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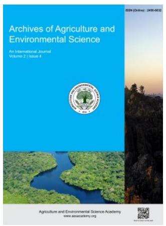

ORIGINAL RESEARCH ARTICLE

CrossMark

Evaluation of maize hybrids for agro-morphological traits and grain yield during winter season at Rampur, Chitwan, Nepal

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ABSTRACT

Maize is a vital cereal crop in Nepal, contributing to food security and livestock feed. Enhancing its productivity through high-yielding maize hybrids is essential to meet the increasing demand. This study aimed to evaluate the performance of maize hybrids based on agro-morphological traits, yield-attributing parameters, and flowering attributes to identify promising hybrids for cultivation in maize growing regions of Nepal. The experiment was conducted during the winter season of the year 2023 at the National Maize Research Program (NMRP), Rampur, Chitwan, Nepal, using a Randomized Complete Block Design (RCBD) with three replications. Data were collected on days to 50% flowering and silking, plant height, cob height, ear number per hectare, kernel rows per cob, kernel count per row, and grain yield. Analysis of variance (ANOVA) and correlation analysis were performed to assess variability and trait relationships with yield. Results showed the significant ($p<0.05/p<0.01$) differences among hybrids, with the commercial hybrid SULTAN achieving the highest grain yield (11.00 t/ha), followed by CML161/RML96 (10.68 t/ha) and RML36/RML2244 (9.87 t/ha), both statistically on par with SULTAN. These hybrids outperformed the national checks Rampur Hybrid 10 (4.82 t/ha) and Rampur Hybrid 16 (7.11 t/ha). Correlation analysis indicated strong positive associations between grain yield and plant height, cob height, kernel rows per cob, and kernel count per row. Therefore, maize hybrids demonstrating superior yield potential and favorable trait combinations will advance to multi-location trials, holding promise as future recommendations for the inner terai maize-growing zones of Nepal.

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INTRODUCTION

Maize (*Zea mays* L., 2n = 2x = 20), is the most adaptable plant in the globe, with a wide range of kinds and uses. It is monoecious, cross-pollinated C_4 plants a member of the Maydeae tribe of the Poaceae family of grasses (Rai *et al*., 2022). In the 2023 world maize production comprised 1.24 billion tonnes, which is approximately 40.63%. The USA ranks as the leading global producer of maize, contributing about 31.54%, followed by China with 23.37%, Brazil with 10.28%, and Argentina with 4.45%. On the other hand, Nepal produces 2.9 million tonnes of maize, which comprises 0.002% of the world's production (FAO, 2023). It occupies 940,256 ha of land with 2,976,490 metric tonnes with an average productivity of 3.16 metric tons per hectare (MoALD, 2023).

Maize is a crucial crop that fulfills the requirements of both humans and animals. It is the second most important cereal crop after rice in Nepal which is used as food, feed, fodder, and industrial raw material. Maize is mainly grown in Terai and Inner Terai as a feed crop that generates revenues, with over 90% of the crop being used as an animal feed (Kulkarni *et al*., 2023a). The requirement for maize in Nepal is anticipated to increase in the future, mainly driven by the escalating demand from the livestock and poultry feed industries, as higher amounts of animal protein are incorporated into the Nepalese food consumption (Poudel *et al*., 2024). The demand for hybrids has increased due to higher yield potential, a growing poultry and livestock business, a rising population, and a secure market for maize grains (Tripathi & Shrestha, 2016). Because of limited choices in maize hybrids in Nepal, only 17% of farmers' option for hybrid maize varieties, while the majority 83%, continue to grow open-pollinated varieties (OPVs). The seed production of available hybrids is hindered by issues with anthesis and silking of parents, leading to unsatisfactory results (Gairhe *et al*., 2021). There is wide gap between potential yield of OPVS having 5 t/ha and hybrid which have the potential yield of 10 t/ha. The productivity of maize is still very low and the current figure is only 143 metric tons which contribute only 3-4% of annual coverage. To date, Nepal has released 109 maize varieties; among them, 81 are Multi-National Company Hybrids (MNCH), 29 OPVs and 10 are national hybrids (CIMMYT/NARC, 2023). Although the country's diverse environment is capable of sustaining maize production throughout the year, maize seeds and grain are mainly brought in from other sources annually (Dhakal *et al*., 2022). Therefore, increasing investment in hybrid maize research is essential to enhance productivity and adaptability. Additionally, only verified hybrids and inbred lines that are preferred by farmers should be aggressively promoted in target environments. These should be accompanied by appropriate management strategies to ensure optimal performance under changing climatic conditions (Kandel *et al*., 2018).

The creation of hybrid maize is one of the most significant achievements in plant breeding. Maize hybrids play a crucial role in enhancing productivity and ensuring food security, particularly in regions with diverse agro-ecological conditions (Kunwar & Shrestha, 2014). Farmers rapidly adopted hybrid maize because it manifested uniform phenotypes that exhibited improved yields, grain quality, and resistance to disease and pests along with other valuable agronomic traits. As a result, it became more practical for suppliers to handle the collection, storage, and packaging of seeds for the new crop (Adhikari *et al*., 2021). In terai, farmers have earned relatively more income from hybrids grown in winter season due to higher yields. Despite its significance, maize productivity remains suboptimal, primarily due to the dominance of multinational hybrid seeds in the market. Farmers widely adopt these hybrids due to their higher yield potential, but their dependency on expensive imported seeds increases production costs and limits seed sovereignty (Tripathi *et al*., 2022). As a result, Nepal relies heavily on foreign seed companies, which compromises long-term agricultural sustainability. Strengthening the development of high-yielding national hybrids is crucial to reducing dependency on multinational corporations and ensuring food security. Although the market for hybrid maize seeds is growing every year, few commercial hybrids have been suitable for cultivation because of the diverse agro-ecological conditions of the nation. The objective of the study was to identify maize varieties that excel in performance, adaptation and recommend those especially suitable for winter seasons in the hybrid maize growing areas of Nepal.

MATERIALS AND METHODS

Experimental site

The trial was carried out at the National Maize Research Program (NMRP) in Rampur, Chitwan, Nepal, from 24 November, 2023, to 07 May, 2024. The study site was located at 27° 37' North Latitude and 84° 29' East Longitude, with an elevation of 225 meters above sea level (Figure 1). The soil at the site is mainly composed of sandy loam with an acidic pH. The area belongs to the subtropical climate zone. Planting materials used for the study were acquired from the National Maize Research Program and Multi National Company. The description of maize genotypes used in this research is given in Table 1.

Experimental details

The field trial was carried out with three replications utilizing a Randomized Complete Block Design (RCBD). A total of 21 maize genotypes were tested, alongside two national standard varieties (RH 10 and RH 16) and one commercial variety (SULTAN). Each plot measured 4 meters in length, with two rows spaced 0.78 meters apart. Within each row, the plant-to-plant spacing was maintained at 0.20 meters. A mixture of pre-emergence herbicides atrazine (2.5 ml per liter) and pendimethalin (5 ml per liter) was applied 72 hours after sowing. Irrigation was provided at key growth stages: knee-high, tasseling, and milking. The major nutrients (NPK) were applied at a rate of 120:60:40 kg/ha. Nitrogen was provided in three splits: half as a basal dose and the remaining half side-dressed at six-leaf stage and knee-high stage of maize in the form of urea (46%). Phosphorus (DAP) and potassium (MOP) were applied entirely as a basal dose at the time of sowing.

Weather condition of the research site

The agro-meteorological data revealed distinct seasonal trends in temperature, rainfall, and relative humidity over six months. The maximum temperature steadily increased from November, starting at approximately 28°C, and reached its peak in May at around 34°C. Similarly, the minimum temperature followed a gradual upward trend, rising from 14°C in November to about 18°C in May. Rainfall was minimal throughout the winter months, with negligible precipitation recorded from November to February. However, rainfall slightly increased in March (4 mm) and April (2 mm) and then significantly rose in May to around 10 mm. Relative humidity showed a decreasing pattern from November (24%) to January (18%), followed by a steady increase, and reached its highest level in May (30%). These observations indicated that as the season progresses, both temperature and humidity rose, with a noticeable increased in rainfall during late spring, highlighting the transition from a dry winter to a more humid and rainier environment as shown in Figure 2.

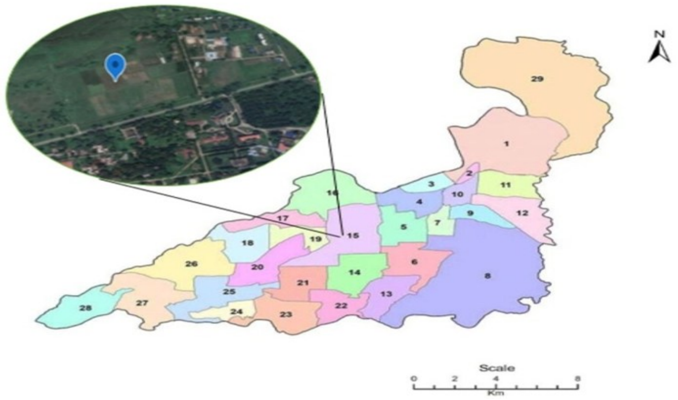

Figure 1. *Map showing location of experimental sites at Rampur, Chitwan, Nepal.*

Table 1. Names of the hybrid maize genotypes utilized at NMRP Chitwan, Nepal.

E.N.	Genotypes	Source
1	SULTAN (Commercial Check)	MNCH
2	RH10 (National Check)	NMRP
3	RH16 (National Check)	NMRP
4	RL143/RML96	NMRP
5	RL240/RML96	NMRP
6	RL252/RML98	NMRP
7	RL284/RML146	NMRP
8	RL35-1/RML2001	NMRP
9	RML108/RL2118	NMRP
10	RML14/RML76	NMRP
11	RML142/RML17	NMRP
12	RML145/TZEIO157	NMRP
13	RML147/CML430	NMRP
14	RML150/RL111	NMRP
15	RML152/RML96	NMRP
16	RML187/RML96	NMRP
17	RML2137/RL2118	NMRP
18	RML32/CML613	NMRP
19	RML36/RML2244	NMRP
20	RML5/RML17	NMRP
21	RML62/RML2	NMRP
22	RML76/TZEIOR157	NMRP
23	RML98/RML145	NMRP
24	CML161/RML96	NMRP

Collection of data

Data on the number of days required for fifty percent of the plants to reach tasseling, silk emergence, and the interval from tasseling to silking (TSI) were collected on a plot basis. In contrast, measurements such as plant height (cm), cob height (cm), cob position ratio, ear count per plant, plant population per hectare, ear number per hectare, cob length (cm), cob grith (cm), Kernel row count, Kernel count per row, thousand-kernel weight (g), and moisture content (%) were taken from five representative plants within each plot. The harvested cobs were de-husked, cleaned, and the grain weight along with the stalk weight was measured to determine the shelling percentage. After normalizing the moisture content to 12.5%, 1000 kernels from the shelled bulk of each plot were counted and weighed in grams to get the thousand-grain weight. The days needed for fifty percent tasseling were subtracted from the days needed for fifty percent silking to calculate the tasseling-silking interval (TSI). By converting the yield to a per-hectare basis and setting the grain moisture at 12.5%, the formula used by (Kafle *et al.*, 2020) was used to estimate grain yield.

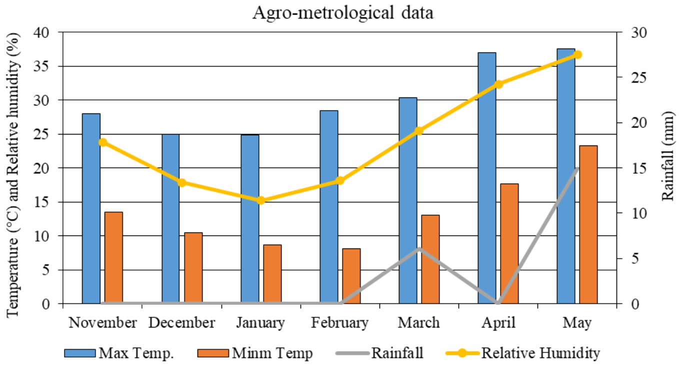

Figure 2. *Weather conditions of the study location throughout the research period (2023-2024) at NMRP, Chitwan, Nepal.*

Grain yield (kg/ha) = (E.W (kg/plot) × (100 – GMH) × C.S × 10000) / ((100 – GMD) × PHA)

Where,
E.W. = Ear fresh mass Kilograms per plot at the point of harvest; GMH = Grain moisture level (%) at the time of harvest; GMD = Preferred grain moisture level, 12.5%; PHA = Effective harvested plot area (m^2); C.S. = Cob-shelling ratio, set to 0.8.

Statistical analysis

The data collected for various traits during the field study were initially organized and processed using Microsoft Excel (MS Excel 2016). Subsequently, the data were analyzed in R-Studio (Version 1.4) to perform analysis of variance (ANOVA). Correlation coefficients among different characteristics were computed following the method outlined by (Magar *et al.*, 2021) using the IBM SPSS 25 program.

RESULTS AND DISCUSSION

Days to fifty percent tasseling, days to fifty percent silk emergence and tasseling-silking interval, plant height, cob height, cob position, ear count per hectare, cob length, cob grith, number of rows per cob, kernel count per row and yield of grain of maize showed a highly significant ($p<0.05/p<0.01$) difference among different maize hybrids (Tables 2 and 3). In contrast, thousand kernel weight showed a considerable variation. Among the hybrids evaluated, commercial hybrid SULTAN recorded the highest grain yield (11.00 t/ha), followed by CML161/RML96 (10.68 t/ha) and RML36/RML2244 (9.87 t/ha). The two experimental hybrids, CML161/RML96 and RML36/RML2244, significantly out yielded national hybrids RH10 (4.82 t/ha) and RH16 (7.11 t/ha), revealing their better agronomic potential. The grain yield superiority of CML161/RML96 and RML36/RML2244 can be attributed to a few key parameters. Both hybrids possessed higher plant height (233 cm and 225 cm) and higher cob height (128 cm and 122 cm), which might have facilitated greater light interception and photosynthetic efficiency. RML36/RML2244 also recorded the highest number of kernels per row (35.67), followed by CML161/RML96 with a high number of kernels per row (33.67), indicating their superior grain-setting ability. Ears/ha were also relatively higher

Table 2. Flowering and height traits of maize hybrids evaluated during winter season of 2023 in Rampur, Chitwan, Nepal.

E.N.	Genotypes	TD	SD	TSI	PH	CH	CP	NOEPP
1	SULTAN	111^{bcd}	111^{abcde}	0.67^{abc}	202^{bcd}	108^{bcde}	0.54^{abcd}	1.1^{cd}
2	RH10	110^{bcd}	111^{abcde}	1.33a^{bc}	196^{bcd}	96^{cde}	0.49^{cd}	1.1^{bcd}
3	RH16	108^{bcd}	108de	-0.67^{bc}	201^{bcd}	103^{bcde}	0.51^{abcd}	1.2^{bcd}
4	RL143/RML96	108^{bcd}	109^{cde}	1.00^{abc}	196^{bcd}	99^{bcde}	0.51^{bcd}	1.0^{d}
5	RL240/RML96	105^{d}	106^{e}	0.33^{abc}	214^{bcd}	104^{bcde}	0.49^{cd}	1.2^{bcd}
6	RL252/RML98	118^{a}	117^{a}	-0.67^{bc}	268^{a}	146^{a}	0.54^{abcd}	1.0^{d}
7	RL284/RML146	114^{abc}	115^{abc}	1.00^{abc}	232^{ab}	127^{abc}	0.55^{abcd}	1.4^{abcd}
8	RL35-1/RML2001	111^{bcd}	114^{abcd}	3.00^{a}	182^{d}	100^{bcde}	0.55^{abcd}	1.0^{d}
9	RML108/RL2118	108^{bcd}	110^{bcde}	2.00^{ab}	218^{bcd}	132^{ab}	0.60^{a}	1.8^{a}
10	RML14/RML76	110^{bcd}	110^{bcde}	0.33^{abc}	189^{cd}	88^{e}	0.47^{d}	1.1^{bcd}
11	RML142/RML17	110^{bcd}	110^{bcde}	0.33^{abc}	189^{cd}	102^{bcde}	0.54^{abcd}	1.4^{abcd}
12	RML145/TZEIO157	104^{d}	105^{e}	1.00^{abc}	182^{d}	90de	0.49^{bcd}	1.1^{bcd}
13	RML147/CML430	106^{d}	106^{e}	-0.33^{bc}	178^{d}	83^{e}	0.47^{d}	1.6^{abc}
14	RML150/RL111	114^{abc}	113^{abcd}	-1.33^{c}	202^{bcd}	107^{bcde}	0.52^{abcd}	1.2^{bcd}
15	RML152/RML96	107^{cd}	107de	0.00^{abc}	199^{bcd}	111^{bcde}	0.56^{abc}	1.4^{abcd}
16	RML187/RML96	105^{d}	105^{e}	0.33^{abc}	212^{bcd}	110^{bcde}	0.52^{abcd}	1.4^{abcd}
17	RML2137/RL2118	107^{cd}	109^{cde}	1.67^{abc}	215^{bcd}	111^{bcde}	0.52^{abcd}	1.1^{cd}
18	RML32/CML613	108^{bcd}	109^{cde}	0.67^{abc}	176^{d}	83^{e}	0.48^{cd}	1.3^{abcd}
19	RML36/RML2244	114^{ab}	116^{ab}	1.67^{abc}	225^{bc}	122^{abcd}	0.54^{abcd}	1.4^{abcd}
20	RML5/RML17	109^{bcd}	110^{bcde}	0.67^{abc}	198^{bcd}	96^{cde}	0.48^{cd}	1.1^{bcd}
21	RML62/RML2	109^{bcd}	110^{bcde}	1.00^{abc}	198^{bcd}	116^{abcde}	0.59^{ab}	1.0^{d}
22	RML76/TZEIOR157	106^{d}	106^{e}	-0.67^{bc}	199^{bcd}	104^{bcd}	0.53^{abcd}	1.1^{cd}
23	RML98/RML145	109^{bcd}	109^{cde}	-0.33^{bc}	206^{bcd}	98^{cde}	0.47^{d}	1.6^{ab}
24	CML161/RML96	111^{bcd}	110^{bcde}	-0.33^{bc}	233^{ab}	128^{abc}	0.55^{abcd}	1.4^{abcd}
	Mean	109	110	0.53	205	107	0.52	1.2
	Sem	1.29	1.24	0.93	9.27	6.15	0.41	0.024
	F test	***	***	***	***	***	***	***
	LSD (0.05)	3.59	3.55	2.68	22.21	17.04	0.05	0.27
	CV %	2	1.97	309.27	6.61	9.71	5.97	13.22

Note: AD=Tasseling days, SD= Silking days, TSI=Tasseling and silking interval, PH= Plant Height (cm), CH= Cob Height (cm) and CP=Cob Position ratio, NOEPP=Number of ear per plant, **Significant at 1% level of significance, *** significant at 0.1 percent level.

Table 3. Yield and related parameters of maize hybrids evaluated during winter season of 2023 in Rampur, Chitwan, Nepal.

E.N.	Genotypes	NOEha	CL	CG	NOKR	NOKPR	TKW	GY/ha
1	SULTAN	75000^{abc}	15.37^{abc}	5.16^{a}	16.93^{a}	35.00^{ab}	335.67^{cd}	11.00^{a}
2	RH10	40556^{e}	16.45^{abc}	4.61^{bcd}	13.47^{bc}	27.00^{bc}	402.33^{a}	4.82^{e}
3	RH16	76666^{abc}	14.01^{bc}	4.65^{bcd}	13.47^{bc}	22.33^{c}	348.67^{cd}	7.11^{abcde}
4	RL143/RML96	58889^{cde}	13.49^{c}	4.99^{ab}	13.20^{bc}	24.33^{bc}	370.67^{abc}	6.69^{bcde}
5	RL240/RML96	62222^{bcd}	16.79^{abc}	4.82^{abc}	13.60^{bc}	30.00^{b}	383.00^{abc}	7.35^{abcde}
6	RL252/RML98	62778^{bcd}	17.25^{abc}	4.76^{bcd}	13.60^{bc}	31.00^{b}	371.33^{abc}	8.95^{abcd}
7	RL284/RML146	73333^{abc}	16.95^{abc}	4.61^{bcd}	14.13^{b}	34.67^{ab}	337.67^{cd}	9.37^{abcd}
8	RL35-1/RML2001	60556^{cde}	15.73^{abc}	4.79^{abc}	14.27^{b}	31.33^{b}	324.33^{cd}	8.32^{abcde}
9	RML108/RL2118	93333^{a}	14.92^{abc}	4.27^{d}	12.80^{bc}	31.00^{b}	307.67^{d}	9.07^{abcd}
10	RML14/RML76	50556de	14.83^{abc}	4.50^{cd}	12.53^{bc}	31.33^{b}	372.33^{abc}	5.75^{de}
11	RML142/RML17	68333^{bcd}	16.25^{abc}	4.57^{bcd}	13.47^{bc}	34.00^{ab}	334.00^{cd}	8.23^{abcde}
12	RML145/TZEIO157	67222^{bcd}	15.57^{abc}	4.60^{bcd}	13.60^{bc}	31.33^{b}	329.00^{cd}	6.62^{cde}
13	RML147/CML430	74444^{abc}	14.53^{abc}	4.80^{abc}	13.20^{bc}	28.67^{bc}	387.67^{ab}	8.12^{abcde}
14	RML150/RL111	73333^{abc}	15.15^{abc}	4.79^{abc}	13.47^{bc}	31.00^{b}	383.33^{abc}	8.81^{abcde}
15	RML152/RML96	68889^{bcd}	14.85^{abc}	4.80^{abc}	14.00^{b}	29.00^{bc}	314.67^{d}	8.26^{abcde}
16	RML187/RML96	59444^{cde}	14.65^{abc}	4.65^{bcd}	14.80^{ab}	29.67^{bc}	321.67^{d}	6.62^{cde}
17	RML2137/RL2118	73333^{abc}	17.25^{abc}	4.26^{d}	13.47^{bc}	32.00^{b}	352.00^{cd}	8.36^{abcd}
18	RML32/CML613	58333^{cde}	13.57^{bc}	4.49^{cd}	11.33^{c}	29.33^{bc}	385.33^{ab}	6.70^{bcde}
19	RML36/RML2244	82778^{ab}	17.32^{ab}	4.41^{cd}	13.87^{b}	35.67^{a}	329.00^{cd}	9.87^{abc}
20	RML5/RML17	61111^{cde}	15.97^{bc}	4.59^{cd}	13.60^{bc}	33.00^{b}	345.33^{cd}	7.57^{abcde}
21	RML62/RML2	57222^{cde}	18.03^{a}	4.92^{ab}	14.13^{b}	33.33^{b}	374.33^{abc}	9.27^{abcd}
22	RML76/TZEIOR157	58889^{cde}	14.69^{abc}	4.64^{bcd}	14.40^{b}	29.67^{bc}	331.67^{cd}	6.42^{cde}
23	RML98/RML145	76666^{abc}	16.69^{abc}	4.99^{ab}	13.33^{bc}	31.00^{b}	400.67^{a}	9.26^{abcd}
24	CML161/RML96	77778^{abc}	16.86^{abc}	4.65^{bcd}	13.87^{b}	33.67^{ab}	399.00^{ab}	10.68^{ab}
	Mean	67153	15.72	4.68	13.69	30.81	355.89	8.05
	SEm	6164.56	0.69	0.07	0.42	2.36	18.91	0.74
	F- test	***	***	***	***	***	**	***
	LSD (0.05)	17726.54	1.95	0.16	1.2	6.79	53.91	2.16
	CV %	15.99	1.97	2.71	5.32	13.55	9.31	16.35

Note: NOCha = Ear count per hectare, CL= Cob length (cm), CG= Cob girth (cm), NOKR = Number of kernel rows per cob, NOKPR= kernel count per row, TKW= Thousand kernel weight and GY= Grain yield per hectares.

for both genotypes, with RML36/RML2244 producing 82,778 ears/ha and CML161/RML96 producing 77,778 ears/ha, which further contributed to their yield advantage.

The genotypic responses of the evaluated maize hybrids exhibited significant (p<0.05) variability across all observed traits, underscoring the importance of genetic diversity in maize breeding programs. The substantial variation observed among hybrids provides a strong basis for selecting superior genotypes with enhanced yield potential under similar environmental conditions. These findings align with previous research by (Kulkarni *et al*., 2023b), who reported similar results for days to 50% anthesis and days to 50% silking. Likewise, (Elmyhun *et al*., 2020) observed significant variation in the anthesis-silking interval, further confirming the influence of genetic diversity on reproductive timing. Winter-planted maize is particularly vulnerable to cold stress during flowering, which can delay anthesis and silking, resulting in poor synchronization between pollen release and silk emergence. This study observed variations in anthesis-silking intervals among the hybrids, consistent with findings by Kumar *et al*. (2023) and Kandel *et al.* (2018), who reported that maize cultivated in winter requires a longer duration to reach flowering than the same variety grown in summer. Delayed pollination can lead to pollen desiccation, thereby reducing fertilization success. Zhang *et al.* (2021) emphasized that precise synchronization between pollen shedding and silk emergence enhances kernel formation, a crucial factor in determining grain yield. The hybrids CML161/RML96 and RML36/RML2244 exhibited shorter anthesis-silking intervals, contributing to their higher grain yields, while delayed silking in other hybrids negatively affected kernel setting.

Plant height and ear height significantly (p<0.05) influenced the agronomic performance of the maize hybrids evaluated in this study. The results demonstrated notable variations in plant height, consistent with findings by Shrestha *et al.* (2023). Similarly, differences in ear height among genotypes were observed, aligning with the reports of Annor *et al.* (2020) and Koirala *et al.* (2020). These variations play a crucial role in determining plant architecture and lodging resistance, factors that directly affect grain yield. In general, semi-dwarf maize hybrids are preferred over tall varieties due to their improved response to fertilizers and reduced susceptibility to lodging (Bastola *et al*., 2021). Lodging resistance is particularly influenced by ear placement, with an optimal ear position ranging between 0.4 and 0.5. This study supports previous findings by Wang *et al.* (2022), which suggest that genotypes with lower ear placement are advantageous as they minimize the risk of root and shoot lodging, thereby contributing to higher yield stability.

The number of cobs per plant is a critical determinant of grain yield in maize hybrids. In this study, genotypes with values greater than 1.33 were associated with double cobs, while most of the evaluated genotypes had values below this threshold, indicating their single-cob-bearing nature. This finding aligns with the results of Adhikari *et al.* (2024), reinforcing the predominance of single-cob hybrids in maize breeding programs. Significant (p<0.05) variations in cob length and cob diameter were observed among the tested hybrids, consistent with findings reported by (Islam *et al*., 2020; Kandel & Shrestha, 2020). Similarly, differences in the number of kernel rows per cob and kernel count per row were recorded, supporting previous studies by Bastola *et al.* (2021). These traits play a crucial role in determining final grain yield, as an increased number of kernel rows and higher kernel density per cob contribute to improved productivity. Furthermore, thousand kernel weight exhibited considerable variation among genotypes, consistent with the previously reported findings (Jaiswal *et al*., 2019; Subedi *et al*., 2021; Bastola *et al*., 2021). The genetic variability among maize hybrids in grain yield potential supports of the previously reported findings of a number of researchers (Patil *et al*., 2016; Bista *et al*., 2021; Joshi & Gautam, 2021; Khanal *et al*., 2024).

Correlation between traits

Days to fifty percent tasseling, days to fifty percent silking, plant height, cob height, cob position, ear number per plant, ear count per hectare, cob length, cob girth, number of kernel rows per cob, and kernel count per row all have a positive and significant correlation with grain yield, according to the results (Table 4). This suggests that as the value of these traits rises, so will the yield of maize. Non-significant but positive association was observed between yield and anthesis-silking interval, cob length and cob diameter. Similarly non-significant negative correlation observed in maize between thousand grain weight and yield. The strong association between ear counts per hectare observed in this study corresponds with the findings of Rai *et al.* (2022). Similarly, a positive correlation between days to 50% anthesis and days to 50% silking was reported by Tripathi *et al.* (2022), while Thapa *et al.* (2022) and Gautam *et al.* (2022) identified significant associations between cob length and cob girth. Verma *et al.* (2020) noted a similar correlation between plant height, cob height, kernel row number, and kernel count per row, findings that align with this study's results. Taller plants tend to have a greater leaf area, leading to increased dry matter accumulation, which enhances grain yield through effective assimilate partitioning (Kharel *et al*., 2017; Yadav *et al*., 2024). However, cob height should be optimally positioned, as excessively low placement can hinder mechanical harvesting, while higher placement increases lodging risk (Gautam *et al*., 2022). The significant correlation observed between kernel count per row, cob length, plant height, and ear height further confirms their role in yield determination. Lodging resistance, strongly influenced by plant height, remains a key selection criterion in maize breeding (Adhikari *et al*., 2024).The positive and significant correlation between grain yield and kernel row number, as well as kernel number per row, suggests that these traits can serve as reliable indicators for yield improvement in hybrid maize (Kandel & Shrestha, 2020). In contrast, the relationship between yield and cob diameter was positive but non-significant, consistent with the findings of Neupane *et al.* (2020). Similarly, previous studies by Sharma *et al.* (2018) reported non-significant but positive correlations between yield and anthesis-silking interval, cob length, and cob diameter, reinforcing the results of this study. These findings emphasize the importance of selecting hybrids with optimal plant height, ear height, kernel number, and cob dimensions to maximize yield potential.

Table 4. Pearson's correlation coefficients of maize traits.

	TD	SD	TSI	PH	CH	NOEha	CL	CG	NOKR	NOKPR	TKW	GY
AD	1											
SD	.904**	1										
ASI	0.203	.235*	1									
PH	.506**	.460**	0.096	1								
EH	.487**	.500**	0.037	.877**	1							
NOEha	0.105	0.133	0.065	.310**	.431**	1						
CL	.338**	.344**	0.019	.342**	.305**	-0.057	1					
CD	0.040	0.034	0.168	0.084	0.067	-0.100	0.086	1				
NOKR	0.086	0.174	0.204	0.152	.268*	0.146	0.041	.424**	1			
NOKPR	.333**	.323**	0.016	.234*	.238*	0.108	.607**	0.026	0.077	1		
TKW	0.056	0.022	0.178	0.106	0.228	-.275*	0.117	0.215	-.289*	-0.138	1	
GY	.365**	.376**	0.031	.477**	.569**	.735**	0.229	0.200	.373**	.339**	0.102	1

Note: AD=Tasseling days, SD= Silking days, TSI= Tasseling-silking interval, PH= Plant height, EH= Cob height, CL= Cob length, NOEha= Ears count per Hectare, CG= Cob girth, NOKR = Number of kernel rows per cob, NOKPR= kernel count per row, TKW= Thousand Kernel Weight and GY= Grain yield, *Significant at 5% level of significance and ** significant at 1% level of significance.

Conclusion

High-yielding hybrids that are consistent are thought to be superior varieties and are appropriate for widespread cultivation. The observed significant differences in agronomic traits suggest that further breeding efforts focusing on these characteristics could enhance yield and overall performance in diverse growing environments. The study revealed that the national hybrids CML161/RML96 (10.68 tons/ha) and RML36/RML2244 (9.87 tons/ha) exhibited competitive grain yields compared to the commercial hybrid SULTAN (11tons/ha). Both hybrids also outperformed the national hybrids RH10 (4.82 tons/ha) and RH16 (7.11 tons/ha). Additionally, Grain yield showed positive significant correlation with days to 50% anthesis, days to 50% silking, plant height, ear height, number of plants per hectare, number of ear per hectare, number of kernel row and number of kernel per row. These findings highlight the potential of these national hybrids for commercial production under similar conditions, as their performance is on par with high-yielding commercial hybrids. Further multi-location trials and adaptability assessments are recommended to validate their yield stability and optimize agronomic management practices for broader adoption.

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DECLARATIONS

Author contribution statement

Conceptualization: M.P. and B.M.; Methodology: M.P.; Software and validation: M.P., and B.M.; Formal analysis and investigation: B.M.; Resources: M.P.; Data curation: B.M., B.P, and P.B.; Writing—original draft preparation: B.M.; Writing—review and editing: B.M.; Visualization: B.M.; Supervision: M.P.; Project administration: M.P.; Funding acquisition: M.P. All authors have read and agreed to the published version of the manuscript.

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