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Research article

Performance evaluation of maize hybrids in inner-plains of Nepal

Bishnu Prasad Kandel [a,*], Kumar Shrestha [b]

[a] Department of Plant Breeding, Post Graduate Program, Institute of Agriculture and Animal Science, Tribhuvan University, Kirtipur, Nepal
[b] Department of Plant Biology, Ecology and Evolution, Oklahoma State University, Stillwater, OK, 74078, USA

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ABSTRACT

Hybridization plays a vital role in increasing the production and productivity of maize. Evaluating maize hybrids in a specific environment is a key task for the hybrid maize program. The objective of this study was to identify a promising maize hybrid for winter planting in inner terai regions. Ten maize hybrids were evaluated in a randomized complete block design (RCBD) with three replications during the winter season of 2018 and 2019 at the research field of Purwanchal Agriculture Campus, Jhapa, Nepal. The results suggested that among tested hybrids, P3396 (11.18 tons ha^{-1}), Shresta (10.67 tons ha^{-1}), and Rampur Hybrid 6 (10.37 tons ha^{-1}) produced significantly higher yield in 2018 whereas P3396 (11.10 tons ha^{-1}), Shresta (10.20 tons ha^{-1}), and Ganga Kaveri (10.03 tons ha^{-1}) were the ones with the highest grain yield in 2019. Comparing both years, P3396 and Shresta consistently outperform the other hybrids in terms of grain yield, which is an important traits for the farmers. Correlation studies suggested that ear weight and thousand-grain weight showed a positive significant correlation with grain yield. Therefore, we suggest P3396 and Shresta as promising hybrids for the maize growers in the inner terai regions of Nepal.

1. Introduction

Maize (*Zea mays*) is the second most important crop in terms of area and production in Nepal. Besides a major food crop, it is also a key component of poultry and livestock ration [1]. Maize demand has been increasing constantly by 5% in the last decade and is expected to grow 4–6% every year for the next 20 years [2]. According to the Food and Agriculture Organization (FAO), maize is grown over 954,158 ha and with an annual production of 2,473,283 tons [3]. The annual yield of maize is 2.59 tons ha^{-1} which is significantly lower in comparison to developed countries, such as the USA (11.86 tons ha^{-1}), and China (6.10 tons ha^{-1}) [3]. The higher yield in the USA is credited to the rapid adoption of hybrid maize with the continued adoption of fertilizers, pesticides, and agricultural mechanization [4].

The National Maize Research Program (NMRP) established in 1972 at Rampur, Chitwan is focused on research, development, and extension activities on maize. Initially, NMRP was focused on open-pollinated varieties (OPVs) but now it has shifted its focus to hybrid maize research and development. To date, NMRP has released 34 maize varieties; among them 29 are open-pollinated and five are hybrids. Among five released maize hybrids, one was recommended for mid-hills and the other four for Terai, inner valleys, and river basins. Gaurav, Rampur Hybrid 2, Khumal Hybrid 2, Rampur Hybrid 4, Rampur Hybrid 6 are the single cross yellow maize hybrids. Besides that, NMRP has also been evaluating and registering the hybrid maize developed by an international organization. Heat Stress Tolerant Maize for Asia/International Maize and Wheat Improvement Centre (HTMA/CIMMYT) developed hybrid maize, Rampur Hybrid 8 and Rampur Hybrid 10, through the yellow single cross has been evaluated and registered by NMRP. Moreover, private sectors and multinational companies developed hybrids have also been registered in Nepal. In total there are 53 hybrids with significantly higher yield in comparison to hybrids developed in Nepal. These 53 hybrids are developed from multinational companies and they have been registered in Nepal for marketing purpose [5].

Given the open border with India, farmers in Nepal started to import and grow hybrid maize in the 1980s [6]. Hybrid maize has covered approximately 80 percent and 10 percent of maize production in terai and mid-hills respectively [7]. In terms of area of cultivation, hybrid maize occupies around seven to ten percent [6] and the area is increasing every year. Nepal imports around 20 percent of maize seeds [7] and nearly 100 percent of hybrid seeds from India every year [4]. The increase in the hybrid seed import is due to fewer hybrids developed by the national research system and those released being less competitive [8] First, this release variety has less yield, and secondly, seed availability is

* Corresponding author.
E-mail address: bkandel33@gmail.com (B.P. Kandel).

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insufficient for general cultivation. Though the number of hybrid seeds growing area is increasing, national yield is still far below (2.59 tons ha^{-1}) in comparison to developed countries (6–10 tons ha^{-1}). The possible reason behind this is the unchecked distribution of imported hybrid seeds without undertaking any performance trials. Currently, the NMRP is accelerating on the development of the hybrid maize, and additionally, it is evaluating and registering the hybrid seeds from multinational companies. But given the diverse agro-ecological regime of our country, not all hybrids are suitable for cultivation in all areas [8] So, there is a need for a region-specific performance trials before recommending hybrid maize for that region. Therefore, our objective is to conduct a performance evaluation to identify the superior maize hybrids for the eastern inner plains of Nepal.

2. Materials and methods

2.1. Study area

This study was carried out at the research field of Purwanchal Agriculture Campus (PAC), Gaurada-1, Jhapa. The research site lies at an altitude of 182 m above mean sea level on the south-facing slopes at 26.56 °N latitude and 87.72 °E longitude coordinates. Geographically, the experimental location falls in the eastern inner plains of Province-1 of Nepal. The area has humid weather with cold winters and very hot summers. The climatic details of the experimental site are presented in Figure 1. The soil composition of the study area was found to be sandy loam to clay loam with pH ranges around 5.5. Soil available nitrogen, phosphorus, and potash were measured by Kjeldahl distillation, spectrophotometer, and a flame photometer. pH was measured by a deluxe pH meter. Details of soil characteristics separated by year are presented in Table 1.

2.2. Experiments details

The experiment was conducted in RCBD with ten maize hybrids of three replications each during the winter of 2018 and 2019. The hybrids used in both seasons were four registered hybrids of multinational seed companies, three recently released hybrids, two pipeline hybrids, and one registered hybrid developed by NMRP, Rampur, Chitwan for both seasons, shown in Table 2. Rampur Hybrid 2 is the most popular hybrid in that area and therefore was used as a standard check. The maize was shown in the first and second weeks of November in 2018 and 2019. Each genotype was grown in the plots of 3 m × 3 m area with the net plot area of $90m^2$ per block. Detailed layouts of the field is shown in Figure 2. Seed sowing was performed at the rate of two seeds per hill with a crop geometry of $75 \times 25cm^2$ (RR × PP). Each genotype was sown in four rows of a 3m long plot. Farmyard manure was applied at the time of land preparation. Fertilizer was applied at the rate of 150:60:40 NPK kg ha^{-1} (urea, diammonium phosphate (DAP) and muriate of potash (MoP)). A half dose of N and a full dose of P_2O_5 and K_2O were applied as a basal dose. The remaining half of the N was applied in two splits at knee-high and pre-tasseling/silking stages.

2.3. Data collection and statistical analysis

All agro-morphological, yield and yield-attributing traits were obtained from sample row except phenological traits namely 50 % anthesis, silking, and harvesting date. The data were collected on plant height (cm), ear height (cm), number of kernels per row, number of kernel row per ear, ear weight (g), thousand kernel weight (g), and grain yield (tons ha^{-1}). All collected data were entered in computer software MS excel version 16. A Tukey test was performed at a 5 % level of significance, mean, coefficient of variation (CV), and analysis of variance (ANOVA) was computed from the statistical package R version 3.6.1. The correlation coefficient was computed using SPSS version 25 using the formula given by Weber and Moorthy [9] as Eqs. (1, 2).

$$rg\ (xy) = \frac{cov\ g\ (xy)}{\sigma\frac{1}{2}g(x)\ \times\ \sigma\frac{1}{2}p(y)} \tag{1}$$

$$rp\ (xy) = \frac{cov\ p\ (xy)}{\sigma\frac{1}{2}g(x)\ \times\ \sigma\frac{1}{2}p(y)} \tag{2}$$

where,

rg (xy) and rp (xy) are genotypic and phenotypic correlation coefficients, respectively covg (xy) and covp (xy) are genotypic and phenotypic covariance of xy. $\sigma^{1/2}$ g(x), $\sigma^{1/2}$ p(x) and $\sigma^{1/2}$ g(y), $\sigma^{1/2}$ p(y) are genotypic and phenotypic standard deviations of x and y respectively.

Grain yield (tons ha^{-1}) at 15% moisture content was calculated using fresh ear weight with the help of the below formula given in Eq. (3):

$$Grain\ \ yield\ \left(\text{tons ha}^{-1}\right) = \frac{F.W.(kg/plot) \times (100 - HMP) \times S \times 10000}{(100 - DMP) \times NPA \times 1000} \tag{3}$$

where,

F.W. = Fresh weight of ear in kg per plot at harvest
HMP = Grain moisture percentage at harvest
DMP = Desired moisture percentage, i.e. 15%

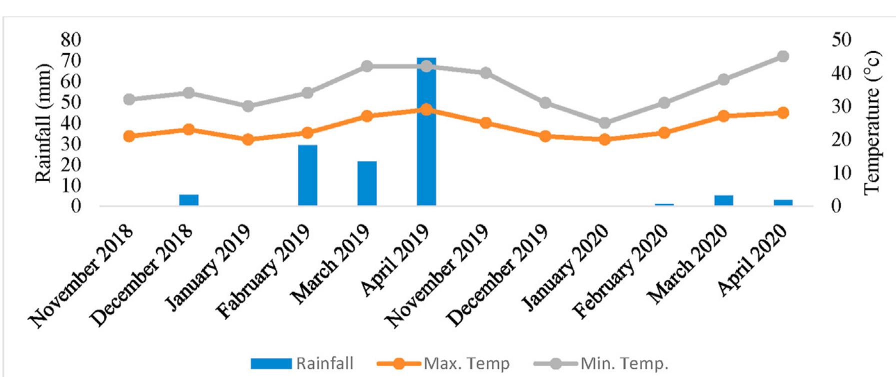

Figure 1. Climatic details of experimental site (Gauradha, Nepal) in 2018, 2019 and 2020.

Table 1. Soil properties of experimental site.

Soil pH		Nitrogen (%)		Phosphrous (kg ha^{-1})		Potassium (kg ha^{-1})	
2018	2019	2018	2019	2018	2019	2018	2019
5.13	5.09	0.07	0.07	34.28	31.01	89.00	79.08

Table 2. List of hybrid maize used at Gauradaha, Jhapa during winter of 2018 and 2019.

S.No.	Name of genotypes	Parentage/Company	Hybrid details	Source
1	Rampur Hybrid 2*	NML-3/NML-2	Single cross released	NMRP, Rampur
2	Rampur Hybrid 4	RML-32/RML-14	Single cross released	NMRP, Rampur
3	Rampur Hybrid 6	RML-4/RML-17	Single cross released	NMRP, Rampur
4	Rampur Hybrid 10	RML-150/RML-18	Registered maize	NMRP, Rampur
5	RML-86/RML-96	RML-86/RML-96	Single cross pipeline	NMRP, Rampur
6	RML-95/RML-96	RML-95/RML-96	Single cross pipeline	NMRP, Rampur
7	P3396	DuPont Pioneer	Single cross multinational company	Local market
8	Ganga Kaveri	Ganga Kaveri Seed Companies	Single cross multinational company	Local market
9	Rajkumar	Bio seed Research India, Pvt.	Three-way cross multinational company	Local market
10	Shresta	Nuziveedu Seeds companies	Single cross multinational company	Local market

* Standard check.

NPA = Net harvest plot area, m^2
S = Shelling coefficient, i.e. 0.8
This formula was also adopted by Carangal *et al.* [10] and Kandel *et al.* [11] to adjust the grain yield (tons ha^{-1}) at 15% moisture content.

3. Results and discussion

3.1. Analysis of variance in maize performance

The results of the ANOVA are shown in Tables 3 and 4. From the table, a significant difference was observed in phenological traits (anthesis days and silking days), growth traits (plant height, ear height), and yield and yield components (ear weight, test grain weight, and grain yield). The significant difference in these traits was probably due to the diverse background of parental lines, from where the hybrids were developed [12].

3.2. Phenological traits

Flowering traits like anthesis days and silking days showed significant difference while anthesis-silking interval and maturity days showed non-significant. The anthesis days ranged from 100-110 and 100–111 in 2018 and 2019 respectively (Tables 3 and 4). Similarly, silking days range from 102–112 and 102–113 in 2018 and 2019 respectively. Rampur Hybrid 10 had earlier anthesis and silking period for both years while Rampur Hybrid 2, Rampur Hybrid 4, Ganga Kaveri, and RML-86/RML-96 had later anthesis and silking days and they flowered after the mean value of anthesis and silking of 105 and 106 respectively. There were no significant differences in anthesis-silking interval and maturity days between the studied hybrids for both seasons. Previous findings have also reported differences for days to anthesis and silking in hybrids [13]. For maize, silking period is one of the most sensitive periods when planted in cold stress [14]. The silking duration was quite long in winter maize because of low temperature and low solar radiation in Terai [8]. The cold stress during flowering has a direct effect on the silking time, which further increases the anthesis-silking gap resulting in fertilization and ultimately fewer kernels number per ear and less yield [8]. The hybrids (P3396 and Shresta) with silking days ranging from 105 to 107 (similar to mean value 107) showed higher grain yield in comparison to longer and shorter silking days (Tables 3 and 4).

3.3. Growth traits

Plant height significantly differed between hybrids in 2018 and 2019; however, only ear height was found to be significantly different in 2019 (Tables 3 and 4). Ganga Kaveri, Rajkumar, P3396, Rampur Hybrid 6, and Shresta had the highest plant height than their mean value of 203 cm (2018) and 201 cm (2019). Similarly, Ganga Kaveri, Rajkumar, Rampur

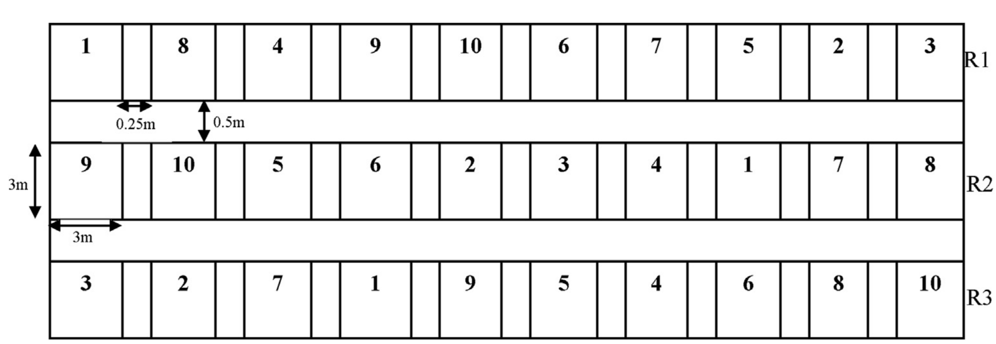

Figure 2. Layout of the field. Each box of '3 m × 3 m' represent a single plot, the number represent the hybrid maize number in Table 1. Each plot contains 4 rows with 12 plants in each row (total = 48 plants, 75 × 25cm^2 (RR × PP)). There are ten plots in each replication and the numbers are randomized and each replication is repeated three times. R1, R2 and R3 represent replication first, second and third respectively.

Table 3. Mean performance of hybrid maize at Gauradaha, Jhapa during winter 2018.

Maize hybrids	AD	SD	ASI	MD	PH	EH	NKPR	NKRPE	EW	TGW	GY
Ganga Kaveri	106ab	108ab	2	167	211ab	104	32.0	13.7	69ab	405bc	10.04ab
P3396	103ab	105ab	2	165	205abc	91	29.1	12.6	75a	468a	11.18a
Rajkumar	104ab	105ab	1	166	216a	109	27.2	14.7	63cd	383c	8.99ab
Rampur Hybrid 10	100b	102b	2	163	179d	96	27.3	14.6	65bc	401bc	9.31ab
Rampur Hybrid 2	110a	112a	2	166	194cd	93	28.4	12.4	57d	388c	8.08b
Rampur Hybrid 4	107ab	108ab	1	166	204abc	104	28.2	13.7	61cd	408abc	9.82ab
Rampur Hybrid 6	105ab	107abc	2	165	216a	104	26.5	14.6	69ab	440abc	10.37ab
RML-86/RML-96	107ab	108ab	1	167	191cd	95	27.7	12.4	70ab	383c	9.72ab
RML-95/RML-96	105ab	106ab	1	167	197abc	106	27.3	14.6	60.0cd	383c	8.69ab
Shresta	104ab	106bc	2	168	218a	104	28.0	14.3	72a	453ab	10.67ab
MSD	7.73	7.42	6.94	6.94	16.26	-	-	-	6.98	59.66	2.51
CV (%)	2.58	2.37	41.05	1.42	2.73	8.40	8.05	8.19	7.22	4.91	8.88
Grand Mean	105	107	1.53	166	203	100.70	28.18	13.89	66.1	414.68	9.68
F test	*	*	ns	ns	*	ns	ns	ns	*	**	*

Mean value in a column having the different letter indicate significant difference at 0.05 level (*) and 0.01 level (**), ns = non-significant, MSD = Minimum significant difference, AD = 50% anthesis days, SD = 50 % silking days, ASI = Anthesis-silking interval, MD = Maturity days, PH = Plant height (cm), EH = Ear height (cm), NKPR = Number of kernel per row, NKRPE = Number of kernel row per ear, EW = Ear weight (g), TGW = 1000 grain weight (g) and GY = Grain yield (tons ha^{-1}).

Table 4. Mean performance of hybrid maize at Gauradaha, Jhapa during winter 2019.

Maize hybrids	AD	SD	ASI	MD	PH	EH	NKPR	NKRPE	EW	TGW	GY
Ganga Kaveri	106abc	108abc	2	169	216a	105ab	30.6	13.7	69ab	416bc	10.03abc
P3396	105abc	106abc	1	166	206ab	91de	29.1	12.6	70ab	468a	11.10a
Rajkumar	105abc	107abc	2	166	215a	110a	27.2	14.7	67ab	381c	9.03cd
Rampur Hybrid 10	100c	102c	2	163	188c	106ab	27.3	14.6	69ab	401bc	9.78bc
Rampur Hybrid 2	111a	113a	2	166	193bc	89e	28.4	12.5	59c	395bc	9.43bcd
Rampur Hybrid 4	107abc	108abc	1	166	196bc	93cde	29.2	14.4	66abc	405bc	8.98 cd
Rampur Hybrid 6	107abc	108abc	1	165	198bc	101bc	26.5	14.6	69ab	371c	9.83bc
RML-86/RML-96	108ab	109ab	1	169	187c	99bcd	26.7	12.8	63bc	412bc	9.95bc
RML-95/RML-96	103bc	104bc	1	167	192bc	106ab	27.3	14.6	67ab	389bc	8.50d
Shresta	104abc	105bc	1	170	221a	104ab	29.6	15.1	74a	436ab	10.20ab
MSD	7.27	7.23	-	-	16.35	8.77	-	-	7.76	49.01	1.06
CV (%)	2.35	2.30	30.19	1.49	2.77	2.98	7.51	7.96	3.93	4.10	3.76
Grand mean	105.60	107.20	1.60	168.00	201.32	100.59	27.81	13.83	67.33	407.75	9.68
F test	**	**	ns	ns	*	*	ns	ns	**	**	**

Mean value in a column having the different letter indicate significant difference at 0.05 level (*) and 0.01 level (**) ns = non-significant, MSD = Minimum significant difference, AD = 50% anthesis days, SD = 50 % silking days, ASI = Anthesis-silking interval, MD = Maturity days, PH = Plant height (cm), EH = Ear height (cm), NKPR = Number of kernel per row, NKRPE = Number of kernel row per ear, EW = Ear weight (g), TGW = 1000 grain weight (g) and GY = Grain yield (tons ha^{-1}).

Table 5. Combined Phenotypic correlation coefficients between pairs of traits studied in ten maize hybrids, correlation among agronomic parameters.

	AD	SD	ASI	PH	EH	NKPR	NKRPE	EW	TGW	MD	GY
AD	1										
SD	.987**	1									
ASI	-.100	0.000	1								
PH	-.457	-.400	.375	1							
EH	-.535	-.538	.048	.623*	1						
NKPR	.059	.059	0.000	.422	-.047	1					
NKRPE	-.674*	-.712*	-.198	.456	.782**	0.000	1				
EW	-.245	-.172	.092	.342	-.095	.524	.097	1			
TGW	-.061	-.015	.128	.120	-.451	.675*	-.227	.841**	1		
MD	.325	.303	-.563	.037	.048	.396	-.059	.166	.165	1	
GY	-.426	-.402	-.023	.122	-.101	.474	.254	.869**	.783**	-.027	1

***Highly significant ($P < 0.01$), *Significant ($P < 0.05$),* AD = 50% anthesis days, SD = 50 % silking days, ASI = Anthesis-silking interval, PH = Plant height (cm), EH = Ear height (cm), NKPR = Number of kernel per row, NKRPE = Number of kernel row per ear, EW = Ear weight (g), TGW = 1000 grain weight (g), MD = Maturity days and GY = Grain yield (tons ha^{-1}).

Hybrid 10, RML-95/RML-96, and Shresta had higher ear height than their average height (101 cm). Ear height was found to be non-significant in 2018 but in 2019, 60% of hybrids bear cobs above the middle parts of maize plants. These varieties were more lodging prone due to cob weight at upper parts of maize plants. Rampur Hybrid 10 showed the lowest plant height in both years; the low plant height is attributed to its drought tolerance capacity. Low plant height will lower the transpiration rate and ultimately reduce moisture stress during drought [15]. Rampur Hybrid 10 is registered as a drought-tolerant hybrid by NMRP. The difference in plant height among genotypes is attributed to genetic as well as environmental factors [16, 17]. Our result on plant height of Nepalese hybrids, RML-95/RML-96, RML-86/RML/RML-96, and Rampur Hybrid-10 is consistent with previous research done in inner terai [17]. Several research articles in maize has reported plant height difference among genotypic variability [18]. The plant height is influenced by the competitive environments, light interception, carbon and nutrient capture, and weed competition [19]. The growth traits like plant height and leaf area have a positive correlation as well as a positive direct effect on the grain yield [20].

3.4. Yield and yield-component traits

A significant difference was noted on grain yield, ear weight, and thousand-grain weight (TGW) while other yields attributing traits were non-significant (Tables 3 and 4). In both years, P3396 (468 g) showed the highest TGW followed by Shresta and in 2018 Rampur Hybrid 6 and Rampur Hybrid 4 TGW were significantly at par with these top performers. In addition, P3396 and Shresta both had higher ear weight in comparison to other hybrids in both years. In terms of yield, P3396, Shresta and Rampur Hybrid 6 were the top three performers of 2018, whereas P3396, Shresta, and Ganga Kaveri were top yielders in 2019. Kandel et al. [13] evaluated 10 maize hybrids in Chitwan and reported Shresta, RML-86/RML-96, and RML-95/RML-96 as a top three yielder. Our results were partially consistent with previous findings. In both years, P3396 (11.18 and 11.10 tons ha^{-1}) and Shresta (10.67 and 10.20 tons ha^{-1}) displayed consistent high yield. Therefore, our results suggest that these two hybrids have high potential to succeed in the inner terai condition of Nepal. Koirala et al. [17] found that P3396 possessed good stability and adaptability over the years and across the diverse environment of the Terai region. Worku et al. [21] reported that farmers ranked yield, early maturity, ear size, and a number of ears as the most important traits during variety preferences which supports the significance of yield trait and ear weight.

The grain yield ranged from 8.08 to 11.18 tons ha^{-1} in both years; similar results have been reported on maize hybrids having different yield potentials [8, 13]. The variation in the yield potential is probably due to the diverse background of parental lines, from which the hybrids were developed [12]. In both years Shresta and P3396, having higher yield, also showed plant height greater than the mean. The increased in plant height provides more areas for photosynthetic activities and assimilates needed for grain filling [22]. Koirala et al. [17] reported that hybrids having highest plant height produced higher yield.

3.5. Correlation of grain yield with yield attributing traits

The result shows that grain yield has a positive and highly significant correlation with test weight and ear weight (Table 5). Other traits did not show a significant relationship with yield traits, but showed positive and negative correlations (Table 5). Plant height, number of kernels per row, number of kernels per ear, indicated positive correlation with yield while anthesis days, silking days and anthesis-silking interval, ear height, and maturity days indicated negative correlation with yield. A similar significant positive correlation was observed in maize between grain yield to ear weight and thousand-grain weight [12, 13, 23]. Similarly, non-significant positive correlations were observed between grain yield and other traits: plant height [13, 24], the number of kernel per row per year [13] and negative non-significant association were observed between grain yield and ear height [13], anthesis and silking date [25]. Though a significant correlation is not observed between grain yield to anthesis, negative association suggests that genotypes with higher days to anthesis have less grain yield, and while making a selection, it is preferred to choose a hybrid with shorter days to anthesis. Tables 3 and 4 reveals that top-yielding hybrids had the highest ear weight and thousand-grain weight, and they have a positive and significant correlation. Positive and significant association of ear weight and thousand-grain yield contribute to more grain yield. The significant positive correlation between grain yield to test weight and ear weight implies that the selection of these traits is important to improve the grain yield of the hybrid maize.

4. Conclusion

Location-specific evaluation of maize hybrid is crucial for the hybrid maize program. The hybrids having consistent and high yield are regarded as a superior hybrid variety and are suitable for general cultivation. There was a significant variation in agro-morphological traits among the maize hybrids. All the tested genotypes significantly differed for grain yield, test weight, ear weight, plant height, ear height, and flowering traits. The two years of field experiments indicated that P3396, Shresta, and Rampur Hybrid 6 in 2018 and P3396, Shresta, and Ganga Kaveri in 2019 were promising maize hybrid in inner terai condition. In both years, P339 and Shresta showed higher and consistent yields. The higher yield in the hybrid is correlated to the ear weight and thousand-grain weight and needs to be considered for selection. Thus, these two hybrids should be promoted to farmer field trials test before recommending this to the maize growers in the inner terai of Nepal.

Declarations

Author contribution statement

Bishnu Prasad Kandel: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Kumar Shrestha: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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