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Field Performance of Three-way Cross Yellow and White Maize Hybrids in Nepal

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Authors' contributions

This work was carried out in collaboration among all authors. Author MPT performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KBK, DG, SS and JU contributed in field and paper work also. Authors HKS and ARBI managed genetic materials, coordinated in field work and provided valuable feedback regarding this research. All authors read and approved the final manuscript.

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ABSTRACT

Maize hybrids can increase production, bridge the yield gap, and boost up domestic production in Nepal. Three-way cross hybrid introduces an alternative to produce low cost hybrid seed for resource poor farmers. A study was performed to identify promising yellow and white maize hybrids developed by International Centre for Maize and Wheat Improvement (CIMMYT), Mexico in Rampur, Nepal. Nineteen three-way cross white maize hybrids with two checks and seventeen yellow maize hybrids with one check were tested in field experiments on 2017 and 2018. Treatments were replicated twice in α-lattice design with each experimental plot of 9.6-m^2 (4-m × 2.4-m). AF17A-426-13/14, AF17A-426-1/2, AF17A-426-28/39, and AF17A-426-15/16 were the three-way cross white hybrids produced grain yield of more than 9000 kg ha^{-1}. Similarly, AF17A-473-20/29 and AF17A-473-18/27 yielded about 9000 kg ha^{-1} among the three-way cross yellow maize hybrids. These hybrids have commercial potentials to increase maize yield in Nepal if the provided parents are successful in the seed production.

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1. INTRODUCTION

Maize (*Zea mays* L.) is the second most important crop after rice based on area of production and productivity [1]. It is grown in about 20 percent of the total cereal production area and provides 30 percent of total calories in Nepal. Therefore, maize has important role in food and nutritional security of Nepal, mostly in rural areas. Increased productivity of the maize eventually can benefit the resource poor farmers. Maize is considered as a versatile crop that has been grown in a wide range of agro-ecological zones from sub-tropical Terai to temperate high Hills. About 33 percent of total cereal production area in high hills (above 1800 masl), 39 percent in mid-hills (900-1800 masl), and nine percent in Terai (below 900 masl) is dedicated for maize production. Maize is the main crop in the hills, a rain-fed cropping system covering more than two-third of the national maize production area. Yellow corn is primarily used and traded as raw material for animal feed (about 55 percent of annual national production) while white maize is the main staple food for about 15 percent of the total population in Nepal.

The demand of maize grain is in rise along with increasing population and changing dietary habits. The demand for maize grain for the feed industries is also growing at a rate of 11 percent annually i.e., 13 percent in poultry and 8.5 percent in livestock sector in Nepal over the last five years [2]. Approximately 10.03 million tons of feed are required i.e., equivalent to 2750 tons of feed per day for the poultry and livestock industries in Nepal. Current domestic maize production falls short of demand; grains are being imported into the country to meet the demand. Only about 20 percent of the national maize demand for feed is fulfilled by the domestic production. Approximately 80 percent import (483639.87 MT) of national maize demand created annual trade deficit of 12 billion rupees (109.18 million USD) in the fiscal year 2017/18 [3]. This shows opportunity to fulfill the national demand by increasing production and productivity of maize grains for the feed industry in Nepal.

Majority of small scale farmers are in marginal areas and cultivate low yielding Open-Pollinated Varieties (OPVs). OPVs are planted in greater acreage (about 86 percent) than hybrid cultivars (14 percent) [2]. This demonstrates potential for expanding hybrid maize area in Nepal. A wide yield gap exists between OPVs and hybrids in both hills and Terai region. The 2.84 t ha^{-1} of national average maize yield in Nepal is around 50 percent of global average while attainable yield of OPVs and hybrids is 5.70 t ha^{-1} and 7.27 t ha^{-1} respectively. Large area coverage by OPVs with lower yield than hybrids is one of the bottlenecks to increase production and productivity of maize. Therefore, development of hybrid cultivars and their access to farmers can narrow the yield gap and fulfill the national demand since the yield level of OPVs has already reached in the plateau. Hybrid maize is one of the economic and sustainable alternatives for boosting domestic production, narrowing the yield gap, and making the country self reliant on maize grain. If grown under suitable conditions, hybrids generally yield higher than OPVs. Devkota et al. [4] demonstrated that hybrid adoption alone can raise grain yield by 50 percent in maize. The yield advantage over OPVs is the decisive factor for hybrid attraction [5,6]. Farmers have limited choices to grow nationally released maize hybrids in Nepal. The recommended hybrids are not enough to meet the demand of the farmers. Government sector cannot produce enough hybrid maize seed due to its limited capacity but only few seed companies are being involved in the seed production of publicly bred maize hybrids. As a result, hybrid maize seed has been imported, mostly from India, either through formal market channel or informally through the porous border. The farmers must pay higher prices for hybrid maize seed. Some of the hybrids are not doing well in the farmer's field even though the cultivation of formally registered high cost hybrid.

One of the major obstacles to the large scale adoption of hybrid maize production is the high cost of seeds [7]. If low cost hybrid maize seeds are accessible to the farmers and available in local markets, this will help to generate more food production for a secure future. Biotic stresses such as northern leaf blight (NLB), southern leaf blight (SLB), and banded leaf and sheath blight (BLSB), gray leaf spot (GLS), stalk rot, stem borer and fall army worm, and abiotic stresses such as drought, heat, cold and water logging are some of the other production constraints [8]. High yielding yellow and white maize hybrids tolerant against multiple stresses can improve maize productivity and livelihoods of smallholder farmers. Three-way cross hybrids might be an attractive alternative for low-cost hybrids to the small holder farmers and has potentially to increase national production. Therefore, the objective of this study was to identify high yielding three-way cross yellow and white maize hybrids suitable for Terai, inner Terai and the foothills of Nepal.

2. MATERIALS AND METHODS

2.1 Study Location and Maize Cultivars

The study was carried out at the National Maize Research Program (NMRP) research farm in Rampur (27°40'N latitude, 84°21'E longitude and 228 masl altitude) in the central Terai region of southern Nepal. The experiment was performed under rainfed conditions during the consecutive winter season of 2017-18 and 2018-19. The experimental materials in this study consisted of two sets of hybrids; 19 three-way cross white maize hybrids and Rampur Hybrid-10 and P-3396 as checks; and 17 three-way cross yellow maize hybrids and P-3396 as commercial check. These testing materials were developed by International Maize and Wheat Improvement Center (CIMMYT), Mexico and were provided by the Nepal Seed and Fertilizer Project (NSAF/CIMMYT), a project funded by USAID.

2.2 Experimental Details

In both years, the maize genotypes were arranged in α-lattice design with two replicates. Each plot consisted of four 4-m long row ridges with row to row distance of 0.60-m with plant spacing of 0.25-m within a row. The recommended rate of fertilizer was applied (180:60:40 kg ha^{-1} N:P_2O_5:K_2O) in the form of Urea, Di-ammonium phosphate, and Murate of Potash. A full dose of Phosphorous and Potash along with farmyard manure (15 t ha^{-1}) was applied as basal application. Urea was top dressed as three split doses. Immediately after sowing, Attrazin @ 2.0 g + Pendimethalin @ 4.5 ml L^{-1} were applied to control weeds. Plots were kept free of weeds by two manual weeding and intercultural operations during the crop season. Army worm was managed by a spray of Fighter (chlorpyrifos+cypermethrin, 2.0 ml L^{-1}) at a knee high stage followed by manual larva picking. Plots were flood irrigated six times during the entire crop cycle as needed.

2.3 Data Collections and Analysis

Days to 50 percent anthesis and silking were recorded per plot and converted into growing degree day (GDD). Daily growing degree day (GDD) of maize was calculated by using following formulae: GDD (°C) = Daily average temperature-10°C (base temperature). Five plants were randomly selected in a plot to measure plant height, ear height, and cob length as the method suggested by CIMMYT [9]. Numbers and plants and ears grain yield were recorded on plot basis and converted into hectare. Each plot was harvested separately. Cobs were weighed to record the field weight after dehusking and converted to grain yield by multiplying the conversion factor 0.8. Grain moisture content was estimated using the Wile 55 grain moisture meter. Then the yield per plot was finally converted to kg ha^{-1} with 12.5 percent moisture adjustment. For each disease (NLB, SLB and BLSB), the disease severity was scored on a 1-5 scale following the protocol developed by CIMMYT for diseases [10]. Analysis of variance was performed for each year and combined to detect differences among the maize genotypes using META-R software developed by CIMMYT [11]. Broad sense heritability (H^2) was calculated by $H^2 = \sigma^2g / \sigma^2p$ where, σ^2g and σ^2p are the genotypic and phenotypic variances, respectively.

3. RESULTS

The analysis of variance revealed that genotypes varied significantly for GDD in anthesis and silking at both populations and planting years (Tables 1-2). In general, anthesis was earlier than silking in both populations and years. However, initiation of anthesis and silking was the same day on three-way cross white hybrids in 2017-18 and three-way cross yellow hybrids in 2018-19. High heritability of 0.70-0.95 in both populations observed for flowering traits. Combined analysis showed that anthesis and silking had not significant difference among the genotypes and their sub sources of variation (top, rest and check) in both types of hybrids (Table 3).

Table 1. Descriptive statistics of three-way cross white maize hybrids for the characters recorded on two consecutive years in Rampur

Characters	**2017-18**				**2018-19**			
	H^2	**Range**	**Mean±SEm**	**Sig.**	**H^2**	**Range**	**Mean±SEm**	**Sig.**
GDD anthesis	0.91	901-1031	956±5.18	**	0.93	912-1000	967±2.99	**
GDD silking	0.89	901-1059	976±5.57	**	0.70	938-1038	988±4.21	*
Plant height (cm)	0.42	165-275	229±3.85	ns	0.87	209-294	247±3.51	**
Ear height (cm)	0.21	85-165	114±3.03	ns	0.83	88-144	119±1.82	**
Cob length (cm)	0.22	12.2-16.0	14.0±0.16	ns	0.55	14-19	15.7±0.20	ns
No. of rows cob^{-1}	0.76	13.2-18.0	15.4±0.19	**	0.50	13-20	15.6±0.19	ns
No. of grains row^{-1}	0.79	24.0-36.4	28.7±0.44	**	0.43	19-33	26.6±0.53	ns
No. of plants ha^{-1}	0.79	29167-72917	47285±1335	**	0.53	29167-59722	48963±1160	ns
No. of ears ha^{-1}	0.50	38542-77083	57811±1524	ns	0.62	36111-86111	63391±1858	*
Grain yield (kg ha^{-1})	0.42	5150-11082	7773±214	ns	0.68	3958-12096	8120±343	*
TKW (g)	0.08	316-516	412±6.28	ns	0.49	270-526	426±7.36	ns
NLB (1-5 scale)	0.53	1.0-2.0	1.19±0.04	ns	0.30	1.5-3.0	2.08±0.05	ns
SLB (1-5 scale)	0.00	1.0-2.5	1.97±0.06	ns	0.70	2.0-3.5	2.26±0.06	*
BLSB (1-5 scale)	0.00	1.0-2.5	1.50±0.05	ns	0.48	2.0-3.5	2.43±0.07	ns

*NB: Sig.=significance, * significant at ≤0.05 p level,** significant at ≤0.01 p level, and ns=non-significant at 0.05 p level; TKW=thousands kernel weight, NLB=northern leaf blight, SLB=southern leaf blight, BLSB=banded leaf and sheath blight*

There was non-significant difference among the genotypes for plant height and ear height in yellow hybrids in both the years (Tables 1-2). But there was significant difference in plant heights of white hybrids tested in 2018-19. In general, the white hybrid was taller than yellow hybrids. The mean plant height of white hybrids was 229±3.85 in 2017-18 and 247±3.51 in 2018-19. Similarly, mean plant height of yellow hybrids was 216±2.70 in 2017-18 and 230±2.61 in 2018-19. In both types of hybrids, overall mean plant and ear height was taller in second year. Low (0.05-0.28) to medium (0.41) heritability was calculated in yellow hybrids while low (0.21), medium (0.42) and high (0.83-0.87) heritability was recorded in white hybrids for plant and ear height.

There was difference observed between years for all yield component traits except cob length and thousands grain weight in three-way cross white hybrids (Table 1). Likewise, difference was recorded between years for yield component traits except numbers of plants and ears per hectare in three-way cross yellow hybrids (Table 2). The overall grain yield was higher in three-way cross white hybrids than yellow hybrid, and in the first year than second year. Only in the second year of evaluation, there was significant difference among the genotypes with respect to grain yield on both populations. The recorded highest grain yield was ≥11000 kg ha^{-1} in case of white hybrids while ≥8000 kg ha^{-1} in case of yellow hybrids on both research years. Hybrid AF17A-426-13/14 out-yielded all other white hybrids by producing 10335 kg ha^{-1} as against lower grain yield of 60667 kg ha^{-1} produced by the hybrid AF16A-431-20/38. Likewise, yellow hybrid AF17A-473-18/27 and AF17A-473-20/29 produced highest grain yield of nearly 9000 kg ha^{-1} as against lower grain yield of 4367 kg ha^{-1} produced by the hybrid AF17A-473-1/2. In comparison between two years data, contrasting results was observed in white hybrids for yield component traits with respect to broad sense heritability. Numbers of rows per cob, grains per row and plants per hectare showed high heritability (0.76-0.79) in the first year but medium heritability (0.43-0.53) in the second year. Numbers of ears and grain yield showed medium heritability (0.42-0.50) in the first year but high heritability (0.62-0.68) in the second year. In yellow hybrids, high heritability (0.87-0.89) was observed for numbers of plants and ears per hectare in both the years while high to medium heritability (0.35-0.83) recorded between the years in numbers of rows per cob, grain per row, grain yield and weight.

The group of top yielding entries combined over two years was compared with the group of remaining entries and checks for all major traits in both types of hybrids (Table 3). The results depicted that the group mean value differed significantly ($P \le 0.05$) for numbers of grains per row, numbers of plants, numbers of ears, and grain yield in yellow maize hybrids. Similarly, the group mean value differed significantly for height, numbers of rows per cob, numbers of grains per row, numbers of plants, numbers of ears, and grain yield in white maize hybrids. The best yielding lines obviously yielded significantly higher than the checks and remaining ones, which was always accompanied by higher values for three yield components, *viz*. the numbers of grains per row, numbers of plants per hectare, and numbers of ears per hectare. Average yield of almost 9000 kg ha^{-1} was obtained from four three-way cross white and two three-way yellow hybrid. As the results of ratio between numbers of ears and numbers of plants in both population, higher E:P ratio (≥ 1.33) was found in the top group than in the other group. The mean grain yield of selected group was 24.3 percent and 44.5 percent higher than that of the non selected group and commercial checks respectively in three-way cross white hybrids. Similarly, the mean grain yield performance of selected entry was 40.7 percent and 15.9 percent higher than that of the non selected group and check respectively in three-way cross yellow hybrids.

Correlation analysis of grain yield with other traits largely confirmed the relative importance of different characters contributing to good yield performance in each population (Table 4). Grain yield was positively correlated in both the years with plant height, ear height and numbers of grains per row in three-way cross white hybrids while it was positively correlated with numbers of plants and ears per hectare in three-way cross yellow hybrids. In addition to this, northern leaf blight, growing degree day for flowering, numbers of plants and ears per hectare is positively correlated with grain yield in white hybrids. Similarly, plant height and numbers of rows per cob was negatively correlated with grain yield in yellow hybrids. Therefore, plant height, ear height, number of grains per row, number of plants and number of ears were the important traits contributing for grain yield.

Table 2. Descriptive statistics of three-way cross yellow maize hybrids for the characters recorded on two consecutive years in Rampur

Characters	**2017-18**				**2018-19**			
	H^2	**Range**	**Mean±SEm**	**Sig.**	**H^2**	**Range**	**Mean±SEm**	**Sig.**
GDD anthesis	0.92	930-1118	1000±6.88	**	0.95	939-1100	978±6.16	**
GDD silking	0.92	944-1153	1027±7.82	**	0.90	939-1119	993±6.31	**
Plant height (cm)	0.28	175-250	216±2.70	ns	0.05	187-261	230±2.61	ns
Ear height (cm)	0.41	70-140	102±2.64	ns	0.10	72-133	110±2.16	ns
Cob length (cm)	0.73	12.0-17.0	14.4±0.24	*	0.45	15.5-21.5	18.7±0.24	ns
No. of rows cob^{-1}	0.83	12.4-16.4	13.8±0.13	*	0.43	13.6-21.9	15.3±0.31	ns
No. of grains row^{-1}	0.66	23.8-38.8	31.1±0.66	*	0.35	21.2-34.2	29.5±0.60	ns
No. of plants ha^{-1}	0.87	17708-70833	38426±1552	**	0.87	9722-62550	36398±2579	**
No. of ears ha^{-1}	0.87	23958-87500	45370±2111	**	0.89	13889-88890	55788±3879	**
Grain yield (kg ha^{-1})	0.57	2416-8104	5787±206	ns	0.79	2163-12992	7758±520	**
TKW(g)	0.39	304-540	422±7.70	ns	0.76	350-545	447±6.72	**
NLB (1-5 scale)	0.16	1.0-2.0	1.10±0.04	ns	0.03	1.5-3.0	1.97±0.06	ns
SLB (1-5 scale)	0.00	1.0-2.5	1.61±0.07	ns	0.54	1.5-3.0	2.17±0.05	ns
BLSB (1-5 scale)	0.65	1.0-2.5	1.40±0.07	*	0.49	2.0-3.5	2.60±0.08	ns

*NB: Sig.=significance, * significant at ≤0.05 p level,** significant at ≤0.01 p level, and ns=non-significant at 0.05 p level; TKW=thousands kernel weight, NLB=northern leaf blight, SLB=southern leaf blight, BLSB=banded leaf and sheath blight*

Table 3. Combined mean of three-way cross maize hybrids and comparison of the best yielding entries (top) with the others

Character	Mean of white maize hybrids				Mean of yellow maize hybrids			
	Top (4)†	Rest (15)	Check (2)	Sig.	Top (2)	Rest (15)	Check (1)	Sig.
GDD anthesis	966	963	940	ns	987	989	1018	ns
GDD silking	985	984	961	ns	1005	1013	1027	ns
Plant height (cm)	250	238	220	*	216	225	209	ns
Ear height (cm)	125	115	109	*	108	106	105	ns
Cob length (cm)	15.1	14.7	15.7	ns	16.6	16.3	15.9	ns
No. of rows cob^{-1}	16.2	15.5	13.9	**	13.7	14.7	14.1	ns
No. of grains row^{-1}	29.5	27.5	25.3	**	30.8	30.5	25.7	*
No. of plants ha^{-1}	51452	46516	53534	*	42014	35849	61806	**
No. of ears ha^{-1}	68396	58636	59569	*	63442	46388	83160	**
Grain yield (kg ha^{-1})	9568	7700	6616	**	8813	6262	7602	*

*NB: Sig.=significance, * significant at ≤0.05 p level,** significant at ≤0.01 p level, and ns=non-significant at 0.05 p level, †figures in the brackets showed the number of entries*

Table 4. Genetic correlation coefficients (rg) between grain yield and other traits in each year of evaluation at Rampur. Only significant (P≤0.05) coefficients are reported

Character	Three-way white hybrids		Three-way yellow hybrids	
	2017-18	2018-19	2017-18	2018-19
GDD anthesis	0.05ns	0.81**	0.04ns	-0.22ns
GDD silking	-0.09ns	0.96**	-0.09ns	-0.10ns
Plant height (cm)	0.76**	0.71**	-0.99**	-
Ear height (cm)	0.99**	0.88**	0.06ns	0.73**
Cob length (cm)	0.64*	0.06ns	0.32ns	-0.25ns
No. of rows cob^{-1}	0.39ns	0.20ns	-0.21ns	-0.71**
No. of grains row^{-1}	0.89**	0.99**	0.04ns	0.66*
No. of plants ha^{-1}	0.23ns	0.63**	0.65**	0.90**
No. of ears ha^{-1}	-0.10ns	0.66**	0.78**	0.81**
NLB (1-5 scale)	0.61**	0.37ns	0.02ns	-

*NB: * significant at ≤0.05 p level,** significant at ≤0.01 p level, and ns=non-significant at 0.05 p level*

Three major diseases, northern leaf blight (NLB), southern leaf blight (SLB) and banded leaf and sheath blight (BLSB) were screened for the incidence, severity and impact of diseases. There was non-significant difference among the genotypes for all recorded diseases except SLB in white hybrids in the second year. Similarly, non-significant difference was found among the yellow hybrids for all three diseases except BLSB in the first year. In three-way cross white hybrids, medium heritability was observed for NLB and fluctuating heritability for SLB and BLSB while low heritability was found for NLB and UNPREDICTABLE heritability for SLB and BLSB in three-way cross yellow hybrids. However, in the second year only the critical range of disease incidence was occurred in some entries for SLB along with BLSB in white hybrids and for BLSB in yellow hybrids. Highly significant positive correlation was observed between grain yield and NLB in three-way cross white hybrids in 2017-18.

4. DISCUSSION

In Nepal, maize is a crop of opportunities with multiple uses as food, feed, fodder and industrial applications. Despite the difference in color, the acceptability of yellow and white maize for the consumer is remarkable. Maize varieties with yellow/yellow-orange/orange kernels (collectively referred to as yellow maize) are commonly preferred as poultry feed. It is a rich source of β-carotenes and xanthophylls that give yellow color to egg yolk and poultry skin that is appreciated by consumers. In many parts of the hills, where the basic staples are rice and wheat, white maize is of minimal and mostly localized significance. Over the last two-three decades, however, maize as a human food intake has decreased due to changes in food preferences and increasing incomes. In the street market, the use of green cobs roasted as a favorite snack food is increasing tremendously. Out of total maize produced in the hills, only 55-60 percent and 30-35 percent are used for feed and human food respectively while more than 80 percent of maize produced in Terai is used for feed and 15-20 percent for human consumption [12,13]. This figure illustrates how yellow and white maize are primarily connected to society's livelihoods.

Because of results obtained in the parameters studied, the set of hybrids used in this study should derive from a spectrum of diverse genetic and morphological backgrounds. Variations in flowering time, plant and ear height, and yield component traits observed were due to differences among the genotypes. The significant difference among the entries on these traits indicated that it was possible to achieve outstanding hybrids desired by consumers through selection. This result was consistent with the previous study of Issa et al. [14]. However, the variability found in the parameters studied relative to the subsequent year is environmental. For this experiment, a comparative study of flowering time in both populations and years showed full season hybrids. High heritability for anthesis and silking time indicated that these traits were less influenced by environments and controlled by major gene. This was agreement with the conclusions reached in earlier studies [15,16] which stated that dominance effects was responsible for flowering. The dominance effect in maize flowering time was also of significant importance in this scenario. In line with the previous studies of Sher et al. [16], the trait could be utilized in selection of hybrids.

Irrespective of population as evidenced by above results, it can be argued that growing environment (year) had significant effect in plant height variation. The experimental results confirmed the finding of Gyenes-Hegyi et al. [17], who stated that the environment had a significant influence on plant and ear height of maize. The differential pattern of maize varieties for plant height was due to genotype and environment interaction as reported earlier by Revilla et al. [18]. Cai et al. [19] reported that twenty-two and fifteen QTLs were associated with plant height and ear height respectively in maize. In majority of the cases, correlation analysis of plant height revealed highly significant positive relationship with grain yield. This result was in conformity with the earlier finding of Khan et al. [20]. Low and medium heritability of plant and ear height suggested that genetic improvement might be difficult to achieve through simple selection. There was a substantial variation observed in the position of ear bearing node in the stalk. In the top yielding hybrids, the first cob was positioned at 50 percent of the plant height. The position of the ear on the plant could affect ear growth and finally grain yield in maize. This result was supported by the findings of Subedi and Ma [21].

Yield and yield attributes are governed by cumulative action of growth and phenological traits, and their interaction with bio-physical environment. Cob length, cob placement height, plant height, number of rows per cob, number of grains per row, number of plants and numbers of ears influenced significantly for grain yield. As reported earlier by Younas and Hayder [22] grain yield was the product of number of sub-fractions called yield associated traits. The mean grain yield of maize genotypes differed across years, which might be due to differing planting times between the years. The years themselves differ greatly in key attributes, such as temperature, rainfall, and growing duration that ultimately affect on crop performance. Despite of equivalent plant density, it can be argued that plants produced more numbers of ears in the second year, thus resulted into higher grain yield. The greatest per hectare grain yield of top four white hybrids and superior yellow hybrid might be attributed to its genetic make-up. The finding of this study was in agreement with those of Younas and Hayder [22] who observed positive correlation between yield component traits and increased grain yield.

From the above results it was clear that multiple hybrids displayed varying degrees of performance for the characters studied. A perusal of the data revealed that white hybrids exhibited the highest grain yield performance than yellow hybrids. Further numbers of plants and ears in yellow hybrids, and numbers of grains per row in white hybrids showed positive significant correlation with grain yield. This gave an indication of traits to be focused while selection of genotypes. The two superior three-way cross yellow hybrid, *viz.* AF17A-473-20/29 and AF17A-473-18/27 out-yielded than single cross check. Similarly, top four three-way cross white hybrids *viz.* AF17A-426-13/14, AF17A-426-1/2, AF17A-426-28/39 and AF17A-426-15/16 out-yielded than single cross check. The key reason was that diversified parents involved in the cross combination or unknown gene (s) had traits that resulted into maximum grain yield. These genotypes also had other agronomic characters better than or equal to that of commercial checks. Such new hybrids could be useful for exploitation in the future.

5. CONCLUSION

A separate set of three-way cross white and three-way cross yellow maize hybrids tested in NMRP, Rampur on two consecutive years showed significant variation for days to flowering, plant and ear height, grain yield, and other yield attributing traits. There were some experimental lines that out-yielded the commercial checks, indicating the superior hybrid was being introduced through NSAF/CIMMYT. High yielding three-way cross white hybrids might substitute the relatively low yielding OPVs in inner Terai as well as food hills, and superior three-way cross yellow maize hybrids might compete with expensive single cross hybrids in Terai. Hence, these promising hybrids had wide scope and needs to be further tested in large scale trials at various locations to validate their superiority and stability across locations before starting commercial seed production. If provided parents successful in seed production, these identified hybrids might be the future potential three-way cross maize varieties for Nepal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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