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Evaluation of maize genotypes for resistance to fall armyworm under natural infestation conditions

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ABSTRACT
The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), is one of the most significant invasive insect pests of maize in Nepal. Host plant resistance is a cost-effective, ecologically sustainable, and stable approach to reducing fall armyworm damage. This study aimed to identify maize genotypes that exhibit resistance or tolerance to fall armyworm damage in the Nepalese context. Total thirty-seven maize genotypes were screened for resistance to fall armyworm at the research field of the National Maize Research Program, Chitwan, Nepal, during the winter seasons (September/October–February/March) of two consecutive years, 2020 and 2021. The maize genotypes were evaluated using a randomized complete block design with three replications. Data were collected on foliar damage at the knee-high stage (V6 stage), before the tasseling stage (V12 stage), ear damage, and yield losses measured after harvesting. Statistically significant differences were observed among genotypes for ear damage score, cob length, cob diameter, thousand-grain weight, and grain yield, whereas leaf damage score did not show significant variation. None of the genotypes were found to be completely resistant or tolerant to fall armyworm in this study. However, Arun-3, SO1STYQ, Posilo makai-2, S0128, R-POP-2, BGBYPOP, Mankamana-3, Manakamana-7, RML86/RML96, Rampur hybrid-10 and CAH 1715 were identified as less susceptible to fall armyworm. These genotypes can be utilized as parents or sources of resistance in breeding programs. Grain yield exhibited a strong negative correlation with ear damage score (−0.529) and a weaker negative correlation with leaf damage score (−0.216), indicating that damage significantly reduces yield, particularly due to ear and leaf damage.

Keywords: Maize genotypes, fall armyworm, damage, resistant mechanism

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INTRODUCTION

Maize (*Zea mays* L., 2n=2x=20), commonly known as the "queen of cereals," is the second most important staple crop in Nepal in terms of area and production, with a total cultivation area of 985,565 hectares, a production of 3,106,397 metric tons, and a yield of 3.15 metric tons per hectare (MoAD 2022). Over 56 insect pests are known to cause varying levels of damage to maize from sowing to harvest; however, about a dozen are considered highly significant and require control measures (Bhandari et al 2020).

The fall armyworm (*Spodoptera frugiperda*; Lepidoptera: Noctuidae) is an invasive insect pest native to the tropical and subtropical regions of the Americas (Capinera 2020) but has already spread to Africa, Asia, and Oceania (Overton et al 2021). It was first identified in Nepal in May 2019 from Gaindakot, Nawalpur district (N 27°42'16.67", E 084°22'50.61") (Bajracharya et al 2019). Since then, the pest has spread across various maize-growing agro-ecological zones in Nepal, ranging from the southern plains below 100 meters above sea level to the northern high hills at altitudes of up to 1,700 meters (Bajracharya et al 2019). According to CABI (2019), Nepal's climatic conditions are highly suitable for the establishment of fall armyworm populations, which could potentially cause up to 100% crop loss in maize if not managed properly. Adults can mate and lay eggs multiple times, with an average of 1500 eggs and a maximum of 2000 eggs (Capinera 2000). Larvae feeds on the leaves and whorl of over 350 plant species across 76 families, including maize, rice, millet, and vegetables, causing severe damage (CABI 2020). Maize is a preferred host, but the pest also inflicts significant damage on crops such as sorghum, rice, wheat, finger millet, sugarcane, cabbage, beet, groundnut, soybean, onion, cotton, tomato, potato, and fodder grasses (Prasanna et al 2018). Fall armyworm larvae feed on both the vegetative and reproductive parts of maize, including leaves, whorls, tassels, and cobs. This pest is a strong flier with migratory and localized dispersal habits. Yield losses due to *S. frugiperda* larvae have been estimated at 20.15% in African countries (Abrahams et al 2017) and 34% in Brazil (Cruz et al 1999). This pest is adapted to warm climatic conditions, which allow it to complete its life cycle in a short period, resulting in multiple generations per cropping season, in addition to the fact that it does not undergo diapauses (Flanders et al 2017; Kumela et al 2018). These biological traits of FAW enable maximum damage infliction and yield loss per season (FAO 2018; Prasanna et al 2018).

To address these challenges, eco-friendly management options for fall armyworm have been evaluated under natural field conditions. Given the health and environmental risks posed by chemical control methods, there is an urgent need for sustainable alternatives, such as host plant resistance (HPR). The use of resistant crop varieties is one of the most effective strategies for managing fall armyworm, particularly in maize (Luginbill 1969). Many naturally occurring maize populations and germplasm showing resistance to FAW were identified in the Americas (Prasanna et al 2018). Various maize genotypes exhibit morphological and genetic traits that influence their resistance mechanisms. For example, increasing leaf epidermis thickness can enhance resistance by tolerating insect infestations (Davis et al 1995). Resistance mechanisms may also include structural barriers (e.g., waxes or tougher cell walls), antibiosis through toxic or repellent metabolites, or the release of hormones that attract natural enemies of the pest (McMullen et al 2009). Additionally, traits such as leaf length, leaf width, and trichome density negatively impact leaf damage caused by fall armyworm (Tiwari et al 2023). This study aimed to identify sources of fall armyworm resistance in different maize genotypes/varieties of Nepal, which can be utilized in breeding programs to develop resistant genotypes.

MATERIALS AND METHODS

Site selection

To screen the relative susceptibility of different maize genotypes to fall armyworm under field condition, field experiments was carried out in a randomized complete block design during 2020 and 2021 winter seasons (September to February) at National Maize Research Program, Chitwan, Nepal. The experimental site has the latitude of 27^0 40'N, longitude of 84^0 19'E and altitude of 228 m mean sea level.

Genotypes selection

An experiment composed of 37 elite maize genotypes were pulled from Open Pollinated Varieties (OPV=24 genotypes), Quality Protein Maize (QPM=7 genotypes) and (Hybrids=6 genotypes). The genotypes included standard checks such as Rampur composite, Arun-2, Deuti, Posilo Makai-1 and Rampur hybrid-10. Genotypes CAH 1715 and RML86/RML96 which were released by NMRP as Rampur hybrid-12 and Rampur hybrid-14, respectively, were also included.

Natural field condition

Fall armyworm is invasive insect pest and infestations occur throughout the year due to the absence of diapauses. Maize is the most preferred crop of the fall armyworm, and the condition in experimental site is highly suitable for maize farming round- year with irrigation facilities. This insect highly infests the crop under natural field conditions; therefore, this experiment was conducted under natural field conditions. The damage symptoms of fall armyworm in maize are more distinct than those caused by other insects associated with maize crop.

Crop geometry

For each genotype, two rows of maize, each five meters long, were maintained with crop geometry 60×25 cm. The individual plot area was 6 m^2. The recommended package of practices was followed during crop growth, as per the guidelines provided by National Maize Research Program (NMRP), Rampur, Chitwan. The maize crop was sown on the same date in both years during winter season (September, 19, 2020).

Data measurements

The genotypes were screened based on percent damaged plants and leaf injury scale. Infestation data, as mentioned below, was recorded first at knee height stage (25 days after seed sowing) and second at before tasseling stage (45 days after seed sowing). Yield parameters were measured during harvesting stage.

Foliar damage ratings

Early instar larvae scratch the leaf surface and consume the cholorophyll, while later instar larvae damage whorl of the maize crop.

Table 1. Indicating maize leaf rating scale (1-9 scale)

Scale	Description	Host reaction
1	No visible leaf feeding damage	Highly resistant (RH)
2	Few pin holes on older leaves	Resistant (R)
3	Several shot-holes injury on a few leaves	Resistant (R)
4	Several shot-hole injuries common on several leaves or small lesions	Moderately resistant (MR)
5	Elongated lesions (> 2 cm long) on a few leaves	Moderately resistant (MR)
6	Elongated lesions on several leaves	Susceptible (S)
7	Several leaves with elongated lesions or tattering	Susceptible (S)
8	Most leaves with elongated lesions or severe tattering	Highly susceptible (HS)
9	Plant dying as a result of foliar damage	Highly susceptible (HS)

Leaf-feeding damage caused by fall armyworm larvae was assessed using the modified scale developed by Davis and Williams (1992), which ranges from 0 (no visible damage) to 9 (whorl and furl leaves almost totally destroyed). The response of maize genotypes was classified as highly resistant, resistant, moderately resistant, susceptible and highly susceptible (Table 1 and 2).

Table 2. Indicating leaf damage rating scale/classification

Categories	Explanation/definition of damage	Rating
1	Minimum visible leaf damage (Least susceptible)	1-4
2	Marginal leaf damage (Moderately susceptible)	>4-7
3	Extensive leaf damage (Highly susceptible)	>7-9

Ear damage rating

Ear infestation data were measured during the harvesting stage using the rating scale developed by Paul and Deole (2020), as described in Tables 3 and 4. All plants in each plot were thoroughly examined, and the data were recorded as follows.

Table 3. Indicating maize ear and kernel rating scale

Description	Rating scale
No damage to any ears;	1
Tip (<3cm) damage to 1-3 ears	2
Tip damage to 4-7 ears	3
Tip damage to 7 and more ears and damage to 1-3 kernels below tips on 1 to 3 ears	4
Tip damage to 7 and more ears damage to 1-3 kernels below tips of 4 to 6 ears	5
Ear tip damage 7-10 ears and damage to 1-4 kernels below tips of 7 to 10 ears	6
Ear tip damage 7-10 ears and damage to 4-6 kernels destroyed on 7-8 ears	7
Ear tip damage to all ears and 4-6 kernels destroyed on 7-8 ears	8
Ear tip damage to all ears and 5 or more kernels destroyed below tips of 9010 ears	9

Table 4. Indicating corn ear and kernel rating scale/ classification

Explanation/definition of damage	Rating scale
Minimal damage to any ears (Least susceptible)	1-4
Kernels and ears damaged (Moderately susceptible)	>4-7
Ear and kernels extensively destroyed (Highly susceptible)	>7-9

Yield attributes

Cob diameter, cob length, 1000 grain weight were measured after harvesting of five sample cobs from each treatment. Cob diameter was measured by using Vernier caliper. Grain yield (kg per plots) at 15 percent moisture was converted into mt/ha and calculated with the help of following formula (Shrestha et al 2019):

$$\text{Grain yield (ton/ha)} = \frac{\text{Grain yield}\left(\frac{\text{kg}}{\text{plot}}\right) \times \text{selling \%} \times 10\,(100 - \text{moisture \%})}{\text{Net plot area (m}^2) \times 85}$$

Statistical analysis

During the current investigation, the mean leaf damage score of all plants within the genotype was calculated. The data collected from all genotypes were subjected to a one-way ANOVA (RBD).

Weather Parameters

Climate and weather can significantly influence the growth, development, and distribution of insects. During the experimental period, weather parameters were recorded from the weather station established at the National Maize Research Program. The recorded data are presented below in Figure 1.

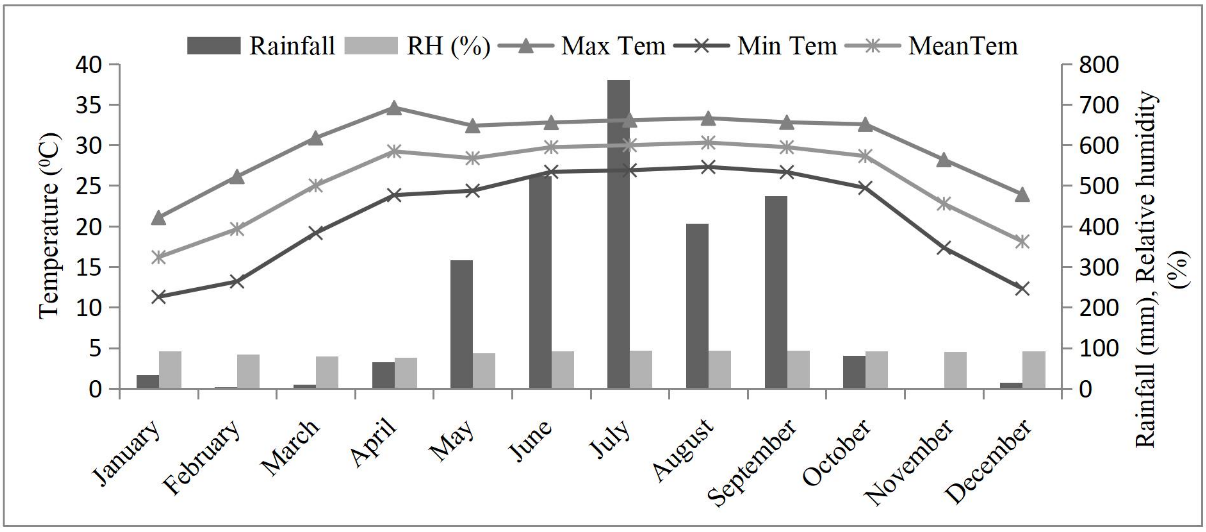

Figure 1. Meteorological data during experimental period (2020 and 2021) at Rampur, Chitwan, Nepal

RESULTS

Leaf and ear damage

Table 5 provides data on the performance of different maize genotypes categorized as early, quality protein maize, full-season, and hybrid genotypes, evaluated for leaf and ear damage using a 1-9 scale over two years (2020 and 2021) and a pooled analysis. The mean leaf damage scores of the maize genotypes ranged from 5.2 to 7.3 during the foliar stage and 2.0 to 6.0 during the ear stage in 2020, while in 2021, the scores ranged from 4.0 to 7.3 for leaf damage and 1.0 to 4.0 for ear damage. In the combined analysis, leaf damage scores ranged from 4.5 to 7.3, while ear damage scores ranged from 1.9 to 4.5 (Table 5). All the tested genotypes were found statistically non-significant on leaf damage score but significantly varied on ear damage, cob length, cob diameter, thousand grain weight and grain yield. Based on the rating scale, none of the genotypes were found resistant/tolerant against fall armyworm in this study and few of them were occurred least susceptible categories. The result showed that the mean damage score per plant was lowest in CAH 1715 (4.5) followed by Posilo makai-2, S0128 (5.2), Arun-3 (5.3), Rampur hybrid-10 (5.4), Manakamana-7 (5.5), R-POP-2 (5.6), RML86/RML96 (5.6), RML95/RML96 (5.7), Mankamana-3 (5.7) and SO1STYQ (5.8) and these wee at par with one another. In hybrid genotypes, variability in leaf damage is higher in hybrid genotypes (e.g., Rampur hybrid-6 has the highest pooled score of 7.0) but Rampur hybrid-10 and CAH 1715 showed the least ear damage in pooled analysis, with scores as low as 1.9 and suggesting potential resilience.

Table 5. Leaf and ear damage caused by fall armyworm on maize genotypes at Rampur, Chitwan during winter seasons, 2020 and 2021

Category	Genotypes	Leaf damage score (1-9 scale)			Ear damage score (1-9 scale)		
		2020	**2021**	**Pooled analysis**	**2020**	**2021**	**Pooled analysis**
Early genotypes	Arun-1	6.8	6.3	6.6	4.0	4.0	4.0
	Arun-2	6.3	6.0	6.2	4.3	3.3	3.8
	Arun-3	5.2	5.3	5.3	4.0	2.7	3.4
	Arun-4	6.5	6.7	6.6	4.0	3.3	3.7
	Arun-6	7.2	7.3	7.3	5.0	4.0	4.5
	EEYC-1	6.8	5.3	6.1	5.0	3.7	4.4
	02SADVI	6.7	5.7	6.2	4.7	4.0	4.4
	Across pp402	7.0	5.3	6.2	2.7	3.0	2.9
Quality protein maize	Posilo makai-1	6.2	6.3	6.3	3.7	3.3	3.5
	Posilo makai-2	5.2	5.0	5.1	2.7	1.7	2.2
	SPPTLYQ-HBAB	7.3	7.1	7.2	3.3	3.7	3.5
	SO3TLYQAB-02	6.3	6.7	6.5	2.7	2.0	2.4
	SO1STYQ	5.3	6.3	5.8	2.3	1.7	2.0
	SPPTLYQ-A	6.3	5.7	6.0	4.7	3.0	3.9
	CORRALJOS002SIYQ	6.0	6.0	6.0	2.7	3.0	2.9
Full season genotypes	ZM-401	6.7	6.7	6.7	3.7	4.0	3.9
	ZM-627	6.0	6.3	6.2	6.0	3.0	4.5
	Mankamana-3	6.3	5.0	5.7	2.3	1.7	2.0
	Manakamana-7	5.7	5.2	5.5	4.3	1.7	3.0
	Rampur composite	6.7	6.0	6.4	2.7	3.3	3.0
	Rampur-4	7.3	6.0	6.7	4.3	2.7	3.5
	Deuti	6.7	6.3	6.5	3.3	2.0	2.7
	BGBYPOP	6.7	5.7	6.2	4.3	2.0	3.2
	TLBRSO7F16	7.0	7.3	7.2	4.3	2.3	3.3
	RampurS13F26	6.3	6.0	6.2	3.3	1.7	2.5
	05SAVDI	7.2	7.3	7.3	5.0	4.0	4.5
	07SAVDI	6.3	6.3	6.3	4.3	3.3	3.8
	R-POP-2	5.7	5.5	5.6	4.0	2.3	3.2
	HG-7	6.0	6.3	6.2	4.7	3.7	4.2
	KSYNF10	6.7	6.0	6.4	6.0	3.0	4.5
	S0128	5.0	5.3	5.2	4.0	3.0	3.5
Hybrid genotypes	RML86/RML96	5.1	6.0	5.6	2.3	2.0	2.2
	RML95/RML96	5.7	6.3	6.0	3.3	1.7	2.5
	Rampur hybrid-4	6.8	6.7	6.8	3.3	1.0	2.2
	Rampur hybrid-6	7.3	6.7	7.0	3.3	1.3	2.3
	Rampur hybrid-10	5.5	5.3	5.4	2.0	1.7	1.9
	CAH 1715	5.0	4.0	4.5	2.7	1.0	1.9
	Grand mean	6.3	6.0	6.2	3.8	2.7	3.2
	CV, %	12.5	16.3	11.3	36.8	30.2	26.2
	P value	ns	ns	ns	*	**	**
	LSD	1.291	1.594	1.133	2.258	1.311	1.372

Note: CV=coefficient of variance, LSD=least standard deviation, ns=non significant, *=significant, **=highly significant

Cob length and Cob diameter

This dataset presents the results on cob length and cob diameter for different maize genotypes over the years 2020 and 2021, along with a pooled analysis (Table 6). In early genotypes**,** cob length ranged from 12.1 cm (Arun-1 and Arun-4) to 14.2 cm (Across pp402), with Across pp402 recording the highest pooled cob length in this group. Among quality protein maize genotypes, the highest cob length was observed in SO1STYQ (15.1 cm), followed by Posilo makai-1 (14.8 cm). In full-season genotypes, Deuti achieved the highest cob length (15.6 cm), followed closely by BGBYPOP and Mankamana-3 (15.2 cm each). Similarly, CAH 1715 recorded the highest cob length (16.5 cm), significantly surpassing other hybrid genotypes presented in Table 6. The study highlights genotypes such as CAH 1715 (hybrid), Deuti (full-season), and Across pp402 (early) for their superior performance in cob length and diameter. These results provide valuable insights for selecting high-yielding maize varieties suitable for different growing conditions and breeding programs.

Thousand grain weight and yield

The results presented in Table 7 showed that the thousand-grain weight ranged from 301g (Arun-1) to 409g (02SADVI). Among the categories, Across pp402 performed well with a weight of 388.0 g in early genotypes, whereas the highest thousand-grain weight in quality protein maize was recorded by SO1STYQ (452g), followed by Posilo Makai-1 (423g). Similarly, in open-pollinated full-season maize, Manakamana-7 (465g) and Deuti (460g) displayed superior performance, with Manakamana-3 (467g) leading slightly. Among the hybrid genotypes, CAH 1715 exhibited the highest thousand-grain weight (456g), outperforming the others.

The study recorded grain yields ranging from 1303 kg/ha (Arun-1) to 3201 kg/ha (Across pp402), with Across pp402 consistently demonstrating high productivity among early genotypes. In quality protein maize, SO1STYQ achieved the highest yield (4288 kg/ha), followed by Posilo Makai-1 (3406 kg/ha). Similarly, in open-pollinated full-season genotypes, BGBYPOP led this category with a remarkable yield of 4752 kg/ha, followed by Deuti (4155 kg/ha). Among hybrid genotypes, CAH 1715 exhibited an outstanding yield (6200 kg/ha), followed by RML86/RML96 (4888 kg/ha) (Table 7).

Table 6. Evaluation of cob length and cob diameter of different genotypes against fall armyworm at NMRP, Rampur during winter season 2020 and 2021.

Category	Genotypes	Cob length (cm)			Cob diameter (cm)		
		2020	2021	Pooled analysis	2020	2021	Pooled analysis
Early genotypes	Arun-1	11.6	12.5	12.1	3.7	3.8	3.8
	Arun-2	13.6	12.5	13.1	4.2	3.8	4.0
	Arun-3	12.5	11.8	12.2	4.1	4.0	4.0
	Arun-4	12.9	11.2	12.1	4.0	3.5	3.8
	Arun-6	10.7	14.2	12.5	3.1	4.2	3.7
	EEYC-1	12.3	12.2	12.3	4.0	3.9	3.9
	02SADVI	13.9	11.9	12.9	4.6	3.9	4.2
	Across pp402	14.3	14.1	14.2	4.6	4.2	4.4
Quality protein maize	Posilo makai-1	15.0	14.6	14.8	4.7	4.1	4.4
	Posilo makai-2	13.4	14.1	13.8	4.3	4.0	4.2

Category	Genotypes	Cob length (cm)			Cob diameter (cm)		
		2020	2021	Pooled analysis	2020	2021	Pooled analysis
	SPPTLYQ-HBAB	12.7	12.5	12.6	4.2	3.8	4.0
	SO3TLYQAB-02	13.3	13.1	13.2	4.1	3.6	3.8
	SO1STYQ	14.2	16.0	15.1	4.4	4.1	4.2
	SPPTLYQ-A	13.0	14.7	13.9	4.4	4.1	4.3
	CORRALJOS00 2SIYQ	12.9	13.9	13.4	4.3	3.8	4.1
Full season genotypes	ZM-401	14.3	14.8	14.6	4.3	3.8	4.1
	ZM-627	12.6	13.2	12.9	5.0	4.1	4.5
	Mankamana-3	14.4	15.9	15.2	4.6	4.1	4.4
	Manakamana-7	14.7	14.5	14.6	4.5	3.7	4.1
	Rampur composite	13.9	14.6	14.3	4.4	4.3	4.3
	Rampur-4	13.2	13.3	13.2	4.2	3.9	4.1
	Deuti	16.0	15.2	15.6	4.9	4.2	4.6
	BGBYPOP	14.9	15.5	15.2	4.7	4.5	4.6
	TLBRSO7F16	14.0	16.3	15.1	4.7	4.3	4.5
	RampurS13F26	13.8	15.0	14.4	5.1	4.0	4.6
	05SAVDI	14.3	15.7	15.0	4.7	4.1	4.4
	07SAVDI	12.4	12.6	12.5	4.5	3.9	4.2
	R-POP-2	13.3	14.3	13.8	4.5	4.3	4.4
	HG-7	14.7	12.7	13.7	4.7	4.1	4.4
	KSYNF10	13.4	13.7	13.6	4.4	3.9	4.1
	S0128	13.0	12.6	12.8	4.5	3.8	4.2
Hybrid genotypes	RML86/RML96	14.4	15.1	14.7	4.6	4.3	4.4
	RML95/RML96	14.4	15.2	14.8	4.5	4.2	4.4
	Rampur hybrid-4	15.3	14.4	14.9	4.2	3.8	4.0
	Rampur hybrid-6	15.5	15.5	15.5	4.7	4.3	4.5
	Rampur hybrid-10	13.6	12.9	13.3	4.0	3.7	3.9
	CAH 1715	15.3	17.7	16.5	4.1	3.9	4.0
	Grand mean	13.7	14.1	13.9	4.4	4.0	4.2
	CV, %	8.1	9.5	6.2	8.5	7	5.5
	P value	**	**	**	**	*	**
	LSD	1.803	2.176	1.413	0.608	0.453	0.374

CV=coefficient of variance, LSD=least standard deviation, *=significant, **=highly significant

Table 7. Evaluation of thousand grain weight and grain yield of different genotypes against fall armyworm at NMRP, Rampur during winter season 2020 and 2021.

Category	Genotypes	Thousand grain weight (gm)			Grain yield (kg/ha)		
		2020	2021	Pooled	2020	2021	Pooled
Early genotypes	Arun-1	329.3	272.0	300.7	1308	1298	1303
	Arun-2	441.3	312.0	376.7	2765	1644	2205
	Arun-3	360.0	293.3	326.7	1990	1590	1790
	Arun-4	349.3	272.0	310.7	2641	1626	2134
	Arun-6	336.0	442.7	389.3	1191	1765	1478
	EEYC-1	365.3	349.3	357.3	2131	1713	1922

Category	Genotypes	Thousand grain weight (gm)			Grain yield (kg/ha)		
		2020	2021	Pooled	2020	2021	Pooled
	02SADVI	432.0	386.7	409.3	2812	917	1865
	Across pp402	408.0	368.0	388.0	3929	2474	3201
Quality protein maize	Posilo makai-1	458.7	386.7	422.7	4896	1915	3406
	Posilo makai-2	424.0	410.7	417.3	3973	1742	2858
	SPPTLYQ-HBAB	424.0	392.0	408.0	3000	2054	2527
	SO3TLYQAB-02	373.3	378.7	376.0	4474	2097	3286
	SO1STYQ	482.7	421.3	452.0	5585	2992	4288
	SPPTLYQ-A	405.3	362.7	384.0	3427	2578	3002
	CORRALJOS002SIYQ	402.7	362.7	382.7	2998	2579	2789
Full season genotypes	ZM-401	429.3	373.3	401.3	3946	2933	3440
	ZM-627	456.0	362.7	409.3	2775	1270	2022
	Mankamana-3	482.7	450.7	466.7	5092	2530	3811
	Manakamana-7	557.3	373.3	465.3	4185	1971	3078
	Rampur composite	432.0	418.7	425.3	4072	2401	3237
	Rampur-4	450.7	398.7	424.7	3418	2386	2902
	Deuti	485.3	434.7	460.0	5290	3019	4155
	BGBYPOP	465.3	445.3	455.3	5902	3602	4752
	TLBRSO7F16	421.3	442.7	432.0	5377	1826	3602
	RampurS13F26	410.7	392.0	401.3	4185	2524	3355
	05SAVDI	408.0	410.7	409.3	4459	2018	3239
	07SAVDI	432.0	394.7	413.3	4147	1545	2846
	R-POP-2	464.0	408.0	436.0	3017	2391	2704
	HG-7	400.0	418.7	409.3	5085	2002	3543
	KSYNF10	429.3	413.3	421.3	4305	2797	3551
	S0128	418.7	413.3	416.0	3793	2547	3170
Hybrid genotypes	RML86/RML96	454.7	416.0	435.3	6726	3050	4888
	RML95/RML96	405.3	405.3	405.3	4819	2542	3681
	Rampur hybrid-4	381.3	390.7	386.0	5403	2851	4127
	Rampur hybrid-6	323.0	370.7	346.8	4339	2251	3295
	Rampur hybrid-10	464.0	421.3	442.7	4569	2439	3504
	CAH 1715	506.7	405.3	456.0	7116	5284	6200
	Grand mean	420.8	388.4	404.6	4031	2302	3166
	CV, %	15.6	11.8	10.3	22.7	35.7	18.2
	P value	*	**	**	**	**	**
	LSD	106.74	74.54	67.86	1488.1	1336.3	936.2

CV=coefficient of variance, LSD=least standard deviation, *= significant, **=highly significant

Susceptible categories

The rating of maize genotypes for fall armyworm susceptibility over the years 2020 and 2021 is presented in Table 8. Genotypes such as Rampur Hybrid-6, TLBRSO7F16, BGBYPOP, 05SAVDI, Arun-6, and SPPTLYQ-HBAB, were identified as highly susceptible to fall armyworm infestation. Among these, Arun-6, TLBRSO7F16, Rampur Hybrid-6, SPPTLYQ-HBAB and 05SAVDI consistently exhibited high susceptibility in the pooled analysis. A broad range of genotypes, including ZM-401, ZM-627, Mankamana-3, Deuti, BGBYPOP, Posilo Makai-2, SO1STYQ, Arun-1, Arun-2, Arun-4, 02SADVI, Across pp402, Rampur Composite, KSYNF10, EEYC-1, and 05SAVDI, were categorized as moderately susceptible.

Similarly, the genotypes Arun-3, Posilo makai-2, Manakamana-7, R-POP-2, S0128, RML86/RML96, Rampur hybrid-10, CAH1715 were the least susceptible in 2020. In contrast, Arun-3, EEYC-1, Mankamana-3, Mankamana-7, 02SADVI, BGBYPOP, 05SAVDI, R-POP-2, Across pp402, Posilo makai-2, SO1STYQ, S0128, Rampur hybrid-10, CAH 1715 exhibited lower susceptibility in 2021. In the combined analysis, genotypes such as Arun-3, SO1STYQ, Posilo makai-2, S0128, R-POP-2, Mankamana-3, Manakamana-7, RML86/RML96, Rampur hybrid-10 and CAH 1715 consistently showed the least susceptibility, demonstrating strong resilience across both years (Table 8).

Table 8. Classification of maize genotypes against fall armyworm based on kernel damage rating (1-9 scale)

Maize genotypes			Categories	Rating scale
2020	**2021**	**Pooled**		
Rampur hybrid-6, TLBRSO7F16, BGBYPOP, 05SAVDI	Arun-6, SPPTLYQ-HBAB, Rampur hybrid-6	Arun-6, TLBRSO7F16, Rampur hybrid-6, SPPTLYQ-HBAB, 05SAVDI	Highly susceptible	>7-9
ZM-401, ZM-627, Mankamana-3, Deuti, TLBRSO7F16, RampurS13F26, 07SAVDI, R-POP-2, HG-7, SO1STYQ, SPPTLYQ-A, CORRALJOS002SIYQ, Posilo makai-1, Across pp402, EEYC-1, Arun-6, Arun-4, Arun-2, Arun-1, Rampur composite, Rampur-4, RampurS13F26, SO1STYQ, SPPTLYQ-HBAB, , 02SADVI	Arun-1, Arun-2, Arun-4, , Posilo makai-1, SO3TLYQAB-02, ZM-401, ZM-627, Rampur composite, RampurS13F26, 07SAVDI, HG-7, RML86/RML96, RML95/RML96, Rampur hybrid-4, SPPTLYQ-A, CORRALJOS002SIYQ, Rampur-4, Deuti, KSYNF10,	Arun-1, Arun-2, Arun-4, 02SADVI, Across pp402, Posilo makai-1, , SO3TLYQAB-02, ZM-401, ZM-627, Rampur composite, RampurS13F26, 07SAVDI, HG-7, RML95/RML96, Rampur hybrid-4, Deuti, BGBYPOP, RampurS13F26, HG-7, KSYNF10, EEYC-1, CORRALJOS002SIYQ,	Moderately susceptible	>6-7
Arun-3, Posilo makai-2, Manakamana-7, R-POP-2, S0128, RML86/RML96, Rampur hybrid-10, CAH1715	Arun-3, EEYC-1, Mankamana-3, Mankamana-7, 02SADVI, BGBYPOP, 05SAVDI, R-POP-2, Across pp402, Posilo makai-2, SO1STYQ, S0128, Rampur hybrid-10, CAH 1715	S0128, CAH 1715, RML86/RML96, R-POP-2, SO1STYQ, Posilo makai-2, Mankamana-3, Manakamana-7, Arun-3, Rampur hybrid-10	Least susceptible	1-5

Correlation among the parameters

The correlation among yield parameters showed that cob length is positively correlated with cob diameter (p value>0.521) and grain yield (p value>0.657) (Table 9), indicating that longer cobs are generally associated with wider cobs and higher grain yields. Cob diameter also showed a positive correlation with 1000-grain weight (0.400) and grain yield (0.298), suggesting that thicker cobs contribute to heavier grains and slightly higher yields. Weak negative correlations were observed between leaf damage score and cob length (p value-0.123), cob diameter (p value-0.173), and grain yield (p value -0.216), implying that leaf damage negatively affects these parameters, though not strongly. Similarly, ear damage score showed negative correlations with cob length (p value-0.386) and grain yield (p value-0.529), suggesting that ear damage significantly reduces both cob length and yield. Among the yield-related traits, grain yield exhibited the strongest positive correlation with cob length (0.657), followed by cob diameter (0.298) and 1000-grain weight (0.260), highlighting the importance of cob size and grain weight in achieving higher yields. In contrast, grain yield had a strong negative correlation with ear damage score (-0.529) and a weaker negative correlation with leaf damage score (-0.216), demonstrating that damage, particularly ear damage, significantly reduces grain yield (Table 9).

Table 9. Correlation coefficient of yield parameters with leaf and ear damage

Parameters	Cob length (cm)	Cob diameter (cm)	1000 grain weight (gm)	Leaf damage Score (no.)	Ear damage score (no.)	Grain yield (kg/ha)
Cob length (cm)						
Cob diameter (cm)	*0.521					
Thousand grain weight (g)	0.337	*0.400				
Leaf damage Score (no.)	-0.123	-0.173	-0.216			
Ear damage score (no)	-0.386	-0.022	-0.118	0.032		
Grain yield (kg/ha)	*0.657	0.298	0.260	-0.216	*-0.529	

*cm=centimeter, gm=gram, kg=kilo gram, ha=hectare, *=significant, **= highly significant*

DISCUSSION

None of the genotypes in this study were found to be resistant or tolerant to fall armyworm. However, eight genotypes recorded a leaf damage score below 5, namely S0128, CAH 1715, RML-86/RML-96, R-POP-2, SO1STYQ, Mankamana-3, Manakamana-7, and Arun-3, which were classified as least susceptible genotypes. The present report supports the findings reported by Sapkota et al (2022), who noted that while no maize genotypes were completely resistant to fall armyworm, Rampur Composite, Posilo Makai, and Local Seto Makai showed lower susceptibility based on foliar damage intensity and yield performance. Davis et al (1992) reported that CML491, a QPM line, scored 6.0 on a standardized scale, classifying it as least susceptible to FAW. Gowda et al (2022) reported that the genotypes ENT 2-3, CML 111, CML 334, CML 336, BML 7, CML 139, CML 338, CM 500, CML 144, BML 6, AEBY 5-34-1, CML 330, CM 400, and CM 501 were identified as susceptible to fall armyworm, whereas the genotypes CML 71, CML 67, DMRE 63, CML 561, AEBY-1, CML 335, CML 345, and CML 337 were classified as moderately resistant. Many naturally occurring maize populations and germplasm showing resistance to FAW were indentified in the Americas (Prasanna et al 2018).

Recent studies by Farias et al (2014); Abrahams et al (2017); Kumela et al (2018) indicated that integrating host plant resistance has significant potential to enhance the effectiveness of FAW management programs. However, commercial maize cultivars with resistance to FAW are not yet available in Nepal. In contrast, the United States employed both native and transgenic FAW-resistant maize, with transgenic varieties demonstrating the highest levels of resistance (Wightman 2018; Williams and Davis 1997). This study highlighted the urgent need to screen diverse genetic resources and identify promising maize genotypes for FAW resistance breeding (Prasanna et al 2017).

Genetic mechanisms conferring resistance to fall armyworm (FAW) in maize can involve morphological features, such as structural barriers (waxes or tougher cell walls); antibiosis, which involves the production of metabolites toxic or repellent to insects; or hormones that attract insect predators (McMullen et al 2009). A study by Davis et al (1998) found that resistance in young plants was associated with the thickness of the cuticle and epidermal cell wall complex, which was nearly twice as thick in resistant plants compared to susceptible ones and contained higher levels of hemicellulose.

Our results also showed that leaf damage begins to escalate 7–10 days after infestation, with the most susceptible plant stage occurring around 21 days after infestation, when plants are more succulent, and larval development progresses. Moderately resistant/least susceptible genotypes such as S0128, CAH 1715, RML86/RML96, R-POP-2, SO1STYQ, Posilo makai-2, Mankamana-3, Manakamana-7, Arun-3, Rampur hybrid-10 exhibited less severe damage, possibly due to resistance mechanisms such as antixenosis or antibiosis (Wiseman et al 1981). Kasoma et al (2020a) also identified two landraces (ZM 4236 and ZM 7114) and one open-pollinated cultivar (Pool 16) for their desirable agromorphological traits and FAW resistance, making them valuable for developing maize cultivars suited to local conditions. One technique to enhancing maize resistance is increasing the thickness of the leaf epidermis, which enables plants to better tolerate insect infestations could be one of the best approaches (Davis et al 1995).

Our data showed that grain yield has a strong negative correlation with ear damage score and a weaker negative correlation with leaf damage score (Table 9), indicating that damage significantly hampers yield. Grain yield also showed negative correlations with fall armyworm leaf and ear damage, corroborating findings from previous studies (Hruska and Gould 1997; Lima et al 2010; Kumela et al 2018).

CONCLUSION

Based on leaf and ear damage ratings, none of the genotypes in our study were identified as resistant or tolerant to fall armyworm. However, some genotypes, including Arun-3, SO1STYQ, Posilo Makai-2, S0128, R-POP-2, BGBYPOP, Manakamana-3, Manakamana-7, RML86/RML96, Rampur hybrid-10, and CAH 1715 were categorized as least susceptible. These findings highlight the variations in susceptibility among maize genotypes across different years and emphasize the importance of selecting resilient genotypes for enhanced resistance and improved yield. Therefore, these cultivars can be further utilized in breeding programs to support research advancements. Additionally, breeding for insect resistance should prioritize identifying new resistance or tolerance lines while also deepening the understanding of previously identified resistance-related traits and mechanisms.

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Authors' Contributions

GS Bhandari: Conceptualization, writing, data analysis, methodology, writing–original draft. review and editing; P Bhandari and L Sah: writing, review and editing original draft.

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

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