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Performance of Single Cross Maize Hybrids for Summer Planting in Western Nepal

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ABSTRACT

In addition to being a major source of food, feed, and fodder, maize is one of the important cereals for the livelihood of hill farmers in Nepal. Low maize productivity in the western hills of Nepal has traditionally been associated with the absence of high yielding varieties. The purpose of this study was to find single cross maize hybrids that would be highly productive and adaptable for summer planting in western hills of Nepal. An alpha lattice design with three replications was used to evaluate one hundred single cross hybrids, including checks at NMRP, Rampur; DoAR, Surkhet; and DoAR, Doti during the summer season of 2019. In the evaluated maize hybrids, all measured traits showed significant genetic variation, indicating the presence of substantial genetic diversity among tested hybrids and significant genotype by environmental interaction highlighting the variable performance across locations. RML-145/RL-105, RML-97-1/RML-98, RML-145/RML-146, RML-138/RML-2, and RML-97-2/RL-105 was among the top 17 hybrids with grain yields of 8-9 t ha^{1}. Significant correlations of grain yield with plant height, ear height, test weight, cob length, and cob diameter suggest that these are the important traits while selecting the hybrids for yield. The study also employed 20 SSR markers to explore genetic diversity of 25 inbred lines which were used for developing top yielding hybrids, grouped these inbred lines into five distinct cluster showed moderate genetic diversity, and higher yield performance of hybrids associated with diverse background of parental lines. The genotype by environment interactions highlights the importance of multilocation testing to ensure consistent or location specific performance across varied conditions. The results suggest the possibility of exploring high yielding, adaptive, and location specific hybrids that can help to enhance maize productivity of western Nepal and narrow down the yield gap.
Key words: Maize, Hybrid, Genetic diversity, Yield

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INTRODUCTION

Maize (*Zea mays L*) is the important cereal in terms of area, production and use in Nepal. It is associated with the livelihood of Nepalese hill farmers for food, poultry and livestock feed, and fodder. It is cultivated in 0.98 million ha with production of 3.10 million metric tons (FAOSTAT 2024). According to MoALD (2018), the mid hills account for 73% of the total area planted to maize, while the Terai and high hills make up 18% and 9%, respectively. Similarly, summer maize occupies around 65% of the total area while spring and winter maize occupy 20% and 15% of the land respectively. The demand for maize grain has been increased by 5% yearly over the last 10 years and is expected to remain similar for the next 20 years (Sapkota and Pokharel 2019). More than 85% of maize area is covered by hybrid maize in the global context while nearly 25-30% area is occupied by hybrids. The national productivity (3.15 t ha^{-1}) of maize is quite low in comparison to average of World's (5.71 t ha^{-1}), Asia (5.71 t ha^{-1}), China (6.10 t ha^{-1}), and USA (11.86 t ha^{-1}). The higher yield in the USA, China, and other countries is credited to the rapid adoption of input responsive high yielding hybrid maize varieties, irrigations, fertilizers, machineries, and other inputs.

It is a major crop in the western hills of Nepal, serving as both a staple food, feed, fodder, and important source of income for rural households. The terrain and climate of the region, with its diverse agro-ecological zones ranging from foot hill areas to high altitude regions, make it well-suited for maize cultivation. Promoting the adaptive and climate resilient hybrid maize varieties, and improved agronomic practices might be the basic steps for addressing the food security and improving the livelihoods of farmers in the western hills of Nepal. The western hills are characterized by lower rainfall and delayed summer monsoon in comparison to eastern part of the country. This makes maize cultivation in these areas more challenging, especially for rain-fed agriculture. As a result, the development and promotion of early-maturing maize hybrids are critical for ensuring food security and achieving higher productivity in these regions. Hybrids are more responsive to fertilizer and irrigation as compared to open pollinated varieties (OPVs) and has yield advantages of 15-50% depending on the specific varieties and growing conditions (Setimela and Kosina 2006, Malik et al 2011, Koirala et al 2020). However, out of 10 released maize hybrids in Nepal, none of them are recommended for western hills of Nepal. Therefore, this study was conducted to find productive and adaptative single cross maize hybrids that are suitable for summer planting in western hills of Nepal.

MATERIALS AND METHODS

Experimental sites

Field experiments were conducted in the summer of 2019 at three locations: the Directorate of Agricultural Research (DoAR) in Sudurpashchim Province, Doti with coordinates 29°15' N, 80°55' E and an altitude of 610 masl (DoAR 2023); the Directorate of Agricultural Research (DoAR) in Karnali Province, Surkhet with coordinates 28°30' N, 81°47' E and altitude 580 masl (DoAR 2022); and the National Maize Research Program (NMRP), Bagmati Province, Chitwan with coordinates 27°40' N, 84°19' E and altitude of 228 masl (NMRP 2024).

Climate and soil

DoAR, Doti represents the foothills and river basin regions of Sudurpashchim Province. The climate is subtropical, with a dry and very hot pre-monsoon period. The monsoon season begins in late July and is highly erratic. The annual rainfall usually does not exceed 1000 ml. The area receives high solar radiation with high fluctuation on day and night temperature. Soil in the experimental field is shallow, porous, stony, sandy loam texture, acidic (pH 5.5-6.0), low nitrogen (12%) and low organic matter (0.6%). Because of its light texture and low organic matter content, the soil has a very low water-holding capacity. Similarly, DoAR, Surkhet has a subtropical climate, average annual rainfall is 1100 mm with 84.6% occurring between June and September. The temperatures vary from 5°C in January to 37.5°C in April. The soil in the experimental field is sandy loam and acidic, with a pH range of 5.3 to 5.8. It has low organic matter and nitrogen content, but medium levels of phosphorus and potassium. Due to its light texture and low organic matter content, the soil has very low water holding capacity. NMRP Rampur has a humid, subtropical climate characterized by cool winters and hot summers. The site receives over 2000 mm of annual rainfall, with more than 75% occurring between mid-June and mid-September. The experimental field soil is sandy loam and acidic, with a pH of 5.3. It features medium levels of nitrogen and potassium but is rich in organic matter and phosphorus (Khadka et al 2016).

Genetic materials

Ninety-three single cross hybrids, four national hybrids, two popular company hybrids, and an open pollinated variety were evaluated in multilocation trial at Chitwan, Surkhet, and Doti in the summer of 2019 (Table 1).

Experimental management

The experimental field was fertilized by applying well decomposed farm yard manure (FYM) @ 10 t ha^{-1} along with chemical fertilizers @ 180:60:40 N P_2O_5 K_2O kg ha^{-1} in the form of Urea, DAP, and Murate of Potash (MoP). All FYM, phosphorous, potash and one-third of nitrogen was uniformly incorporated and final leveling was done to ensure uniformity across the plots, preventing waterlogging or uneven moisture distribution. Remaining nitrogen was applied as side dressing into two splits at 45 and 60 days after sowing. Planting occurred in late May on flat bed at Doti and Surkhet, and ridge beds at Rampur with R-R spacing of 0.75m and P-P spacing of 0.2m in a 4m long row. A tank mixture of (atrazine@ 2.5 g+5.0 ml of pendimethalin per liter of water) was applied within 48 hours of sowing. Two applications of insecticides (Alcora and Spinosad @ 0.5 ml litre^{-1}) were used against fall armyworm at 30 and 45 DAS. Earthing up and irrigation was provided at key growth stages. The crop was harvested after drying, ears counted, and weight measured.

Experimental design and data collection
The experiment, involving 100 genotypes, was laid-out in an α-lattice design with three replications, 10 blocks in each replication at each site. Data were collected on flowering, agro-morphological traits, yield, and yield component traits, and disease scores using CIMMYT, protocol (CIMMYT 1985). Key measurements included days to 50% anthesis and silking, number of plants and cobs harvested, field weight for the whole plot. Five central random plants were selected for measuring plant and ear height, ear length and diameter. Husk cover was rated on a1-5 scale, grain yield was estimated at 12.5% moisture and 80% shelling coefficient by following formula previously used by Shrestha et al (2014) and Adhikari et al (2018).

Statistical analysis
Excel 2013 for Microsoft Office was used for data entry. Statistical analysis was performed by META-R, version 6.0. Heritability was categorized as low 0-30%, medium 30-60%, and high >60% according to Johnson et al (1955).

Genotyping of parents of superior hybrids
A total of 25 maize inbred lines producing 17 superior hybrids were analyzed using SSR markers at National Seed Science Research Centre, Khumaltar in 2020. DNA was extracted from 21 days old maize seedling by using a modified cetyltrimethylammonium bromide (CTAB) method as described by (Doyle, 1990) with slight modifications. Twenty SSR markers were selected based on polymorphism, discrimination ability, and band quality. The presence or absence of specific SSR marker bands was recorded as 1 (present) and 0 (absent). Polymorphic Information Content (PIC) was calculated using Botstein et al (1980), Jaccard's similarity coefficients were determined using SequentiX software (version 1.9.3.0).

RESULTS

The analysis of variance revealed significant genetic difference among maize hybrids for all traits, including phenological traits (anthesis and silking days), growth traits (plant and ear height), and yield components (test weight, kernel rows, cob length and diameter, and grain yield) (Table 2-3). This indicates substantial genetic diversity among the hybrids, likely due to diverse parental lines (Figure 1-2). A significant genotype-by-environment interaction was also noted for most traits except cob length and diameter, suggesting the genotype performance varied by environment. Environmental factors significantly affected the phenotypic expression of these traits, except for cob length.

Traits like test weight, number of kernels per row, cob diameter and length, plant and ear height, and grain yield have high heritability, indicating they were predominantly controlled by genetic factors. In contrast, days to 50% anthesis and silking, anthesis silking interval showed moderate heritability, suggesting both genetic and environmental influences. The coefficient of variation ranged from 2.31 to 30.1%, with grain yield showing the moderate variability, indicating significant differences among genotypes, while other traits exhibit lower variability, implying more consistency.

Phenological traits
Phenological traits like days to 50% anthesis, days to 50% silking, and anthesis-silking interval showed highly significant difference due to genotypic effects, environmental conditions, and their interactions among the tested hybrids. Days to 50% anthesis ranged from 54.4 to 58.0 days with mean of 56.7. Likewise, days to 50% silking varied from 56.7 to 61.4 days with mean 59.3 and silking anthesis interval ranged from 1.7 to 3.7 with mean of 2.5 days. Anthesis and silking days, and anthesis-silking interval of top seventeen hybrids were statistically at par with Rampur Hybrid 10.

Growth traits
Plant and ear height showed significant variation due to genotype, environment and genotype by environment interaction among tested genotypes. Plant height varied from 183 to 236 cm with mean 213 cm while ear height ranged from 94 to 125 cm with mean of 107 cm. Many of the high yielding hybrids were taller both in plant and ear height compared to Rampur Hybrid 10.

Table 1. List of maize genotypes under study, 2019

SN	Genotypes	Source	SN	Genotypes	Source
1	RML-145/RML-146	NMRP	51	RML-145/RL-105	NMRP
2	RL-36/RL-105	NMRP	52	KH-2	NMRP
3	RML-76/RL-105	NMRP	53	RL-251/RML-17	NMRP
4	RML-83/RL-197	NMRP	54	RL-84/RML-62	NMRP
5	RML-57/RL-174	NMRP	55	RL-215/RML-17	NMRP
6	RL-243/RML-17	NMRP	56	RML-138/RML-140	NMRP
7	RML-95/RL-105	NMRP	57	RL-248/RML-96	NMRP
8	RML-98/RL-105	NMRP	58	RML-88/RML-18	NMRP
9	RML-4/RL-105	NMRP	59	RML-138/RML-2	NMRP
10	RL-236/RML-146	NMRP	60	RL-173/RML-18	NMRP
11	RML-84/RML-17	NMRP	61	RML-87/RML-146	NMRP
12	RML-57/RML-17	NMRP	62	RL-280/RML-96	NMRP
13	RML-84/RML-96	NMRP	63	RML-94/RL-298	NMRP
14	RML-95/RML-140	NMRP	64	RML-11-1/RL-298	NMRP
15	RML-65/RML-18	NMRP	65	RML-145/RML-96	NMRP
16	RL-272/RML-96	NMRP	66	RL-280/RML-18	NMRP
17	RML-87/RL-105	NMRP	67	RML-117/RL-111	NMRP
18	RML-4/RL-111	NMRP	68	RML-145/RML-98	NMRP
19	RML-89/RL-105	NMRP	69	RL-283/RML-18	NMRP
20	RL-298/RML-17	NMRP	70	RL-29/RML-140	NMRP
21	RML-98/RML-96	NMRP	71	RML-145/RML-84	NMRP
22	RL-243/RML-140	NMRP	72	RL-239/RML-17	NMRP
23	RL-294/CML-226	NMRP	73	RL-213/RL-105	NMRP
24	RL-222/RML-96	NMRP	74	RL-222/RML-2	NMRP
25	RML-5/RML-17	NMRP	75	RL-249/RML-96	NMRP
26	RML-11-1/RML-18	NMRP	76	RL-246/RML-17	NMRP
27	RML-76/RML-17	NMRP	77	RML-93/RML-18	NMRP
28	RML-138/RL-105	NMRP	78	RL-280/RML-17	NMRP
29	RL-234/RML-96	NMRP	79	RL-219/RL-151	NMRP
30	RML-89/RML-140	NMRP	80	RL-217/RML-18	NMRP
31	RML-97-2/RL-105	NMRP	81	RML-145/RML-140	NMRP
32	Gaurav Hybrid	NMRP	82	RML-145/RL-298	NMRP
33	RL-232/RL-197	NMRP	83	Rampur Hybrid -10	NMRP
34	RML-97-1/RL-105	NMRP	84	RL-215/RL-151	NMRP
35	RML-83/RL-236	NMRP	85	RML-37/RML-17	NMRP
36	RML-105/RML-140	NMRP	86	RL-153/RL-105	NMRP
37	RL-180/RL-197	NMRP	87	RL-165/RML-18	NMRP
38	RML-2/RML-62	NMRP	88	RL-248/RML-140	NMRP
39	RML-84/RL-105	NMRP	89	RL-248/RML-17	NMRP
40	RML-76/RML-146	NMRP	90	RL-35-1/RML-18	NMRP
41	RML-68-1/RL-101	NMRP	91	RML-68-2/RL-101	NMRP
42	RML-98/RML-17	NMRP	92	RML-37/RL-105	NMRP
43	RML-138/RML-96	NMRP	93	RL-298/RML-96	NMRP
44	CAL-1465/RML-18	NMRP	94	RML-145/RML-7	NMRP
45	RML-5/RML-140	NMRP	95	RML-236/RML-96	NMRP
46	RML-85/RML-146	NMRP	96	Rampur Composite	NMRP
47	RML-97-1/RML-98	NMRP	97	Rampur Hybrid-6	NMRP
48	RL-180/RL-105	NMRP	98	RL-84/RML-140	NMRP
49	RML-85/RML-17	NMRP	99	CP808	MNCH
50	RL-232/RL-111	NMRP	100	Rajkumar	MNCH

Yield component traits

Yield component traits such as 1000 kernel weight and number of kernel rows cob^{-1}, exhibited significant variation due to genotype and environment among tested genotypes. Cob length showed significant differences due to genotypes whereas cob diameter varied with both genotypes and location. However, non-significant genotype by environment effect on observed yield component traits showed consistence performance of genotypes. Thousand kernel weight ranged from 272-385g with mean of 318g, number of kernel rows cob^{-1} ranged 14-16, cob length ranged 15.7-20.3cm and cob diameter varied 3.1-4.1cm. Bold seed was found in RML-

97-1/RML-98 and RML-138/RML-2, RML-88/RML-18 had long cob length, and RML-97-1/RML-98 had large cob as compared to Rampur Hybrid 10 (Table 2).

Grain yield

The grain yield was found statistically highly significant at all tested locations indicating the existence of genetic variability on yield potential on the tested genotypes. Combined analysis also has shown highly significant response for genotypic, environmental and genotype by environment interaction. The significant genotype by environment, suggests that the yield performance of genotypes varied across environments. Likewise, significant environment showing that environmental conditions have a significant effect on the expression of traits. It indicated that environmental factors play a crucial role in determining the yield expression of these hybrids.

Combined yield result showed that genotypes RML-145/RL-105, RML-97-1/RML-98, RML-145/RML-146, RML-138/RML-2, and RML-97-2/RL-105 were top five high yielding hybrids across locations which produced average yield of 8945, 8552, 8195, 8193 and 8183 kg ha^{-1} respectively (Table 3). The high heritability suggested a strong genetic influence on yield performance. The percentage yield advantages indicated the performance of each genotype relative to standard check (Rampur Hybrid 10), commercial check (Rajkumar), and open pollinated variety (Rampur Composite). RML-145/RL-105 showed a 27% advantage over the standard check, 45% over commercial, and 86% over local checks. Likewise, RML-97-1/RML-98 produced a 21% yield advantage over the standard check, 39% over commercial check, and 78% over local check. Similarly, RML-145/RML1-46 showed 16% yield advantage over standard check, 33% over commercial check, and 70% over OPV check.

Surkhet and Doti have produced significantly higher mean yield than Rampur. Grain yield at Surkhet ranged from 5241 to 11432 kg ha^{-1} with a mean yield of 8109 kg ha^{-1}. Similarly, yield ranged from 5398 to 11400 kg ha^{-1} with grand mean of 7914 kg ha^{-1} at Doti. Rampur environment was found to be less suitable for summer maize, as it produced approximately 65% less mean yield than other two locations. Lack of consistency among genotypes observed in yield, for example, genotypes RML-88/RML-18 and RML-111/RL-298 ranked in the top five at Surkhet but fall below the 10^{th} position at Doti and Rampur, indicated significant genotype by environment interactions, emphasizing the need for selecting location specific genotypes. Seventeen hybrids out of 100 that produced higher mean yield than Rampur Hybrid 10 and ASI of less than 3.0 days were presented along with checks. Yield advantages over standard, commercial, and local check with statistical measures is presented in table 2 and table 3.

Correlation between yield and other traits

The correlation between grain yield and agronomic traits showed positive correlation for all traits in all locations. Plant height, ear height, the number of plants per hectare, and 1000 grain weight had positive correlations with grain yield, suggesting that increases in these traits were associated with higher yields. The correlation between plant height and grain yield in Surkhet is 0.45***, which was statistically significant and positive. Days to 50% silking had a negative correlation (0.32**) with grain yield, particularly in Doti indicating that earlier silking was associated with higher yields (Table 4)

Significant positive correlations between most of the traits across location was observed. Strong correlation was observed for 1000 grain weight (0.65*** Doti *vs* Surkhet, 0.92*** Doti *vs* Chitwan, 0.68*** Surkhet *vs* Chitwan). Similarly, the relationship between the traits found stronger for numbers of kernel rows (0.99*** Doti vs Chitwan, 0.62***Doti vs Surkhet and Surkhet vs Chitwan), cob length (0.86*** Doti vs Chitwan), cob diameter (0.99*** Doti vs Chitwan) and grain yield (0.65*** Doti vs Surkhet. A similar trend observed between plant height and numbers of plants across all three locations.

The dendogram and unrooted neighbor joining tree constructed for 20 maize inbred lines based on SSR marker data grouped inbred lines into five distinct clusters based on distance matrix that measures the similarity/dissimilarity between inbred lines (Figure 1 and 2). Inbreeds RL-36, RML-76 and RML-145 grouped in cluster I whereas RML-140, RML-96, RML-138, RML-85, RL-298 and RML-146 consisted in cluster II. Similarly, cluster III is formed by including RML-17, RL-180, RML-95, RML-83 and RML-84. The fourth cluster included RML-11-1, RL-232, RML-97-2, RML-97-1, RL-111 and RML-18 and the fifth cluster formed by the grouping of RL-105, RL-236, RML-98, RML-88 and RML-2. The parentage combination of all top yielding hybrids except RML-85/RML-146 (ranked 9^{th} in yield) and RL-232/RL-111 (ranked 17^{th} in yield) are belongs from different clusters. This showed the heterosis and hybrid vigor observed in grain yield of hybrids indicating that hybrids with genetically diverse parents tend to perform better.

Table 2. Yield attributing traits of top 17 maize hybrids, 2019

Genotypes	AD	SD	ASI	PH	EH	TKW	NKR	CL	CD
RML-145/RL-105	57.7	59.9	2.3	232	125	342	16	18.0	4.2
RML-97-1/RM--L98	57.1	59.7	2.6	228	115	368	14	17.8	4.1
RML-145/RML146	56.4	58.9	2.6	223	110	338	14	19	3.7
RML-138/RML-2	57.8	60.2	2.5	220	117	359	14	18.1	3.6
RML-97-2/RL-105	56.9	59.3	2.5	221	108	300	14	19.2	3.4
RML-145/RML-98	56.0	58.1	2.3	219	111	340	14	17.3	3.8
RL-36/RL-105	57.6	59.9	2.4	216	106	342	14	19.4	3.7
RL-180/RL-105	57.1	59.4	2.4	220	113	335	14	18.3	3.5
RML-85/RML-146	57.5	59.8	2.3	230	118	303	14	18.8	3.7
RML-76/RML-146	57.0	59.4	2.5	235	119	277	14	19	3.7
RML-83/RL-236	57.4	59.5	2.2	217	109	309	14	19.5	3.7
RML-95/RML-140	57.0	59.5	2.6	203	105	279	14	17.9	3.7
RML-84/RM-L96	56.2	58.3	2.3	218	103	301	14	17.1	3.7
RML-11-1/RL-298	56.4	58.9	2.6	209	101	325	14	18.6	3.6
RML-98/RML-17	57.0	59.1	2.2	209	107	328	14	17.5	3.8
RML-88/RML-18	57.6	59.9	2.4	209	99	315	14	20.1	3.8
RL-232/RL-111	56.8	58.9	2.3	215	108	344	14	17.4	3.5
Rampur Hybrid-10	56.5	59.1	2.6	201	101	318	14	18.3	3.8
Rajkumar	55.9	59.0	3.1	216	104	327	14	19.9	3.6
Rampur Composite	55.4	58.6	3.2	209	103	307	14	17.2	3.7
Grand mean	56.7	59.3	2.5	213	107	318	14	18.3	3.7
Minimum	54.4	56.7	1.7	183	94	272	12	15.7	3.1
Maximum	58.0	61.4	3.7	236	125	385	16	20.3	4.1
Genotype significance	***	***	***	***	***	***	***	*	*
Env significance	***	***	***	***	***	***	Ns	Ns	*
Gen × Env significance	***	***	***	***	***	Ns	Ns	Ns	Ns
CV, %	2.9	2.31	30.1	6.59	11.72	9.79	6.38	10	6.4
$LSD_{0.05}$	1.66	1.68	1.2	14.75	12.71	28.1	0.78	1.6	0.2
Heritability	0.58	0.59	0.5	0.77	0.66	0.87	0.88	0.7	0.8

Note: *, **, *** and Ns: Significant at 0.05, 0.001, <.001 probability levels and nonsignificant respectively. AD= Days to 50% anthesis, SD= Days to 50% silking, ASI=anthesis silking interval days, PH=Plant height (cm), EH=Ear height (cm), TKW= 1000 kernel weight (g), NKR=Numbers of kernel rows, CL=Cob length (cm), CD= Cob diameter (cm), Statistics presented is drawn from all tested entries.

Table 3. Average grain yield (kg ha^{-1}) and yield advantage% of top 17maize hybrids over checks

Genotypes	Doti	Chitwan	Surkhet	Mean	% Yield advantages over checks		
					Standard	Commercial	Local
RML-145/RL-105	11400	3624	11432	8945	27	45	86
RML-97-1/RM--L98	11242	4450	9658	8552	21	39	78
RML-145/RML146	10573	4314	9315	8195	16	33	70
RML-138/RML-2	9170	4487	10721	8193	16	33	70
RML-97-2/RL-105	10505	4301	9422	8183	16	33	70
RML-145/RML-98	9454	4215	10294	8058	14	31	67
RL-36/RL-105	10194	3100	10166	7879	12	28	64
RL-180/RL-105	10276	4196	8568	7794	11	26	62
RML-85/RML-146	8647	3220	10372	7458	6	21	55
RML-76/RML-146	8190	3737	9988	7335	4	19	52
RML-83/RL-236	9351	3936	8316	7254	3	18	51
RML-95/RML-140	8792	2856	9865	7221	2	17	50
RML-84/RM-L96	8961	2538	9971	7201	2	17	50
RML-11-1/RL-298	7888	3130	10538	7195	2	17	49
RML-98/RML-17	8475	3468	9458	7190	2	17	49
RML-88/RML-18	7809	2860	10692	7145	1	16	48
RL-232/RL-111	8863	3050	9029	7058	0	14	47
Rampur Hybrid-10	8126	3913	9037	7047			
Rajkumar	8192	2292	7959	6170			
Rampur Composite	6585	2048	6031	4815			
Grand mean	7914	2885	8109	6303			
Maximum	5398	1477	5241	4386			
Minimum	11400	4584	11432	8945			
Genotype	***	***	***	***			
Environment				***			
G ×E				***			
CV, %	19.75	27.12	20.82	22.33			
$LSD_{0.05}$	2164	1111	2410	1572			
Heritability	0.70	0.74	0.75	0.76			

Note: *** Significant at 0.001 probability levels, Statistics presented is drawn from all tested entries.

Table 4. Phenotypic coefficient of correlations between grain yield and other traits, and association of same trait under different locations

Traits	Correlation between yield and others traits			Association of traits under different locations		
	Doti	Surkhet	Chitwan	Doti *vs* Surkhet	Doti *vs* Chitwan	Surkhet *vs* Chitwan
Grain yield (kg ha^{-1})				0.65***	0.56***	0.43***
Days to 50% silking	0.32**	0.13	0.14	0.35***	0.17	0.53***
Plant height (cm)	0.26*	0.45***	0.44***	0.51***	0.55***	0.51***
Ear height (cm)	0.27**	0.38***	0.48***	0.45***	0.29**	0.49***
No. of plants ha^{-1}	0.56***	0.61***	0.55***	0.35**	0.39**	0.41***
1000 grain weight (g)	0.31**	0.07	0.22*	0.65***	0.92***	0.68***
No. of kernel rows	0.14	0.31**	0.03	0.62***	0.99***	0.62***
Cob length (cm)	0.01	0.15	0.16	0.26*	0.86***	0.27**
Cob diameter (cm)	0.26*	0.47***	0.09	0.55***	0.99***	0.55***

Note: *,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively

Table 5. Analysis of the DNA finger printing/genetic diversity of parental lines of maize

SN	Primer code	Molecular wt. range (bp)	No. of alleles	Polymorphism information content (PIC)
1	UMC1363	100-200		
2	UMC1370	100-200		
3	UMC1587	100-200		
4	UMC1060	100-200	4	0.68
5	UMC1413	100-200	3	0.51
6	UMC1859	100-200	3	0.65
7	Bnlg 1867	100-200	5	0.73
8	Phi053	100-200	3	0.67
9	UMC1962	100-300	6	0.76
10	UMC1196	100-200	2	0.48
11	UMC1380	100-200	2	0.44
12	UMC1241	100-200	3	0.65
13	UmC2265	100-200	3	0.56
14	Bnlg 1257	100-200	3	0.99
15	UMC1600	100-200	4	0.67
16	UMC1630	100-200		
17	UMC1069	300-400	5	0.8
18	Bnlg1810	100-200		
19	UMC2013	100-200	4	0.54
20	Bnlg1189	100-200	4	0.49
			Total alleles = 54 Mean = 3.6	Mean PIC = 0.64

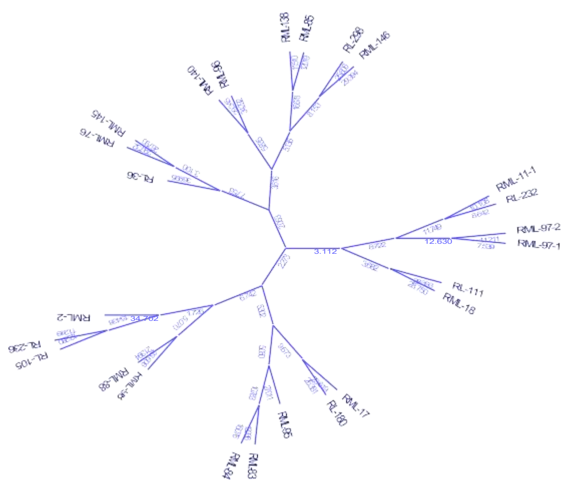

Figure 1. An Unrooted Neighbor Joining Tree showing the genetic relationships between 25 maize inbred lines based on SSR data

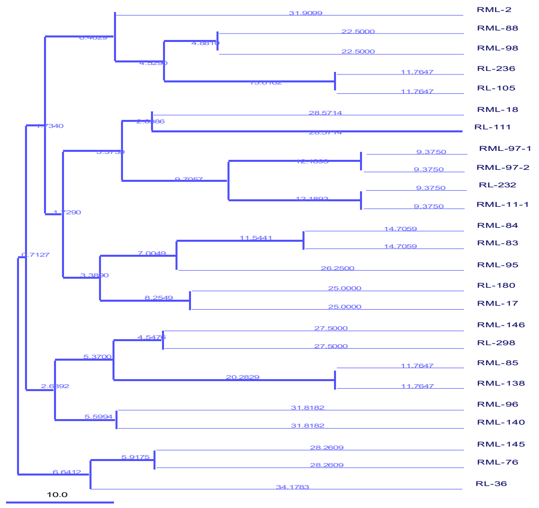

Figure 2. Dendrogram for 25 maize inbred lines derived from a UPGMA cluster analysis using SSR data

DISCUSSION

The genotypic responses of the evaluated single cross hybrids were highly significant for all the measured traits in the study, exploring considerable genetic variation among the hybrids, which should facilitate selecting for improved grain yield and other traits under the study conditions. In accordance with this study, genetic differences were previously reported among maize hybrids for grain yield (Kamara et al 2014, Adhikari et al 2018, Ajala et al 2020, Elmyhun et al 2020 and Tripathi et al 2022).

The significant variance of tested locations for measured agronomic traits indicates the existence of differences among sites. Variation in soil and climatic conditions between locations could be the main cause of the observed significant variance. Similar observations were reported by other studies (Ajala et al 2020 and BaduApraku et al 2017). Moreover, the significant environmental response indicated that the test locations were unique in discriminating among the genotypes, and that testing of the genotypes in a wide array of locations over years will be required to identify the suitable genotypes (BaduApraku and Akinwale 2011). The significant genotype by environment interaction (GEI) for yield and other agronomic traits indicate that genotypes respond differently across locations, and that such variations in genotypic response could be due to the presence of different growing environments at the test sites. This variation provides the importance of assessing hybrids in diverse environments to identify those with consistent performance. These findings are consistent with results from previous studies (BaduApraku and Akinwale 2011 and Akaogu et al 2013).

The detected genetic divergences, genetic diversity reflected on the inbred lines, could be exploited through maize breeding for alleviating grain yield, maturity and resistance to biotic and abiotic stress. The existence of genetic variability among inbred lines facilitates developing and selecting promising hybrids based on agronomic performance by exploiting heterosis and hybrid vigor. Dendrogram based on SSR (Simple Sequence Repeat) markers visually represents the genetic relationships among individuals or populations by clustering them according to detected alleles. The dendrogram is constructed using allele frequency data, where similar genetic profiles are grouped together. Each branch point, or node, indicates a divergence between genetic profiles, revealing how closely related or distantly related the samples are. The length of branches reflects genetic distances, with shorter branches signifying closer genetic relationships. This visual tool aids in understanding genetic diversity, assessing population structure, and identifying potential genetic clusters or subgroups within the studied group.

Numerous studies on hybrid maize had shown that inbred lines derived from genetically diverse parents generally exhibit high heterosis and thus tend to be more productive than crosses of inbred lines from same source (Vasal et al 1992). The expression of heterosis in the hybrid is usually depended on the genetic divergence of two parents (Saxsena et al 1988). Moll et al (1962) observed that the effectiveness of any heterosis breeding depends on the amount of genetic diversity present in the material. Genotypic difference among hybrids indicated high variability among genotypes. The high heritability of 1000 kernel weight and cob diameter suggested their potential use in breeding programs for crop improvement. However, the significant genotype by environment interaction for most traits underscores the importance of considering environmental factors in genotype evaluation.

The correlation provided insights into the relationships between grain yield and various traits, as well as the associations of these traits across test locations. High correlations between locations suggest that these traits were consistently expressed across different environments. Moderate correlations indicated some consistency but also variability in trait expression across locations and weaker correlations, indicating more variability in trait expression across different environments. Significant positive correlation observed on this study among yield and its attributing traits such as Plant height, ear height, number of grain rows cob^{-1}, cob length, cob diameter and 1000 kernel weight revealed that selection for these traits could be considered as the criteria for higher maize yield, as they were mutually and directly associated. In line with this finding (Ogunniyan and Olakaago 2014, Bhusal et al 2017, Adhikari et al 2018 and Kandel et al 2018) reported significant positive correlation between grain yield and attributing traits.

CONCLUSION

This study provided valuable insights into the genetic and environmental effect on maize hybrids. Analysis of variance revealed significant genetic differences in phenological traits, growth characteristics and yield components that is emphasizing the diverse genetic back grounds of the parental lines used in hybrid development. The significant genotype by environment interactions, particularly for yield and other agronomic traits pointed out the necessity of evaluating hybrids in various environments to identify those with consistent performance. Plant height, ear height, and thousand grain weight were positively associated with grain yield which suggested that these traits can be prioritized in selection for yield improvement. Five distinct cluster were formed by clustering SSR data of 25 inbred lines showed moderate genetic diversity among parental lines and conformed that hybrid vigor. The high yielding hybrids, including RML-145/RL-105, RML-97-1/RML-98, RML-145/RML-146, RML-138/RML-2 and RML-97-2/RL-105, demonstrated substantial yield advantages over standard and local checks, indicating future potential of these tested hybrids in western Nepal. Meanwhile, RML-145/RML-146 had already been released in the name of Rampur Hybrid 12 for general cultivation in Nepal.

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AUTHORS’ CONTRIBUTION

Bhim Nath Adhikari: Design and execute experiment, data analysis and manuscript preparation
Surya Kant Ghimire: Manuscript editing
Madav Prasad Pandey: Manuscript editing
Krishna Hari Dhakal: Manuscript editing

CONFLICT OF INTEREST

The authors declare no conflict of interests or personal relationships that could have appeared to influence the work reported in this paper.

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