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PERFORMANCE EVALUATION AND TRAIT ASSOCIATION ANALYSIS OF PROSO MILLET GENOTYPES IN BAJURA DISTRICT, NEPAL

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ABSTRACT

Proso millet (Panicum miliaceum L.), an indigenous crop cultivated by the farmers in Bajura for generations, was once the major millet crop of the area. The crop is now experiencing a sharp decline due to shifting food preferences, yield reduction and limited crop improvement program, which has threatened the existence of the crop in Nepal's hill and mountains region. Therefore, an on-farm experiment was conducted using a randomized complete block design for the first time in Bajura, aimed at evaluating eight genotypes of proso millet—including two local landraces (Mal Chino and Dudhe Chino) and six accessions (NGRC07344, NGRC07345, NGRC07348, NGRC07349, NGRC07350, and NGRC07351) from the National Agriculture Genetic Resource Center (NAGRC)—under local conditions. The local landrace - Mal Chino outperformed all other genotypes yielding 2.06 t/ha and driven by maximum tillering (10.2), leaf number (69.73), and longest flag leaf (49.19 cm). Among the introduced lines, NGRC07345 recorded the second-highest yield (1.7 t/ha) and demonstrated adaptability in the studied region. Correlation and regression analysis identified flag leaf length and tiller number as a key determinant for grain yield. The study emphasized the potential of millets and landrace crops to improve food security and livelihoods in hilly and Himalayan areas of Nepal. Future efforts should be explored for multi-year and multi-location crop improvement study of promising and adapting genotypes to integrate in Nepal's formal seed system.

Keywords:

Future smart crops, landraces, revitalization, food security, yield performance

1 INTRODUCTION

Millet crops take sixth position among cereal crops that contribute to sustaining global food security, hence proclaiming them as future smart crops (Changmei and Dorothy, 2014). Proso millet (*Panicum miliaceum* L.) (*Chino* in Nepali) is one of the oldest domesticated millets, cultivated more than 10,000 years ago in Northern China (Liu et al., 2015; Rajasekaran et al., 2023). Though exact timing for domestication of proso millet is still a subject of debate, most of the archaeologists believe Northwest China, Central China, and Inner Mongolia as

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a primary centre of origin (Zhao, 2005; Lu et al., 2009; Bettinger et al., 2010). The crop is widely cultivated in the northern altitude of Hindu Kush Himalayan regional countries such as China, Nepal, India, Myanmar, Sri Lanka, Pakistan (Joshi et al., 2023). It thrives under low input conditions, tolerates drought, and performs well in marginal and less fertile soils, making it suitable for dry and high-altitude areas with erratic rainfall (Samineni et al., 2025; Kalinova and Moudry, 2006). In Nepal, although proso millet is typically cultivated in high hills and mountainous areas, successful cultivation has also been reported in low-altitude regions such as the western Terai, at around 200 masl (Raut et al., 2024). The inherent character it possesses makes it a potential crop to deal with the growing climate change impacts (Lagler et al., 2005).

Renowned for its unique nutritional qualities, it is considered a healthy food due to its high protein content, easily absorbed amino acids, and balanced array of trace elements including vitamin precursors (Habiyaremye et al., 2017). These traits make proso millet an increasingly important and valuable crop in the context of existing food and nutrition consumption. The high-hills and hilly areas of western region of Nepal including Bajura are highly rich in diversity proso millet (Ghimire et al., 2018). Bajura district, located in the far-western hills of Nepal, is one of the remotest regions that takes 77th position in terms of Human Development Index (0.364) with 71% of households residing below the poverty line (Human Development Index Report, 2015 and 2020). Agriculture is the prime source of livelihood with more than 80% of people engaged in it (Bhattarai et al., 2022). Millets have contributed a significant part among the communities of Bajura with production of 2,050 tons in 2,460 ha in the year 2022/23 (MoALD, 2023). A recent article by ‘The Kathmandu Post, 2025’ reported an export of 2.200 quintals of millets worth of 6.6 million Nepalese rupees in the FY 2023/24. Proso millet had served as a staple crop for the ages, contributing significantly to local food security and agricultural resilience (Rajput & Santra, 2016).

Despite its traditional importance and nutritional values, its cultivation has been gradually declining in hilly regions, and the farmers have shifted towards the cultivation of other cereal crops such as rice, wheat, and maize in recent years (MoALD, 2022). The low productivity, change in food habits, and shift in paddy farming are the reasons for decline for millet production, particularly proso millet (Ghimire et al., 2018). Moreover, the decline of millet production can be linked with more focus on crop improvement programs for rice, wheat and maize crops, and negligence in the study of millet crops (The Rising Nepal, 2023). In Bajura, proso millet cultivation is limited by several challenges, including rugged terrain, lack of improved varieties, poor input and manure supply, irrigation difficulties, traditional intercultural practices, and biotic stresses (Dhakal et al., 2023; Prechsl, 2008).To date, only a single variety of proso millet has been registered in Nepal (MoALD, 2022).Farmers continue to rely on local landraces with minimal agronomic support, limited mechanization, and poor market access. Moreover, water management practices are poorly adopted despite their significance in improving yield under increasingly erratic rainfall patterns. With the prioritization in conservation and promotion of millet crops by the year 2023 (FAO, 2018), the crop is revitalizing and is gaining changes in the local economy of the mountain region. Local initiatives and support from agricultural extension agencies in Bajura are beginning to promote millet cultivation through awareness campaigns, biodiversity block establishment, seed distribution, and the introduction of improved post-harvest practices (Dhakal et al., 2023; Bhandari et al., 2021; The Rising Nepal, 2023). The growing recognition of millet's role in climate adaptation and food sovereignty has stimulated interest in identifying and evaluating resilient landraces suitable for variety development and formal registration. Therefore, we studied six genotypes collected from the National Agriculture Genetic Resource Center (NAGRC) (Genebank) and two local landraces commonly available in the Bajura district to compare the phenological and yield performance of local landraces with collected genotypes from NAGRC. This study will be the baseline for generating evidence for identifying promising and resilient lines for further crop improvement programs and variety registration of local landraces of Bajura district. Moreover, this is the first systematic study conducted in Bajura to evaluate and compare the growth and yield performance of local landraces and collected genotypes of proso millet.

The objective of this study was to evaluate the growth and yield performance of local genotypes and collected accession lines to contribute to generating evidence for identifying promising and resilient lines for further crop improvement program and baseline for formal variety registration of local landraces of Bajura district. Moreover, research was also conducted to examine the interrelationships among agro-morphological and yield-related traits and to identify key determinants influencing grain yield, thereby supporting data-driven selection and breeding strategies.

2 MATERIALS AND METHODS

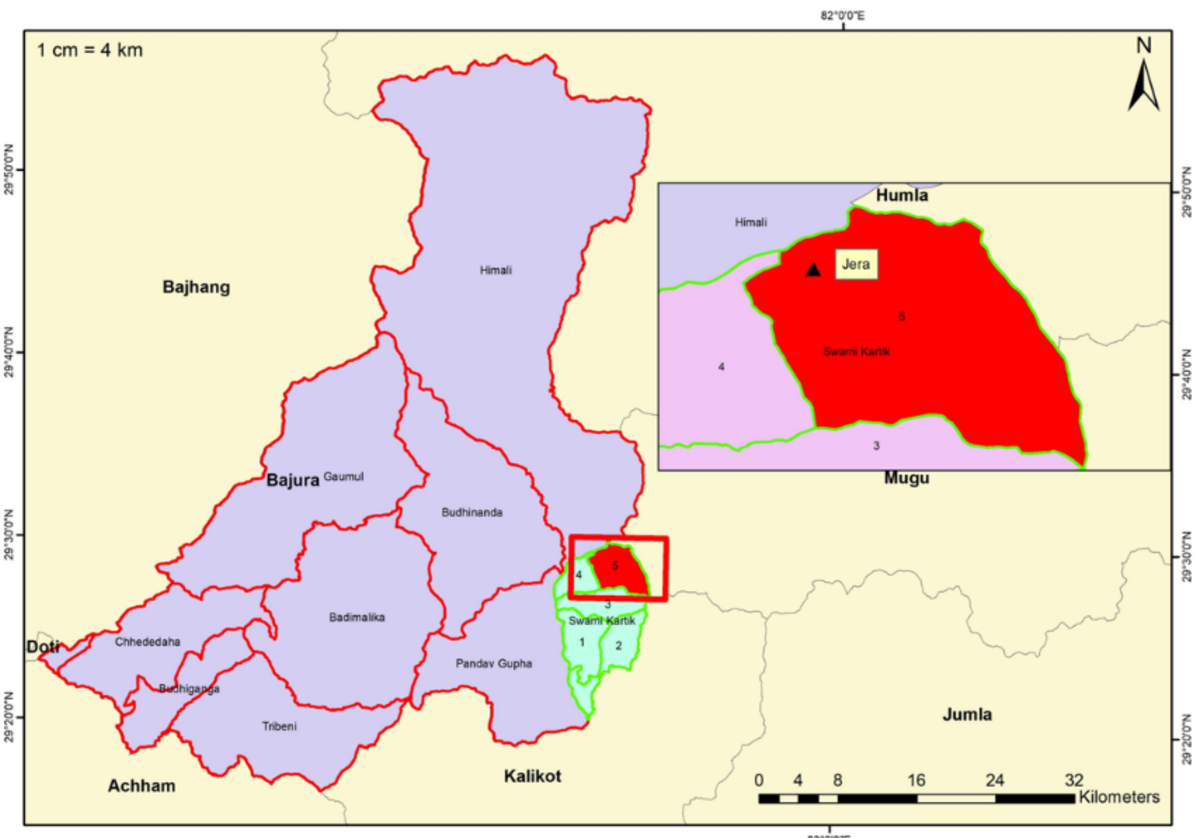

Figure 1 Geographical map locating the study area

2.1 STUDY AREA

The study was conducted from June to August 2023 at Jera village of Swamikartik Khapar Rural Municipality-5, Bajura district. The study site was geographically located at 29.4948°N latitude and 81.751°E longitude with an elevation of 1255 meters above sea level (masl). The region has an arid climate with minimal annual rainfall (500-850 mm) and the soil is mostly rocky and sandy (Environment Statistics of Nepal, 2019; Paudel et al., 2012). The climatic conditions over here and soil structure pose challenges for agricultural production, especially the climate sensitive high value vegetables and other crops, making it suitable for producing drought-resistant indigenous crops including proso millets.

2.2 TREATMENTS AND EXPERIMENTAL DESIGN

The field trial was conducted using a Randomized Completely Block Design (RCBD) with 8 treatments, representing 8 proso millet genotypes (two local landraces: Mal Chino and Dudhe Chino, and 6 accession lines from NAGRC) and three replications (Table 1). Mal Chino has the characteristics of shallow roots, narrow with dark green colored leaf, flat and pointed shaped seeds with shiny grey or umber color lined with creamy color. Similarly, Dudhe chino were characterized by thicker and longer roots, long, flat and light green colored leaves, oval to spherical seeds and creamy white to soft, beige-colored seeds. The accessions from NAGRC were selected based on the history of their origin and recommendations provided by the genebank. These accessions were previously collected from high altitudes of western region (Ghimire et al., 2018). These local landraces and accession lines were chosen to evaluate their performance under the local environmental conditions of Bajura. Each plot measuring 1.25m^2 (1m × 1.25m) was prepared, maintaining a spacing of 10 cm between the plants and 25 cm within the rows. At the beginning, continuous line sowing was made and upon emergence of seedlings the spacing between the plants was adjusted at 10 cm by scouting the surplus seedlings. Each individual plot was separated by 50 cm distance to minimize the edge effect and facilitate other intercultural operations. Five plants were selected randomly from each plot as a sample plants.

Table 1 Treatment details and source of collection of proso millet genotypes

Treatment	Genotypes	Source of Collection
T1	NGRC07344	NAGRC, Genebank Khumaltar
T2	NGRC07345	NAGRC, Genebank Khumaltar
T3	NGRC07348	NAGRC, Genebank Khumaltar
T4	NGRC07349	NAGRC, Genebank Khumaltar
T5	NGRC07350	NAGRC, Genebank Khumaltar
T6	NGRC07351	NAGRC, Genebank Khumaltar
T7	*Mal Chino*	Locally collected from Jera village
T8	*Dudhe Chino*	Locally collected from Jera village

2.3 LAND PREPARATION AND CULTIVATION PRACTICES

The experimental field was prepared by clearing any weeds and debris from the area. We applied a surface irrigation a week before ploughing to retain some moisture in soil. It was then ploughed to a depth of approximately 20-25cm with the use of spade followed by breaking up large soil clod and levelling the land to ensure uniformity across the experimental plots. Before ploughing, Farmyard Manure (FYM) was applied at the rate 750 kg/ropani to the whole plot. No additional organic or chemical fertilizers were applied at the time of field preparation. All agronomic practices such as irrigation and weeding were applied uniformly for all treatments in each plot. Irrigation was applied for three times i.e. 1 week prior to ploughing, 30 days after sowing (DAS) and 45 DAS). Weeding was done two times and was done 1 day before each irrigation applied after sowing of crops.

2.4 OBSERVED PARAMETERS

During the field experiment the following parameters were observed, and data were collected for further analysis.

2.4.1. Plant height

Plant height is an important growth parameter reflecting vegetative vigor and nutrient assimilation efficiency that is directly related to biomass accumulation and potential grain yield. It was recorded by measuring the above ground length of five tagged prosomillet plants from ground height to the tip of the uppermost leaf with the help of 1.5 m scale. Data was recorded when all of the plants ceased vegetative stage i.e. 45 DAS.

2.4.2. No. of tillers

Tillering capacity directly affects panicle number and hence grain yield. A higher number of fertile tillers is generally associated with increased yield potential in proso millet. The number of tillers was recorded at 45 DAS by counting the tillers bearing panicles or showing signs of panicle development.

2.4.3. Flag leaf length

The flag leaf is crucial for photosynthesis during grain filling. Its size, especially length, contributes significantly to the assimilated supply during reproductive stages. It was measured from the leaf base (ligule) to the leaf tip on the main tiller of five randomly selected plants per plot, when the flag leaf is fully expanded i.e. on 55 DAS. Measurements were taken using a measuring tape or scale.

2.4.4. Panicle length

Panicle length was measured from the base (peduncle attachment) to the tip of the panicle on five randomly selected plants per plot on 60 DAS. Measurements were recorded after panicle emergence and full development using a measuring scale.

2.4.5 Plot yield

At full maturity, all plants from the net plot area were harvested, threshed, and cleaned. The grain yield from each plot was weighed using a digital balance and recorded in grams.

Grain yield in grams per plot was extrapolated to tonnes per hectare using the following formula:

$$Grain\ yield\ \left(\frac{t}{ha}\right) = \frac{plot\ yield\ (gm)}{plot\ area\ (m2)} * 10$$

2.5 STATISTICAL ANALYSIS

The collected data was tabulated using MS Office Excel (2019) and subjected to analysis of variance (ANOVA) to assess the significance of difference among the genotypes using GenStat. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at a 5% level of significance using the method given by Gomez and Gomez (1984). The association of different growth and yield parameters were analyzed using correlation and regression analysis using SPSS software (version 24.0). Regression model was calculated by using the formula,

$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ip}$

Where,

i=*n* observations y_i =dependent variable x_i=explanatory variables

β_0=y-intercept (constant term) β_p = slope coefficients for each explanatory variable

3 RESULTS

3.1 YIELD AND YIELD ATTRIBUTING TRAITS

3.1.1 Plant height

The Analysis of Variance (ANOVA) showed significant differences in plant height ($p < 0.05$) for the tested genotypes. The plant height (149.49 – 198.25 cm) ranged with the mean average of 179.04 cm across the genotypes. Local landrace, *Mal Chino* possessed the lowest plant height (149.49 cm) followed by NGRC07344 (176.04 cm) and NGRC07348 (176.03 cm). In contrast, *Dudhe Chino*, another local landrace, recorded the tallest plant height (198.25 cm) (Table 2).

3.1.2 Tiller number

Tiller number does not possess a significant difference among the tested genotypes. The tiller number (6.27 – 10.2) ranged with the mean average of 7.3 across the genotypes. *Mal Chino* recorded a maximum tiller number (10.2) followed by the genotypes NGRC07345 (8.33) and NGRC07344 (7.67). A minimum tiller number was recorded in genotype NGRC07350 (Table 2).

3.1.3 Leaf number

A significant difference ($p < 0.01$) was observed among the tested genotypes for leaf number. The leaf number (38.8 – 65.6) ranged with the mean average of 51.89 across the genotypes. The highest leaf number was recorded in *Mal Chino* and lowest in NGRC07350 (Table 2).

3.1.4 Panicle length

Panicle length showed a significant variation among the tested genotypes ($p < 0.01$). The panicle length (39.84 cm – 45.6 cm) ranged with the mean average of 43.84 cm across the genotypes.

The results showed maximum length of panicle in *Mal Chino*, resembling a statistically similar value with *Dudhe Chino*, NGRC07344, NGRC07345, NGRC07350 and NGRC07351. In contrast, minimum panicle length was observed in NGRC07349 (Table 2).

3.1.5 Flag leaf length

ANOVA revealed significant differences in flag leaf length ($p < 0.05$) across the tested landraces. The flag leaf length (42.21 cm – 49.19 cm) ranged with the mean average of 44.73 cm across the genotypes. *Mal Chino* was characterized by the longest flag leaf followed by NGRC07345 and NGRC07350, and NGRC07344 possessed the shortest flag leaf (Table 2).

3.1.6 Grain yield

Grain yield (MT/ha) showed a significant variation for the tested genotypes of proso millet ($p < 0.01$). The highest yield (2.06 MT/ha) was observed in *Mal Chino followed by NGRC07345 (1.7 t/ha) and NGRC07348 (1.7 t/ha), which are statistically similar with Mal Chino.* In contrast, another local variety, Dudhe Chino exhibited the lowest grain yield (1.24 t/ha) (Table 2).

Table 2 Mean comparison of yield and yield attributing traits of proso millet genotypes

Genotype	Plant height (cm)	No. of tillers	No. of leaves	Panicle length (cm)	Flag leaf length (cm)	Yield (t/ha)
Mal Chino	149.49^{a}	10.2^{a}	65.6^{a}	45.60^{a}	49.19^{a}	2.06^{a}
Dudhe Chino	198.25^{c}	6.27^{b}	51.05^{b}	44.52^{a}	42.72^{bc}	1.24^{c}
NGRC07344	176.04^{b}	7.67^{ab}	52.2^{b}	44.35^{a}	42.21^{c}	1.35^{bc}
NGRC07345	190.78^{bc}	8.33^{ab}	53.07^{b}	46.29^{a}	47.60^{ab}	1.7^{ab}
NGRC07348	176.03^{b}	7.07^{b}	50.47^{b}	39.84^{b}	44.06^{bc}	1.7^{ab}
NGRC07349	177.62^{bc}	6.67^{b}	50.70^{b}	41.33^{b}	42.53^{bc}	1.32^{bc}
NGRC07350	181.01^{bc}	5.9^{b}	38.80^{c}	44.07^{a}	46.23^{abc}	1.4^{bc}
NGRC07351	183.1^{bc}	6.33^{b}	53.20^{b}	44.68^{a}	43.30^{bc}	1.4^{bc}
GM	179.04	7.3	51.89	43.84	44.73	1.4
Sem (±)	7.15	0.95	3.28	0.82	1.563	0.13
LSD (α=0.05)	22.68	2.87	9.94	2.49	4.741	0.9656
CV (%)	6.92	22.51	10.94	3.24	6.1	15.1
F test (α=0.05)	*	ns	**	**	*	**

3.2 ASSOCIATION OF YIELD AND YIELD ATTRIBUTING TRAITS

The significance of the association of yield and yield attributing traits was examined using simple correlation analysis. The coefficient of yield was strongly significant and positively correlated with the tiller number ($r = 0.757^{**}$), leaf number ($r = 0.659^{**}$) and flag leaf length ($r = 0.65^{**}$), and weak but positive correlation with panicle length ($r = 0.323$), suggesting that more tillers and leaves, and longer flag leaf and panicle contribute to increased yield. In contrast, yield showed weak but negative correlation with plant height ($r = -0.316$) (Table 3).

Table 3 Correlation analysis among yield and yield attributing traits

	Plant height	Tiller number	Leaf number	Panicle length	Flag leaf length	Yield
Plant height	1					
Tiller number	-0.365	1				
Leaf number	-0.301	0.854**	1			
Panicle length	0.13	0.36	0.383	1		
Flag leaf length	-0.292	0.445*	0.347	0.357	1	
Yield	-0.316	0.757**	0.659**	0.323	0.65**	1

***Significant at p<0.01, *Significant at p<0.05*

A multiple regression analysis was conducted to evaluate the relationship between grain yield and yield attributing traits and the calculated regression model is,

$$Y = -267.893 - 2.181 X_1 + 25.510 X_2 + 1.049 X_3 + + 0.211 X_4 + 12.064 X_5$$

$$r^2 = 0.7$$

Where Y is grain yield, X_1 is plant height, X_2 is tiller number, X_3 is leaf number, X_4 is panicle length, and X_5 is flag leaf length.

The regression analysis revealed that grain yield of the tested genotypes showed significant coefficients of determination ($r^2 = 0.7$) with yield attributing traits. These indicate that 70% variation in grain yield was due to the combined effect of five yields attributing traits i.e. plant height, tiller number, leaf number, panicle length, and flag leaf length, and the rest of 30% variation in grain yield is due to other factors.

Among the independent variables, tiller number and flag leaf length are the most influential variables, given their larger positive coefficients, indicating that focusing on the improvement in these traits could significantly boost grain yield. Plant height has a negative effect, which might suggest that taller plants could be less productive due to resource allocation on vegetative parts rather than the yield.

4 DISCUSSIONS

The study showed significant variations in the parameters observed which highlight the potential of genetic diversity within these millet genotypes. The result suggested the promising adaptability of some genotypes to the low moisture and nutrient deficient soils typical of Bajura district. Notably, the local landrace Mal Chino recorded the highest grain yield at 2.06 t/ha, attributed to its superior character for tiller number, total number of leaves, panicle length, and flag leaves length, which likely enhanced its photosynthetic efficiency. Mal Chino has been traditionally cultivated in the region, suggesting its adaptation may be deeply rooted in its long-term exposure to local agroecological stresses. Bajura, characterized by poor soil fertility, erratic rainfall, and limited access to agricultural inputs, might benefit significantly from the promotion of such resilient cultivars.

In addition to Mal Chino, NGRC07345 also showed potential, producing 1.7 t/ha grain yield with a comparatively high tiller number, and long flag leaves. Its performance, close to that of Mal Chino, suggests it could be a promising genotype for future participatory trials and breeding efforts, especially if combined with locally adaptive traits. NGRC07347, though having equal yield potential to NGRC07345, had slightly shorter panicles and fewer tillers. Yet, its yield parity with NGRC07345 indicates efficient genetic potential, resource use and potentially better stress adaptation.

In contrast, Dudhe Chino, despite its taller height, recorded a lower yield (1.24 MT/ha). This might be due to its lower tiller number (7.2 tillers / plant) and shorter flag leaves (21.4 cm) limiting its overall grain production efficiency. The variation among genotypes might be due to genetic potential. Our findings align with the study of Asnake et al. (2023) and Dash et al. (2018), who highlighted differences among crop varieties associated with their genetic makeup.

Our result also aligns with the study of Saline et al. (2010), Subedi et al. (2022), Khatun et al. (2023), Singode et al. (2023) and Raut et al. (2024), who found significant difference among germplasms. Phenotypic correlations among plant traits can inform the selection of genotypes with desirable characteristics for breeding programs. Traits like tiller numbers, panicle length, and flag leaf dimensions, which are positively associated with grain yield components, highlight their potential as key indicators for enhancing productivity and selecting lodging-resistant genotypes (Selvi et al., 2014). Tiller numbers can significantly contribute to yield suggesting selection of germplasm with high tillering behavior for higher productivity (Liu et al., 2015). The higher tillering capacity of local landrace *Mal Chino* could better explain its superior yield performance even under a low moisture and poor nutrient soil. This statement is supported by Martinez et al. (2015), which states that the tiller number is positively correlated with the grain yield in rice. In our study, flag leaf length, associated with the photosynthesis capacity of the plant, is associated positively with the grain yield (β=12.064). Larger flag leaves provide greater surface area for photosynthesis, enhancing grain filling. This is consistent with the research conducted by Siddique et al. (1989) which states, larger leaves, particularly flag leaves contribute significantly to wheat yield under water limited conditions, as larger flag leaves help capturing more light for photosynthesis, especially in the later stage of crop development. Flag leaves play a critical role in supporting grain development, as their removal led to significant defects, including delayed maturation, reduced grain size, and increased sterility (Racz et al., 2022). The observed two-fold reduction in 100-grain weight in rice cultivars underscores the importance of flag leaves as a primary source of photosynthates essential for grain filling and overall yield (Rahman et al., 2013). The higher yield achieved in *Mal Chino* may partly be associated with its longer flag leaf enhancing photosynthesis during critical stage of grain development.

5 CONCLUSIONS AND RECOMMENDATIONS

The study highlights the agronomic superiority of the local landrace *Mal Chino,* which exhibited significantly higher yield and better morphological traits including shorter plant height, greater tiller and leaf numbers, longer panicles and flag leaves under low-input, stress-prone conditions in Bajura. NGRC07345, an accession collected from the national gene bank, also demonstrated yield potential comparable to *Mal Chino*, supporting its scope for further participatory breeding and selection programs. The findings reveal that tillers, leaves and flag leaf length are critical yield determinants, accounting for a major portion of yield variability that needs more emphasis in future selection and breeding strategies. Importantly, this is the first scientific evaluation of proso millet genotypes conducted in Bajura, offering a crucial baseline for future variety selection and registration. To validate and scale these results, multi-location and multi-year trials are essential in the same agro-ecological condition of Bajura district. Strengthening local seed systems through participatory approach might be the key steps towards genetic conservation, and revitalization of millet-based farming systems in the marginal and resource poor conditions of hill regions Bajura.

DECLARATION

The authors declare no conflict of interests.

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