (92.2, 96.4%). The highest mid-parent heterosis for growth and yield attributing traits was found in RML-98/RL-105, followed by RML-5/RL-105, RML95/RL-105, and RML-4/NML-2. The hybrid RML-98/RL-105 had the highest better parent heterosis for growth and yield attributing traits, followed by RML-5/RL-105, RML-95/RL-105, and RML-4/NML-2. These findings suggested that hybrids like RML98/RL-105, RML-5/RL-105, RML-95/RL-105, and RML-4/NML-2 are promising hybrids that the farmers should grow these hybrids in order to increase maize production.

INTRODUCTION

Maize (*Zea mays* L, 2n = 2 = 20), a grass species (Poaceae), was one of the oldest crops cultivated on earth (Paliwal 2000 Farnham et al. 2003). According to Sleper and Poehlman (2006), maize is largely wind-pollinated, but self-pollination is possible. Maize is the only grain native to the Americas that can be grown worldwide in tropical and subtropical climates (Britannica 2021). In 125 developing countries, maize is grown on an area of approximately 100 million hectares, of which 75 are among the top three crops (FAO 2010). Maize is the second most important grain crop in Nepal after rice and contributes to the country's agricultural economy in various ways. Cultivated area and corn productions were 9.6 million hectares and 2.96 Mt ha^{-1}, respectively (MoAD 2020). The seed replacement rate for maize in Nepal is also low (11.3%) (Pokharel 2013). It has been reported that the demand for corn has increased by 5% in the last ten years (Sapkota and Pokhrel 2010). It accounts for about a quarter of total grain production, 6.54% of GDP and 3.15% of GDP (MoAD 2013). Terai and Mid Hills accounted for approximately 80% and 10% of maize production, respectively (Adhikari 2014). Hybrid maize covered 7-10% of the land in Nepal in 2010 (Gurung et al. 2011) and the area under hybrid maize is increasing every year. Nepal imports about 20% of maize seeds each year (Adhikari 2014) and almost all of the hybrid seeds come from India (Gurung et al. 2011). However, between 40% and 45% of corn kernels used in animal feed are imported from India annually (CDD 2013). Heterosis (hybrid vigor) refers to an increase in the size, height, fertility and productivity of the offspring compared to their parents (Britannica 2021). Hallauer and Miranda (1988) showed that heterosis is due to genetic differences between the two parental species and that parental genetic variation can be inferred from heterotic models presented in a series of crossover combinations. The new maize hybrid should outperform existing varieties in terms of grain yield and other economic characteristics. The evaluation of heterosis is critical for the generation of superior

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hybrids. The objective of this study was to estimate heterosis in single-cross maize hybrids.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted at the National Maize Research Program (NMRP), Rampur, Chitwan, Nepal, from the first week of October 6, 2015 to March 5, 2016. The experimental site was located at 27 ° 40 'North latitude, 84 ° 21' East longitude and at an altitude of 228 m above sea level. During the experiment, the highest temperature recorded was 27.32 ° C and the lowest was 14.33 °C. The minimum temperature ranged from 8.76 ° C to 24.08 ° C. The greatest amount of precipitation (42.5 mm) fell in October 2015, the least (4.66 mm) in January, 2016. During the growing season, 95.66 mm of precipitation fell.

Selection of plant materials

Eleven single cross maize hybrids were collected from National Maize Research Program, Rampur, Chitwan, Nepal. Their name along with parentage lines is given in Table 1.

Experimental design and treatment details

Eleven single-cross hybrid maize were evaluated in a randomized complete block design with three replications. The plot was divided into two rows of three meters each, 60 cm × 25 cm apart. The net area for each person was 3.6 m^2 (3 m × 1.2 m). The structure of the soil is sandy-loamy, slightly acidic. FYM @ 10 t ha^{-1} and 180:60:40 kg NPK ha^{-1} in the form of Urea, Di-ammonium phosphate, and Murate of Potash was used in the experiment. Half of the nitrogen dose and the full dose of phosphorus and potassium were added during sowing. The remaining nitrogen dose is split in half and top dressed at 30 DAS and 45 DAS. For weed control, atrazine 2.0 g + pendimethalin 4.5 ml L^{-1} water was used. During the planting season, two manual weeding was used to keep plots free of weeds. Grain yield data were collected. Grain yield was calculated by fixing the grain moisture at 15% as used by Carangal et al. (1971) and Shrestha et al. (2015).

Data Collection and Observations

Plant height, ear height, days to 50% silking, days to 50% tasseling, ear length, ear diameter, number of kernel rows per ear, number of kernels per row, and test weight (1000 kernel weight) were all taken into account. The following formula can be used to calculate mid parent and better parent heterosis (Hayes et al. 1955).

$$\text{Mid parent heterosis (\%)} = \frac{\text{F1} - \text{Mid parent}}{\text{Mid parent}} \times 100$$

$$\text{Better parent heterosis (\%)} = \frac{\text{F1} - \text{Better parent}}{\text{Better parent}} \times 100$$

Statistical Analysis

Using Microsoft Excel 2016 and GenStat version 18, all data was analyzed using one-way ANOVA. Duncan multiple range test (DMRT) was used for mean comparison; means were separated by least significance difference (LSD) at $P < 0.05$.

RESULTS AND DISCUSSION

Over the mid parent, the amount of heterosis for all agronomic traits was measured, and the better parent exhibited significant differences in all yield-attributing parameters. Because positive heterosis indicates a larger yield, it is preferred. In crop breeding, hybrids outperform OPV and composite varieties. Several researchers have reported the expression of grain yield heterosis above the standard check in maize (Venugopal et al.2002; Tiwari 2003;Twumasi et al. 2003; Amiruzzaman et al. 2010; Wali et al. 2010). For estimation of mid parent and better parent heterosis, this field experiment was carried out. The results were discussed, and evidence from previous studies was used to support them.

Table 1. List of hybrids used in the experiment

S.N.	Genotypes	Parentage line
1	RML-95/RL-105	PUTU-17/UPAHAR-B-20-2-4-1-1
2	RML-115/RML-96	PUTU-17/AG-27
3	RML-153/RL-105	POOL-21-12-1-2-1-1-1/UPAHAR-B-20-2-4-1-1
4	RML-85/RL- 105	PUTU-14/UPAHAR-B-20-2-4-1-1
5	RML-98/RL-105	L-3/UPAHAR-B-20-2-4-1-1
6	RML-4/NML-2	CA00326/CML-430
7	RML-4/RML-17	CA00326/ CML-287
8	RML-95/RML-96	PUTU-17/ AG-27
9	RML-32/RML-17	CA00320/ CML-287
10	RML-86/RML-96	PUTU-20/ AG-27
11	RML-5/RL-105	CA00314/UPAHAR-B-20-2-4-1-1

Plant height

Because plant height is one of the most significant growth characteristics for commercial hybrids, small hybrids are less likely to lodge. Table 2 shows that the heterosis for plant height was highest (58.7%) in RML-95/RL-105 and was comparable to RML-85/RL-105 (57.5%). For plant height, the amount of heterosis over mid and better parent heterosis ranged from 43.5% to 76.4%, and 43.1% to 58.7%, respectively. Over better parent, plant height heterosis ranged from -52.8% (RML-4/RML-17) to 58.7% (RML-95/RML-105), and

43.5% (RML-95/RML-96) to 76.4% (RML-98/RL-105) over mid parent. In the mid and better parent heterosis, there was >43% heterosis. CP-666 revealed a significantly significant difference in heterosis among four standard check hybrids, while the other three were non-significant for this trait. This meant that the single cross hybrids had shorter plant heights than the control variety, which was a good characteristic for lodging resistance. These kinds of outcomes have also been documented by Saleh et al. (2002). Gadad (2003) revealed positive and significant heterosis for plant height, which is similar to the current findings.

Table 2. Heterosis for plant height of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	61.1	58.7
RML-115/RML-96	57.6	45
RML-153/RL-105	52.8	51
RML-85/RL- 105	56.7	57.5
RML-98/RL-105	57.2	52.6
RML-4/NML-2	51.7	50.1
RML-4/RML-17	76.4	52.8
RML-95/RML-96	43.5	44
RML-32/RML-17	55.7	46.3
RML-86/RML-96	50.8	43.1
RML-5/RL-105	61.1	49.6
Mean	56.8	50.1
F test	NS	NS
LSD (0.05)	22.7	28.2
CV (%)	23.5	33.1

NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Ear height

Short plant height hybrids are less likely to lodge since ear height is one of the most important development features. Better parent heterosis in ear height over better parent was highest in RML-98/RL-105 (56.9%), followed by RML-95/RL-105 and RML-95/RL-105 (50.7%) (Table 3). Mid parent heterosis ear height ranged from 40.6 percent to 66.6 percent, and better parent heterosis ear height ranged from 13.8 percent to 56.9%, respectively. Over mid parent, better parent heterosis, the amount of heterosis was obtained at >50% and >38%, respectively. Although the results were non-significant, negative heterosis is advantageous for this feature since short-statured hybrids are resistant to lodging. These results are generally in accordance with the findings of Devi et al. (2007), Saleh et al. (2002) and Gadad (2003) as they obtained similar heterosis values for ear height.

Table 3. Heterosis for ear height of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	54.1	50.7
RML-115/RML-96	66.6	41.4
RML-153/RL-105	49.7	38
RML-85/RL- 105	57.9	49.1
RML-98/RL-105	58.9	56.9
RML-4/NML-2	43.2	38.1
RML-4/RML-17	40.6	13.8
RML-95/RML-96	53.4	45.8
RML-32/RML-17	50	16.6
RML-86/RML-96	54.2	38.3
RML-5/RL-105	65.8	49
Mean	54.0	39.8
F test	NS	NS
LSD (0.05)	12.3	40.0
CV (%)	27.9	59.1

NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Days to 50% silking

Table 4 reveals that heterosis of single cross hybrids in the mid and better parent was not substantially different for days to 50% silking. The highest better parent heterosis in days to 50% silking was RML-153/RL-105 (38.9%) over better parent, followed by RML-95/RML-96 (34.4%). In days to 50% silking, RML-95/RML-96 had the highest heterosis (28.1%), followed by RML-86/RML-96 (26.6%) above mid parent. All genotypes showed heterosis in the days to 50% silking, ranging from 1.6% to 28.1% and 1.5% to 38.9% over mid and better parent, respectively. Negative standard heterosis is desirable because it indicates earlier anthesis of the crosses than the standard check, whereas positive heterosis indicates later anthesis of the crosses than the standard check. In keeping with the current findings, Pandey

Table 4. Heterosis for days to 50% silking of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	2.4	2.8
RML-115/RML-96	27.4	17.9
RML-153/RL-105	17.2	38.9
RML-85/RL- 105	3.8	7.8
RML-98/RL-105	15.5	17.8
RML-4/NML-2	16.6	20.6
RML-4/RML-17	1.6	1.5
RML-95/RML-96	28.1	33.4
RML-32/RML-17	23.1	15.9
RML-86/RML-96	26.6	33.8
RML-5/RL-105	16.5	27.6
Mean	16.9	19.8
F test	NS	NS
LSD (0.05)	28.1	42.1
CV (%)	101	124

NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

and Ransam (2001) reported both positive and negative and significant levels of heterosis for days to silking (Amaregouda 2007). Variation in heterosis for days to 50% silking was also observed by Mir et al. (2015).

Days to 50% tasseling

Table 5 shows that for days to 50% tasseling, heterosis of single-cross hybrids over mid parent, better parent, and four check varieties was non-significant. In days to 50% tasseling, RML-153/RL-105 had the highest heterosis (34.2%) over better parent heterosis, followed by RML-86/RML-96 (32.4%), and RML-95/RML-96 had the highest heterosis (27.3%) over mid parent, followed by RML-115/RML-96 (25.7%). The variation in heterosis in days to 50% tasseling was also found by Mir et al. (2015) and Sedhom et al. (2016).

Table 5. Heterosis for days to 50% tasseling of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	0.4	1.8
RML-115/RML-96	25.7	15.9
RML-153/RL-105	13.6	34.2
RML-85/RL- 105	1.2	5.7
RML-98/RL-105	13.2	15
RML-4/NML-2	14.9	18.7
RML-4/RML-17	-0.5	-1.2
RML-95/RML-96	27.3	31.1
RML-32/RML-17	22.4	14.7
RML-86/RML-96	25.2	32.4
RML-5/RL-105	14	24.9
Mean	14.3	17.6
F test	NS	NS
LSD (0.05)	29.3	43.3
CV (%)	120	115

NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Cob length

Cob length is an important yield characteristic associated with grain production. The larger the cob length, the higher the grain yield. Table 6 shows that heterosis of single cross hybrids over the better parent was non-significant for cob length but significant for the mid parent. Better parent heterosis in cob length was the highest in RML-5/RL-105 (89.3%), followed by RML-95/RL-105 (85.95%). Over mid parent heterosis, RML-5/RL-105 had the highest cob length heterosis (105.5%), followed by RML-98/RL-105 (101.3%). Heterotic effects against their better and mid parent heterosis varied from 43.1% to 57.5% and 43.5% to 76.4%, respectively, among eleven single cross hybrids. In maize populations Abdel-Moneam et al. (2009) and Sofi et al. (2007) found significant positive heterosis values for cob length.

Table 6. Heterosis for cob length of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	96.8	85.9
RML-115/RML-96	30.5	21.5
RML-153/RL-105	48.8	11.9
RML-85/RL- 105	67.9	41.6
RML-98/RL-105	101.3	85.8
RML-4/NML-2	72	59.8
RML-4/RML-17	60.8	39.9
RML-95/RML-96	34.8	28.8
RML-32/RML-17	64.8	39.2
RML-86/RML-96	55.4	41.6
RML-5/RL-105	105.5	89.3
Mean	67.1	49.6
F test	**	NS
LSD (0.05)	38.9	69.4
CV (%)	34.0	82.2

**Significant at 0.01 level of significance, NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Cob diameter

Cob diameter, which is closely linked to grain production, is one of the most important yield factors. The larger the cob diameter higher the grain yield. Table 7 shows that heterosis for single cross hybrid cob diameter over better parent and four check varieties was non-significant, whereas heterosis for mid parent and four check varieties was significant. Over better parent, RML-95/RL-105 had the highest better parent heterosis in cob diameter (112.3%), followed by RML-4/RML-17 (108.6%), and the maximum heterosis in cob diameter was found in RML-5/RL-105(135.8%), followed by RML-95/RL-105(133.7%). In eleven single cross hybrids with mid and better parent heterosis, heterosis effects ranged from 85.2% to 135.8% and 60.6% to 112.3% , respectively. The single cross hybrid RML-5/RL-105 showed the greatest (135.8%) heterosis in cob diameter among the mid parent heterosis. The majority of genotypes had >90% cob diameter heterosis over mid and better parent heterosis. This finding was similar to Sofi et al. (2007) and Mir et al. (2015) found significant positive heterosis values for cob diameter.

Table 7. Heterosis cob diameter of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	133.7	112.3
RML-115/RML-96	103.1	96.6
RML-153/RL-105	94.8	60.6
RML-85/RL- 105	115.8	92.9
RML-98/RL-105	121.5	95.8
RML-4/NML-2	101.1	93.9
RML-4/RML-17	117.2	108.6
RML-95/RML-96	85.2	86.1
RML-32/RML-17	132.9	93.9
RML-86/RML-96	104.8	88
RML-5/RL-105	135.8	101.2
Mean	113	93.6
F test	*	NS
LSD (0.05)	31.5	36.5
CV (%)	16.4	22.9

*Significant at 0.05 level of significance, NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Number of kernel rows per cob

The number of kernel rows per cob is another yield parameter that is important in determining grain yield. In maize, having more rows per cob is beneficial since it has a direct association with grain yield. Table 8 shows that heterosis for the number of kernel rows per cob of single cross hybrids over better parent and four check types was non-significant, but heterosis for the number of kernel rows per cob of mid parent hybrids was extremely significant. RML-5/RL-105 showed the highest better parent heterosis in terms of number of kernel rows per cob (44.8%), followed by RML-4/RML-17 (42.2%). Similarly, RML-32/RML-17 had the highest heterosis in number of kernel rows per cob (81.4%) and RML-5/RL-105 had the highest heterosis in number of kernel rows per cob (52.2%) over mid parent. Over mid and better parent heterosis, heterosis effects in single cross hybrids ranged from 17.2% to 81.4% and 14.3% to 44.8%, respectively. Similar results were recorded by Tollenaar et al. (2004), Frascaroli et al. (2007) and Alam et al. (2008) who also observed varying levels of heterosis for kernel rows per cob.

Table 8. Heterosis for number of kernel rows per cob of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	44.4	31
RML-115/RML-96	35.5	19
RML-153/RL-105	30.5	15.9
RML-85/RL- 105	49.5	39
RML-98/RL-105	38	27
RML-4/NML-2	25.3	14.3
RML-4/RML-17	34	42.2
RML-95/RML-96	17.2	14.3
RML-32/RML-17	81.4	36.7
RML-86/RML-96	28.7	19
RML-5/RL-105	55.2	44.8
Mean	40	27.6
F test	**	NS
LSD (0.05)	27.7	25.6
CV (%)	40.8	54.6

**Significant at 0.01 level of significance, NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

Number of kernels per row

The number of kernels per row is an important yield factor that influences grain yield. It has a substantial relationship with grain yield. Table 9 shows that heterosis of single cross hybrids for the number of kernels per row over better parent was non-significant, whereas heterosis of single cross hybrids for the number of kernels per row over mid parent was significant. In terms of the number of kernels per row, the RML-85/RL-105 showed the most heterosis (175%) over better parent heterosis, followed by the RML-98/RL-105 (170%). The present results are in corroboration with the findings of Tollenaar et al. (2004), Frascaroli et al. (2007) and Alam et al. (2008) who also observed varying levels of heterosis for the number of kernels per row. Similarly, genotype RML-5/RL-105 had the highest the number of kernels per row heterosis (223.3%) above the mid parent, followed by genotype RML-98/RL-105 (203.8%). Over mid and better parent heterosis, the percentages of 42% to 223.3% and 25% to 175%,

Table 9. Heterosis for number of kernels per row of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	144	91
RML-115/RML-96	95.2	54
RML-153/RL-105	82.9	25
RML-85/RL- 105	197.9	175
RML-98/RL-105	203.8	170
RML-4/NML-2	91.5	71
RML-4/RML-17	116.7	11
RML-95/RML-96	42	41
RML-32/RML-17	201.9	115
RML-86/RML-96	80.3	57
RML-5/RL-105	223.3	156
Mean	134.5	98.0
F test	**	NS
LSD (0.05)	65.1	10.7
CV (%)	28.5	64.4

**Significant at 0.01 level of significance, ns: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

respectively ranged from 42% to 223.3% and 25% to 175%. Over the mid parent, RML-5/RL-105 exhibited the highest heterosis (223.3%) in terms of the number of kernels per row.

Test weight (1000 kernel weight)

Because of the substantial positive association between test weight and grain production, it is often utilized as a selection criterion in maize breeding programs. In single cross hybrids, heterosis appeared as a non-significant difference in test weight over the mid parent, better parent (Table 10). The RML-95/RL-105 had the highest test weight heterosis (118.8%) above the better parent, followed by RML-85/RL-105 (117.9%). Over mid parent, RML-115/RML-96 demonstrated the largest heterosis in test weight (123.9%), followed by RML-86/RML-96 (111.6%). Previous researchers (Amiruzzaman et al. 2010) have reported both undesired and beneficial heterosis for 1000 kernel weight in maize, which is similar to the current findings (Wali et al. 2010).

Table 10. Heterosis for test weight (1000 kernel weight) of single cross hybrids

Hybrids	Mid parent (%)	Better parent (%)
RML-95/RL-105	108.7	118.8
RML-115/RML-96	113.9	108.1
RML-153/RL-105	95.2	87
RML-85/RL- 105	105.2	117.9
RML-98/RL-105	102.7	96.1
RML-4/NML-2	75.8	81.5
RML-4/RML-17	83	92.9
RML-95/RML-96	100	93
RML-32/RML-17	76.1	77.8
RML-86/RML-96	111.6	103.1
RML-5/RL-105	109.3	84.5
Mean	92.2	96.4
F test	NS	NS
LSD (0.05)	36.8	38.2
CV (%)	21.8	23.3

NS: Not significant at 0.05 level of significance, CV: Coefficient of variation, LSD: Least significant difference.

CONCLUSIONS

Single-cross maize hybrids namely RML-98/RL-105, RML-5/RL-105, RML-4/NML-2 and RML-95/RL-105 were superior hybrids with higher mid parent heterosis (>40%) and better parent heterosis (>40%) in yield attributes viz cob length, cob diameter, number of kernels per row, and test weight. The results suggest that the farmers should grow these hybrids to increase maize production. The heterosis of 40% and above this value in maize hybrids is considered the best for its commercial exploitation in maize. The information obtained on the heterosis of the maize hybrids for different traits would be useful in planning hybrid maize breeding.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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REFERENCES

Abdel-Moneam M.A. Attia A.N. El-Emery M.I. Fayed E.A. (2009) Combining ability and heterosis for some agronomic traits in crosses of maize. Pakistan Journal of Biological Science, 12(5): 433-438.

Adhikari J. (2014) Seed sovereignty: Analyzing the debate on hybrid seeds and GMOs and bringing about sustainability in agricultural development. Journal of Forest and Livelihood, 12: 33-46.

Alam A.K.M.M. Ahmed S. Begum M. Sultan M.K. (2008) Heterosis and combining ability for yield and its contributing characters in maize. Bangladesh Journal of Agricultural Research, 33(3): 375-379.

Amaregouda H.M. (2007) Combining ability analysis of S2 lines derived from yellow pool population in Rabi maize. M.Sc. Thesis. University of Agricultural Sciences, Dharwad.102p.

Amiruzzaman M. Islam M.A. Hassan L. Rohman M.M. (2010) Combining ability and heterosis for yield and Component characters in maize. Academic Journal of Plant Science, 3(2): 79-84.

Britannica (2021) Food crops. https://www.britannica.com/place/South-America/Food-crops

Britannica (2021) Heterosis. https://www.britannica.com/science/heterosis

Carangal V.R. Ali S.M. Koble A.F. Rinke E.H. (1971) Comparison of S1 with testcross evaluation for recurrent selection in maize. Crop Science, 11: 658-661.

CDD (2013) Crop Development Directorate. Impact of maize mission program. http://cddnepal.gov.np/uploaded/Impact Maize Mission Program.pdf

Devi B. Barua N.S. Barua P.K. Talukar P. (2007) Analysis of mid parent heterosis in a variety diallel in rainfed maize. Indian

Journal of Genetics and Plant Breeding, 67(2): 67-70.

FAO (2010) Statistical databases and data-sets of the Food and Agriculture Organization of the United Nations. http://faostat.fao.org/default.aspx.

Farnham D.E. Benson G.O. Pearce R.B. (2003) Corn perspective and culture. Chapter 1. In: PJ White, LA Johnson, eds. Corn: chemistry and technology, Edition 2nd. American Association of Cerial Chemicals, Inc. St. Paul, Minesota, USA. pp 1- 33.

Frascaroli E. Cane M.A. Landi P. Pea G. Gianfranceschi L. Villa M. Morgante M. Pe M.E. (2007) Classical genetic and quantitative trait loci analyses of heterosis in a maize hybrid between two elite inbred lines. Genetics, 176(1): 625-644.

Gadad S.K. (2003) Genetic analysis for quantitative traits, starch and oil in single cross hybrids of maize (*Zea mays* L.). M.Sc. (Agri.) Thesis, University of Agricultural Sciences, Dharwad, India.

Gurung D.B. Upadhyay S.R. Pandey B.R. Pokhrel B.B. Kshetri J.B. (2011) Hybrid maize seed production: A new initiative for reliable and sustainable hybrid maize seed supply. Nepal Agriculture Development Journal, 8: 1-8.

Hallauer A.R. Miranda J.B. (1988) Quantitative Genetics in Maize Breeding. 2nd ed. Iowa State University Press, Iowa, Ames. USA.

Hayes H.K. Immer F.R. Smith D.C. (1955) Methods of Plant Breeding. Mc. Grow Hill Book. Co., Inc., New York.

Mekbib F. Bjornstad A. Sperling L. Synnevag G. (2009) Factors shaping on-farm genetic resources of sorghum. Moench in the Centre of diversity, Ethiopia. International Journal of Biodiversity and Conservation, 1(2): 045-059.

Mir S. D. Ahmad M. Parray G.A., Zaffar G. Dar S.H. (2015) Heterosis studies in single crosses of inbred lines in maize (Zea mays L.). Electronic Journal of Plant Breeding, 6(4): 1073-1077.

MoAD (2013) Statistical Information on Nepalese Agriculture. Government of Nepal, Ministry of Agriculture Development Agri-business Promotion and Statistics Division. Singha Durbar, Kathmandu, Nepal.

MoAD (2020) Statistical Information on Nepalese Agriculture. Government of Nepal, Ministry of Agriculture Development Agri-business Promotion and Statistics Division. Singha Durbar, Kathmandu, Nepal.

Paliwal R.L. (2000) Introduction to maize and its importance. Chapter 1. In: Tropical Maize: Improvement and Production. Food and Agriculture Organization of the United Nations Rome. pp 1-3.

Paudyal K.R. Ransom J.K. (2001) Resource use efficiency and effective incentives of Nepalese maize farmers. In: N. P. Rajbhandari, J. K. Ransom, K. Adhikari and A. E. F. Palmer (eds.) Sustainable Maize Production System for Nepal. Proceedings of a maize Symposium, December 3-5, 2001, Kathmandu, Nepal. pp. 239-245.

Pokhrel T. (2013) Impact of Maize varieties Disseminated in Chitwan, Nepal. Economic Journal of Nepal , 42(6): 45-53.

Russel F. Eisensmith S.P. (1983) MSTAT-C. Crop and Soil Sci. Dept. Michigan State Univ. USA.

Saleh G.B. Abdullah D. Anuar A.R. (2002) Performance of heterosis and heritability in selected, tropical maize single, double and three way cross hybrids. Journal of Agricultural Sciences, 138: 21-28.

Sapkota D. Pokhrel S. (2013) Community based maize seed production in the hills and mountains of Nepal: A review. Agronomy Journal of Nepal, 1:107–112. https://doi.org/10.3126/ajn.v1i0.7550

Sedhom Y.S. Ali M.M.A. Awaad H.A. Rabie H.A. (2016) Heterosis and factor analysis for some important traits in new maize hybrids. Zagazig Journal of Agricultural Research, 43(3): 711-728.

Shrestha J. Koirala K.B. Katuwal R. Dhami N. Pokhrel B. Ghimire B. Prasai H.K. Paudel A. Pokhrel K. KC G. (2015) Performance evaluation of quality protein maize genotypes across various maize production agro ecologies of Nepal. Journal of Maize Research and Development, 1(1): 21-27. http://dx.doi.org/10.3126/jmrd.v1i1.14241.

Sleper D.A. Poehlman J.M. (2006) Breeding of field crops (No. Ed.5). Blackwell publishing, ISBN 1-56022-278-6, pp. 424.

Sofi P.A. Rather A.G. Dar Z.A. (2007) Association of heterotic expression for grain yield and component traits in maize (*Zea mays* L.). International Journal of Agriculture research, 2(5): 500-503.

Tollenaar M. Lee E.A. (2002) Yield potential, yield stability and stress tolerance in maize. Field Crops Research, 75 (2-3): 161-169.

Twumasi Afriyie S. Yihun K. Napir G. (2003) Exploitation of combining ability and heterotic responses in maize germplasm to develop cultivars for the Eastern African Highlands. Book of abstracts: Arnel R. Hallauer international symposium on plant breeding. In Text Book of abstracts: Arnel R. Hallauer international symposium on plant breeding. A Mexico, DF (Mexico)BCIMMYT C2003 (No. 631.53 BOO. CIMMYT.).

Venugopal M. Ansani N.A. Murthy G.K. (2002) Heterosis and its component characters in maize (*Zea mays* L.). Crop Research, 3:72-74.

Wali M.C. Kachapur R.M. Chandrashekhar C.P. Kulkarni V.R. Devaranavadagi S.B.(2010)Gene action and combining ability studies in single cross hybrids of maize (*Zea mays* L.). Karnataka, Journal of Agricultural Sciences, 23(4): 557-562.