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Enhancing crop-livestock systems: Unveiling the impact of leaf stripping on maize hybrid yield in Sundarbazar-Lamjung, Nepal

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Abstract

In local maize agro-ecosystems in Nepal leaf stripping is, historically, practiced as a source of fodder for livestock. However, its effects on hybrid maize have not been studied. The aim of this study was to determine how defoliation below the cob affects the grain and fodder production of hybrid maize and what value the stripped leaves have as fodder for ruminants. Seven hybrid maize cultivars were evaluated for their response to leaf stripping in a randomized complete block design with three replications in Sundarbazar, Lamjung, Nepal. Evaluation of phenological parameters, agronomic factors, cob properties, and grain yield revealed significant cultivar-related differences. While leaf stripping at grain silking stage had little or no impact on yield characteristics, the outcomes confirmed the significance of cultivar selection for the best grain and stover characteristics. Leaf stripping can be a clever way to increase ruminant's feed availability while maintaining grain output. The results of the study support the integration of leaf stripping as a sustainable management technique within crop-livestock systems, particularly in comparable agroecological zones. These findings provide smallholder farmers with useful advice for the use of green leaves as fodder during the grain silking stage of hybrid maize-based agricultural systems.

Keywords: defoliation, fodder, grain yield, ruminants, silking, sustainable

1 Introduction

Maize (*Zea mays* L.) is one of the most widely cultivated crops in the temperate, subtropical, and tropical climate zones of the world. It was domesticated about 7000 years ago in central Mexico. Maize, with a 2n = 20 chromosome, belongs to the tribe Maydeae and the family Poaceae. Due to its superior production potential compared to other cereals, it is often referred to as "the queen of cereals" (Singh, 2002). After paddy (*Oryza sativa* L.), maize is the second-most significant cereal crop in Nepal in terms of acreage and production. The area under maize cultivation in Nepal is 956,447 ha, with a total yield of 2,713,635 Mg and a mean productivity of 2.84 Mg ha^{-1} (MoALD, 2020). Most of Nepal's maize cultivation area is situated in the hilly regions (73.5 %). Specifically, in Lamjung, maize is cultivated across 43,896 ha with a productivity of 2.35 Mg ha^{-1} (MoALD, 2022). Maize offers a wider range of uses as food, fuel, and fodder as compared to other cereals.

Numerous global corporations have registered maize hybrids with Nepal's National Seed Board, leading to a substantial growth in hybrid maize cultivation in several districts of Nepal (Tripathi *et al*., 2016). Currently, 83 % of farmers in Nepal grow open-pollinated maize varieties, while 17 % cultivate hybrid varieties (Gairhe *et al*., 2021). The adoption of hybrid maize is increasing annually, although the diverse agro-ecological conditions in the country limit the suitability of commercial hybrids for cultivation (Tripathi *et al*., 2016). Therefore, identifying improved maize hybrids suitable for various agro-ecological zones is crucial.

Among various agronomic practices in maize cultivation, leaf stripping is a significant management technique in Nepal's crop-livestock farming system. The stripped leaves are used as fresh livestock feed. While the practice has been well adopted in Nepal, its impact on the production for hybrid maize varieties remains unknown. Leaf stripping not only affects maize grain yields but also alters stover yields, providing a valuable fodder resource. First, maize leaf stripping can influence both grain and stover (crop residue) yield (Komarek *et al*., 2021). Second, defoliating maize at times

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when access to forage is limited because farmers need to restrict livestock movement and access to pasture to protect crops, can increase the availability of green forage during the maize growing season (Komarek *et al*., 2021). Farmers in Lamjung use bullocks for draught purposes, especially during nursery bed preparation of paddy. That timeframe aligns with the maize silking period, and the removed leaves could serve as a valuable fodder source during this phase. Therefore, this study aimed to investigate how leaf stripping in maize hybrids influences grain and forage production and to assess the contribution of stripped leaves to livestock feed.

2 Materials and methods

2.1 Experimental site

The experiment took place from March to July 2023 in Sundarbazar, Lamjung, Nepal. Sundarbazar is located in Nepal's subtropical climate zone, experiencing an average annual rainfall of 203 mm. The experimental site was situated at an elevation of 610 m asl, with coordinates 28.1448° N latitude and 84.4120° E longitude. During the growing season (March to July 2023), the site received a total rainfall of 582 mm. The soil at the experimental site has a slightly acidic pH and a silt loam texture.

2.2 Experimental materials

In the experiment, seven hybrid maize cultivars, namely MX 77, Pioneer, Rampur Hybrid 10 (standard check), Rajkumar, CP 666, All-rounder, and CP 838, were used. Among these, three cultivars, CP 666, CP 838, and MX 77, were obtained from the Karma Group of Companies, while the remaining cultivars were sourced from the local market.

2.3 Experimental design and crop management

The experiment was designed as a 7×2 factorial experiment and implemented using a randomized complete block design (RCBD) with three replications. Within each replication, a total of 14 plots were established, comprising seven plots for each cultivar subjected to leaf stripping treatments and seven plots for control treatments (no leaf stripping). Each experimental plot measured 10.5 m^2 (3.5×3). The spacing between rows and plants was maintained at 65 cm × 25 cm (70 plants per plot). Fertiliser was applied at the rate of 120:60:40 NPK kg ha^{-1}. The complete dose of phosphorus (P) and potassium (K) and half the dose of nitrogen (N) were applied at the time of sowing. The remaining half dose of N was split into two applications: one at the knee-high stage during earthing up and the next at the pre-tasseling stage.

2.4 Leaf stripping

In the stripping treatment plots, all leaves below the cob were manually stripped when the cultivar reached the 50 % silking stage. The timing for leaf stripping varied among cultivars due to their different maturity lengths. In contrast, the control treatment plots were left untouched.

2.5 Data collection

Observations were made on various parameters including plant height 15 days after stripping (cm), leaf length and breadth (three randomly selected leaves above the ear height) 15 days after stripping (cm), stem girth 15 days after stripping (mm), and at harvest cob diameter (cm), cob length (cm), 1000 grain weight (g), and grain yield (Mg ha^{-1}). These observations were made on ten randomly selected plants from each plot. Only for grain yield the entire plot was considered, excluding the border rows. Leaf area index (cm^2) was calculated using leaf length and breadth as per Equation 1, as proposed by Mokhtarpour *et al*. (2010). Additionally, date of 50 % germination, date of 50 % silking stage, and date of 50 % tasseling stage were recorded for the entire plot. Similarly, observations were made on stripped leaf fresh weight (kg $plot^{-1}$), stripped leaves dry weight (kg DW $plot^{-1}$), and at harvest stover fresh weight (Mg ha^{-1}), and stover dry weight (Mg DW ha^{-1}). Dry weight was measured after keeping finely chopped leaf or stover in an envelope at 65 °C until constant mass. Grain yield (kg ha^{-1}) was calculated using the formula provided in Equation 2, adjusting for the desired moisture percentage at 12 %, a method also adopted by Shrestha *et al*. (2018) and Carangal *et al*. (1971), and later converted into Mg ha^{-1}.

$$\text{Leaf area index (cm}^2) = \text{L} \times \text{B} \times \text{A} \qquad (1)$$

Where, L = leaf length; B = leaf maximum width; and A = constant i.e., 0.75.

$$\text{Grain yield} = \frac{\text{FWT}(\frac{\text{kg}}{\text{plot}}) \times (100\text{-HMP}) \times \text{SCF} \times 10000}{(100\text{-DMP}) \times \text{NPS}} \qquad (2)$$

Where, grain yield in kg ha^{-1}; FWT = fresh weight of ear in kg per plot at harvest; HMP = grain moisture % at harvest; DMP = desired moisture percentage, i.e. 12 %; NPA = net harvested plot (m^2); SCF = shelling coefficient, i.e. 0.8.

2.6 Statistical analysis

MS Excel was employed to process all the collected data. The acquired data were statistically evaluated using the "Analysis of Variance" method with the computer program R

Studio. To determine the mean differences between the treatments, Duncan's Multiple Range Test (DMRT) was used (Gomez & Gomez, 1984) at $p < 0.05$ significant level.

3 Results

3.1 Phenology of maize cultivars

The results of the analysis of variance revealed significant variation in all the traits studied (Table 1) and showed significant cultivar-by-cultivar differences (at $p \leq 0.05$), indicating that the cultivars evaluated for genetic variation were quite diverse. Table 1 displays the mean value and coefficient of variance percentage for each of the qualities. All cultivars, except Rampur Hybrid, exhibited no significant difference in days to 50 % germination. CP 666 had the shortest duration to 50 % tasseling, followed by Rajkumar and Pioneer. Similarly, Pioneer had the shortest duration to 50 % silking, followed by CP666 and Rajkumar. ASI was highest for the CP 666 and lowest for the MX 77 and Pioneer.

Table 1: *Comparison of maize cultivars for their phenology.*

	Phenology stage in DAS			
Cultivars	*50 % ger.*	*50 % tas.*	*50 % silk.*	*ASI*
MX 77	9.67^{b}	81.00^{b}	82.50^{b}	1.50^{b}
Pioneer	10.17^{b}	75.83^{d}	77.33^{e}	1.50^{b}
RH 10	13.5^{a}	85.00^{a}	87.00^{a}	2.00^{ab}
Raj Kumar	9.67^{b}	77.16^{d}	79.33^{d}	2.17^{ab}
CP 666	10.83^{b}	73.16^{e}	75.83^{e}	2.67^{a}
All-rounder	10.67^{b}	79.50^{c}	81.50^{bc}	2.00^{ab}
CP 838	10.67^{b}	78.67^{c}	80.67^{cd}	2.00^{ab}
Grand mean	10.74	78.61	80.60	1.98
F-Test	***	***	***	*
CV %	10.98	1.50	1.60	29.37
LSD (0.05)	1.385	1.385	1.51	0.682

DAS = days after sowing, ger. = germination, tas. = tasseling, silk. = silking, ASI = anthesis silking interval. Columns with different superscripts are significantly different at $p \leq 0.05$. *significant at 5 % level, **significant at 1 % level, and ***significant at 0.1 % level.

3.2 Comparison of maize cultivars for traits before stripping

Statistical analysis revealed a significant difference in traits as shown in Table 2 due to cultivar. The leaf number was highest in Allrounder, followed by Pioneer and MX77, while it was observed to be lowest in Rajkumar and RH 10. Meanwhile, CP 838 exhibited the highest stripped fresh weight and leaf biomass. The lowest stripped leaf fresh weight was observed in RH 10, and the lowest stripped leaf dry weight was observed in Pioneer.

Table 2: *Comparison of maize cultivars for leaf number, stripped leaves fresh weight, and stripped leaves dry weight.*

		Stripped leaf (kg ha^{-1})	
Cultivars	*LN per plant*	*FW*	*DW*
MX 77	13.10^{ab}	2720.09^{ab}	551.57^{bc}
Pioneer	13.42^{a}	2720.80^{ab}	293.18^{d}
RH 10	12.54^{b}	948.89^{c}	642.53^{ab}
Raj Kumar	12.42^{b}	2463.51^{ab}	581.11^{bc}
CP 666	12.98^{ab}	1740.93^{bc}	428.88^{cd}
All-rounder	13.53^{a}	2444.04^{ab}	497.82^{bc}
CP 838	12.98^{ab}	3388.44^{a}	758.09^{a}
Grand mean	13.00	2346.67	536.17
F-Test	*	**	***
CV %	4.47	24.51	21.62
LSD (0.05)	0.682	1023.64	145.85

LN = leaf number (at the moment of stripping), FW = fresh weight, DW = dry weight. Columns with different superscripts are significantly different at $p \leq 0.05$. *significant at 5 % level, **significant at 1 % level, and ***significant at 0.1 % level.

Table 3: *Effect of leaf stripping and cultivar on plant height, leaf area index, and stover diameter at 15 days after stripping.*

	Plant height (cm)	*LAI (cm^{2})*	*stem diam. (mm)*
Stripping			
No stripping	189.18^{a}	424.10^{a}	13.56^{a}
Stripping†	189.19^{a}	432.08^{a}	14.08^{a}
F- Test	ns	ns	ns
Cultivar			
MX 77	211.36^{a}	521.66^{a}	15.01^{a}
Pioneer	204.82^{a}	407.52^{bc}	13.81^{abc}
RH 10	197.46^{ab}	476.96^{ab}	14.12^{ab}
Raj Kumar	174.68^{c}	385.22^{cd}	12.80^{bc}
CP 666	169.43^{c}	327.89^{d}	12.63^{c}
All-rounder	181.97^{bc}	379.14^{cd}	13.76^{abc}
CP 838	184.6^{bc}	489.23^{a}	14.61^{a}
Grand mean	189.19	428.09	13.82
F-Test	***	***	**
CV %	7.84	13.72	8.01
LSD (0.05)	17.60	69.71	1.314

†stripping at 50 % silking, LAI = leaf area index. Columns with different superscripts are significantly different at $p \leq 0.05$. *significant at 5 % level, **significant at 1 % level, and ***significant at 0.1 % level, ns = non-significant

3.3 Comparison of maize cultivars for traits 15 days after stripping

In this study, leaf stripping did not affect the agronomic traits as presented in Table 3. Plant height, leaf area in-

Table 4: *Effect of leaf stripping and cultivar on stover yield, cob characteristics, thousand-grain weight, and grain yield at final harvest.*

	Stover yield (Mg ha^{-1})		*Cob (cm)*		*1000 grain weight (g)*	*Grain yield (Mg ha^{-1})*
	FW	*DW*	*diametre*	*length*		
Stripping						
No stripping	18.36^{a}	6.31^{a}	3.90^{a}	16.66^{a}	176.23^{a}	5.09^{a}
Stripping†	14.81^{b}	5.20^{a}	3.86^{a}	15.67^{a}	162.25^{a}	4.45^{a}
F- Test	*	ns	ns	ns	ns	ns
Cultivar						
MX 77	23.27^{a}	9.07^{a}	3.75^{bc}	16.77^{abc}	131.28^{c}	4.74^{bc}
Pioneer	17.07^{ab}	5.82^{b}	4.12^{a}	15.83^{bc}	166.17^{abc}	5.26^{b}
RH 10	21.51^{a}	6.34^{b}	3.50^{c}	17.62^{ab}	173.33^{ab}	3.40^{c}
Raj Kumar	13.27^{bc}	5.01^{bc}	3.59^{c}	16.16^{abc}	176.36^{ab}	4.52^{bc}
CP 666	9.88^{c}	3.30^{c}	4.10^{ab}	13.34^{d}	200.78^{a}	4.20^{bc}
All-rounder	12.99^{bc}	4.86^{bc}	3.73^{bc}	14.94^{cd}	157.10^{bc}	4.06^{bc}
CP 838	18.11^{ab}	5.90^{b}	4.39^{a}	18.49^{a}	179.68^{ab}	7.19^{a}
Grand mean	16.58	5.76	3.88	16.16	169.24	4.77
F-Test	**	**	***	**	*	**
CV %	32.64	33.37	7.71	12.09	16.88	27.22
LSD (0.05)	6.42	2.28	0.355	2.32	33.91	1.54

†stripping at 50 % silking, FW = stover fresh weight, DW = stover dry weight. Columns with different superscripts are significantly different at $p \leq 0.05$. *sign. at 5 % level, **sign. at 1 % level, ns = non-significant.

dex, and stem diameter remained statistically similar in both stripped and non-stripped plants after 15 days of leaf stripping. However, all the attributes exhibited significant cultivar-by-cultivar differences ($p \leq 0.05$), with MX 77 displaying the highest values and CP 666 showing the lowest plant height, leaf area index, and stover diameter.

3.4 Comparison of maize cultivars for fodder yield after stripping

Leaf stripping had a significant effect on stover fresh weight yield at final harvest ($p \leq 0.05$). Non-stripped plants had a higher fresh fodder weight (Table 4). However, there was no significant difference between stripped and non-stripped plants in terms of stover dry weight yield. Statistical analysis revealed a significant ($p < 0.05$) variation in both stover fresh and dry weight yield among cultivars, with MX 77 having the highest mean in both, followed by RH 10 and CP 838. CP 666 was found to have the lowest stover fresh weight and dry weight yield.

3.5 Comparison of maize cultivars for grain yield after stripping

Leaf stripping did not have a significant effect on cob diameter, cob length, 1000 grain weight, and grain yield, as shown in Table 4. However, all the traits exhibited significant ($p < 0.05$) variations among maize cultivars. CP 838 had the highest mean cob diameter and cob length. CP 666 and RH 10 had the shortest cob length and smallest cob diameter, respectively. CP 666 exhibited the highest 1000-grain weight, while MX 77 had the lowest. In terms of grain yield, CP 838 had the highest yield, followed by Pioneer and MX 77. RH 10 was found to have the lowest grain yield.

4 Discussion

Comparable to our current research, Ogunniyan & Olakojo (2014) identified significant genotypic variations for 50 % tasseling and silking, anthesis-silking interval (ASI), and other traits in inbred lines of maize in Nigeria. They also highlighted significant genotypic variation among traits such as leaf number and leaf biomass in maize varieties. Stripped leaf biomass holds significance as a crucial feed source for ruminants during lean periods. According to the studies by Komarek *et al*. (2021) on the feeding of sheep with stripped leaves, the sheep in the control treatment (pasture only) lost weight on average daily, while the sheep in the stripping treatment (feeding with stripped leaves and subsequent rearing on pasture) gained weight daily. Despite the statistical insignificance of characteristics like LAI, plant height, and stem diameter between stripped and non-stripped plants, non-stripped treatments displayed a higher mean LAI, consistent with the findings of Reza Safari *et al*. (2013). The leaf's capacity to increase its surface area after defoliation is due to higher cell division or cell enlargement (Khaliliaqdam *et al*., 2012). According to Meyer (1998), after defoliation, since the leaf cannot form new leaf primordia, there is the possibility of increasing growth by enlarging the individual leaf area.

Defoliation did not impact stem diameter, as reported by Remison (1978). However, non-stripped plants yielded, obviously, higher fodder fresh weight at grain harvest as compared to stripped plants. This is due to the absence of leaves below ear height in stripped plants, affecting yield directly by altering aerial components and indirectly by reducing photosynthesis, as noted by Reza Safari *et al*. (2013). The dry weight percentage (DW %) in the stripped plants at the final harvest is 35.11 %, compared to 34.37 % for the non-stripped plants. Because the number of grains was determined 18 days after 50 % silking, Kabiri (1996) reported that the remobilisation of soluble solid materials from the stem to grains varied with the time of leaf removal, influencing the remobilisation of assimilates. The later the leaf removal after 50 % silking, the higher the remobilisation of assimilates from stem to grains. Additionally, when leaves were removed 12 days after 50 % silking, the concentration of stem carbohydrates was lost with less gradient than when leaves were removed 24 days after 50 % silking, according to Jones & Simmons (1983). Since stripping was performed precisely at 50 % silking stage, no significant difference in stover dry weight yield was observed in this study.

Similarly, cob length remained unaffected by defoliation, aligning with the findings of Remison (1978). Heidari & Amiriani (2022), also reported that the cob is crucial for seed development and needs to be fully developed before the actual seed formation takes place, and it appears to achieve substantial growth during the seed milking stage. The total grain yield showed a nonsignificant difference between stripping and non-stripping treatments which may be due to the older lower leaves being less photosynthetically active and contributing less to final grain filling. According to the study by Heidari & Amiriani (2022), the removal of the lower leaves of the ear at the seed milking stage, which are of limited importance for the production of photosynthetic material due to their age and shaded position, does not have a negative impact on seed weight. Moreover, the control plots displayed a higher 1000-grain weight, as demonstrated by Setter *et al*. (2001), who found that corn grain setting was influenced by leaf photosynthesis, sugar, starch, and abscisic acid concentrations. The difference in kernel weight can be attributed to the stem's relative capacity for storing assimilates, as indicated by Jones & Simmons (1983). Hence, in regions where forage is scarce during the maize silking stage, harvesting the maize leaves below the ear as livestock feed can be a viable option, and the fodder and grains can be harvested later without notable losses.

Overall, the study investigated the impact of maize leaf stripping on grain and fodder production in seven different hybrids in Lamjung. It is essential to further quantify the additional benefits of maize leaf stripping, particularly in meeting the fodder demands for animals, as this study found no statistically significant impact on maize grain output. Overall analysis of the results suggests that stripping leaves from maize plants could be a valuable farm management strategy worth exploring in the context of sustainable intensification choices within crop-livestock systems. Furthermore, the results indicated that selecting maize varieties with high grain production and desirable stover features was feasible. Leaf stripping could fulfil fodder requirements for maintaining ruminant body weight, without apparent effects on grain productivity and fodder biomass. Also, the need of green fodder for draught bullocks during nursery bed preparation of paddy (which often coincides with the spring maize silking period) could be sustainably fulfilled by utilising the stripped leaves. This implies that smallholder crop-livestock farmers in Sundarbazar, Lamjung, and similar agroecological zones should consider stripping maize leaves to provide fodder for their livestock during the maize silking period and excess leaves could be used for an extended period.

Conflict of interest

The authors declare that there are no conflicts of interest associated with the publication of this manuscript.

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