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On-Farm Experiment to Assess the Suitability of Millet Types and Landraces

Rajendra Dhakal[1], Kailash Bhatta[2], Pragati Sipkhan[2] and Oshin Sharma[1]

[1]International Centre for Integrated Mountain Development (ICIMOD), Lalitpur; RD radhakal@icimod.org , OS ossharma@icimod.org

[2]Local Initiatives for Biodiversity, Research and Development (LI-BIRD); KB kailash.bhatta@libird.org, PS pragati.sipkhan@libird.org

Abstract

In Nepal's Himalayan regions, millets hold significance as resilient cereal crops, valued for their nutrition and adaptability to challenging climates and contributing to food and nutrition security. However, their cultivation and consumption have declined due to shifting food preferences, market constraints, climate change, pests, and diseases. The on-farm experiment was conducted in Bajura to address these challenges, allowing farmers to directly experience the benefits of millet cultivation and select landraces based on desired parameters. The on-farm experiment featured five millet types ie finger millet, sorghum, foxtail millet, barnyard millet, and porso-millet and 14 landraces collected from the local farmers, diversity fairs, seed exchange, and the National Agriculture Genetic Resource Centre (Gene Bank). Agro-morphological parameters such as plant height, days to flowering, seed yield, disease, plant resistance to disease, and pests were monitored by farmers, revealing significant diversity among millet landraces and millet types. Proso-millet emerged as a standout performer, displaying a shorter day to maturity, moderate disease resistance, and a high yield of 1.7 tons per hectare. Finger millet, while yielding up to 0.9 tons per hectare, exhibited disease susceptibility. Sorghum's *Jera Sthaniya* demonstrates high disease resistance with a 0% incidence of blast disease, making it a promising choice for disease-prone regions. Foxtail millet exhibited moderate disease resistance, yielding 0.8 tons per hectare. Notably, local millet landraces consistently outperformed imported landraces in disease resistance and yield, underscoring the value of preserving indigenous genetic resources. Collaborative efforts between farmers and researchers provide immediate benefits and support the long-term conservation and improvement of millet crops.

Keywords: Agricultural resilience, agro-morphological parameters, food security, landraces, millets, on farm experiment.

Introduction

Millets are a group of small-seeded cereal crops renowned for their remarkable adaptability to various challenging agro-ecological environments (Fuller 2014). In the Himalayan regions of Nepal, millets have served as cornerstones of sustenance and culture for generations (Kumar et al 2018). These hardy cereal crops are renowned for their remarkable adaptability to various challenging agro-ecological environments, including the demanding climatic conditions of Nepal's high mountains (Sukumaran Sreekala et al 2023).

There are 12 cultivated millet species, nine wild relative species, and 1,100 millet landraces in Nepal. Finger millet is the most important crop in area and production, followed by proso millet and foxtail millet. Sorghum, barnyard millet, pearl millet, little millet, and kodo millet are also grown in some parts of the country (Ghimire et al 2017, NARC 2023). Millet's historical significance is deeply rooted in their role as not just sources of nutrition but as symbols of resilience against the backdrop of challenging terrain and unpredictable weather patterns. Millets, serving as staple food sources, have played a pivotal role in bolstering food security, and sustaining the livelihoods of local communities in these regions (FAO 2023).

However, the traditional cultivation and consumption of millets have experienced a gradual decline, influenced by a constellation of factors (Kumar et al 2018). Rapid changes in dietary preferences driven by urbanization, limited availability of diverse millet varieties, and the pervasive influence of mainstream crops have shifted the landscape of agricultural practices (de Bruin et al 2021). Modern market constraints and the allure of alternative food sources have further marginalized millets, diminishing their once-central status (Hawkes et al 2017). The CBS annual household survey data presents a significant shift in consumer preferences between 2015/16 and 2016/17, with a marked decrease in urban millet consumption and a slight dip in rural areas. This shift is notable as only 3.5 percent of households nationwide now opt for millet as a dietary choice. Similarly, Thapa et al (2019) studied dietary patterns from 1993 to 2011 in Nepal unveiled a gradual transformation in consumer choices. Nepalese consumers moved from low-cost, calorie-rich foods to more expensive, calorie-dense alternatives. This shift in dietary preferences was facilitated by factors such as rising income levels, evolving lifestyles, and other contributing elements. Over the past 32 years (1990/91 to 2021/22), Nepal's millet cultivation area has remained relatively stable despite a decrease in the percentage of agricultural households. While total millet production has shown an upward trend, it falls short of making Nepal self-sufficient in cereal production (MoAD 2015, MoALD 2023). The country's heavy reliance on millet imports is evident, substantially increasing from Rs 722 million in 2021/22 to Rs 732 million in 2022/23 (TAE 2023).

Millet faces several constraints and challenges in Nepal's food system. Policy constraints hinder the effective implementation of well-intentioned millet promotion policies due to inadequate coordination (Gyawali 2021), limited resources, political instability (Joshi and Joshi 2021), and a lack of evidence-based research (Khadka et al 2014). Market challenges include poor access, lack of standards, certifications, branding, and market information. From a consumer perspective, millet is often perceived as a crop for the marginalized, with low social status compared to rice and wheat (de Bruin et al 2021). Technological constraints involve labour-intensive processes, a need for improved seed varieties, and inadequate equipment (Gyawali 2021, Shrestha et al 2020). Behavioural issues include negative perceptions of millet and a lack of awareness of its nutritional benefits. Disappearing culinary traditions compound the problem, as more convenient options replace millet due to urbanization and globalization.

Bajura is one of the remote areas of Nepal that lies in 77th position in terms of the Human Development Index (HDI) with the lowest value (0.364) (Human Development Report 2015). About 71% of Bajura's households live below the poverty line (Human Development Report 2020). The Agricultural Knowledge Centre (AKC) in Bajura has reported a production of 5,250 metric tonnes from 50,250 hectares of land in the fiscal year 2021/2022. This trend has been declining due to the lack of facilities such as market access, road transportation, agri-input facilities, and storage facilities. Due to all these factors and the low production potential of indigenous crops, the farmers are shifting cultivation to paddy and wheat crops using improved and hybrid varieties. According to a news report by The Rising Nepal (2021), millet production in the Bajura district is only 15% compared to native crops such as paddy and wheat. In the past, farmers used to grow mainly landrace such as proso millet (*Kathine Chino, Mal Chino, Aulo Chino,* *Dudhe Chino, Lekali Chino*), foxtail millet (*Rato Kaguno, Seto Kaguno, Bariyo Kaguno*), barnyard millet, sorghum (*Hunalo, Junalo*), finger millet (*Kano Kodo, Kalo Kodo, Goro Koda, Laafre Kodo, Dalle kodo*), buckwheat (*Tite Phapar, Mithe Faapar, Bhadule Fapar*), barley (*Thanga jau, Jhuse jau, Lekali Jau*), local landrace of rice (*Jumli Marsi, Satuke, Thapa Chino, Kalo Dhan*) and wheat (*Mule Gahu, Jhuse Gahu, Rato Bhabri, Seto Bhabri, Ramale, Geru Gahu).* However, most landraces are in the extinction phase or have disappeared completely.

Compounding these issues is the shadow cast by climate change, which has introduced a layer of uncertainty and instability to agricultural systems. The emergence of new pests and diseases, often facilitated by changing climatic conditions, has added to the challenges farmers face (FAO 2023). In the face of these multifaceted challenges, there is a pressing need for innovative approaches that revive millet cultivation and enhance its resilience in an increasingly unpredictable environment.

In the Bajura district of Nepal, an on-farm experiment is being conducted to find the suitable millet type and landrace at Bajura district. Moreover, it shows the diversity of millet types and landrace among farmers. It aimed to create a platform for farmers to directly experience the benefits of millet cultivation and collaboratively select specific landraces based on desired parameters. This experiment bridges traditional wisdom and modern agricultural science, creating a dynamic platform to test the boundaries of millet cultivation under real-world conditions. The experiment features a curated selection of five millet types-finger millet, sorghum, foxtail millet, and proso millet—alongside 15 distinct landraces, providing an experimental arena for exploring the possibilities of millet cultivation.

The core philosophy of the on-farm experiment centres on experiential learning and active collaboration with the primary stewards of these lands—the farmers themselves. By blending local wisdom and external expertise, the on-farm experiment harnesses the power of traditional knowledge while infusing it with scientific rigour. This synergy creates an environment where farmers can directly witness the benefits of diverse millet landrace, helping them make informed decisions about which landrace best suits their specific needs and the demands of their local ecosystems.

Methodologies

The study was conducted in the Swamikartik Khapar rural municipality, Ward 5, Jera of Bajura district, Nepal. The study site has a long history of growing millet such as finger millet, foxtail millet, proso millet, sorghum, and barnyard millet for consumption. This area's climate and soil conditions are ideal for growing millet, and the farmers have a wealth of knowledge about traditional millet cultivation practices. The region was selected for this study because of its high millet diversity and the farmers' willingness to participate in research.

This study employed an on-farm experiment approach to assess the performance of various millet types (finger millet, foxtail millet, proso millet, sorghum, and barnyard millet) and highlight the rich diversity within the millet group. The on-farm experiment consisted of five millet species and 14 different landraces (**Table 1**), procured from various sources, including local seeds collected from the farmers, seeds collected through diversity fairs and seed exchange programmes, and the National Agriculture Genetic Resource Centre (Gene Bank). Farmers' preferences for specific agro-morphological parameters were considered during the selection process. Each millet landrace was cultivated in plots measuring 2 meters by 3 meters. The experiment was carried out using the Randomized Completely Block Design (RCBD), which is well-suited for our homogeneous field conditions. Each treatment was replicated three times to ensure robust results. All landrace crops and genotypes received the same level of inputs and irrigation to ensure a fair comparison. The plot preparation and plantation were done on June 10, 2023, and the harvesting was done on different dates based on the crops and their landrace. Irrigation and weeding were done twice at 30 DAS and 45 DAS.

The study meticulously recorded data on agro-morphological parameters such as plant height, days to flowering, seed yield, disease incidence, and insect infestation. The disease incidence and insect infestations were recorded based on the farmer's visual observation and the frequency of infection and infestation on plots. This method involves counting the number of plants in a population affected by the disease and dividing that number by the total number of plants in the population. The result is expressed as a percentage. Importantly, this data collection process was carried out in close collaboration with farmers, who actively participated in all experiment stages, from planting to data collection and subsequent analysis.

Using Python, a one-way analysis of variance (ANOVA) was conducted to assess the significance of variations among different millet landraces. Descriptive statistics were employed to comprehensively summarise its agro-morphological parameters for a deeper understanding of the dataset. Moreover, to look at the significance of variances among millet on key parameters (Days to maturity and yield), we aggregated the data by taking the mean of parameters for each landrace to ensure that all groups have the same number of data points before running ANOVA. The ANOVA test was performed at a significance level of 0.05.

Table 1. Millet and landrace selected for the study and their source.

Millet Crops	Landrace	Seed source
Proso Millet	Maal Chino	Swamikartik Khapar RM -5, Jera, Bajura
	Dudhe Chino	Swamikartik Khapar RM -5, Jera, Bajura
	NGRCO 7350	National Agriculture Genetic Resource Center- Genebank
	NGRCO 7345	National Agriculture Genetic Resource Center- Genebank
	NGRCO 7348	National Agriculture Genetic Resource Center- Genebank
Finger Millet	Kaalo Kodo	Budhinanda Municipality -10, Dimmarpani, Bajura
	Dalle Kodo	Budhinanda Municipality -10, Dimmarpani, Bajura
	Laafre Kodo	Budhinanda Municipality -10, Dimmarpani, Bajura
Sorghum	Jeraa Sthaniya	Swamikartik Khapar RM -5, Jera, Bajura
Fox tail millet	Rato kaaguno	Swamikartik Khapar RM -5, Jera, Bajura
	Seto Kaaguno	Himali RM -6, Dhim, Bajura
	Jukot Sthaniya	Swamikartik Khapar RM -3, Jukot, Bajura
Barnyard millet	Jukot Sthaniya Jhumuro	Swamikartik Khapar RM-3, Jukot, Bajura
	Jeraa Sthaniya Jhumuro	Swamikartik Khapar RM -5, Jera, Bajura

Results

Table 2 presented the results of a study that compared various millet landraces of proso millet, finger millet, sorghum, foxtail millet, and barnyard millet across nine agro-morphological parameters. These characteristics included plant height, the number of tillers, the number of leaves, days to 50% flowering, days to 50% maturity, length of panicle, and yield (in kg/ha). The results were reported regarding F-values and p-values, essential statistical measures in the context of ANOVA tests.

For proso millet, the data showed no significant differences among landraces for plant height, number of tillers, number of leaves, days to 50% flowering, panicle length, yield, blast disease, or spot disease incidence. However, the P-value for days to 50% maturity is relatively low, indicating a significant difference in the time it takes for different landraces of proso millet to mature.

On the other hand, the finger millet landrace exhibited significant variation in several important agro-morphological parameters, including plant height, number of tillers, days to 50% flowering, days to 50% maturity, panicle length, yield, and spot disease incidence. This was evident from the relatively low P-values for all these parameters, with the strongest significance observed for days to 50% maturity.

In the foxtail millet, landrace differed significantly in some agro-morphological parameters but not others. For example, the P-values for plant height, days to 50% flowering, days to 50% maturity, panicle length, and blast disease incidence were relatively high, suggesting that the differences in these parameters among landraces were not statistically significant. However, the P-values for F-value, number of tillers, number of leaves, and yield were relatively low, indicating significant differences among landraces in these parameters.

Similarly, barnyard millet landrace exhibited similar mixed results to proso millet. For some agro-morphological parameters, such as plant height, number of tillers, and panicle length, there were significant differences among landrace, as indicated by the relatively low P-values. However, for other parameters, such as a number of leaves, days to 50% maturity, blast disease incidence, and spot disease incidence, the P-values were higher, suggesting no significant differences among landraces.

In the ANOVA analysis conducted among the millet landraces, focusing on two specific parameters, days to maturity and yield, it was found that significant differences exist among the millet landraces for these characteristics.

Table 2. One-way ANNOVA of different landraces of millet

Millet		Plant Height (cm)	No. of Tillers	No. of Leaves	Days to 50% Flowering	Days to 50% Maturity	Length of Panicle (cm)	Yield (kg/ha)	Blast disease	Spot disease incidence
Proso Millet	F-value	0.02	0.60	0.18	0.80	2.30	31.10	39.70	62.13	83.90
	P-value	0.97	0.50	0.90	0.50	0.12	1.14	4.14	5.03	1.18
Finger Millet	F-value	3.25	7.44	0.30	6.21	70.78	17.10	5.16	19.00	1.57
	P-Value	0.11	0.02	0.78	0.03	6.69	0.00	0.05	0.00	0.28
Sorghum		NA	NA	NA	NA	NA	NA	NA		
Foxtail Millet	F-value	2.04	15.34	78.65	33.71	70.87	2.70	3.23	0.38	0.60
	P-Value	0.21	0.01	4.95	0.00	6.69	0.14	0.11	0.70	0.58
Barnyard Millet	F-value	1.89	1.99	0.40	24.99	30.38	0.20	0.79	0.02	0.46
	P-Value	0.24	0.23	0.56	0.01	0.01	0.67	0.79	0.09	0.53
Millet type	F-value						273.78			10.91
	P-Value						3.61			0.00

Finger millet landraces exhibited more extended maturation periods, ranging from 55 to 79 days to flowering and an additional five days to maturity. Sorghum's Jera Sthaniya took 47 days to flower and 65 days to mature. Proso millet's mal Chino landrace offered a shorter day to maturity, with 31 days to flowering and 40 days to maturity. Foxtail and barnyard landraces fell between these ranges, taking 41 to 65 days to flower and 40 to 56 days to reach maturity.

Disease resistance was another critical consideration in crop cultivation. **Figure 1** illustrates the incidence of two common diseases: blast and spot. *Sorghum's Jera Sthaniya* demonstrated excellent disease resistance with a 0% incidence of blast disease, making it a promising choice for disease-prone regions.

However, it did exhibit a 5% incidence rate of spot disease. In contrast, foxtail millet landraces, including *rato kaaguno, seto kaaguno, and jukot sthaniya,* all had a 10% incidence rate for blast and 5% for spot diseases, indicating moderate disease resistance. Finger millet landraces, such as *kaalo kodo, dalle kodo, and laafre kodo,* presented a higher disease susceptibility. They exhibited a 15% incidence rate for blast disease and a 20% incidence rate for spot disease. The cultivation of these landraces necessitated comprehensive disease management strategies to ensure successful crop yields. Proso millet landraces, including mal chino, dudhe chino, NGRCO 7350, NGRCO 7345, and NGRCO 7348, also exhibited varying degrees of disease susceptibility. They ranged from 5% to 21.6% in blast disease incidence and 7% to 16.6% in spot disease incidence. Both local landraces had less disease incidence than those obtained from gene bank. Barnyard millet landraces, including *jukot sthaniya jhumuro and jera sthaniya jhumuro*, displayed a higher incidence of diseases. They both had a 17% incidence rate for blast disease, with the latter landrace demonstrating a 23% incidence rate for spot disease. These millet landraces necessitated robust disease management practices for successful crop production.

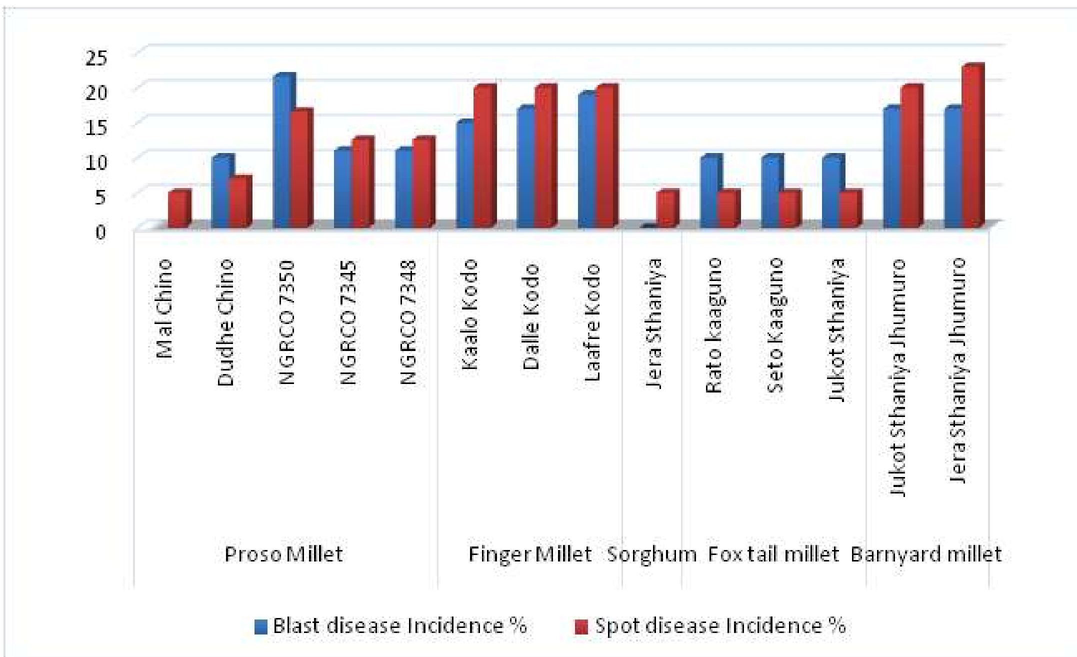

Figure 1. Disease incidence by millet landraces

Finger millet landraces, including kaalo kodo, dalle kodo, and laafre kodo, consistently yielded approximately 0.90 tons per hectare, showcasing their reliability for consistent production. In contrast, proso millet's mal chino landrace had a higher yield, producing 1.70 tons per hectare, making it a robust choice for those seeking higher yields. *Sorghum's jera sthaniya* yielded 0.82 tons per hectare, indicating moderate productivity. Foxtail Millet landraces*, rato kaaguno and seto kaaguno*, yielded 0.70 to 0.80 tons per hectare. Lastly, barnyard millet landraces, *jukot sthaniya jhumuro and jera sthaniya jhumuro,* yielded 0.70 and 0.71 tons per hectare, respectively.

Table 3. Millet mean agro-morphological parameters across various landraces.

S. N	Millet	Landrace	Plant Height	No. of tillers	No. of leaves	Days to 50% flowering	Days to 50% maturity	Yield (Ton/ha)
1	Proso Millet	NGRCO 7350	183.33	7.47	59.13	33.67	43.33	0.80
2		Mal Chino	121.27	12.97	65.70	33.33	45.00	1.70
3		NGRCO 7345	177.13	7.33	56.40	35.33	46.67	0.85
4		Dudhe Chino	194.26	6.84	58.28	36.20	50.00	1.10
5		NGRCO 7348	176.93	6.42	56.20	38.33	52.33	0.88
6	Finger Millet	Kaalo Kodo	72.00	6.67	34.67	55.67	75.00	0.90
7		Dalle Kodo	59.33	3.67	29.67	58.33	79.00	0.87
8		Laafre Kodo	70.00	4.33	31.00	61.33	88.00	0.92
9	Sorghum	Jera Sthaniya	126.00	4.50	30.00	47.00	65.00	0.82
10	Fox tail millet	Rato kaaguno	105.33	3.67	31.33	41.00	65.00	0.70
11		Seto Kaaguno	96.00	12.33	70.00	45.00	57.00	0.80
12		Jukot Sthaniya	108.00	5.33	21.00	49.00	65.67	0.80
13	Barnyard millet	Jukot Sthaniya Jhumuro	96.33	3.33	18.33	47.33	65.33	0.70
14		Jera Sthaniya Jhumuro	82.33	2.67	18.33	49.33	56.00	0.71

Discussion

Days to maturity

Our finding suggested high diversity in terms of the day to maturity of millets. Our finding aligns with a different study conducted in Nepal on different millet, which found that the days maturity of millets can vary from 60 to 150 days (Ghimire et al 2018a, Ghimire et al 2018b, Ghimire et al 2017, Sthapit et al 2003). With the diversity in maturity periods, millet landrace can be grown in various climatic conditions, from the coldest winters to the hottest summers (Patil 2020). For instance, proso millet's *mal chino*, with its relatively shorter days to maturity, could be an excellent choice for regions with shorter growing seasons. Conversely, finger millet's extended maturation period may necessitate meticulous planning to avoid adverse weather conditions. A study by Ceasar et al (2019) found that the maturity period of millets is likely to increase due to rising temperatures. Hence, it will be increasingly important for farmers to choose millet landraces with shorter maturity periods to ensure their crops mature before adverse weather conditions. Millet landraces with varying maturity periods offer flexibility in crop planning, which is crucial for climate resilience. Short-duration millet landraces, such as proso millet, can be cultivated in regions with erratic rainfall, while longer-duration landraces, like finger millet, can withstand extended dry periods (Kumar et al 2013). The staggered maturity periods of millet landraces reduce the risk of total crop failure due to unexpected climate events. For instance, a delayed monsoon may affect one variety but not others, ensuring some level of harvest (Satyavathi et al 2021).

Disease resistance

Most millets showed low to moderate levels of infestation to blast and spot diseases, indicating resistance to these diseases. Various studies reported that millet has specific genes and proteins that help the plant protect itself from the harmful effects of stress (Nagaraja and Das 2016, Shivhare et al 2022). The local landrace exhibits remarkable resistance to both diseases within the millet landrace. Multiple research studies have underscored that local or native crop landraces are often more tolerant to biotic and abiotic stresses than their improved counterparts. It is because local landrace has been selected over generations for their ability to survive in the local environment. They have accumulated genetic mutations that resist pests, diseases, and other environmental stresses (Subbu Thavamurugan et al 2023, Sudisha et al 2012, Tefera et al 2021).

Conversely, the higher incidence rates of blast and spot diseases in some finger millet and barnyard millet landraces emphasize adopting comprehensive, integrated pest management strategies to mitigate disease-related risks (Senthil et al 2018). Consistent with our research, Yoshida et al (2016) also affirmed that blast disease poses the greatest threat to finger millet. It highlights the importance of crop rotation and the meticulous choice of disease-resistant millet landrace as essential measures for minimizing potential yield losses.

Yield considerations

One of the most pivotal aspects of crop selection is yield potential, and (**Table 2**) demonstrates significant yield variations among the diverse millet landraces. Proso millet's *mal chino* landrace is a high-yielding option, boasting an impressive hectare yield of 1.70 tons. Additionally, the finger millet landrace consistently provides a reliable 0.9 ton per hectare yield, reinforcing its reputation as a steady source of millet grain (Upadhyaya et al 2014). These findings underscore the importance of selecting a millet landrace well-suited to specific environmental conditions and yield requirements.

It is worth noting that local millets, especially local proso millet landrace, have demonstrated superior performance, indicating their adaptation to local conditions and climate resilience. This local landrace possesses unique attributes such as local adaptation, climate resilience, genetic diversity, and traditional farming practices, contributing to their consistently high yields (Antony et al 2022, Roe 2010).

However, it is essential to recognize the value of alternative millet landraces as a contingency plan, particularly if local landraces face challenges in the future. A diversified approach to millet cultivation, encompassing both local and alternative landrace, can enhance food security and bolster the resilience of millet-based agriculture (UNEP GEF 2013, Gauchan et al 2019, Gairhe et al 2021).

Farmer's response/perception

The on-farm experiment was established in collaboration with the farmers. The intention of engaging farmers from the land preparation to harvesting the millets was to raise awareness about different millet landraces and their peculiar parameters, such as resistance to disease and pests, days to maturity and productivity. Engaging farmers in the research helped convince them to select the best-performing landraces in their area.

Out of 15 farmers engaged during the on-farm experiment and asked about their opinion on their engagement during the on-farm experiment, more than 90% responded positively, believing that their engagement enhanced their capacity. When asked about the performance and their preference among the cultivated millet types, all of them were fascinated with the performance of sorghum's jera sthaniya, as this landrace showed resistance to blast and spot disease. However, most of the farmers preferred mal chino over other landraces because it had higher production as compared to other landraces.

Picture 1. Farmers measuring plant height of the millet landraces at on-farm experiment at Bajura.
Photo credit: Kailash Bhatta

Picture 2. Tillers of Kalo Kodo. Kalo Kodo are features with compact, round panicles clustered tightly together, like Dalle Kodo except one additional finger at the neck and are adorned with black grains in appearance.
Photo credit: Kailash hatta

Picture 3. Tillers of Laafre Kodo. Laafre kodo possess with long fingers clustered loosely with each other.
Photo credit: Kailash Bhatta

Picture 4. Tillers of Dalle Kodo. Dalle Kodo are showcased with their compact, round panicles tightly clustered together, giving them a small and condensed appearance.
Photo credit: Kailash Bhatta

Conclusion

The findings derived from the on-farm experiment have significant implications for enhancing agricultural resilience. The exceptional performance of proso-millet highlights its potential as a valuable crop for mitigating the impacts of climate change and disease outbreaks. The varying performance of different millet types emphasizes the need for tailored strategies that consider local conditions and preferences. The superior performance of local millet landrace underscores the importance of preserving and effectively utilizing indigenous genetic resources. The on-farm experiment, with the collaborative engagement of farmers and researchers in this process, offers a pathway for immediate benefits and contributes to the long-term conservation and enhancement of millet crops.

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