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

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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.

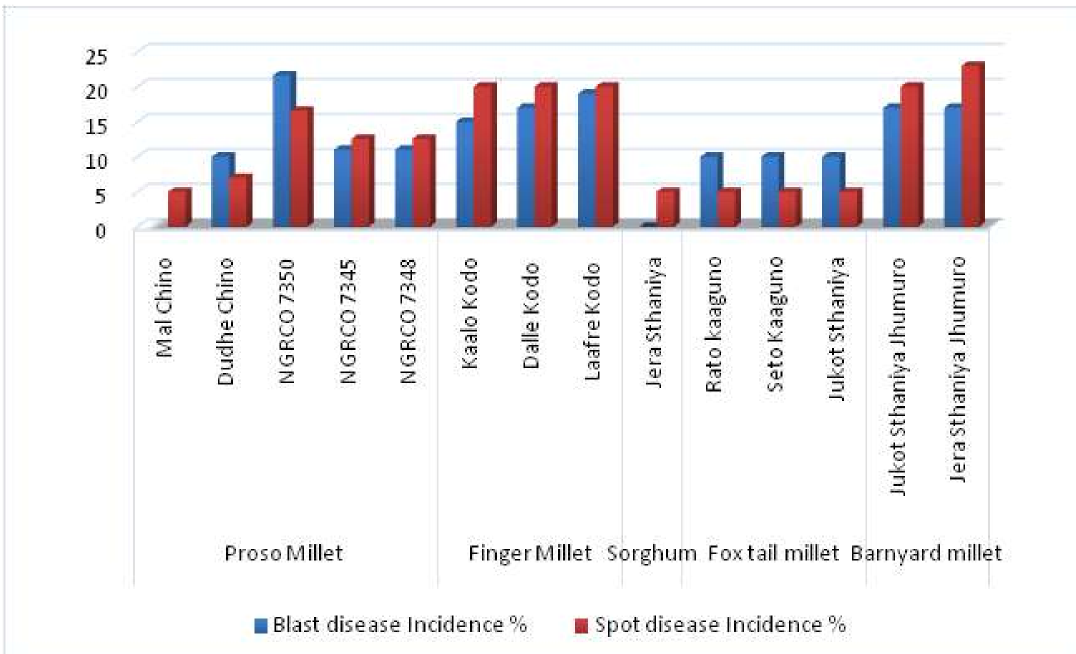

Figure 1. Disease incidence by millet landraces

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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Revival of Future Smart Foods for Sustainable Food Systems in Nepal: A case of Millets

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Abstract

Millets are one of the Future Smart Foods (FSFs), indigenous to Nepal. Millets are rich in micronutrients, more resilient to water and heat stresses and can be cultivated in marginal lands and at different altitudes ranging from plain terai to high hills. They can contribute to the overall sustainability of food systems through their potential contribution to nutrition security, rural income, and resilience to climate change. Beyond their immediate agricultural significance, millets offer potential in advancing agro-/eco-tourism and culinary science. This research paper, rooted in rigorous peer review and a SWOT analysis of the current millet landscape, develops an operational framework. This framework, exemplified through the case of millets, outlines a sustainable, long-term approach for the revival of traditional crops, thereby ensuring the sustainability of food systems in Nepal. In addition to this, the paper provides recommendations that span multiple fronts, including behavioral, technological, market, and policy aspects, to facilitate the revival of millets within the food system. By adopting a holistic approach that considers behavioral changes, technological innovations, market dynamics, and policy measures, we can create an enabling environment for the sustainable revitalization of millets and other FSFs. This comprehensive strategic way will not only contribute to the restoration of agrobiodiversity and dietary diversity but also enhance the resilience of Nepal's food systems in the face of climate change and other challenges.

Keywords: Millets, future smart food crop, revival, agricultural policy, indigenous crop

Introduction

Indigenous crops have been an integral part of the food systems in the Hindu-Kush Himalaya (HKH) for centuries. However, due to several socioeconomic and climatic factors, these crops are gradually declining in the food systems. Due to a decline and underutilization of these crops, these are also called as 'neglected and underutilized species. In 2017, the FAO relabeled these crops as 'future smart foods' in view of their importance for climate change resilience, agrobiodiversity, agriculture sustainability, and food and nutrition security (Hussain and Qamar 2020). Millets are also part of the indigenous crops in Nepal and HKH region and are deeply intertwined with the nation's culture and history. However, along with traditional perception associating millet with lower socio-economic groups and other factors such as evolving dietary preferences due to globalization, limited awareness of their nutritional benefits, restricted market access and a shift toward modern agricultural practices favoring different crops have collectively contributed to a decline in millet consumption (Mal et al 2010) relegating it to the category of neglected and underutilized crops. Recognizing its exceptional nutritional potential, climate resilience, economic viability, and local adaptability, the United Nations Food and Agriculture Organization designated millet as a Future Smart

Food crop in 2018. Furthermore, in 2023, the International Year of Millet is being celebrated with the theme 'Millet Crops for Food Nutrition, Security, Environment, and Rural Transformation.'

In the context of Nepal, Future Smart Food (FSF) crops, including millets, can play a pivotal role in addressing food security, enhancing climate resilience, and transforming the rural economy. They have the potential to bridge the growing production and nutrition gaps in our food system (Li and Siddique 2018). Millets, in particular, can serve as a compelling entry point for advocating the revival and mainstreaming of FSFs in Nepalese agriculture. However, it is essential to recognize that these efforts should not be limited solely to millets. A comprehensive, long-term plan is needed to integrate a wide range of FSFs into our agricultural practices. This paper aims to develop an operational framework, using millets as an example, to guide the long-term revival of traditional crops and ensure the sustainability of our food systems in Nepal.

Methodology

This study is secondary research conducted based on the existing scientific literature and government reports to analyze the status of millet in current food system. Literature is mainly searched from ResearchGate, Nepalese agriculture research journals and Google Scholar based on relevant keywords search including neglected and underutilized species, millets, seed system, mechanization, market, and ethnobotany. Following the literature review, SWOT analysis is conducted focusing on both production and consumption side of the millet food system and finally recommendations are drawn for revival and mainstreaming. In this process will also develop an operational framework with an example of millets for long term revival of traditional crops for sustainability of food systems in Nepal.

FSFs and Food System

For centuries, people across Nepal have utilized a diverse array of nourishing foods. They held a profound understanding of edible food sources within their ecosystem, ranging from wild edibles and medicinal plants to domestically cultivated cash crops (Joshi 2022). Regrettably, due to the forces of increasing globalization, agricultural intensification, and demographic shifts, newer generations are gradually distancing themselves from many of these traditional foods (De Bruin et al 2021). This trend has led to an interruption in the transfer of valuable knowledge, resulting in a rise in food monotony. This shift poses potential issues such as an increased risk of micronutrient deficiency, diminished resilience within the food system, compromised food sovereignty and loss in agrobiodiversity.

In Nepal, demographic and health survey of 2022 states that 69% of children aged 6–23 months consumed unhealthy foods. And throughout the country 30% of children under five-year age are stunted, and 22.3 % children are underweight, of which mountain kids are the most suffering from stunting. Future Smart Food, as defined by the FAO, encompasses Neglected and Underutilized Species (NUS) that are rich in nutrition, resilient to climate variations, economically viable, and locally available or adaptable. These crops are now being considered essential entry points for transforming nutritional and agricultural challenges into opportunities in rural settings (Adhikari et al 2017, Li et al 2019).

Millets are Future Smart Foods, indigenous to Nepal. Compared to popular cereal crops, millets are resilient. Their ability to thrive in marginal lands, resist pests, excel in intercropping setting, coupled with their nutrient-dense composition, makes them a compelling choice for enhancing food and nutritional security and ecological sustainability (Kumar et al 2018). Furthermore, millets demonstrate adaptability across varying altitudes, rendering them suitable for diverse geographical contexts (Khadka et al 2016). Importantly, millets are deeply ingrained in the social fabric of Nepal's food culture, enhancing their acceptance and integration within local diets and contribute to local economy.

Food, nutrition, and tradition are societal concerns associated with millets, which are closely intertwined with economic and environmental aspects through fields like ethno-botany and household economics respectively. The potential for income generation from millets also intersects with environmental considerations due to their relatively superior agroecosystem services, including reduced resource pressure, when compared to other major cereal crops (UNRIC 2023). Based on these functions of millet, which addresses all aspects (social, economic, and environmental) of sustainability in Nepalese food system, a framework is presented in **Figure 1**.

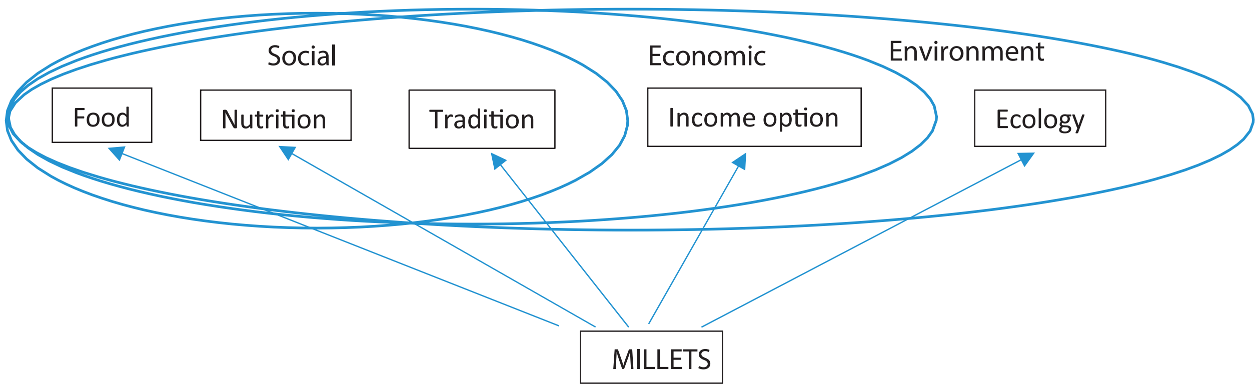

Figure 1. The impacts of Millet in food systems (based on the sustainability framework and authors analysis from on literature review)

In Nepalese food system, millets are used as cereal crop, animal fodder, and for making brewery items. Even though use of millet is engraved in our food system, there is some resistance making it underutilized crop. The resistance to consuming millets in Nepal is often rooted in its socio-cultural perception as 'poor man's food.' Grains like rice and wheat, cultivated in more fertile areas with greater resource requirements, have historically been regarded as more desirable and prestigious. In contrast, millets, grown in less fertile regions, have become associated with lower socioeconomic groups. This ignorance towards millet was also observed in policy level as very less attention was given to agricultural research and development (Shrestha et al 2020a) until recently as scientific evidence increasingly underscores millets' nutritional importance and their resilience in the face of climatic events and pest incidence, the integration of these nutrient-rich traditional foods into the broader food system has become more critical than ever. Beyond their immediate agricultural significance, millets also offer potential in promoting agro- eco-tourism and advancing culinary science.

The Situation of Millets Production and Consumption in Nepalese Food System

Traditional dishes made from millets, such as *dhindo*[1], *kodoko roti*[2], *kagunoko khir*[3], *chinoko bhat*[4], and *Kodoko khole*[5] were once typical local food just a generation ago. However, as discussed earlier, people's preferences have now become limited to food options based on rice, wheat, and maize.

The Annual Household Survey data showing sharp decline in urban consumption and slight decline rural urban consumption of millet in from 2015/16 to 2016/17 suggests a notable change in consumer preferences with only 3.5% household in the nation consuming millet as food option. Similarly, another study examining dietary patterns between 1993 and 2011 revealed that Nepalese consumers gradually

1 Dhindo is made by gradually adding finger millet flour to boiling water while stirring.
2 Kodoko roti is a pancake type flat bread made from thick batter (finger millet) with water and salt or sugar.
3 Kaguno ko kheer is pudding made from proso millet, milk, sugar and dry fruits.
4 Chinoko bhat is rice like food made from proso millet
5 Kodoko khole is soup made from finger millet flour.

shifted from low-cost, calorie-rich foods to more expensive, calorie-dense items. This dietary diversification was made possible due to increased income, changing lifestyles, and other factors (Thapa et al 2019). Another study conducted in a Nepalese village indicated that over the last decade, cash crops like mustard and cardamom replaced traditional food crops, limiting calorie consumption from traditional crop to a mere 7% (Adhikari et al 2019).

Table 1. Consumption of millet in rural and urban populations

Year	Share of millets in average per capita food consumption (%)		
	Urban population	Rural Population	Overall population
2015/16	4.1%	5.7%	5.1%
2016/17	1.8%	4.7%	3.5%

Source: Annual household surveys (CBS 2016, 2017)

Over the 32-year (1990/91 to 2021/22) dataset from Statistical Information on Nepalese agriculture by government of Nepal shows that the area under millet cultivation remained relatively consistent despite decrease in agricultural household percentages over the years. While the total millet production has showed an overall upward (**Figure 2**) trend but in a bigger picture looking at the production of other cereal crops, this is far from status for Nepal being independent on own cereal production. This rise, however, remains insufficient to attain increasing food and nutrition demand. Nepal's imports of millet alone have been substantial, reaching around 22,226 tonnes in the fiscal year 2021, marking an increase from 11,945 tonnes in 2017 (FAO 2023). Despite of an increase in production and import of millets, per capita consumption of millets is decreasing (**Table 1**). This scenario might be result of growing population, use of millets for livestock feed and brewery and changing consumers' dietary habits and social stigma attached with indigenous crops. Similarly, forecasts for 2030 suggest that the gap between domestic rice production and households' direct demand may range from 19% to 80%. This deficit in rice production is likely to persist despite efforts like increased irrigation and fertilizer supply (Prasad et al 2011). These estimates, however, do not account for climate extremes. Given this context, it becomes crucial for Nepal to diversify its cereal options, considering those that exhibit climate resilience and are well-suited to the geographical and socio-economic conditions. Future Smart Food crops like millets are a strong contender in this regard.

Figure 2. Millet production in past 32 years
MoAD 2015; MoALD 2023

Despite such significant importance of the crop, inadequate efforts are made to mainstream marginalized types of millets such as foxtail millet, proso millet and pearl millet in the food systems. Only data of a couple of types of millets such as finger millet is captured in national data, other millet varieties remain obscured.

Millets are typically found in cropping pattern of rainfed system (Paudel 2016) intercropped with other crop such as maize and legumes (Gauchan et al 2020), and compared to mono cropping the with traditionally practiced intercropping farmers are better off (Paudel 2016) However research on cropping practices of millets is very limited to finger millet with very few evidence agronomic practice of other millets.

Major Constraints and Challenges to Millets and Other FSFs

It is clear that, millets in agri food system has been facing challenges. In this section we will discuss in detail the constraints that FSF such as millets has been facing in the contemporary condition. As, we are also exploring solutions and opportunity, we will later perform SWOT analysis based on the existing literature review of millet production and consumption in Nepal. The major constrains and challenges of millets in food system are as follow:

Policy constraints: Nepal's policies promoting millets utilization are well-intentioned yet face challenges hindering their effective implementation. The National Agriculture Policy (2061 BS) aims to enhance millet and minor cereal productivity via research, extension, and marketing. The policy underscores the importance of the millet's role in food security and marginalized farmers' livelihoods. Likewise, the Agriculture Development Strategy (2015-2035) designates millets as a priority crop for food security, nutrition, and climate resilience. This strategy envisions a 25% increase in millet cultivation area, 50% in production, and 20% in productivity by 2035. It emphasizes improved varieties, value addition, processing, and market linkages. Similarly, the National Nutrition Policy (2072 BS) seeks better nutritional status through diversified and nutritious food availability. The policy promotes millet and nutrient-rich crops in balanced diets and backs millet flour fortification with micronutrients. However, despite these well-defined policies, effective implementation has encountered challenges stemming from various factors:

- Inadequate coordination and collaboration among diverse stakeholders, including government bodies, research institutions, farmer groups, private sector entities, NGOs, and donors, have hindered progress. This lack of synergy can result in redundant efforts, conflicting strategies, and operational inefficiencies (Gyawali 2021).
- Rice and wheat are also more widely available and subsidized by the government in some countries, making them cheaper and more accessible than millet (WFP 2022).
- Insufficient resources, encompassing financial allocations, human capital, infrastructure, and technological capabilities, have constrained the efficacy and scope of policy implementation and monitoring efforts (Joshi and Joshi 2021).
- Political commitment and stability gaps have posed obstacles, impacting the sustainability and continuity of policy initiatives. Interference and corruption within political realms have further eroded transparency and accountability within the policy framework (Joshi and Joshi 2021)
- The absence of evidence-based research and rigorous analysis has led to suboptimal policy design and evaluation. Policy outcomes may suffer when decisions are based on assumptions, opinions, or personal interests rather than concrete data and information (Khadka et al 2016)
- The involvement and awareness of target groups, such as millet farmers and consumers, must be improved. It may diminish the acceptance and endorsement of policies and their potential outcomes. Sociocultural factors also play a role in shaping the preferences and behaviors of these target groups (Gyawali 2021)

Market Constraints: Millets farmers are grappling with challenges that hinder their ability to tap into markets and capitalize on value-addition opportunities effectively. One prominent issue is the need for access to markets and processing facilities, which directly impacts their ability to sell their produce at reasonable prices. Unfortunately, Millets are often sold at lower prices or relegated to uses like home consumption or animal feed.

The lack of established standards, certifications, branding strategies, proper packaging, unambiguous labelling, efficient distribution networks, and promotional efforts all contribute to Millet's struggles in the market (Dos-Santos, 2020). Another crucial missing link is the scarcity of comprehensive market information and connections between various stakeholders in the millet supply chain. The disconnection between millet producers, processors, traders, and consumers exacerbates the challenges all parties involved face. Similarly, in market failures are also observed that has limit consumers from obtaining reliable information regarding traditional variety characteristics (Pallante et al 2016).

From the consumer's perspective, millets are often considered a poor people's crop or a famine food and has low social status compared to rice, wheat, and maize. Millet consumption is also declining due to changing food habits and urbanization (de Bruin et al 2021). There is a need for more awareness and promotion of millet as a healthy and nutritious food that can contribute to food security and malnutrition reduction. A recent study shows that the preference of tourists towards "*Dhido,*" a traditional dish made from millet flour, has increased its demand in recent years (Gyawali 2021).

Technological constraints: Millets are labor-intensive and drudgery-prone crop, requiring manual harvesting, threshing, dehulling, milling, and processing (Naik et al 2022). These operations are time-consuming and tedious, often resulting in low yields and quality losses. Manual processing exposes millet to contamination and spoilage by insects, rodents, fungi, and bacteria (Datta Mazumdar et al 2022). There is a lack of improved seed varieties, innovation, and land management practices to enhance millet productivity and quality. Millet is often grown in marginal lands with poor soil fertility, erratic rainfall, high temperatures, and pest and disease infestation. Millet farmers have limited access to quality seeds, fertilizers, pesticides, irrigation, mechanization, and extension services (Gyawali 2021). There is also a lack of appropriate technologies and equipment to reduce the labor and drudgery involved in millet processing and improve millet products' efficiency and hygiene (Shrestha et al 2020). Most of the existing millet processing technologies are based on traditional methods or adapted from wheat and rice milling technologies. These technologies are unsuitable for the small size, hard texture, and diverse shapes of millet grains. They often result in high energy consumption, low milling recovery, poor product quality, and high wastage (Joshi et al 2023).

A case study by Shrestha et al (2020) in Nepal examined the gender roles and drudgery of millet production and processing in the mid-hills. They found that women farmers were involved in almost all stages of millet production, such as land preparation, sowing, weeding, harvesting, threshing, dehulling, and milling. They also found that women farmers spent more time and energy than men farmers in these activities, especially in the post-harvest processing of millets. They reported that women farmers faced various challenges and drudgery in millet production and processing, such as physical fatigue, health problems, low productivity, low income, and lack of access to improved technologies and services. They suggested that empowering women farmers with improved technologies and skills could enhance their livelihoods and food security.

Behavioral constraints: Millet has a negative perception among many people as a crop only for festivals, rituals, or poor people (Kane-Potaka et al 2021). This is because marginalized communities traditionally consumed millet during famine or scarcity. Millets are also associated with specific religious or ethnic groups with lower social status in some societies (Prasad et. al 2010). Millet is often considered inferior to rice or wheat, which are seen as more modern, refined, and prestigious (Kane-Potaka et al 2021).

There is a lack of awareness and appreciation of the nutritional and health benefits of millets among consumers. Millets are rich in protein, fiber, minerals, antioxidants, and phytochemicals that can prevent or manage chronic diseases such as diabetes, obesity, cardiovascular problems, and cancer (Anitha et al 2021, Anitha et al 2021).

Another pressing challenge is disappearance of local culinary recipes and traditions that use millet as an ingredient. Due to urbanization, globalization, and changing lifestyles, many people have lost their connection with their ancestral food culture and heritage (Adhikari and Dangol 2013). Millet is often replaced by other cereals or processed foods that are more convenient, fast, and appealing (Hawkes et al 2017).

In following subsection, we perform a SWOT analysis based on the existing literature review on contemporary context of millet production and consumption in Nepal. (S: Strength, W: Weakness, O: Opportunities and T: Threats)

		Production/supply side	Consumption/demand side
Socio-cultural	S	• Socially acceptable in several ethnic communities of Nepal • Traditional knowledge to cultivate in Nepal • Linked with indigenous and local customs and norms	• Know how to consume in Nepalese rural households • Millet has many benefits, such as being rich in protein, iron, calcium, zinc, and antioxidants, as well as being gluten-free, drought-tolerant, and adaptable to different soils and altitudes (Saxena et al 2018) (Kumar et al 2021) • Linked with heritage of several ethnic and indigenous groups (Khanal 2022)
	W	• Requiring high labour input mainly during transplanting, weeding, harvesting, threshing, and grinding (Khadka et al 2016). • Millets are more challenging to process initially compared to rice and wheat, with the most demanding processing required for minor millets • (Joshi and Shrestha 2019, Pandey and Bolia 2023)	• Consider socio culturally inferior (Joshi and Shrestha 2019). • Less palatable in traditional culinary practice (Pandey and Bolia 2023) • Disappearance of local cuisine (Adhikari and Dangol 2013)
	O		• Gluten free (Kumar et al 2021), • Population growth (Li and Siddique 2018) • Changing costumer attitude with rise in income and literacy (Thapa et al 2019)
	T	• Decreasing agricultural land (FRTC 2022)	• Compete with cheaper junk food option • Consumer ignorance of nutritional value
Economic	S	• Low volume production in scattered area	• Relatively cheaper and healthier option of food

		Production/supply side	Consumption/demand side
	W	• Lack of knowledge and investment for processing technology (Joshi et al 2020) • High prices of hybrid varieties and poor economic conditions of small and marginal farmers is preventing them from using improved varieties. • Lack of financial facilities (credit and insurance support) (Pandey 2022)	• Low economic evaluation of crops compared to its agroecosystem service. • Farmers are not getting good prices for their products. • Informal value chain • Poor shelf life of millet flour (especially pearl millet) (Pandey and Bolia 2023b) • Grain colour and astringent flavour (Pandey and Bolia 2023b) • Technological interventions are required to handle some of the limitations of small millets like possibility of rancidity during storage (Pandey and Bolia 2023a) • and presence of antinutrients like phytic acid [AP] • Millet based enterprise lack proper linkages • Market failures (Pallante et al 2016)
	O	• Low investment required for water and inputs as majorly grown in rainfed condition (Pandey and Bolia 2023) • Rice and maize yield very susceptible to decline in climate change scenario (Nelson et al 2009). However millets are tolerant to stresses and require less investment in adaptation measures.	• Baby food ingredient • Certification (mountain food, gluten free, vegan, organic) • Use modern culinary science to make it more palatable and attract urban consumer • UN international year of millets • National Policy initiatives (NAP 2016, ADS 2072, NNP 2072) • Public procurement • Growing middleclass costumers • Innovation in machineries (Pandey and Bolia 2023a)
	T	• Hybrid varieties of other cereal crops • Farmers have limited access to quality seeds, fertilizers, pesticides, irrigation, mechanization, and extension services (Gyawali 2021) • Lack of research in agronomic practices (Joshi and Shrestha 2019, Khadka et al 2016, MFSC 2014)	• Cheaper import from neighboring country
Environmental	S	• Fit easily into integrated practice (mix cropping) • Intercropping system is profitable (Paudel 2016) • Ability to tolerate and withstand stress. Less pressure to resources (ie, water) • Low input requirement	• Local produce, low carbon footprint
	W	• -	• -
	O	• Agroecological agronomic package of practices	• Contributes to Agrobiodiversity conservation
	T	• -	• -

Towards a Framework for Sustainable Food Systems; Case of Millets

Based on the earlier section of SWOT analysis of consumption and production aspects of Millet, transformative initiatives are recommended

Behavioral

Linking habit, heritage, and health: At the Himalayan Policy forum in May 2023, an example was shared regarding Natto, a fermented Japanese dish made from soybeans. It was explained how, despite its unpleasant taste, the Japanese actively seek it out for consumption no matter where they are in the world. It was emphasized that, similar to Natto, millets should be linked with habits established from early childhood, health and nutrition benefits, and the cultural heritage of the Nepalese. Such an approach will have a sustainable impact.

Millets can be linked with habit and health by encouraging their consumption among children through child health workers during health advice sessions to new parents, integrating it in school midday meal program and organizing dedicated campaigns. Millets could be further associated with heritage by acknowledging indigenous community for their contribution in preserving the traditional knowledge and considering traditional millet dishes as Nepalese delicacies in international platform.

Technological

Seed system and varietal development: Seed system of all the millets are highly informal in Nepal (Baniya et al 1970; Gurung et al 2020) In a study on genotypes of finger millet, high level of diversity among the genotypes was observed for grain yield indicating their superior trait value suggesting for further research for breed improvement (Dhami et al 2018). Gurung et al (2020) suggest that to address limited knowledge and skill of farming communities in seed selection, processing and storage, strengthening of local seed system could be carried by our research and development work on the traditional mountain crops focusing on community seed banks and other community-based approaches to promote linkage with formal seed system. Similarly, to improve seed genotypes, Ghimire et al 2018 suggest that research institutes can employ an innovative method of using participatory diversity kits to promote farmer selection for immediate benefits.

Agroecological farming approach: As millets are neglected crops, they receive limited attention in research overall. To establish resilient millet farming system in Nepal, it is suggested to research in agroecological agronomic package of practices of millet farming and make technologies available throughout the nation.

Agriculture mechanization: One of the challenges in the millets value chain is post-harvest handling. Proper research is needed to develop suitable machinery that is compatible to local setting and can reduce drudgery associated with millet processing. Potential machinery includes the multi feed dehuller build by Tamil Nadu Agricultural University and Central Institute of Agricultural Engineering (Pandey and Bolia, 2023a), Finger Millet Harvesting Machine developed by Department of Automobile and Mechanical Engineering, Tribhuvan University Institute of Engineering, pedal millet thresher developed by Nepal Agricultural Research Council.

Research in culinary science: The limited consumption of millets in urban contexts often stems from a lack of recipes. Addressing this issue can involve research in culinary science, including the collection of traditional recipes and the study of fusion cuisine in gastronomy. Examples like the *Raithanee*[6] restaurant (Thomas Heaton 2019) demonstrate how this approach can be successful.

6 Raithaane is an urban restaurant situated in Kupondol, which serves food, derived from diverse ethnic groups of Nepal.

Market

Rebranding: Millets have long been associated with lower socio-economic status, perpetuating a stigma around their consumption. To counter this, rebranding millets is recommended. Millets are gluten-free and vegan food options, and when grown using agroecological practices, they can be labelled as organic, fairtrade, and mountain products in Nepalese context. Leveraging these certifications and labels can help change the perception of millets among consumers.

Business incubators for millet base enterprise: Millets based products such as based baby food, lunch item, brewery, and other food item often rely on traditional knowledge for production and marketing. Incentives such like business fellowships for small and medium enterprises can enhance production quality and marketing capabilities, enabling these enterprises to reach a wider audience.

Policy

Financial investment: Government should invest in research on varietal improvements, post-harvest processing technologies, appropriate machinery development, and market structure and infrastructure development of millet to create enabling environment for millet producers.

Awareness raising campaign: Public awareness campaigns to educate consumers, farmers, and food businesses about the economic, nutritional, and environmental advantages of millets. This will also contribute to counter market failures.

Incentives: Through government programs, incentives such as support price, subsidies, public procurement, and insurance should be provided to the millet producer to encourage production. Local government can play crucial role in this regard.

Mainstreaming all the millets: The Nepal Agriculture Research Council have identified 11 millet domesticated millet crops. However, there has been limited research on these millets concerning their traditional agronomic practices, varietal development, post-harvest handling, and food technology. Additionally, disaggregated data on production and yield for different types of millet is also lacking. To mainstream millets, relevant agencies must address these gaps.

Concluding Remark for Solution

As a result of this research, several recommendations emerge to facilitate this transformation. Firstly, it is crucial to establish a strong connection between millets and elements of habit, heritage, and health to encourage behavioral shifts toward millets consumption. Moreover, technological advancements are important in enhancement of seed systems, varietal development, the adoption of agroecological farming practices, mechanization in agriculture, and increased research in culinary science should be prioritized.

In terms of market perspective, it is essential to embark on transformative initiatives such as rebranding millets through ethical and environmental certification and fostering business incubators for millets-based enterprises. Lastly and most importantly, policy intervention plays a critical role in addressing challenges costumer behavior, technology, market failures. It can create enabling environment for revival with approaches such as financial investments, awareness-raising campaigns, the provision of various incentives, and the mainstreaming of all types of millets.

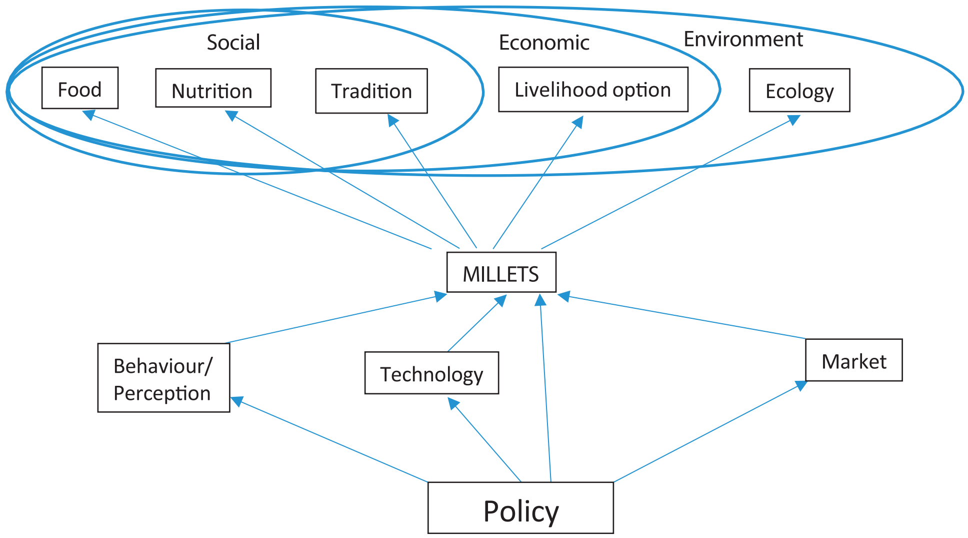

Figure 3: Factors influencing the integration of Millets into the food system and the impacts of Millet- based food systems.

By implementing these multifaceted recommendations drawn via comprehensive strategic way, we can pave the way for a more sustainable and inclusive food system that harnesses the potential of millets and other FSF to address pressing societal, economic, and environmental challenges.

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