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Potential of Underutilized Grain Crops in the Western Mountains of Nepal for Food and Nutrient Security

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Abstract: Malnutrition, hunger, and rural poverty in Nepal are prevalent issues that have been exacerbated by the negative impacts of climate change on crop production. To create a more sustainable and resilient food system, it is crucial to explore alternative options beyond the small number of input-intensive crops that the country currently relies on. In this study, we conducted a comprehensive investigation of six underutilized food crops—amaranth, buckwheat, finger millet, foxtail millet, naked barley, and proso millet—in four mountainous districts of the Karnali province, Nepal. Using several approaches that included a literature review, key informant surveys, focus group discussions, and direct observations, we explored the production and utilization aspects of these crops, as well as their potential for improving nutrition and food security. Our findings indicate that these underutilized crops continue to be a vital element of the diets of people residing in Karnali and play an important role in their livelihoods. This study also highlights the diversity and potential of these underutilized crop landraces, and their significance in addressing nutrition and food insecurity, as well as in improving livelihoods in regions with marginal lands and inadequate food supply. Thus, promoting the cultivation and consumption of underutilized crops can create a more sustainable and diverse food system that is resilient to climate change. However, further investigation is needed to fully understand the socioeconomic importance and other potential benefits of these crops.

Keywords: underutilized crops; food security; climate change; nutritional security; climate resiliency

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1. Introduction

Underutilized crops, defined as species grown in local or marginal conditions and often neglected in terms of policy, breeding, research, and trade, possess unique advantages, including reliable yield in adverse climatic conditions and biotic or abiotic stress with low inputs [1,2]. These crops also have higher nutritional content compared to widely cultivated crops [1]. In recognition of their agronomic potential and high nutritional value, the United Nations General Assembly has declared 2023 as the International Year of Millets, highlighting the importance of these underutilized crops [3].

The Green Revolution of the 1960s led to the widespread adoption of high-yielding fertilizer responsive crops to address poverty and hunger [4,5]. However, this resulted in a reduction in genetic diversity and reliance on a limited number of staple crops, such as rice, wheat, maize, and potato [2]. Despite the increase in production and productivity of these staple crops, hunger and malnutrition remain persistent issues, and current efforts to address them have been insufficient [6,7]. To address this, it is necessary to diversify the food crop base to include other crops rich in essential micronutrients [6]. Additionally, climate change poses a significant threat to crop production and food security, with projections indicating a potential 8% mean yield loss of major crops by 2050 in African and South Asian regions [8]. Developing countries, including Nepal which relies heavily on subsistence agriculture and is highly vulnerable to the impacts of climate change [9], must consider alternative, climate-resilient crops to secure food supplies.

Despite the global trend towards modern agriculture systems that pose a threat to biodiversity loss [10,11], Nepal stands out as a country endowed with rich agrobiodiversity [12]. Due to a relatively low level of influence from the Green Revolution, many farmers in Nepal still practice subsistence agriculture [13], contributing to the abundance of agrobiodiversity in the country. With a remarkable diversity of flora, Nepal is home to 3.2% of the world's known species [14], including 790 food utility plant species (with 577 being cultivated), 484 of which are indigenous, and 93 are introduced [12]. Such diversity provides farmers with an extensive range of options to promote sustainable agriculture practices. The conservation of Nepal's agrobiodiversity could play a crucial role in achieving food security and reducing poverty in the region [14], and this particular study highlights the significance of this unique opportunity.

The Karnali region, a north-western mountainous part of Nepal, faces several socioeconomic and environmental challenges, including being one of the most economically backward, geologically challenging, and nutrition/food-insecure regions in the country [15,16]. Despite these obstacles, the region boasts a wealth of agrobiodiversity, including underutilized crops that have the potential to contribute significantly to the region's nutrition/food security [17,18]. These crops, including millets, buckwheat, naked barley, and barley, are the primary food crops grown in the Karnali region [17,19]. As the modern agriculture system is increasingly being criticized for its inability to ensure global nutrition/food security and diversity [19,20], underutilized crops are emerging as potential "smart crops" due to their ability to adapt to various stresses and changing climates, their higher nutritional value, and their potential to support nutrition/food security in marginalized and poor communities [19–21]. With the majority of agricultural goods being imported into Nepal [12] and welcoming the merits of underutilized crops, the preservation, utilization, and promotion of underutilized crops in the Karnali region could be a valuable strategy for addressing issues of climate change, hunger, malnutrition, and food sovereignty. Thus, our study aims to shed light on the potential of underutilized grain crops in promoting nutrition/food security in the Karnali region. In addition, the study delved into the status, cultivation practices uses, and future prospects of these underutilized crops.

The findings of this study can serve as a basis for promoting the cultivation and use of these crops, which, in turn, can contribute to enhancing food security and improving the livelihoods of the local communities. Several approaches adopted in this study serve as a case study for the Upper Karnali region of Nepal, and it can be a valuable approach for exploring and presenting information on different native food crops, their cultivation, use, and the perceptions of farmers regarding these crops, as well as other indigenous knowledge of remote areas of developing countries like Nepal. Furthermore, providing a comprehensive understanding of different aspects of underutilized grain crops and exploring the practices and perceptions of farmers regarding their importance would assist decision-makers in comprehending the status of indigenous food crops in the region.

2. Materials and Methods

2.1. Area and Crops under Study

The current study focused on gathering information related to the nutritional and health benefits, common cultivation practices, distribution, importance, role, and perception of local farmers regarding underutilized food crops grown in the upper mountainous districts (Dolpa, Humla, Jumla, and Mugu) in the Karnali province of Nepal.

Dolpa, Humla, Jumla, and Mugu are the four districts located in the northwestern region of Nepal, with three of them bordering China (Figure 1). These districts have rugged terrain and are known for their high altitudes, remote villages, and harsh climatic conditions [22]. According to the latest census conducted in 2021, the combined population of these districts is 281,066 people [23]. Despite their relatively small population size, these districts are home to a diverse range of ethnic groups, each with its own unique culture and traditions [22]. The local economy is primarily based on agriculture and mainly includes the cultivation of grain crops, such as maize, wheat, paddy, millets, barley, and buckwheat [24]. Due to the mountainous terrain, irrigation systems are limited, and farmers primarily rely on rain-fed agriculture [25].

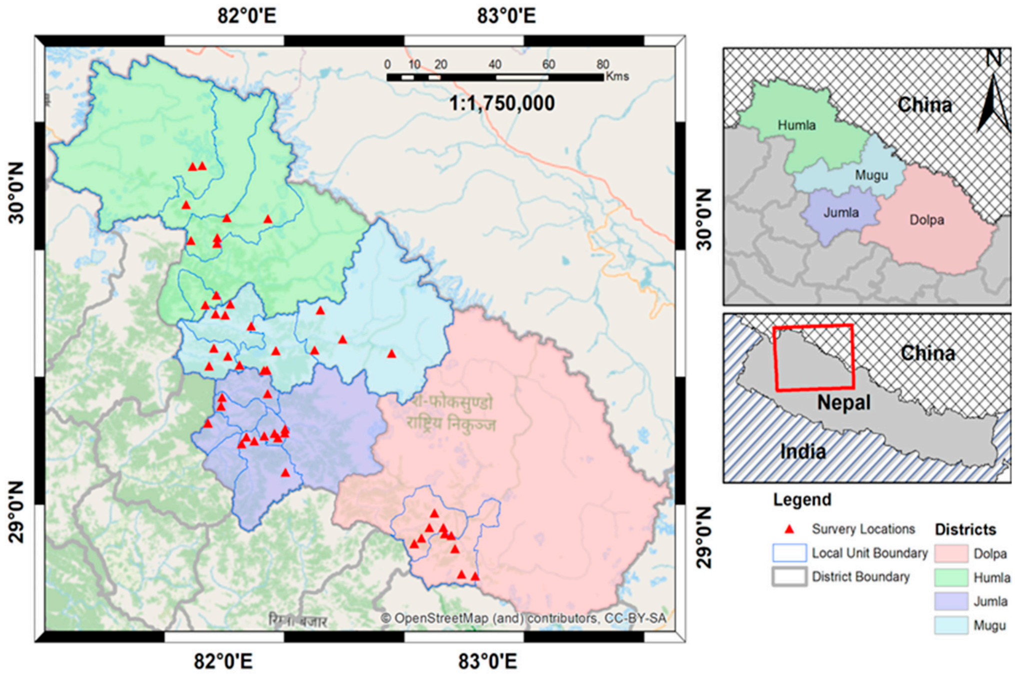

Figure 1. Map representation of the study area (red box); red triangles located within the district boundaries indicate where the field observations and surveys were conducted.

This region was selected for study as it is recognized as the most food-insecure area of Nepal, with the highest level of multidimensional poverty [26–28]. The study specifically focuses on underutilized food crops, including amaranth, buckwheat, finger millet, foxtail millet, naked barley, and proso millet, which are commonly grown in this region.

2.2. Information Collection and Its Validation

This study utilized several approaches, including a literature review, key informant survey, focus group discussion, and direct observation to gather comprehensive information about underutilized grain crops in the region. It also reported new/previously undisclosed information, whilst validating previously reported information. This study has uncovered previously unreported information, specifically regarding the cultivation and production status of foxtail millet, naked barley, and proso millet. Additionally, we extensively explored various aspects of cultivation practices, including seed-sowing methods, planting patterns, and harvesting techniques. Our investigation also delved into the local uses of these crops, which range from their incorporation into food items to their role in apiculture (particularly buckwheat) and the production of alcoholic beverages (such as finger millet). Moreover, we examined farmers' preferences, which encompassed their inclination towards specific landraces, such as rato marshe (amaranth), mithe/common phapar (buckwheat), and jhuse uwa (barley). Furthermore, we documented local perceptions and beliefs surrounding these crops, including the cultivation of amaranth to ward off negative energies in fields and its consumption for blood pressure regulation in pregnant or menstruating women. We also collected insights into the challenges faced by farmers in proso millet farming, as perceived by them. To provide comprehensive coverage, we compiled a list of local landrace names for all six crops. Finally, our research paper thoroughly discusses the economic prospects associated with these crops, and we supplemented our findings with export data on Karnali's finger millet grains, beans, and Jumli Marshi rice. Similarly, we have also validated several previously reported information regarding these underutilized grain crops in the Karnali region. For instance, we compared and confirmed the general productivity status of the underutilized crops as documented in government data, aligning our findings with the previously reported information. In addition, through our field observations and discussions with local farmers, we have verified the existence of diverse landraces of the underutilized crops in the Karnali region, consistent with reports from previous studies. Further, we have also corroborated the local names of these crops mentioned in the existing literature. Moreover, our field observations have demonstrated the resilience of underutilized crops, as they have thrived in the Karnali region over an extended period. As a result, this study presents a collection of interesting facts about underutilized crops in Karnali and highlights their potential role in addressing issues related to nutrition/food security.

The workflow adopted for exploring and presenting the information on the underutilized grain crops from the Karnali region of Nepal is illustrated in Figure 2.

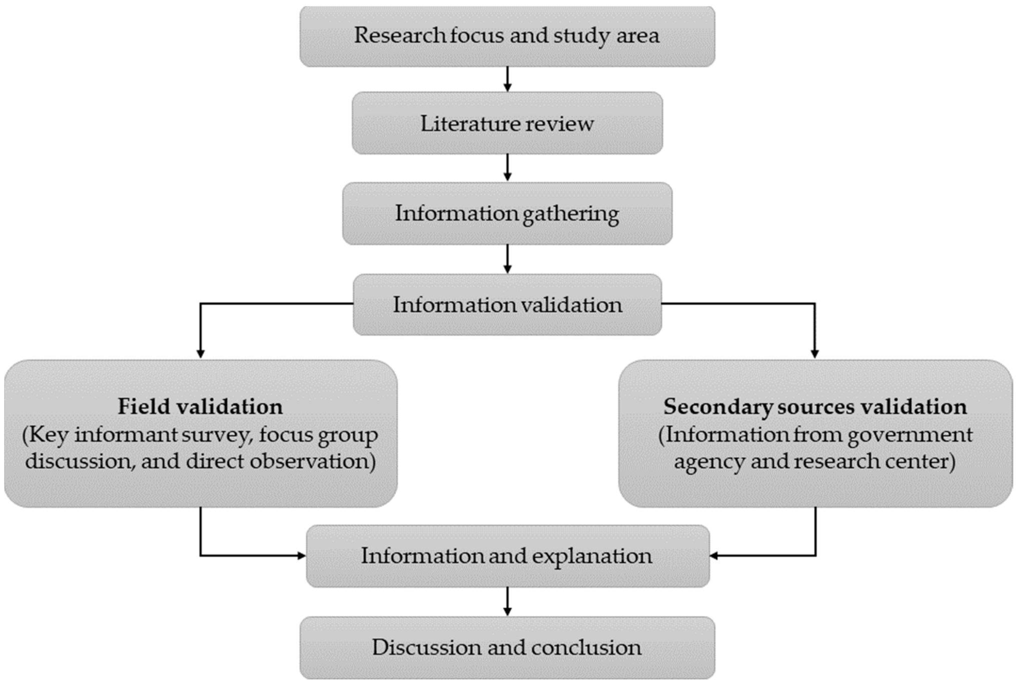

Figure 2. The workflow adopted for exploring the information on underutilized grain crops from the Karnali region of Nepal.

The methodology began with a comprehensive literature review of relevant sources, including 25 published articles (available online), 9 governmental and non-governmental reports, 5 books, and a few websites, covering the keywords such as 'Underutilized crops', 'Underutilized crops benefits', 'Karnali region', 'Karnali agriculture', and 'Food security'. The information obtained from these sources that matched our study's objective about the topic of underutilized food crops, and their role and status in the Karnali region was carefully analyzed and synthesized, and appropriate citations were included in the article to acknowledge their contribution. The literature review provided valuable insights and helped to contextualize the field validation, providing a comprehensive understanding of the current situation and the challenges and opportunities related to the cultivation of underutilized food crops in the region. However, we found a paucity of information regarding local people's perceptions and practices on underutilized crops, and the nutrition/food security prospects of these crops specifically in the Karnali region were missing.

It prompted researchers to understand the ground conditions besides relying solely on the literature review.

To gain a deeper understanding of the situation in the Karnali region, the researcher spent 5 months (February to July 2022) in the area conducting field research, which included direct observations of cultivated food crops, agricultural techniques, farmers' lifestyles, and their perceptions. This information was gathered through a combination of field visits, group discussions, and interviews with key informants. The extended stay in the region allowed for an in-depth examination of the challenges and opportunities related to the cultivation of underutilized food crops.

2.2.1. Key Informant (KI) Survey

A semi-structured questionnaire was created and distributed to 49 key informants (KIs) including government officials, extension agents, and peer farmers actively involved in the cultivation of underutilized grain crops. These KIs were selected from different villages across Dolpa, Humla, Jumla, and Mugu (Figure 1). The questionnaire was designed to elicit information on the indigenous knowledge and traditional practices associated with the cultivation of underutilized grain crops. The questions focused on various aspects, including the abundance and availability of local landraces, cultivation practices, production and uses, sources of seeds, traditional and cultural significance, challenges in production and utilization, and the overall importance of these underutilized grain crops. These formulated questions were discussed with the KIs from each district. The information was collected through in-person interviews and in a few cases, via phone communication with the key informants. Interviews were carried out with the consent of the KIs, and the protection of their privacy was ensured.

2.2.2. Focus Group Discussion (FGD)

To supplement and validate the information gathered through the questionnaire, a one-day workshop was conducted in collaboration with the Agriculture Development Office of Jumla and Mugu districts. During the workshop, open-ended discussions were held with 22 farmers from each district to delve deeper into the topic of food crops, with a focus on underutilized crops. The discussions aimed to gather information on the available landraces, cultivation practices, major challenges faced by farmers, and their perspectives on the cultivation of underutilized crops. The workshop served as a platform for exchanging knowledge and experiences among farmers and provided valuable insights into the status of underutilized food crops in the region.

3. Results

After conducting a comprehensive analysis of the available information, this study presents a detailed report on six underutilized food crops in the Karnali region. Through insightful discussions and accompanying tables, this study provides crucial information on the importance of underutilized grain crops in promoting nutrition and food security in the upper Karnali region of Nepal. Our report presents an accurate representation of the current situation in the Karnali region, delving into the cultivation practices, production, use, and future perspectives of the underutilized food crops. Moreover, the report highlights the challenges faced by farmers in cultivating these crops and their attitudes and perceptions toward them.

To provide a clear overview of the current status of underutilized crops in the region, we have included Table 1. The table displays the production and corresponding cultivated area of the different crops studied. Our findings suggest that despite farmers devoting significant land area to cultivate these crops, their productivity remains considerably low, around 1 Mt/ha, falling short of the productivity levels of major cereal crops like rice, wheat, and maize [29]. This data offer valuable insights into the status of underutilized crops in the region, revealing the need for improvement and support for farmers.

Table 1. Status of underutilized food crops in the study area from 2019/2020–2020/2021.

Crop	District	2019/2020		2020/2021	
		Area (Hectare)	Production (Metric Tons)	Area (Hectare)	Production (Metric Tons)
Amaranth		-	-	-	-
Buckwheat	Dolpa	646	679	807	997
	Humla	636	773	806	893
	Jumla	79	83	87	95
	Mugu	456	433	609	684
Finger millet	Dolpa	277	305	280	310
	Humla	1294	1383	1308	1407
	Jumla	3696	3924	3737	3991
	Mugu	4218	4126	4264	4196
Foxtail millet	Dolpa	300	280	300	280
	Humla	80	84	83	92
	Jumla	13	13	15	15
	Mugu	645	503	642	260
Naked barley	Dolpa	700	700	700	720
	Humla	692	680	696	692
	Jumla	10	15	30	39
	Mugu	293	260	200	190
Proso millet	Dolpa	500	480	500	548
	Humla	305	198	311	233
	Jumla	200	240	50	65
	Mugu	705	700	724	1430

Source: The data for buckwheat and finger millet were obtained from the MoALD [29]. The remaining data were obtained from corresponding District Agriculture Development Offices. "-" in the blanks indicates the absence of available data.

3.1. Amaranth

Amaranth (*Amaranthus* spp.) is a versatile pseudo-cereal crop that serves multiple purposes including human consumption as grain and vegetable, ornamental plants, and animal feed [30–33]. While many species of Amaranth are considered weeds, specific varieties are grown for grain production, including *Amaranthus hypochondriacus*, *A. cruentus*, and *A. caudatus*, and some are grown for vegetable purposes, such as *A. tricolor* and *A. blitum* [30,31,33]. The Himalayan region, including Nepal, is a major area for the cultivation of amaranth [30,34]. In Nepal, the majority of amaranth cultivation takes place in the Karnali region, where *A. hypochondriacus* is the predominant species [34,35]. This crop is grown for grain in the Karnali and north-west regions, while in the mid hills and southern terai it is consumed as a green leafy vegetable [36]. Amaranth is known by different names in different regions, such as "Marshe" in high hills, "Latte" or "Lude" in mid-hills, "Betu" in the far west, and "Ramdana" in southern plains or terai [36].

Farmers of the study area commonly broadcast amaranth seeds along the borders of millet fields, rather than relying solely on amaranth as a crop. During a study, it was found that local people regard amaranth as a minor food crop but a major crop for cultural and tribal purposes. The local farmers had a belief that amaranth wards off the negative and cursing sights in the field. They believe that consuming amaranth in the form of roasted grains or leavened bread normalizes blood pressure in pregnant or menstruating women. As mentioned by the respondent, several previous studies have also reported on the extensive health benefits of amaranth, particularly its antihypertensive properties [37,38]. The variety "Rato Marshe", with high-yielding grain properties [35], was found to be the most desirable among other Amaranth varieties like Seto Marshe, Rato Ladi Marshe, and Seto Ladi Marshe. In 2021, "Rato Latte," a synonym for Rato Marshe, was registered as the second Amaranth variety in Nepal after "Ramechhap Hariyo Latte" in 2018. The Ramechhap Hariyo Latte variety is selected for leafy vegetable purposes, while the Rato

Latte variety is promoted for grain purposes under the leadership of the Hanku Community Seed Bank in Jumla, Nepal [36,39].

This crop, once seen as neglected and underutilized, has regained its value in recent times due to its ability to flourish in adverse conditions and produce nutrient-rich products [32]. This crop boasts rich protein content in its grains and leaves [34], with the grains, in particular, being recognized for their easily digestible and high-quality proteins, as well as their high levels of lysine, a limited amino acid in cereals [40]. Furthermore, its oil composition is also of exceptional quality, containing unsaturated fatty acids and a high amount of squalene, a component with important skincare applications [31,41]. The bioactive components and nutritional elements present in amaranth grains make it a nutritious food, which helps to reduce cholesterol and blood glucose levels, combat anemia, and provide antioxidant functions, all the while being gluten-free [30,32,41]. This crop also boasts superior agronomic attributes, including wide adaptability, C4 photosynthesis, herbicide resistance, a broad variability of germplasm, efficient water use, and stress tolerance, making it a potential crop for future food security [30,34]. With the adverse effects of climate change and population growth looming, the hardiness and nutritional benefits of this crop make it a viable option for ensuring future food security.

3.2. Buckwheat

Buckwheat (*Fagopyrum* sp.; known locally as 'Phapar') is generally considered a pseudo-cereal and a food crop for the poor, yet it continues to play an important role as an indigenous food crop in the Himalayan region of Nepal [42]. Despite being neglected, buckwheat is economically capable of producing higher grain yields compared to other cereal crops [43]. It is also highly resilient, able to grow in less fertile, acidic soils, and withstand moisture stress, low temperatures, and different cropping patterns due to its short lifespan [42,43]. A study conducted by Baniya et al. [44] showed that buckwheat in the Dolpa district of the Karnali province had superior height and seed production compared to other areas (Mustang, Kaski, and Lalitpur), revealing the crop's potential in the region.

Among 18 known species of buckwheat across the world, 5 species are found in the Karnali province of Nepal, including *Fagopyrum esculentum* subsp. *esculentum*, *F. tataricum* subsp. *tataricum*, *F. tataricum* subsp. *potanini*, *F. tataricum* subsp. *annum*, *F. cymosum*, *F. gracilipes*, and *F. megacarpum* [17,42]. Of these, the most widely cultivated species are *Fagopyrum esculentum* (known locally as mithe/common phapar) and *Fagopyrum tataricum* (known locally as tite/tartary phapar) [43]. According to Joshi [43], the Dolpa district in Karnali has the highest diversity of buckwheat, with every family in the area involved in its cultivation. In addition, Dolpa is the only place in the world where the wild species *Fagopyrum megacarpum* can be found [17]. Recent data from 2020/2021, reported by MoALD [29], show an increase in the cultivation area and production of buckwheat in the study area as compared to the past static years.

People tend to prefer mithe/common phapar over tite/tartary phapar because the latter has a higher level of bitterness [17]. To mitigate this bitterness, people were found to consume tartary buckwheat in the form of leavened bread or dhindo, which was mixed with barley or millet flour. Other practices, such as soaking the grains overnight, were also observed to reduce bitterness [45]. There is a specific type of tartary buckwheat called bhate phapar (kalo kishe and seto kishe) that has a loose hull and is less bitter, making it a popular substitute for rice [43]. During our study, we discovered that buckwheat has value not only as a food source but also in apiculture. Respondents were found to be aware of buckwheat's role as a crucial bee forage and have been actively promoting its cultivation in recent years due to its abundant flowers with rich nectar and longer flowering period [43].

During the study, we were informed of the local names for various landraces of buckwheat in the region. Table 2 lists some of the most frequently encountered names. The majority of respondents reported planting buckwheat in July. The crop grows for a period of 60–90 days, and the harvest time was determined to be from September to October.

Table 2. The local name of various landraces of buckwheat in Karnali, Nepal.

Common Buckwheat (Mithe)	Tartary Buckwheat (Tite)
Mithe Phapar, and Ogule	Bhalu, Bharule, Chuchhe, Dalle, Dhahasur, Dhesoi, Jhombre, Kalo Kise, Kambre, Rani Tite, Seto Kise, Tite Phapar, and Tuchhi tite

Source: Joshi [43].

Buckwheat offers numerous health benefits due to its higher content of minerals (such as Zn, Cu, Mn, and Fe) and vitamins (including B1, B2, B3, and E) compared to other common food crops like rice, maize, and wheat [46]. Additionally, it boasts nutritionally valuable proteins, a balanced amino acid composition, healthy lipids, high dietary fiber, and polyphenols [46,47]. The tite/tartary phapar variety of buckwheat has been found to offer both food and medicinal value [17,45]. In Nepal, the bhate phapar landrace is only found in the Dolpa district and has the potential to replace rice as the staple food, contributing to a healthier diet [17]. Buckwheat can play a significant role in improving food security in challenging terrains like the Karnali region, due to its wide range of adaptability, ease of cultivation, tolerance to moisture stress, and poor soil conditions.

3.3. Finger Millet

Finger millet, (*Eleusine coracana*; Nepalese vernacular name: 'Kodo') is the fourth most important crop among millets globally and the most important among the underutilized crops in Nepal [48,49]. In terms of cultivation area and production, it ranks fourth among grain crops after rice, maize, and wheat in Nepal [50]. Nepal is one of the major countries producing finger millet worldwide [51]. With its classification as a C4 crop, ability to adapt to different forms of stress, climate resilience, rich nutritional content, and multiple uses, finger millet plays a critical role in contributing to food and nutritional security in the face of climate change and global warming [49,52].

Finger millet is widely grown in hilly and mountainous areas of Nepal, as reported by Luitel et al. [53]. The Karnali region alone accounts for 6.4% of national production, while the four districts under study produce 3% of the total production [29]. Data from MoALD [29] reveal that the productivity of finger millet in Dolpa, Humla, Jumla, and Mugu has been hovering around 1 mt/ha over the past decade (2011/2012–2020/2021). Approximately 25% of the total finger millet produced in Nepal is utilized for making local alcoholic beverages [54]. Our research also found that finger millet is used for this purpose, as indicated by the responses from the survey participants. Although the yield of finger millet in the four districts under study is lower than the national average of 1.23 mt/ha, it is still on par with the production and cultivation area of major food crops like rice, wheat, and maize in each district, according to [29]. The statistics from MoALD [29] also show that finger millet in the Mugu district surpasses the cultivation area and production of the other major food crops, indicating its significant contribution to the agriculture practices in these regions. As reported by the National News Agency, RSS [55], local finger millet made its debut as a bulk export product in 2021, exporting 3 tons of grain and 1.5 tons of flour to Canada. The traders also exported other local products from the Karnali region, including Jumli Marshi rice (14 tons to Canada and 5 tons to Japan) and beans (to Canada) (unpublished data).

Farmers in the study region have adopted the practice of broadcasting for planting finger millet seeds, typically in April. They have access to a wide range of landraces including Seto Kodo, Kalo Kodo, Khairo Kodo, Riuli Kodo, Kaine Kodo, Damle Kodo, Aangale Kodo, and Samale Kodo. The Hanku Community Seed Bank located in Jumla, Nepal, made significant progress in 2021 by officially registering Rato Kodo as a formal source of finger millet seed [39]. The study also revealed that farmers intercrop soybean seeds between the finger millet crop, which is sown in late May or early June. Threshing of millet, quite the contrary, is done only after the harvested panicles are kept unventilated for a few days. Finger millet is the second most staple crop following rice and is considered to have improved flavor if stored for a longer period. This is evident in popular finger millet-based food and beverage items, such as dhindo (stirred millet flour boiled in water), roti (unleavened bread), raksi (fermented distilled alcoholic liquor), tungba (fermented millet kept in boiling water and consumed through a bamboo straw), Jadh (undistilled fermented alcoholic liquor), and chhyang (diluted Jadh). In fact, according to a CNN article by Cheung [56], the Nepalese alcoholic drink (raksi) was ranked 41st among the world's 50 most delicious drinks.

Table 3 highlights the superiority of finger millet in terms of calcium content, with a concentration of 344 mg/100 g. Furthermore, when compared to other major grains, finger millet boasts an impressive nutritional profile, including higher levels of dietary fiber, phenolic compounds, vitamins, micronutrients, and proteins. Additionally, finger millet offers various health benefits, such as anti-cancer, antioxidant, anti-diabetic, and anti-ulcerative properties, and is gluten-free [49,57].

Table 3. Nutrient composition of different grain crops per 100 g.

Crop	Energy (kcal)	Fiber (g)	Protein (g)	Calcium (mg)	Iron (mg)	Phosphorus (mg)
Rice	345	0.2	6.8	10	0.7	160
Wheat	397 *	1.4	29.2 *	40	6	846 *
Maize	342	2.7	11.1	10	3.3	348
Amaranth seed	375	2.2	9.4	37	5.2	529.1
Buckwheat	323	8.6 *	10.3	64	15.5 *	355
Finger millet	328	3.6	7.3	344 *	3.9	283
Foxtail millet	331	8	12.3	31	12.9	290
Naked Barley	346	2.3	12.6	25	4.1	346
Proso millet	378	1	11	8	3	28.5

Source: The tabulated values were derived from DFTQC [58]. * Signifies the highest value within each column; the abbreviations within the first row, 'kcal', 'g', and 'mg', in parentheses indicate the units of measurement for kilocalorie, gram, and milligram, respectively.

According to a study by Gull et al. [59], the outer surface of finger millet grains contains high levels of phenolics, specifically tannins, which provide protection against fungal and bacterial pathogens and extend their shelf life. In fact, finger millet grain has been known to remain undamaged for up to 50 years, making it a valuable solution to food insecurity and instability [60]. Additionally, finger millet can be used to produce a variety of food and value-added products, which can help to improve the economic situation of local communities. Residents in rural areas, such as Karnali, can grow and consume finger millet for both food and nutritional security due to its ability to thrive in harsh environments. With the national production of millet unable to meet the national demand [49], and successful exports to Canada from Karnali [55], farmers could take advantage of the promising national and international millet market, both for their own consumption and for export.

3.4. Foxtail Millet

Foxtail millet (*Setaria italica*), locally known as "Kaguno" in the Karnali region, is a highly efficient C4 plant, capable of utilizing photosynthesis, nutrients, and water more efficiently [61]. This grain has several important features, such as the ability to thrive in soil with low nutrient levels and withstand drought, saltiness, and pest infestations [62–64]. Nepal is known for having a rich diversity of foxtail millet [65], with the Karnali region being the primary area for its cultivation [66].

During our research, we encountered six local landraces of foxtail millet: Kalo Kaguno, Rato Kaguno, Pahelo Kaguno, Khairo Kaguno, Sano Kaguno, and Thulo Kaguno. These varieties are commonly consumed in the region as porridge or steamed dishes. While many farmers grow foxtail millet alongside finger millet, some cultivate it as a standalone crop. With growing demand and increased market value of foxtail millet [67], farmers in the Karnali region have the opportunity to benefit economically. Our study area, consisting of four districts (Dolpa, Humla, Jumla, and Mugu), is a major foxtail millet-growing region in Nepal [68] and could play a crucial role in preserving the diversity of foxtail millet landraces.

Foxtail millet, despite being an underutilized crop, is packed with valuable nutrients and can be used to create a variety of foods [68]. It boasts the highest zinc content (4.1 mg/100 g) among all millets, as well as higher iron content compared to other crops [69]. Foxtail millet's protein and vitamin (A, and E) content surpasses that of major crops like rice and maize, and it also contains the highest levels of essential amino acids, like methionine and tryptophan, among all food grains [70]. Furthermore, foxtail millet has been linked to several health benefits, such as preventing cancer, regulating hypertension, and reducing blood glucose levels, cholesterol levels, and the risk of cardiovascular diseases [68,71]. There has been a growing demand for healthy foods like foxtail millet grown in the Karnali region in the country's capital, likely due to increased awareness of its nutritional value [67].

Foxtail millet offers a wide range of possibilities as a suitable model for studying plant traits, agronomic practices, and physiology. This is due to its small and simple diploid genome, compact plant size, and short life cycle [64]. Considering food insecurity and climate change, foxtail millet's ability to withstand various types of stress and its nutritionally rich traits make it a crop of interest for conservation and utilization. With its climate resilience and tolerance to both abiotic and biotic stresses, foxtail millet is a valuable resource to address the challenges posed by these global issues.

3.5. Naked Barley

Barley (*Hordeum vulgare*) is a versatile crop that serves a multitude of purposes, including food, feed, and malt [72]. This crop is divided into two categories based on its grain form: hulled barley and naked barley (Nepalese local name "Jau" and "Uwa", respectively). Naked barley, with its loosely attached hull, is favored for human consumption, while hulled barley is typically used as animal feed and malt [73,74]. The ease of threshing in naked barley can be attributed to the presence of a single recessive gene, "nud", located on chromosome arm 7HL [75]. This gene results in a hull that is loosely attached to the grain, unlike the firmly attached hull of hulled barley [72].

Barley is a widely grown grain crop, ranking fourth globally. The high mountains of Nepal and Tibet account for over 95% of naked barley domestication [73,74,76]. This region is considered a center of diversity for barley, hosting the largest number of barley germplasms [77]. Additionally, Nepalese naked barley landraces are known to possess resistance genes against fungal and viral diseases [78,79]. Naked barley is a staple food at high altitudes due to its ability to grow in challenging environments, such as marginal lands with a short growing season [75,80]. It is highly adaptable to high hills and adverse environmental conditions and performs well under rainfed systems and in saline soil, providing substantial yield even with minimal external inputs [80–83].

In our study region, farmers have shown a preference for growing rice and barley over rice and wheat due to barley's comparatively shorter growth cycle. Hulled barley was the dominant crop in the warmer areas, while naked barley was scarcer and primarily grown in marginal regions. In the colder areas, farmers either mixed naked barley with wheat or hulled barley, or grew it on its own. In the 'Maha' village in Mugu, seed sowing typically occurs in November or December, allowing the broadcasted seeds to endure the cold and then flourish with the onset of warmer weather. The harvested grains are utilized to make a variety of food items, such as unleavened bread, satu, dumplings, and thukpa, as well as alcoholic beverages. The study area is known for its cultivation of several landraces including Takule Uwa, Kanalo Uwa, Ful Uwa, Seto Uwa, and Jhuse Uwa. Particularly, 'Jhuse uwa' from Humla has been promoted for cultivation, and farmers have attested to its promising results.

Barley, once considered a neglected and underutilized crop species, is now gaining recognition for its potential health benefits [80,81]. This crop is rich in highly soluble fiber, including β-glucans, essential nutrients, bioactive compounds, and minerals [72,78,83].

These components provide a protective role against harmful agents [72] and have been shown to lower cholesterol levels, decrease the glycemic index, and reduce the risk of colon cancer and cardiovascular disease [72,83–86]. In comparison to wheat, barley boasts 4–6 times higher levels of minerals like calcium, magnesium, and potassium and 10 times higher levels of iron in whole grain form as opposed to pearled grain, which has reduced mineral content [72,80].

Naked barley is a culturally significant, nutritious, and resilient winter food crop that is commonly grown in the high hills and mountainous regions of Nepal [78,87]. Despite being a hardy crop, poor germination is one of the major challenges faced in cultivating naked barley. However, Himalayan landraces of naked barley have been found to have better seed vigor and several advantageous traits, such as tall height, strong stems, large flag leaves, a short growing season, and fewer tillers [80]. The genetic diversity of the Himalayan naked barley, combined with its superior traits, has the potential to support genetic improvement and future breeding programs aimed at enhancing food security and crop production.

3.6. Proso Millet

Proso millet (*Panicum miliaceum*), known locally as "Chino" in the Karnali region of Nepal, is the oldest domesticated food crop in the world and the most important millet after finger millet in terms of food security in Nepal [88–90]. In Nepal, this crop is predominantly grown in the Karnali region [88] and is cultivated in all of the mountainous districts within the region [67].

Farmers in the study region primarily cultivate Proso millet as their main crop, with a limited number incorporating soybean into their fields. Sowing occurs in March or April in warmer areas, while planting in colder regions takes place later. The harvesting process for proso millet is distinct from that of rice. First, the panicles are picked, and a few days later, the straw is cut and used as animal feed. The majority of farmers emphasized the importance of having a proper dehusking machine for the successful cultivation of this underutilized grain. Despite its potential, the farmers face several challenges, including a lack of appropriate machinery, shifts in food preferences, labor shortages, limited research, and inadequate government policies, all of which contribute to a decline in proso millet cultivation [88,91].

Proso millet, also known as "Dhan kodo" or "Rice millet" by local farmers, is often compared to the rice plant in appearance. However, the seed structure of proso millet is distinct. In the region, several landraces, such as Dudhe, Hade, Kalo, Kaptade, Bharbhare, Batale, Kabihare, and Rato are locally available. Of these, Dudhe is the most widely cultivated variety due to its attractive grain quality, delicious taste, easy dehusking process, and shorter crop period. This millet is primarily used to make porridge, unleavened bread, and a steamed version as a rice substitute. With its high yield of 2.2–2.3 t/ha and desirable agronomic performance, Dudhe chino was incorporated into the formal seed system and became the first registered proso millet variety in Nepal, as directed by the Chhipra Community Seed Bank in Humla, Nepal [39].

Proso millet, despite being regarded as an underutilized and neglected crop, contributes to roughly one-third of energy and protein intake in developing nations [92]. The popularity of this crop has now extended beyond pets' feed after the increase in awareness of its health and nutritional benefits [89,90]. Proso millet is nutritionally superior to other major cereal food crops, boasting higher levels of essential amino acids, which results in higher protein quality, as well as greater amounts of minerals and vitamins [89,90,93]. Additionally, its alkaline nature makes it easier to digest, and it has been shown to provide health benefits for issues, such as cancer, diabetes, cholesterol metabolism, heart disease, and liver disease [90,92,94].

In the face of climate change, water scarcity, and food insecurity, proso millet can play a critical role as a crop that requires the least amount of water among foods [92,94]. It is a valuable rotation crop for drylands, with a shorter ripening time of 60–90 days, higher water use efficiency, and tolerance to herbicides [92,95]. Proso millet can also help control weeds, diseases, and insects, and preserve moisture for deeper-rooted plants when grown during the summer [92]. As a C4 plant with efficient photosynthesis and wider adaptability, proso millet performs well in challenging conditions, such as drought, saline soils, and infertile land [88,94–96]. In temperate locations, proso millet can be grown more effectively than other millets [94], making higher altitude areas like Karnali a promising place to cultivate the crop. The unique nutritional properties and potential of proso millet have opened up new opportunities for socio-economic development in the Karnali region, with the establishment of a proso millet biscuit and grain trading industry [67].

4. Discussion

Our study on the four upper mountainous districts of Karnali province signifies that this region holds numerous landraces of underutilized grain crops belonging to amaranth, buckwheat, finger millet, foxtail millet, naked barley, and proso millets. These crops, although possess rare contributions to the diet of today's people, are still the major food source for people in the upper Karnali region. Additionally, these crops are nutritious, healthy, and organic, and grow in marginal lands with minimum or no input demonstrating their suitability in upper Karnali regions that are equipped with rough terrains, poor infrastructure, and food/nutritional insecurity. Local farmers would be benefitted socio-economically if they avail the consumer's increased awareness about underutilized grain crops and connect these crops with industry and big neighboring markets (India and China) by branding them as 'Himalayan Superfoods'.

Despite promoting the virtues of local underutilized grains, the popularity of rice as a staple food in Nepal has affected Karnali people's perception. They began to regard their indigenous food grains as a symbol of inferiority and poor's food, resulting in the shift of preference for the aforementioned underutilized crops to rice [97]. It is judicious to grow highly productive and preferred food crops like rice, maize, and wheat whenever inputs are well available. However, in the Karnali region, reliance on these input-responsive crops over the hardy underutilized crops could aggravate the food insecurity problem due to its difficult geography, low productive lands, poor agricultural facilities, and economically poor farmers. Concerning this, the local underutilized crops have the potential to improve food security in regions like Karnali [98]. The promotion of these crops as organic, nutritious, and healthy food could help Karnali farmers to sell their crops at high prices. Furthermore, the establishment of underutilized grain-based food industries and seed registration processes among underutilized crops could likely benefit Karnali farmers.

When exploring the use of these crops beyond Karnali, it possesses huge promise. Climate change has forced agricultural scientists to evolve tolerance/resistance in crops against biotic and abiotic stresses. In this situation, the stress tolerance/resistance system present in underutilized crops could be harnessed for breeding other crops [99]. Hence, unique, superior, and abundant landraces of underutilized crops in Karnali could be a valuable resource for educational and breeding purposes. In addition to this, the cultivation of these underutilized crops could assist in climate change mitigation. Rice production, as the staple food crop in Nepal, takes place with great environmental costs, releasing greenhouse gases (CH_4 and N_2O) and requiring water in substantial amounts [100]. Thus, underutilized crops could be a viable option for future agriculture if we intend to grow a crop that is safe for the environment, nutrient-dense, and provides reliable output even in the circumstance of stresses and minimal external inputs.

This study will be useful for policymakers, researchers, and stakeholders interested in enhancing nutrition/food security and promoting the cultivation of underutilized crops in the region. With an increase in awareness of the agronomic and health benefits of underutilized grains, and therefore increased market demand, Nepalese policymakers have to reconsider the uneconomical and unsustainable policy of providing subsidized rice in the Karnali region to cope with the food deficiency [97]. Instead, the policy must be formulated prioritizing locally adapted underutilized grains' landraces to grow and produce in the Karnali region, where farmers could secure reliable output from those hardy traditional crops apropos Karnali's harsh land structure, poor agricultural infrastructure, and farmers' low socio-economic status. For increasing the effectiveness of the policy of prioritizing underutilized crops production, measures, such as training farmers in beneficial agronomic techniques like intercropping underutilized crops with leguminous crops to harness nitrogen fixation, establishing seed banks, promoting the markets and trading possibilities, broadening food items and non-food uses, conducting research and disseminating convenient cultivation, intercultural, and harvesting machines or practices, subsidizing on agricultural machines, and incentivizing farmers to grow underutilized crops could be beneficial. It is currently unlikely for farmers to adopt hybrid or genetically superior cultivars as underutilized crops are ignored by plant breeders and researchers, so for now, opting for the best agronomical practices could be advantageous for higher production. However, we assume that plant breeders and researchers will exploit underutilized crops' superior attributes sooner or later in response to climate change's adversities and global food insecurity/malnutrition concerns. Thus, what the future awaits is whether underutilized crops' desired attributes would be incorporated into the present staple crops or underutilized crops would be genetically improved for increased yield while maintaining their superior characteristics. In this study, we pointed out a paucity of information about the status of underutilized crops in the study area. A well-documented characterization of landraces, identification of their agronomic potentials, and rigorous data collection are needed to gain a deeper insight into the underutilized crops in the Karnali region.

5. Conclusions

Despite being undervalued as a food crop, underutilized food crops remain a crucial component of the diets of people living in marginal and developing areas like Karnali. However, the decline in popularity of these underutilized grains in the Karnali region is concerning. To ensure the preservation and continuation of these valuable landraces of underutilized food crops, there is a need for intervention, such as crop improvement, technology, and improved farming practices, as well as increased marketing efforts. Our study sheds light on the vast potential of the Karnali region as a source of future smart crops. By harnessing and improving the genetic bases of agrobiodiversity in the region, we can tackle the persistent problems of poverty, food insecurity, and malnutrition in Karnali. These hardy, climate-resilient, and nutritious underutilized food crops offer not only regional solutions but also the possibility of a global solution in addressing the growing threats of climate change, poverty, hunger, and malnutrition.

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