RESEARCH ARTICLE

Agronomic Evaluation and Nutritional Profiling of Finger Millet (*Eleusine coracana* L. Gaertn) Cultivars

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Abstract

Finger millet (*Eleusine coracana* L. Gaertn) despite being a traditional crop of the Himalayan region, scant information is available on agronomic aspects and nutritional profiling of the cultivars recommended for cultivation in the region. Therefore, the study was designed for agronomic evaluation and nutritional profiling of the finger millet cultivars (VLM-382, VL-352, VL-376, VL-379 along with a local landrace) to identify cultivars best suited for the specific growing conditions and, maximizing the grain and nutritional yield. Grain yield per plant was significantly ($p \leq 0.05$) the highest in cultivar VL-379 (24.88 g) as compared to the other evaluated cultivars and local landrace (12.82 g). The higher grain yield was associated with a higher 1000-grain weight (3.12 g) in the cultivar VL-379. Grain yield was the lowest in the local landrace (12.82 g). The local landrace was found susceptible to leaf blast disease whereas the no symptoms of infestation were found in the other cultivars. The local landrace being taller (plant height of 131.4 cm) than the other cultivars, was susceptible to lodging at the reproductive growth stage. Further, nutrition yield per plant in terms of carbohydrates, proteins, total fat, dietary fibers, energy, minerals, amino acids, and vitamins was significantly higher in cultivar VL-379 than the other cultivars and local landrace. The cultivar was found richer in calcium and iron contents than the bio-fortified varieties identified by the ICAR-Indian Council of Agricultural Research. Thus, the study identified VL-379 as a high-yielding nutri-rich finger millet cultivar suitable for cultivation in Pithoragarh and locations with similar environmental conditions in the middle hills.

Highlights:

- The agronomic evaluation identified VL-379 as a high grain-yielding finger millet cultivar.
- The grain and biomass yield were significantly low in the local landrace.
- The local landrace was found susceptible to leaf blast disease and prone to lodging.
- The cultivar VL-379 was found high-yielding for nutritional parameters such as carbohydrates, proteins, total fat, dietary fibers, energy, minerals, amino acids, and vitamins.
- The study recommends cultivar VL-379 as a high-yielding nutri-rich finger millet cultivar suitable for cultivation in Pithoragarh and similar locations.

Keywords: Agronomy, Finger millet, Grain, Nutrition, Ragi, Yield

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Introduction

Millet is a diverse group of small-seeded cereals often termed nutri-cereals and includes sorghum, pearl millet, finger millet, little millet, foxtail millet, prosomillet, barnyard millet, kodomillet, brown top millet and other minor millets. Climate change and continuous soil degradation are posing a great threat to global agriculture. Therefore, building crop resilience against climate variability and extreme weather events is the key to ensuring food and nutritional security for the growing global population. Millets were among the first crops to be domesticated in India and have been the components of traditional farming systems in drylands since time immemorial (Grovermann *et al.,* 2018). Being C4 plants, millets have higher photosynthetic efficiency, improved water use efficiency and heat tolerance. Due to climate resilience, millets thrive in harsh environments with minimal water and poor soil fertility. These unique features make them perfect for combating climate change impacts like drought and desertification (Numan *et al.,* 2021; Singh *et al.,* 2021; Wilson and VanBuren, 2022). Therefore, millets are also termed famine crops as these crops survive and assure yields in famine situations. The crops though require relatively lesser inputs and respond well to irrigation, fertilizers and other inputs. Further, millets have been a staple food in various cultures for thousands of years, particularly in Africa and Asia, due to their hardiness and nutritional value. The climate resilience exhibited by millets makes them a sustainable crop choice under diverse environmental conditions. Considering the importance of millets, the United Nations General Assembly declared 2023 as the 'International Year of Millets' to create a

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global demand and to provide millet-based nutritional food to the people. Emphasis was given to enhance production, productivity, and consumption by creating awareness of the health benefits of the millet.

The Indian Himalayan region had been a major niche region for millet crops as a component of the ethnic culture and livelihood. Millets were the traditional crops suited to the Himalayan region and part of the culture (Bhat *et al.,* 2019). With the increasing popularity of wheat and rice, the farming community abandoned growing millet despite of nutritional benefits and sustainable nature of the crops leading to a decline in the area under millet cultivation (Grovermann *et al.,* 2018). However, of late, efforts are being made to revive and mainstream the nutrition-rich low-input demanding millet crops in the Himalayan region. Consistent efforts have been initiated by Government bodies to bring back millet cultivation by creating awareness about millet and its foods among the communities.

Finger millet (*Eleusine coracana* L. Gaertn) commonly known as mandua or ragi, is one of the important millet crops grown for grain and fodder purposes under varied agro-climatic conditions. The crop requires low input and is less affected by major pests and diseases. The short-duration crop matures in 90 to 120 days. Besides, higher drought stress tolerance makes this crop ideal for dry land farming (Bhatt *et al.,* 2011; Mude *et al.,* 2020). Finger millet is gaining popularity due to its impressive nutritional profile and adaptability to harsh environments (Sharma and Niranjan, 2018; Maharajan *et al.,* 2022; Chandra *et al.,* 2016). This ancient grain, cultivated for centuries in Africa and Asia, boasts a remarkable composition of essential nutrients, making it a valuable addition to diverse diets. Finger millet is a staple food in many parts of Africa and Asia, and it is becoming increasingly popular in other parts of the world as people become more aware of its nutritional benefits. Finger millet is a highly nutritious grain that is a good source of dietary fiber, protein, calcium, iron, and other essential nutrients (Bisht *et al.,* 2023). Further, being gluten-free, finger millet is ideal for people with celiac disease or gluten sensitivity. The finger millet grains are known to be resistant to storage insect pests with long storage life under minimum attention. Further, its high market value compared to other cereals makes finger millet one of the salient crops among the resource-poor farming communities. A variety of dishes can be prepared from finger millet. The grains can simply be ground into flour and used to make bread, pancakes, porridge, and other baked goods.

Finger millet crop is primarily grown in India, which dominates global production. In India, the crop was cultivated on a 1.16 million hectares area with production of 1.99 million Tonnes of grains in the year 2020-21 (Source: Directorate of Millets Development, Jaipur, India). In India, the crop is majorly grown in Karnataka, Uttarakhand and Tamil Nadu. Karnataka takes the lead with 67.73% (0.79 million Tonnes) of India's total finger millet production (1.16 million tonnes), followed by Tamil Nadu and Uttarakhand. The crop productivity was more than two-fold higher in Tamilnadu (3481 kg/ha) than in Uttarakhand (1459 kg/ha). Further, the productivity in Uttarakhand for the year 2022-21 was also lesser than the national productivity of the crop (1724 kg/ha). Thus, ample scope exists for increasing crop production within the same area under cultivation through the adoption of high-yielding cultivars and good agronomic practices.

Agronomic evaluation of finger millet cultivars is crucial for identifying cultivars best suited for specific growing conditions and maximizing yield and quality (Grovermann *et al.,* 2018). Further, it guides farmers in selecting the most suitable cultivars for their specific growing conditions and end-user needs. Thereby it contributes to food security by ensuring sustainable and high-quality finger millet production. By conducting thorough agronomic evaluations, the full potential of finger millet as a nutritious and sustainable crop, contributing to food security and improved livelihoods for millions worldwide can be unlocked. Therefore, the present study was designed for agronomic evaluation and nutrition profiling of the finger millet cultivars under local climatic conditions in the middle Himalayan hills to identify the high-yielding bio-fortified variety suitable for the region.

Materials and Methods

Study Location

The agronomic evaluation of the finger millet cultivars and a local landrace was carried out at experimental fields of Defence Institute of Bio-Energy Research Field Station Pithoragarh, Uttarakhand India (29.5829° N, 80.2182° E; 1676 m ASL). The study was conducted from June to November 2023.

Seed Material

A local landrace and finger millet cultivars recommended for cultivation in the region were used in the present study. Seed material of the local landrace was collected from the Tankul area of Dharchula tehsil in the Pithoragarh district. Genetically pure seeds of other released finger millet cultivars viz. VLM-382 (Safed), VL-352, VL-376 and VL-379 collected from ICAR-VPKAS (Indian Council of Agriculture Research-Vivekananda Parvatiya Krishi Anusandhan Sansthan), Almora, Uttarakhand.

Soil Analysis

Before the seedling transplantation, soil samples were collected and analyzed for pH, EC, organic carbon, phosphorous, potassium, sulphur, zinc, boron, iron, manganese, and copper contents. The soil samples were analyzed following the standard soil testing methods at the District Soil Testing Laboratory, Pithoragarh, Uttarakhand.

Agronomic Evaluation of Finger Millet Cultivars

The field experiment on agronomic evaluation was laid out in a Randomized Block Design with four replications. Key components of the agronomic evaluation were yield potential, maturity duration, disease and pest resistance, grain quality and lodging resistance. Seeds were sown in the second week of June 2023 to raise seedlings for further transplanting under open-field conditions. Square shape plots measuring 2 × 2 m were prepared. Well-decomposed cow dung manure was mixed in soil at the rate of 10.0 tonnes/ha. Well-grown and healthy seedlings were transplanted in the plots on the 30th day after initial sowing. Seedlings were transplanted to maintain a row-to-row distance of 22.5 cm and plant-to-plant spacing of 10 cm to accommodate

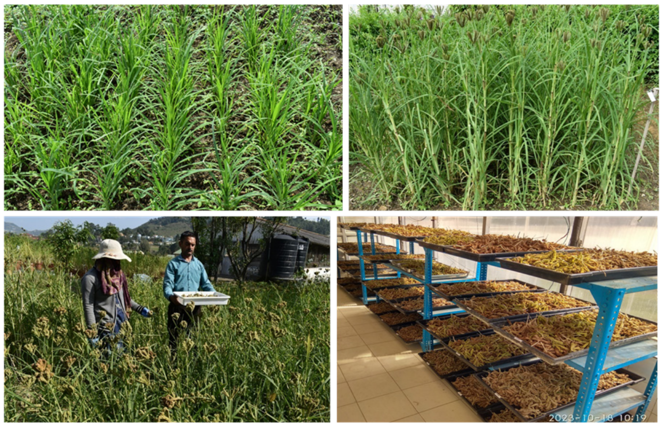

Figure 1: Different crop growth stages and processing during the agronomic evaluation of finger millet cultivars

a total of 128 plants in each plot. Standard agronomic practices were followed during the crop period. Irrigation was provided periodically as per the requirement. Foliar applications of water-soluble nutrients (NPK 20:20:20; 20.0 g/L) were carried out at the tillering and flowering stages. Observations were recorded on vegetative and reproductive traits according to the guidelines for conducting tests for distinctiveness, uniformity, and stability on finger millet (*E. coracana* L. Gaertn) prepared by Protection of Plant Varieties & Farmer's Rights Authority, Government of India and, IPGRI Descriptor for finger millet (*E. coracana* L. Gaertn)-1985 (Fig. 1). Data were recorded on number of leaves, leaf blade length, leaf blade width, culm thickness, leaf sheath length, leaf sheath width, flag leaf length, flag leaf width, days to 50% flowering, plant height, finger numbers, finger width, finger length, grain yield, productive tillers per plant, weight of 1000 grains and biological yield. Details on recording the data have been provided as supplementary information. Data on grain and fodder yield per ha were computed based on the yield data in a plot of 4.0 m^2.

Nutritional analyses of the grains

Grain samples were analyzed for various nutritional parameters viz. total carbohydrates (g/100 g), protein (Nx6.38) (g/100 g), total fat (g/100 g), dietary fiber (g/100 g), ash (%), energy (Kcal/100 g), moisture (%), mineral contents (mg/100g) for calcium, sodium, potassium and iron, vitamin contents (B_1, B_2, B_3; mg/100 g) and amino acids contents (Lysine, Methionine; g/100 g). The grain samples (300 g each) were provided for the analyses at M/S Delhi Test House, Delhi. The testing laboratory is accredited by NABL-National Accreditation Board for Testing and Calibration Laboratories. The analyses were performed by following official methods validated by AOAC-Association of Official Analytical Chemists or IS-Indian Standards. Detailed information on the analyses has been provided as supplementary information. The data for the experiment laid out in Randomized Block Design-RBD was statistically analyzed for Analysis of Variance-ANOVA using CropStat software developed at IRRI, Philippines.

Results

Soil Analysis

Soil pH was close to neutral (7.01–7.65). The soil was non-saline as the electrical conductivity was in the range of 0.155 to 0.337 dS/m. Soil organic carbon was high (1.02–2.33%). The phosphorous content in the soil was medium (17.5–23.3 Kg/Ha) whereas Potash content was high (649.6–996.8 kg/ha). The sulfur content in the soil was medium (14.4–18.9 ppm). The soil Boron content was in the range of 0.62 to 1.54 ppm. The zinc content in the samples was 1.49 to 3.47 ppm whereas the Iron content was 11.2 to 15.2 ppm. Manganese content was 3.4 to 6.19 ppm whereas copper content in soil was 0.68 to 0.85 ppm. Thus, the soil was not deficient for the analyzed minor elements.

Vegetative parameters recorded during agronomic evaluation

Plant height measured at the dough stage from ground level to tip of fluorescence was significantly higher in the local landrace (131.4 cm) as compared to the other cultivars (Table 1; Fig. 1). Among the other cultivars, the plant height was significantly low in VL-376 (102.1 cm) and VL-379 (103.1 cm). Culm thickness measured as a diameter of internodes between 3^{rd} & 4^{th} nodes from the top at the dough stage was significantly higher in VLM-382 (9.0 mm) than the local landrace (7.5 mm) and other cultivars. Leaf sheath length measured from node to ligule of flag leaf from top at the flowering stage was significantly higher

Table 1: Vegetative traits in evaluated finger millet cultivars

Genotype	*Plant height (cm)*	*Culm thickness (mm)*	*Leaf sheath length (cm)*	*Leaf sheath width (mm)*	*Leaf blade length (cm)*	*Leaf blade width (mm)*	*Flag leaf length (cm)*	*Flag leaf width (mm)*	*Number of leaves*
Local Landrace	131.4 a	7.5 b	11.0 b,c	3.9 b	45.9 b	12.8 b	36.1 b	12.1 c	18.7 a
VLM-382	119.2 b	9.0 a	13.1 a	5.1 a	63.7 a	15.6 a	44.4 a	13.8 a	14.9 d
VL-352	114.0 c	7.0 c	11.3 b,c	3.6 c,d	45.2 b	12.8 b	36.0 b	12.0 c,d	16.3 c
VL-376	102.1 d	7.0 c	10.4 d	3.4 d	37.7 c	12.5 b	32.0 c	11.6 d	17.5 b
VL-379	103.1 d	7.5 b	10.7 c,d	3.8 b,c	39.3 c	12.9 b	31.6 c	12.7 b	18.5 a
SE (n= 4)	1.7	0.1	0.2	0.1	0.9	0.2	0.8	0.1	0.3
5% LSD	5.0	0.3	0.6	0.2	2.7	0.6	2.5	0.4	0.9

Mean values for a particular parameter marked with different letters are significantly different according to LSD ($p \leq 0.05$) test.

in VLM-382 (13.1 cm) than the landrace (11.0 cm) and other cultivars. Similarly, leaf sheath width measured across the center of the 4th leaf from top at the flowering stage was significantly higher in VLM-382 (5.1 mm) than the local landrace and other cultivars. Leaf blade length measured from ligule to tip of 4th leaf blade from top at the flowering stage was significantly higher in VLM-382 (63.7 cm) than the local landrace (45.9 cm) and other cultivars. The leaf blade width measured across the center of the 4th leaf from top at the flowering stage was significantly higher in VLM-382 (15.6 cm) than the local landrace (12.8 cm) and other cultivars. Flag leaf length measured from ligule to flag leaf blade tip was also significantly higher in VLM-382 (44.4 cm) than the local landrace (36.1 cm) and other cultivars. Flag leaf width measured at the widest point of flag leaf was significantly higher in VLM-382 (13.8 mm) than the local landrace (12.1 mm) and other cultivars. Number of leaves counted on the main tiller at the flowering stage was significantly higher in the local landrace (18.7) and VL-379 (18.5) than the other cultivars.

Yield attributing parameters recorded during agronomic evaluation

Finger width measured across the center of the longest finger at the dough stage was significantly ($p \leq 0.05$) higher in VL-352 (12.1 mm) than in the local landrace (11.5 mm) and other cultivars (Table 2). Similarly, the finger length measured from base to tip of the longest finger was significantly longer in VLM-382 (11.9 cm) than the local landrace (6.1 cm) and other cultivars (Fig. 2). Peduncle length measured from ear head base

Table 2: Yield attributing traits in finger millet varieties

Genotype	*Finger width (mm)*	*Finger length (cm)*	*Peduncle length (cm)*	*Finger numbers*	*Days to 50% flowering*	*Productive tillers per plant*	*1000 grain weight (g)*
Local Landrace	11.5 b	6.1 e	29.8 a	7.8 b	90.0 a	2.89 b	2.62 d
VLM-382	10.6 c	11.9 a	27.4 b	9.2 a	66.0 d	3.65 a,b	2.68 c,d
VL-352	12.1 a	8.3 b	25.0 c	9.1 a	83.5 c	2.92 b	2.96 b
VL-376	11.6 a	7.4 d	24.1 c	8.6 a	86.7 b	4.43 a	2.78 c
VL-379	11.5 b	8.0 c	22.1 d	8.7 a	86.7 b	4.12 a	3.12 a
SE (n = 4)	0.2	0.1	0.3	0.2	0.4	0.34	0.04
5% LSD	0.5	0.2	0.9	0.6	1.3	1.01	0.13

Mean values for a particular parameter marked with different letters are significantly different according to the LSD ($p \leq 0.05$) test.

Figure 2: Images of mature ears in different finger millet cultivars and the local landrace

to the topmost node of the main tiller at the dough stage was significantly longer in the local landrace (29.8 cm) than the other cultivars. Finger numbers counted on main ears were significantly higher in other cultivars (8.6–9.2) than in the local landrace (7.8). The productive tillers per plant counted at maturity were significantly higher in VL-379 (4.12) and VL-376 (4.43) than in the local landrace (2.89) and other cultivars. The 1000-grain weight was the highest (3.12 g) in the variety VL-379 (Table 2). Among the evaluated cultivars, significantly the highest grain yield per plant and plot was recorded in variety VL-379 (24.88 and 3184.6 g, respectively) (Table 3). Grain yield was the lowest in the local landrace (12.82, and 1641.0 g per plot). The derived data on grain yield per ha suggested significantly higher yield potential in a variety VL-379 (7961.6 kg/ha) than that in the local landrace (4102.4 kg/ha). Fodder yield per plant and plot was significantly higher in variety VLM-382 (75.66 and 9684.5 g, respectively). The derived data on fodder yield per ha suggested significantly higher yield potential in a variety VLM-382 (24211.2 kg/ha) than that in the local landrace (13673.6 kg/ha). Early flowering initiation was observed in cultivars VLM-382 (66 days to 50% flowering) than the other cultivars. The local landrace took a maximum period, i.e., 90 days to complete 50% flowering. Further, the local landrace being taller (plant height of 131.4 cm) than the other cultivars, was susceptible to lodging at the reproductive growth stage. No lodging was observed in other cultivars which were dwarf with plant heights of 102.1 to 119.2 cm.

Other traits/descriptors recorded during agronomic evaluation

Data recorded at the flowering stage revealed pigmentation at leaf juncture only in the local landrace and not in other evaluated cultivars (Table 4). Thumb ear was not present in the local landrace but was present in all other evaluated cultivars. Culm branching recorded at the dough stage was observed in the local landrace as well as other evaluated cultivars. The growth habit recorded at the tillering stage was decumbent for the local landrace and VLM-382 whereas it was erect for cultivars VL-352, VL-376 and VL-379. Leaf-sheath pubescence was absent in all the evaluated genotypes. Ear shape was semi-compact in all the genotypes. Finger branching recorded at the dough stage was present only in VL-379, in which branching was observed in the thumb finger. Multiple finger whorls were not observed in any of the evaluated genotypes. The grain surface was smooth for all the evaluated cultivars and landrace. The grain shape was round for all the evaluated cultivars and landrace. Non-synchronous ear maturity was observed for the evaluated cultivars and landrace. Grains from local landrace were non-uniform as against uniform in other evaluated cultivars. Pericarp was partially persistent in the case of all the evaluated cultivars and landrace. The grain color was copper brown in the local landrace whereas the grains were white in variety VLM-382 (Fig. 3). The grain color was light brown in the rest of the cultivars. The local landrace was found susceptible to leaf blast disease whereas the other cultivars showed resistant response to the disease. Plants of local landrace

Figure 3: Grains are processed from the mature ears of the local landrace and finger millet cultivars

Table 3: Grain and fodder yield in finger millet cultivars

Genotype	*Grain yield*			*Fodder yield*		
	Per plant (g)	*Per plot (g)*	*Per ha (kg)*	*Per plant (g)*	*Per plot (g)*	*Per ha (kg)*
Local landrace	12.82 b	1641.0 b	4102.4 b	42.73 b	5469.4 b	13673.6 b
VLM-382	20.75 a	2656.0 a	6640.0 a	75.66 a	9684.5 a	24211.2 a
VL-352	13.31 b	1703.7 b	4259.2 b	31.48 b	4029.4 b	10073.6 b
VL-376	23.37 a	2991.4 a	7478.4 a	31.32 b	4009.0 b	10022.4 b
VL-379	24.88 a	3184.6 a	7961.6 a	33.52 b	4290.6 b	10726.4 b
SE (n = 4)	1.45	185.6	464.0	4.44	568.3	1420.8
5% LSD	4.28	547.8	1369.6	13.11	1678.1	4195.2

Mean values for a particular parameter marked with different letters are significantly different according to LSD ($p \leq 0.05$) test. The data on yield per ha has been derived based on the data on yield per plot.

being tall with weaker stems were susceptible to lodging whereas lodging was not observed in other evaluated cultivars.

Nutritional Profiling of Finger millet Cultivars

Finger millet grain samples processed from the different cultivars were analyzed for nutritional parameters including proximate nutritional composition (total fat, carbohydrate, protein, moisture, dietary fiber, ash, and energy content), mineral content (Ca, Na, K, Fe), amino acids contents (lysine, methionine) and, vitamin contents (thiamine, riboflavin, niacin, folic acid). The total carbohydrate content was significantly lower in variety VLM-382 and VL-352 (77.93; and 78.34 g/100 g, respectively) than in the local landrace (80.35 g/100 g) (Table 5). The carbohydrate contents in cultivars VL-376 and VL-379 were at par with that in the local landrace. Further, nutrition yield per plant was computed based on grain production data in the tested finger millet cultivars. The analysis revealed the highest carbohydrate yield per plant in VL-379 (19.69 g/plant) than the other cultivars. The carbohydrate yield was the lowest in the local landrace (10.30 g/plant) (Supplementary Data).

Protein content in variety VL-352 (10.96 g/100 g) was significantly higher than that in VL-379 (9.45 g/100 g). However, the protein yield/plant was also the highest in VL-379 (2.55 g) than the local landrace (1.25 g) and other cultivars. The protein content was at par among the other cultivars and the local landrace which ranged between 9.72 g/100 g in the local landrace and 10.96 g/100 g in VL-352. Similarly, total fat content was also at par in the cultivars with that of the local landrace. The fat content of the grains ranged between 1.0-1.3 g/100 g. However, the yield of total fat per plant was the highest in variety VL-379 than the other cultivars.

The dietary fiber content was significantly lower in the local landrace (9.49 g/100 g) than the other cultivars viz. VL-352 (11.71 g/100 g), VL-376 (11.20 g/100 g) and VL-379 (11.04 g/100 g).

Table 4: Other descriptors/traits in finger millet cultivars

Descriptor	*Finger millet variety*				
	Local Landrace	*VLM-382*	*VL-352*	*VL-376*	*VL-379*
Pigmentation	Yes	No	No	No	No
Thumb ear	No	Yes	Yes	Yes	Yes
Culm branching	Yes	Yes	Yes	Yes	Yes
Growth habit	Decumbent	Decumbent	Erect	Erect	Erect
Leaf sheath pubescence	Absent	Absent	Absent	Absent	Absent
Ear shape	Semi Compact	Semi Compact	Semi Compact	Semi Compact	Semi Compact
Finger branching	NA	Absent	Absent	Absent	Present
Finger branching position	NA	NA	NA	NA	Thumb Finger
Multiple finger whorl	Absent	Absent	Absent	Absent	Absent
Grain surface	Smooth	Smooth	Smooth	Smooth	Smooth
Grain shape	Round	Round	Round	Round	Round
Ear Maturity	Non-Synchronous	Non-Synchronous	Non-Synchronous	Non-Synchronous	Non-Synchronous
Grain uniformity	Non-Uniform	Uniform	Uniform	Uniform	Uniform
Pericarp persistence	Partially Persistent	Partially Persistent	Partially Persistent	Partially Persistent	Partially Persistent
Grain color	Copper Brown	White	Light Brown	Light Brown	Light Brown
Disease response	Susceptible	Resistant	Resistant	Resistant	Resistant
Lodging susceptibility	Yes	No	No	No	No

Table 5: Proximate composition analysis in grains of finger millet cultivars

Variety	*Total carbohydrates (g/100 g)*	*Protein (Nx 6.38) (g/100 g)*	*Total fat (g/ 100 g)*	*Dietary fiber (g/100 g)*	*Ash (%)*	*Energy (Kcal/ 100 g)*	*Moisture (%)*
Local landrace	80.35 a	9.72 a, b	1.30 a	9.49 b	2.37 a	371.94 a	6.27 c
VLM-382	77.93 c	10.27 a, b	1.25 a	11.00 a, b	2.45 a	364.03 c	8.11 a
VL-352	78.34 b, c	10.96 a	1.29 a	11.71 a	2.29 a	368.77 a, b	7.13 b
VL-376	80.00 a, b	9.45 b	1.00 a	11.20 a	2.40 a	366.78 b	7.16 b
VL-379	79.12 a,b,c	10.25 a, b	1.18 a	11.04 a	2.34 a	368.08 b	7.12 b
SE (n = 4)	0.38	0.35	0.10	0.39	0.09	0.90	0.09
5% LSD	1.48	1.36	0.38	1.52	0.35	3.54	0.34

The Mean values for a particular parameter marked with different letters are significant as per the LSD ($p \leq 0.05$) test.

Table 6: Composition analysis in finger millet cultivar for minerals contents

Variety	*Mineral contents (mg/100 g)*			
	Calcium	*Sodium*	*Potassium*	*Iron*
Local landrace	880.64 a	39.89 a	428.55 a	4.88 b
VLM-382	671.12 c	21.45 b	489.25 a	6.36 a
VL-352	641.07 c	40.34 a	480.72 a	5.13 a, b
VL-376	786.43 b	30.09 a, b	476.83 a	5.76 a, b
VL-379	696.16 c	37.34 a	485.00 a	5.91 a, b
SE (n = 4)	18.46	3.11	13.35	0.36
5% LSD	72.37	12.19	52.32	1.40

The Mean values for a particular parameter marked with different letters are significant as per LSD ($p \leq 0.05$) test

Table 7: Composition analysis in finger millet cultivar for vitamins and amino acid contents

Variety	Vitamin contents (mg/100 g)			Amino acids Contents (g/100 g)	
	B_1	B_2	B_3	Lysine	Methionine
Local landrace	0.39 a	0.14 a, b	1.07 a	1.45 a	1.75 a
VLM-382	0.44 a	0.14 a, b	1.11 a	1.50 a	1.75 a
VL-352	0.53 a	0.18 a	1.08 a	0.79 a	0.89 a
VL-376	0.43 a	0.11 b	1.11 a	1.26 a	1.43 a
VL-379	0.45 a	0.16 a	1.13 a	1.26 a	1.41 a
SE (n = 4)	0.04	0.01	0.06	0.29	0.32
5% LSD	0.16	0.04	0.25	1.15	1.24

The Mean values for a particular parameter marked with different letters are significant as per LSD ($p \leq 0.05$) test.

However, dietary fiber yield per plant was the highest in cultivar VL-379 than the other cultivars. The ash content in the grains was at par among all the tested samples and ranged between 2.29 to 2.40%. However, ash per plant was the highest in variety VL-379 than the other cultivars.

Energy content in the local landrace was significantly higher (371.94 Kcal/100 g) than that in other cultivars VLM-382 (364.03 Kcal/100 g), VL-376 (366.78 Kcal/100 g) and VL-379 (368.08 Kcal/100 g). However, energy yield per plant was the highest in cultivar VL-379 than the other cultivars. The grain moisture content was significantly lower in the local landrace (6.27%) than in VLM-382 (8.11%) and other cultivars. The yield per plant for the nutritional parameters was the lowest in the local landrace.

The analysis for mineral content revealed the local landrace as the richest source of calcium (880.64 mg/100 g) than the other cultivars which contained calcium in the range of 671.12 to 786.43 mg/100 g (Table 6). Further, based on grain production data nutrition yield per plant was computed in the evaluated finger millet cultivars. The analysis revealed the highest calcium yield per plant in VL-376 (183.81 mg/plant) and VL-379 (173.21 mg/plant) than local landrace (112.91 mg/plant). The calcium yield was the lowest in the VL-352 (85.32 mg/plant).

Sodium content was significantly lower in VLM-382 (21.45 mg/100 g) than in the local landrace (39.89 mg/100 g) and other cultivars. Potassium content was at par in all the cultivars and ranged from 428.55 mg/100 g in local landrace to 489.25 mg/100 g in VLM-382. Iron content was significantly higher in VLM-382 (6.36 mg/100 g) than in the local landrace (4.88 mg/100 g) (Table 6). When computed yield per plant, sodium, potassium and iron yield were almost two-fold higher in variety VL-379 than the local landrace.

Vitamin B_1 content among the cultivars was at par which ranged between 0.39 mg/100 g in the local landrace to 0.53 mg/100 g in VL-352 (Table 7). Vitamin B_2 content in variety VL-352 was significantly higher (0.18 mg/100 g) than in cultivar VL-376 (0.11 mg/100 g). Vitamin B_3 content was at par in all the cultivars and ranged from 1.07 mg/100 g in local landrace to 1.13 mg/100 g in VL-379. However, yield per plant data suggested higher Vitamin B_1, B_2, and B_3 contents in variety VL-379 than the local landrace and other cultivars.

No significant differences were found for lysine and methionine contents among the tested cultivars. Lysine content ranged from 0.79 g/100 g in VL-352 to 1.5 g/100 g in VLM-382 whereas methionine content ranged from 0.89 g/100 g in VL-352 to 1.75 g/100 g in VLM-382 and local landrace. However, when computed the yield per plant, the lysine and methionine contents were higher in the cultivar VL-379 than the local landrace and other cultivars.

Discussion

The study was conducted to identify finger millet cultivar suitable for cultivation in Pithoragarh and similar climatic regions. Finger millet cultivars viz. VLM-382, VL-352, VL-376 and VL-379 released by ICAR-VPKAS, Almora along with a local landrace collected from Tankul (Dharchula, Pithoragarh) were agronomically evaluated for the criteria of maturity duration, grain yield, fodder yield and, tolerance/resistance to the naturally occurring insect pest and diseases. Among the evaluated cultivars, the grain color is white in VLM-382 while the rest of the cultivars have brown-colored grains.

In the present study, the local landrace was taller than the other finger millet cultivars leading to lodging at the maturity stage. Tall cultivars with weak stems are prone to lodging, causing yield losses and harvest difficulties. Therefore, lodging-resistant cultivars are preferred, especially for mechanized harvesting. Lodging was not observed in the other evaluated relatively dwarf cultivars. Leaf blast disease caused by the fungal pathogen *Pyricularia grisea* is known to occur in most finger millet growing areas in India and abroad (Prabhakar *et al.*, 2017). The initial disease infestation was observed in seedlings of the local landrace. Though the disease infestation can be observed during all the growth stages, seedlings are the most susceptible. Other evaluated cultivars were however resistant to the disease and did not show symptoms during either seedling or later growth stages. Cultivars with inherent resistance or tolerance to disease and pests are preferred to minimize yield losses and reliance on chemical control.

Yield potential, measured as grain and nutrition yield per unit area, was the primary consideration for agronomic evaluation. Factors like vegetative growth, productive tillers and grain weight influence yield potential. Further, high genotype x environment interaction may regulate the expression of traits in different environmental conditions (Mishra *et al.,* 2009). In the present study, grain yield per plant and plot was higher in cultivar VL-379 than in the local landrace. The higher grain yield in the cultivar was associated with higher finger numbers, productive tillers, and grain weight. Fodder yield was higher in cultivar VLM-382 than the local landrace and other evaluated cultivars. Besides lower grain and fodder yield, the local landrace took a longer time to complete flowering and grain maturation as compared to the other cultivars. Early maturing cultivars are advantageous in areas with short growing seasons or multiple cropping systems. Long-duration cultivars may offer higher yields but require specific management practices.

Grain quality encompasses physical characteristics like size, color, and test weight, and nutritional content like protein, fiber, and minerals. While finger millet offers an impressive overall nutritional profile, certain variations exist among different cultivars. Besides genetic makeup, other factors such as growing conditions and, pre and post-harvest practices can influence the nutritional profile of finger millet cultivars. While, the inherent genetic makeup of the variety plays a significant role in determining its nutrient composition, growing conditions such as soil fertility, water availability and environmental factors also influence nutrient uptake and accumulation (Sukanya *et al.,* 2022). Besides, post-harvest processing methods like milling and storage can affect nutrient retention and bioavailability.

The results of the present study revealed carbohydrate content in grain ranging from 77.93 g/100 g (VLM-382) to 80.35 g/100 g in the local landrace. Earlier studies have reported carbohydrate content in the range of 72 to 79.5 g/100 g (Bhatt *et al.,* 2003). The slight variation may be attributed to the genotype and climatic conditions during crop cultivation. Similarly, the protein content ranged between 9.72 g/100 g in the local landrace and 10.96 g/100 g in VL-352. The data is in agreement with the earlier reports (Bhatt *et al.,* 2003; Singh and Raghuvanshi, 2012). Further, the proteins in finger millet are unique as rich in sulfur-containing essential amino acid methionine. The methionine contents ranged between 0.89 to 1.75 g/100 g in the finger millet grains. The white-grained cultivars generally have higher protein content than the brown ones (Bisht *et al.,* 2023). In the present study, the protein content in the brown cultivar VL-352 was however higher than that in the white-grained cultivar VLM-382. The total fat contents in the evaluated cultivars and the local landrace ranged between 1.0 to 1.30 g/100g as reported earlier (Sridhar and Lakshminarayana, 1994). Finger millet though is low in fat content, the majority of fatty acids (74.4% of the total fatty acids) are polyunsaturated viz. oleic acid, palmitic acid and linoleic acid whereas only the rest 25.6% account for saturated fatty acids. The dietary fibers ranged between 9.49 g/100g (in the local landrace) and 11.71 g/100 g in VL-352. The exceptionally higher dietary fiber offers significant digestive benefits and promotes gut health. The high dietary fiber content also contributes to satiety (bulkiness) and helps manage blood sugar levels. Energy content in the grains ranged between 371.94 Kcal/100 g in local landrace and 364.03 Kcal/100 g in cultivar VLM-382.

Understanding the nutritional variations among finger millet cultivars is crucial for identifying cultivars with superior nutrient content. It can help in designing diversified diets through the use of specific cultivars to address individual dietary needs and preferences. Further, food security can be ensured through promoting the cultivation and consumption of nutrient-rich finger millet cultivars in regions facing malnutrition. In the present study, the nutrition yield per plant was compared to identify the high nutrition-yielding finger millet cultivar. The total carbohydrate yield per plant was 91.2% higher in VL-379 as compared to the local landrace and 5.3 to 88.8% higher than in the other evaluated cultivars. Similarly, protein yield/plant was 104% higher in VL-379 as compared to the local landrace and 19.7 to 74.7% higher than in the other finger millet cultivars. Similarly, the total fat yield per plant was also 70.6% higher in VL-379 as compared to the local landrace. The variety produced 11.5 to 70.6% higher total fats than that in the other cultivars. The variety VL-379 also produced 125.4% higher dietary fibers than the local landrace. The energy yield per plant was also 92.0% higher in VL-379 than in the local landrace. Mineral yield per plant for calcium, sodium, potassium and iron was also, respectively 53.4, 81.8, 119.6 and 133.3% higher in VL-379 than in the local landrace. Further, the variety VL-379 produced respectively 120, 100, and 100% higher Vitamin B_1, B_2 and B_3 per plant than the local landrace.

Malnutrition has emerged as a major health challenge globally and is being aptly addressed through sustainable development goals chartered by the United Nations. Crop bio-fortification is the most sustainable and cost-effective approach to address malnutrition. Findings of the present study and previous reports suggest finger millet is one of the richest sources of calcium and iron (Singh and Raghuvanshi, 2012). Recently, the National Agriculture Research System (NARS) under ICAR has developed and released 71 bio-fortified cultivars of 16 different important crops (Yadava *et al.,* 2020). These cultivars have been improved for essential nutrients such as calcium, iron, proteins, vitamins, etc. Three-finger millet cultivars viz. VR 929 (Vegavathi), CFMV1 (Indravati) and CFMV 2 have been identified as bio-fortified cultivars for calcium, iron and zinc. A comparison of nutrients in identified bio-fortified and evaluated finger millet cultivars suggested that all the evaluated cultivars had better calcium and iron contents than the identified bio-fortified cultivars CFMV1 and CFMV2. Thus, with the adoption of the bio-fortified finger millet varieties, calcium deficiency leading to bone and teeth disorders and iron deficiency leading to anemia may be overcome.

To summarize, the data on grain and nutritional yield per plant revealed VL-379 as a nutrient-rich cultivar as compared to the local landrace and other evaluated cultivars under Pithoragarh conditions. The present study identified finger millet cultivar VL-379 as a powerhouse of essential nutrients and recommended for cultivation under the local climatic conditions as a high-yielding bio-fortified cultivar. The adoption of the finger millet cultivar for cultivation will be crucial in achieving food and nutritional security in the region under the changing climate scenario. However, at this stage, the need of the region is the adoption of modern agro-production technology, access to machinery for processing the millets and creating awareness about the health and nutritional benefits of millets. Embracing the forgotten millets can be a sustainable solution to food, fodder and nutrition security for the Himalayan region.

Conclusion

Selecting cultivars suited to local environmental conditions is vital. It is imperative to enhance the production and productivity of millets to ensure food and nutritional security keeping in view the changing climate. Constraints for productivity at the farmers' level are mainly due to the non-adoption of high-yielding cultivars and improved production technologies. The agronomic evaluation under field conditions identified VL-379 as high grain yielding, early maturing and tolerant to naturally occurring pests and diseases than the local landrace and other evaluated cultivars. Further, the cultivar VL-379 was found to have a higher yield of essential nutrients per plant than the other cultivars and local landrace. The cultivar was richer in calcium and iron contents than the two cultivars earlier identified as bio-fortified by ICAR. Hence, the cultivation of the cultivar may be promoted to address the problem of malnutrition. Thus, the present study identified VL-379 as a nutrient-rich finger millet cultivar suitable for cultivation in Pithoragarh and locations with similar environmental conditions. Further, appropriate processing and value-addition measures can be taken to overcome the post-harvest challenges. This will boost millet cultivation nationwide and therefore will positively impact the farmers' income vis-à-vis food and nutritional security in the country.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contribution

VYP conceived the study, and contributed to conducting experiments, data analysis, and preparing a first draft of the manuscript; HCP contributed to field experiments; US, VP, and AG contributed to the design of the study and manuscript preparation; DPS contributed to the supervision of the study.

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