Journal of Ethnic Foods

REVIEW ARTICLE

Open Access

Functional foods in the northwestern Himalayan Region of India and their significance: a healthy dietary tradition of Uttarakhand and Himachal Pradesh

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Abstract

The Himalayan mountain range in India is home to some of the most diverse ethnic communities and tribes, especially in the northwestern Himalayan range, which spans between the Indian provinces/states of Uttarakhand and Himachal Pradesh. The rich and diversity of the local flora offers nutritional diversity and ensures therapeutic certainty for the local communities (e.g., Garhwali, Kumaoni, Bhotiya, Jaunsari, Gaddi, and Kinnauri). The local varieties of millet, legumes, leafy vegetables, tubers, and ferns in different forms (fresh, sundried, flour, pickled, or fermented) are commonly used to prepare different dishes and locally produced beverages (e.g., soor/sur, pakhoi/paakuyi, chhang, jann/jan, jhol, lugdi/lugri, etc.). This centuries-old indigenous experience, the knowledge of local flora, and the traditional food preparation are key to meeting the dietary demands of local communities. In addition, these local delicacies are also rich in health-benefiting bioactive molecules and have functional food properties, which are not documented yet. Therefore, this review closely examines the functional food properties of the traditional food prepared in the Uttarakhand and Himachal Pradesh regions and provides the scientific evidence to preserve this rich dietary traditions.

Keywords Uttarakhand and Himachal Pradesh regions, Traditional food, Dietary traditions, Functional foods, Fermented foods

Introduction

One of the highest ecosystems in the world is located in the Himalayan region of India, which extends 3500 km from Jammu and Kashmir to Arunachal Pradesh in the northeastern part of the country. The snow-covered Himalayas are geographically divided into three regions: Eastern Himalayas, which include eastern Sikkim, Arunachal Pradesh, Nepal, the Darjeeling Hills, states of north-east India, the Tibet Autonomous Region (TAR), and Bhutan; the Central Himalayas, which include central and western Nepal and TAR; and the Western Himalayas, which include Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and Ladakh (Fig. 1). Traditional inhabitants of these biodiversity-rich areas know the properties of herbs, vegetables, fruits, and animals, the operation of ecosystems, and techniques for using and managing them. As a result, they make a balanced use of various resources, including wood, fodder, fiber, and medicinal

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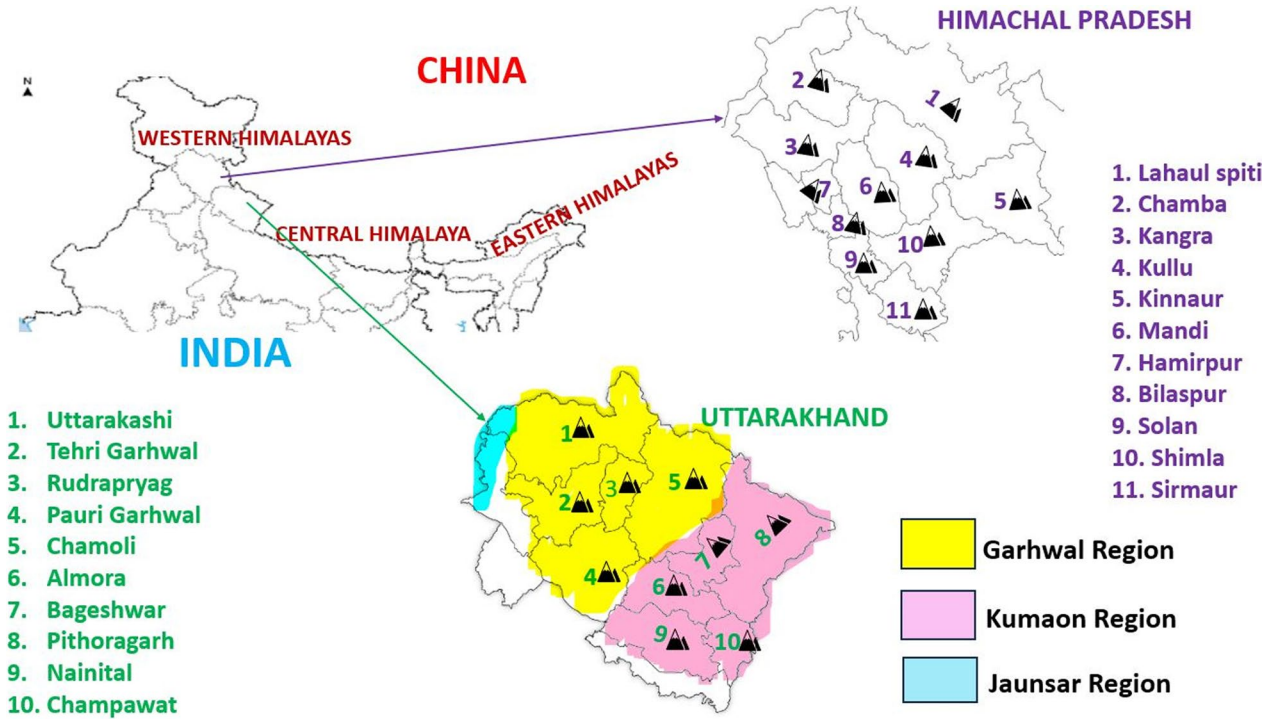

Fig. 1 Indian Himalayan range, including western, central, and eastern Himalayan planes (in purple). The Western Himalayas are located in Himachal Pradesh and Uttarakhand states

and edible plants. New strategies have been investigated, particularly focusing on the numerous linkages between agriculture, ecology, and human nutrition, to better connect environmental and human health. Even though agriculture produces enough food to feed the world, malnutrition problems, including over- and under-nutrition, are still present. Today, more than a billion people in developing nations are undernourished and suffer from acute malnutrition, while a large portion of the industrialized world is simultaneously dealing with obesity issues brought on by over-nourishment, also known as development-driven obesity [1].

"Functional Food" was first coined by Japan in the 1970s. It is defined as foods that go beyond basic nourishment and incorporate physiologically active ingredients (dietary fiber, polyphenols, and other phytochemicals) that support particular biological functions. Additionally, functional foods should positively impact the following: memory, senility postponement, anti-fatigue, immune regulation, body weight reduction, blood glucose regulation, oxygen deficit tolerance, blood lipid regulation, lactation, anti-mutation, anti-tumor, sexual potency, sleep, gastrointestinal functions, vision, bone calcification, and blood pressure regulation [2]. In addition, functional foods also provide certain bioactive molecules, such as dietary fiber and polyphenols, which are further utilized by human gut microbes and offer potential health benefits or disease prevention properties [3].

Northwestern Himalayan populations have a long traditional knowledge about food processing and preservation and their therapeutic effects. Due to functional ingredients, like prebiotics, polyphenols, antioxidants, and other bioactive compounds present in traditional foods from the northwestern Himalayan region can be considered functional foods. Such functional compounds promote weight management, improve immune system, and balance blood glucose levels. Processing methods such as sprouting, malting, and fermentation can further improve the nutritional value of foods [4]. The traditional cuisine of this region (Uttarakhand and Himachal Pradesh state) has enormous potential for reducing the risk of lifestyle diseases, such as obesity, diabetes, and cardiovascular diseases.

Traditional food of Uttarakhand and its functional importance

Uttarakhand hills have a vibrant indigenous cuisine, culture, and tradition. Various cereals, pseudo-cereals, vegetables, spices, pulses, herbs, and millets are grown in the traditional farming environment of the Uttarakhand highlands and can fight non-communicable diseases and malnutrition [1]. Millets are "nutritious grains" and

are considered functional food [3] as they contain multiple bioactive molecules, such as amino-acids (leucine, methionine, thiamine, isoleucine, phenylalanine), vitamins (riboflavin), minerals (iron, calsium), polyphenols (daidzein, epicatechin, catechin, epigallocatechin, gallocatechin, vitexin, taxifolin, myricetin, tricin, quercetin, luteolin, apigenin, procyanidin B1, kaempferol, and procyanidin B2). They are also rich in minerals (2.5–3.5%), dietary fiber (18%), protein (6–13%), calcium (0.34%), phytates (0.48%), and phenols (0.3–3%) [3, 5].

In Uttarakhand, cereals, including buckwheat millet (*Fagopyrum esculentum*), barley (*Hordeum vulgare*), rice (*Oryza sativa*), chaulai (*Amaranthus paniculatus*), wheat (*Triticum aestivum*), and tartary buckwheat or phaphar (*Fagopyrum tataricum*), are used in traditional food preparation [6, 7]. Various types of millets such as Indian barnyard millet or jhanghora (*Echinochloa frumentacea*), foxtail millet or kauni (*Setaria italica*), and finger millet or manduwa/mandua or ragi (*Eleusine coracana*) [8], and pulses such as horsegram or Gahath/kulthi/kulath (*Macrotyloma uniflorum*) [9] chana or chickpea (*Cicer arietinum*), urad or urd (*Vigna mungo*) [10], and kala bhatt or black soybean (*Glycine max var.*) are also used [8, 9, 11]. Other than commonly harvested vegetables like tomato, potato, spinach, pumpkin, onion, garlic, ginger and turmeric, naturally grown wild vegetables such as lingura (*Diplazium esculentum*), kandali (*Urtica dioica*), sakina (*Indigofera pulchella*) are also collected form the forests [12]. Additionally, two mushroom species, Agaricus spp. and Morchella esculenta, are also harvested from the wild for dietary purposes [12].

As part of a staple diet, different local food preparations, such as gathoni, fanu, chaisu, saag, kadhi, thechwani, bodi, kafli, and aloo-gutke, are usually eaten with roti (flat bread) made of corn (*Zea mays*), barley, finger millet, barnyard millet, badi, and kauni or foxtail millet, etc. (Table 1) (Table S1). Rotis made of buckwheat millet or kuttu, chaulai or marsa, and tartary buckwheat or phapar are also eaten, depending on the hill area where they are made (Table S1). Due to their high-altitude cultivation, phapar and kuttu are mostly consumed by the local population. A previous study reported that buckwheat contains compounds that are effective in reducing fat, normalizing blood glucose levels, acting as prebiotics, decreasing cardiovascular risk factors, and promoting antioxidant activity, such as rutin, vitexin, quercetin, anthocyanin, and flavonoids [13]. The kandali /Nettle (*Urtica dioica*) curry is made during the appropriate time of year using the plant's mild leaves and fresh shoots, as they contain a high levels of balanced proteins (20%), minerals (zinc, iron, cobalt, potassium, nickel, and molybdenum), and vitamins (A and C) [14]. Other than that, a local vegetable known as chhachhindu/chhachhinde or snake gourd (*Trichosanthes cucumerina*) is cooked with jhangora and buttermilk [12]. Due to its crude protein (9.39%), fiber (6.3%), and fat (2.0%) content, barnyard millet is used as a rice substitute for diabetic patients. Also, the total antioxidant (59.23%),

Table 1 Traditional food of Uttarakhand hills comprising Garhwal, Juansar, and Kumaon regions (Roti; traditional flat bread)

Food name	Region	Key ingredients	Health benefits	References
Maas/Urad chaisa	Garhwal	Black gram	Prebiotic, rich in protein	[1]
Kandali saag	Garhwal	*Urtica* sp. twigs, Jakhya (dog mustard seeds), Asafetida, and garlic	Anti-stress, stamina enhancing, immunity booster; used to treat cough and cold	
Jhanghora curry	Garhwal	Jhangora *(E. frumentacea)* cooked with buttermilk	Antioxidants, minerals, flavonoids; contains fiber and crude protein; gluten-free; treats bi, constipation, diabetes, and obesity	[12, 43]
Badi	Garhwal/Kumaon	Bottle gourd (*Lagenaria siceraria*), cucumber (*Cucumis sativus*), green gram (*Vigna radiata*), and Black gram (*Vigna moongo*)	Flavonoids; also contains potassium, magnesium, fibers, and vitamins; improves digestion	[44]
Mandua roti	Garhwal/Kumaon	*E. coracana* (finger millet) flour	Stamina enhancing, immunity booster, antidiabetic, anti-obesity; also helpful in curing sinuses and severe cold	[1, 12]
Bhatt dubake	Kumaon	Bhatt (a local variety of black soybean)	Vitamins A & B, protein, iron, phosphorus, calcium, carbohydrates, anthocyanins, and oleic, linoleic, and linolenic acid: immunity booster, antifatigue, anti-obesity	[1, 24, 45]
Chudkani	Kumaon	Bhatt and rice flour		
Jya (salted tea)	Kumaon (Bhotiya community)	Bark of *Taxus baccata*, milk, salt	Antioxidant activity	[46]
Kadiyiek	Jaunsar-Bawar	Finger millets, barley, and stone guard	Strengthens bones	[35]
Lembda	Jaunsar-Bawar	Amaranth seeds, ghee, milk, butter, and salt	Immunity booster, provides strength	

dietary fiber (11.4%), tannin (67.8%), resistant starch (12.81%), and total antioxidant content of jhangora are higher than staple rice and other cereals, making it suitable for diabetic patients [15].

Roti/parantha (a type of flat bread) with cooked vegetables and curd or chutney made of bhangjeera or perilla or purple mint (*Perilla frutescens*) is usually eaten for breakfast [16]. The fresh perilla leaves offer a rich nutritional profile due to its content of folic acid (source of vitamin B), β-carotene (vitamin A precursor), minerals (iron, calcium, zinc, magnesium, and phosphorus), carotenoids (antioxidant properties), and polyphenols (anthocyanins, antioxidants with potential health benefits; alpha-tocopherol, a form of vitamin E and known for its antioxidant properties; phytosterols with cholesterol-lowering effects [17–20]. The addition of perilla seed sprouts at 100, 300, and 1000 mg/kg of body weight can have several positive effects, such as decreased body weight, reduced serum triacylglyceride, decreased hyperglycemia, enhanced glucose tolerance, decreased insulin resistance, induced AMP-activated protein kinase activation, and regulation of gluconeogenesis [21].

At lunch, people often consume boiled jhangora, rice, or kauni, with gathoni ((boiled horsegram cooked with spices and salt), kadhi (made from chickpea flour slurry, spices cooked with curd for an hour), chaisu (Urad dal roasted and ground followed by cooking with spices, salt and water), fanu (overnight soaked horsegram grinded to make paste and then cooked with spices, salt and water), kafli (green gravy made from the leaves of spinach or methi are grinded and cooked along with soaked-rice paste or any lentils cooked with water and spices, bodi (sundried paste of soaked horsegram containing spices, and salt; sundried batter of cucumber or ash-gourd containing spices, and salt), thechwani (crushed potato or radish are fried and cooked with spices, salt, and water), bhattiya or bhatt ke dubke (bhatt is soaked overnight and then ground into a paste and the paste is boiled in an iron utensil with broken rice and salt) and jholi (curd, chickpea flour, and asafetidia cooked together to make a gravy (Fig. 2) (Table S1). At dinner, finger millet and wheat roti are eaten with vegetables. Finger millet is a highly nutritious grain as it contains various minerals (calcium, phosphorus, zinc, iron) and bioactive compounds (polyphenol, flavonoid, phytic acid, dietary fiber) [3]. Additionally, finger millet improves gut health and is associated with numerous health benefits, including anti-diabetic, antioxidant, antitumoral, antimicrobial, and atherosclerogenic effects [3, 22]. Raithu, which is made with boiled pumpkin mixed with curd with salt, coriander, and

Fig. 2 Traditional functional foods of Uttarakhand; these functional foods are mainly prepared using different locally grown pulses, vegetables, herbs, spices, and starter cultures. Pulse-based dishes such as Bhatt dubke, Chudkani, Kafli, Badi, and Ghath dal are particularly protein-rich

roasted cumin seeds, or bhangjeera chutney, is used as an add-on to enhance the flavor of basic dishes.

Black soybean, also called bhatt, kala bhatt, or bhat maas, is an all-time favorite in the Kumaon region and other parts of Uttarakhand, as it is used year-around to prepare different delicacies such as chudkani, bhatwani, and chainsa or dubke. Genetic studies have shown that bhatt varieties found in Uttarakhand are different from normal soybean [23]. They are recognized for their excellent nutritional profile and for being a rich source of therapeutic compounds with potential health benefits [23]. The seed coat of bhatt contains anthocyanins (cyanidin 3-O glucoside), known to have anti-obesity effects, along with different other nutrients such as phosphorus, protein, iron, calcium, carbohydrate, and vitamins (A and B) [24]. Other bioactive compounds are also present in this black soybean variety, such as isoflavones (glycitein, genistein, and daidzein), and phenolic acids (gallic, syringic, vanillin, and p-hydroxybenzoic acid) have antioxidant, antidiabetic, anticancer neuroprotective, cardioprotective, and anti-inflammatory activities [25, 26]. Gahath/kulath or horsegram (*M. uniflorum*) is a type of legume highly appreciated as a regional food. A delicious variation called gathoni is enjoyed with rotis or boiled rice during winters since it is believed that gahath/kulath helps maintain body heat. Usually, gahath/kulath seeds are used as whole to prepare basic lentil preparation, but ground seeds are also used to prepare a delicacy known as phanu, which is consumed with rice all-year round because of its cooling/neutral properties [12]. Another delicious variation called gathoni is enjoyed with rotis or boiled rice during winters since it is believed that gahath helps maintain body heat. Gahath is rich in various nutrients including calcium, iron, magnesium, potassium, zinc, and phosphorus, and has antioxidant properties [27, 28]. Studies also have shown that gahath consumption significantly reduces the stone formation in kidney and has anti-obesity effect [29–31]. The locally produced rajam/rajmah or native red kidney bean (*Phaseolus vulgaris L.*) is commonly consumed in a lentil form and is a rich source of prebiotics (dietary fiber), protein and antioxidants [32].

A study revealed that traditional crops display high therapeutic values ranging from diabetes and cancer risk reduction to antifungal and anti-inflammatory properties [33]. Soybean, rice bean (*Vigna umbellate*), rice, horsegram and finger millet constitute rich sources of carbohydrates, while sesame seed or til (*Sesamus orientale*), mustard seed or sarson (*Brasica juncea*), and cress seed (*Lepidium sativum*) are worthy fat sources [1]. Thus, food supply of local communities offers sufficient options for suitable diets to meet nutritional and energy demands and keep a healthy balance of vitamins and micronutrients [20]. Interestingly, in traditional Uttarakhand cooking, it is essential to cook chudkani, thatwan, and bhatwani in an iron skillet (kadhai) to enhance flavor and nutritional values. As cooking in iron pots increases the iron content of the food, which can enhance the hemoglobin levels in the blood and can prevent iron deficiency or anemia [34].

Fermented foods and beverages are also common, mainly in the Jaunsar-Bawar region of Uttarakhand, where local people continue to follow their age-old customs and cook various ethnic foods and produce different fermented beverages (Table S1). Functional microorganisms, primarily comprising yeast, lactic acid bacteria (LAB), and filamentous molds, are crucial in biotransforming raw and cooked materials of plant and animal origins during the fermentation process. This transformation enhances the nutritional content, extends the shelf life, enhances the flavor, texture, and aroma, and imparts various health benefits to the food or beverage. The ethnic food and beverages in this region include chilra (LAB, yeast), siddhe, aske/kapreudi, kadiyiek, dhinki, taiya, khenda, lambda, baari, mudda and chewda, ghandie/ghaingti, paakyui, mava, and soor/daru [35] (Table S1). The ethnic food of jaunsari people is high in fiber, proteins, calcium, minerals, and vitamins, with great health benefits. Jaunsar-Bawar shares border with Himachal Pradesh and, therefore, has similar customs and ways of life [36, 37]. Jamma, alternatively known as jamma or gemma, is an ethnic fermented sausage crafted from goat meat and is a popular delicacy among people of Kumaon region. It also holds a significant place in the traditional cuisine of the Bhotiya community in the Pithoragarh district. The primary microbial species identified in jamma encompass *Lactobacillus sanfranciscencis, Pediococcus pentosaceus, Enterococcus faecium, Leuconostoc mesenteroides, Lactobacillus divergens, Bacillus subtilis, Micrococcus* spp., *Staphylococcus aureus, Candida albicans,* and *Debaryomyces hansenii* [38].

In Uttarakhand, Bhotiya and Jaunsari tribes prepare their respective alcoholic beverages (Table 1). In the Bhotiya community, jaan/jan, kachhi, and daru are usually prepared by fermenting rice, barley, and rice with jaggery (sugarcane juice which is condensed into a solid mass), respectively, using a single starter culture called balam [39]. For the preparation of balam, the wheat flour is roasted till turned brown after that various herbs such as *Cinnamomum zeylanicum* (cinnamon), *Amomum subulatum* (black cardamom), *Piper longum* (long pepper), and seeds of *Ficus religiosa* (peepal or pipala) were added and kneaded with water to make semi dried balls. These balam balls are then incubated for two weeks in the bed made from bhaang, *Pinus Rouxburghii* (chir pine) and *Cupressus torulosa* (Himalayan cypress). This results in

change of color of balls into white color confirming the presence of desired microbes for further preparation of alcoholic beverages like jann or cahhang. Furthermore, balam is also used to treat cattle weakness and cholera. It has been discovered that infusing herbs into balam balls promotes the colonization of the good bacteria and yeast flora within them, as well as provides antibacterial properties against spoilage-causing bacteria [40]. The analysis of solid-state balam indicated the presence of yeasts (*Saccharomyces cerevisiae*, *Saccharomycopsis fibuligera*, and *Saccharomycopsis malanga*), LAB (*Lactobacillus pentosus* and *Pediococcus pentosaceus*), and bacillus strains (*B. subtilis* and *B. aerophilus*) [40]. In Jaunsari tribes, soor and pakhoi/paakuyi are prepared using barley and finger millet/barley/rice, respectively, using a single starter culture called keem [35, 39]. Keem culture is prepared by mixing barley flour with various dried-ground leaves roots and twigs of local herbs such as *Sapindus mukorossi* or reetha, *Cannabis sativa* or bhaang, *Crassa opaca* or karonda, *Artemisoa rouxburghiana* or chamur, and *Zanthoxylum armatum* or timur [41] kept in dark room for 30–40 days, after which it contains various microbes of plant origin [11]. The study by Tomar et al. 2023 identified that keem culture contains bacteria of the genera *Bacillus*, *Streptomyces*, and *Pediococcus*, with an abundance of *Lichtheimia ramosa*, *Aspergillus glaucus*, *Aspergillus clavatus*, *Aspergillus oryzae*, *Aspergillus terreus*, *and Pichia kudriavzevii* fungi [11]. Traditionally prepared fermented or non-fermented beverages/food are believed to provide strength to the body, purify blood, and improve digestion [42].

Traditional food of Himachal Pradesh and its functional importance

Himachal Pradesh is well known for cultivating fruits for commercial purposes and various cereals (wheat, barley, buckwheat, rice, maize, and millet) to satisfy the dietary requirements of the local communities. Cereals are regularly used to prepare different kind of bread, and local delicacies, such as the traditional flatbreads known as bhaturu, marchu, and chilra, that are the mainstays of the diet of the rural population They are made with wheat or buckwheat flour fermented by inoculating malera/khameer (residual dough from previously fermented wheat flour) or treh (previously fermented wheat flour slurry), inocula which mainly comprise LABs and yeasts [37]. Bhaturu constitutes a staple food in rural areas of Kullu, Lahaul-Spiti, Kangra, and Mandi districts and is also consumed occasionally during special occasions like marriages or local festivals [20]. Also, siddu is a traditional fermented steam-cooked meal made with wheat dough filled with walnuts or lentils; it is prepared in Kullu, Shimla, and Lahaul-Spiti. Aenkadu is another festive delicacy composed of rice flour slurry and is popular in much of the state. The buckwheat leaves are combined with wheat flour and baked into cakes known as aktori in the Lahaul-Spiti valley. Tiskori and mangjangkori are similarly thick chapatis made of buckwheat and wheat bran, respectively. The Sirmaur region is known for its rice flour-based patande, a type of pancake or roti made form rice flour. In both rural and urban settings, gulgule (fermented wheat flour containing jaggery) and malpude (babroo) (fermented wheat flour slurry) are sweet delicacies served during religious and wedding ceremonies. A study was conducted by Pathania et al. 2010 on fermented foods such as chilra, babroo, bhaturu, phab and daheli. It was observed that the yeast was the dominant microflora [47]. Microflora associated with these fermented food produce enzymes that decrease the antinutritive substances to increase their acceptability by enhancing flavor and aroma [48]. In Lahaul-Spiti and Kinnaur, deep-fried salted flatbreads called marchu are prepared, notably during tribal holidays, like phagli, halda, and marriage rituals. In Himachal Pradesh, badi (dried puffed batter of lentils with spices) is quite common. Black gram and ash gourd (*Benincasa hispida*) petioles are usually used to make badi; solid, hollow, spicy balls used as rice or vegetable seasoning [36]. In addition to being nutrient-dense, people think that these traditional fermented food products have the ability to enhance their health. The microflora present on the fermented food products are primarily responsible for their beneficial effects on complex gastrointestinal functioning [49].

Traditional dairy products are also prepared from various local cattle species, such as churu (yak and cow hybrid), buffalo, sheep, and goats. In the Lahaul valley, buttermilk is boiled, the water is drained away, and solids are dried to prepare churpa or chrpe, further used to make soup [36]. In most regions, kadi/kadu is prepared using buttermilk, which is cooked with spices and some gram flour, and served with flatbread or rice. Similarly, wheat flour is cooked in milk with a small bit of salt to make nudu, a ceremonial dish eaten with ghee. Also, Lahaul-Spiti is home to a local beverage called tchaku cha or salty butter tea. The tchaku cha is prepared by boiling tea leaves with a small amount of water, salt, milk, and butter in a traditional pot locally called dongmo [36]. It has been emphasized that the value of these traditional foods nutrition in giving the locals energy, vitamins, proteins and minerals [50] (Fig. 3).

Furthermore, various fermented ethnic foods that are unique to the tribal and mountain belts of Himachal Pradesh are also prepared, such as marchu, bagpinni, bhaturu, manna, siddu, seera, chilra, chhang, lugri, daru, sepubari, behmi, sura/sur, and kinnauri/Angoori (Table 2). The microorganisms present in babru, such as

Fig. 3 Traditional functional foods Himachal Pradesh functional; the traditional cuisine is a mix of various pulses, spices, and plants [51, 52]. In addition, across different regions in Himachal Pradesh, various fermented foods such as chhang, churpa, Kinnauri, etc.

Table 2 Traditional fermented foods and alcoholic beverages of Himachal Pradesh

Food name	Region	Key ingredients	Impact on health	References
Chhang	Lahaul & Spiti, Kullu and Kinnaur	Wheat and phab	The F22 strain obtain from Chhang is able to tolerate and simulate low gastric pH, can survive in high bile salt, and shows antagonism against food-borne spoilage-causing bacteria	[63, 64]
Jhol/Kadu/Khoru	Mandi, Kangra, Hamirpur, Bilaspur	Curd/buttermilk cooked with spices, onions, gram flour	Rich in probiotic microorganisms *Lactobacillus fermentum, L. acidophilus F14, Sacchromyces cerevisiae Bacillus sp. A12, B. mycoides A12*	
Marchu	Lahaul	Fermented by Malera (when shape folded spirals called Dosha)	Improves digestion, high content of different lactic acid bacteria such as *Lactobacillus plantarum, L. acidophilus, L. lactis, Leuconostoc, Bacillus sp., S. cerevisiae*	[64, 65]
Chilra	Lahaul	Buckwheat, wheat and barley flour fermented by Treh	High content of lactic acid bacteria such as *L. plantarum, L. acidophilus, L. lactis, S. cerevisiae, Bacillus sp.*	
Daru/Chakti/ jhol (jaggery and phab)	Shimla, kullu	Jaggery and phab	Act as probiotics, protection against cold	[64]

S. cerevisiae, help improve the digestibility, flavor, and nutritional value of food. Furthermore, LABs acidify food and act as probiotics [53]. Traditional starter cultures, like "Malera" (previously fermented wheat flour dough), "Phab" (dehydrated yeast formulated with *Artemisia* sp.), and "Treh" (previously fermented wheat flour slurry),

are used to prepare fermented products. Bhaturu (tungi or sumekshi roti) is traditionally made by using wheat or barley flour. It is fermented with the help of malera innoculm as the kneaded dough is kept for rest in 3–4 h and then flat rotis are spread over the pattu (woolen/cotton sheet) for further fermentation [54]. Malera microbial analysis reveals the presence of lactic acid bacteria (*Lactobacillus plantarum* MTCC 8296) and yeast (*Leuconostoc sp.* and *Saccharomyces cerevisiae*) [55]. Daheli is also a starter culture that is prepared with different herbs (around 36 herbs) depending on the region: in Kullu, *Varbascum thapsus* (Mullein), *Cannabis sativa* (Marijuana or bhaang), and *Bupleurum lanceolatum* (Lanceleaf thorowax or nimla) *Valeriana jatamansi* (Indian valerian or sugandhbala); in Kangra, *Selinum tenuifolium* (Wallich milk parsley or mathosal), *Picrorhiza kurrooa* (White christmas rose or kadvi/kadu/kutki), *Silene griffithii* (Campion or halim), *Polygonum* sp. (Knotgrass), *Centella asiatica* (Indian pennywort or Gotu kola), *Swertia chirayata* (Bitter stick or chirata), and *Varbascum thapsu* (Common mullein); and in the Lug valley of Kullu, *Pistacia integerima* (Zebrawood or Kaakarasingi), *Solanum xanthocarpum* (Indian nightshade or katari), *Micromeria biflora* (Lemon Scented Thyme or pushanbanda), *Spiranthes australis* (Austral ladies tresses), *Clitoria ternatea* (Butterfly Pea or Kkyal), *Viola cinerea* (Wood violet or Banaksa), *Aegel marmelos* (Wood apple or Bel/Bael/), *Cannabis sativa*, *Trachyspermum copticum* (Bishop's weed or Ajwain), *Bupleurum lanceolatum*, *Arisaema helleborifolium* (Tall cobra lily or Chidi ri chun), *Drosera lunata* (Sundew or Oshtori), *Salvia* sp. (Garden sage or Kotuga), and *Fragaria* sp (Strawberries or dudlukori) [39]. Daheli is prepared by dry roasting barley flour together with 36 herbs collected from wild by the elderly people during the bhadrapada month. The herbs are smashed by using Ukhal (stone cavity) and mussal (wooden bar). The herbs paste is then added to the roasted barley powder called sattu and kneaded to make dough and then put into a wooden mold and then dried to give a brick shape to daheli [37]. Microbial analysis revealed that *S. cerevisiae* is the main microorganism involved in fermentation, along with *Leuconostoc*, *Candida*, and *Lactobacillus* species [37]. In addition to microbes, used cereals and their derivatives are utilized ingredients also act as natural growth transporters/media for probiotics and as a buffer to protect the microorganisms from the harsh conditions of the intestine [56].

Moreover, Himachal Pradesh presents several indigenous fermented beverages consumed and prepared traditionally from various substrates. Sura or sur is a fermented beverage typically made in the Lug valley of Kullu from finger millet (*E. coracana*). It is prepared by allowing natural or spontaneous fermentation of finger millet dough in a container for ten days. Then, half-baked rotis are prepared, placed in a container, and mixed with water. "Dhehli" produced from traditional herbs is added after two days and is fermented for eight to ten days. Sura is consumed during local festivals, like weddings and shoeri saja. Many traditionally fermented alcoholic beverages produced by the Himachal Pradesh tribes with raw materials, such as grains, cereals, and fruits, are more or less known (e.g., chhang, angoori, daru, judima, bhemi, or chakti) [39]. These drinks can be categorized into many varieties, such as rice wine, palm wine, distilled spirit, cereal wine, and distilled alcoholic beverage, depending on the raw materials and preparation techniques employed [37, 57]. Tribal women operate a home-based business producing traditional alcohol using their understanding of the fermentation process. Using local natural resources, tribes in the Himalayan high-altitude region have created their own cultures for the production of alcoholic beverages based on fermentation [58]. In the hill regions, making traditional drinks is a source of income and a significant household and community beverage connected to religious activities [59]. Chang is a rice beer locally produced in the Lahaul-Spiti tribal regions. It is widely enjoyed at weddings and other regional celebrations. In marriages and ceremonial occasions, it is offered to the gods and exchanged as a significant gift. Chhang is a staple of hospitality among the Lahaul Valley's Indigenous people and is thought to ward off the cold during the winter. It is produced by solid-state fermentation of boiled rice for 4–5 days with phab (the customary inoculum). It is then filtered, and the obtained filtrate is chhang. A distilled version of chhang is also prepared, known as sra [36].

Additionally, Himachal Pradesh, particularly the Kinnaur district, is known for its numerous fruit-based fermented beverages. Chulli, angoori/kinnauri, apple/pears, and wild almonds are fermented and used to make rak, arak/ara, and angoori/kinnauri, respectively (Table S2). Analysis of some of the alcoholic beverages of Himachal Pradesh (Lahul and Spiti region) reported that these beverages are acidic in nature and contains ethanol in the range 5–12% (v/v) when undistilled and 13–19% when distilled [60]. Microbial analysis of these beverages reveals the presence of yeast mainly of genera *Sacchromyces* and *Endomyces* as dominant organism and bacteria from genera *Bacillus*, *Lactobacillus* and *Acetobacter* [61]. However, most tribes in the Himalayan region use a similar process that involves boiling the raw material, drying it, adding a starter culture, fermenting it, and then extracting the finished product. Scientific research could be useful in revealing potential new uses for traditionally made alcoholic beverages, and modern scientific advancements could be applied for improvement [62]. As

listed in Table 2 and Table S2, several indigenous beverages are known by different local names for their unique taste, health benefits, and preparation process.

Discussion

This long-carried knowledge of traditional culinary habits and available indigenous local flora, including fruits, vegetables, and grains, supports the healthy diets of local inhabitants. The commonly consumed vegetables in these high hill regions are very distinct and nutritious. Additionally, various bioactive molecules of functional significance such as bhang (hemp) seeds are great source of good-quality protein, dietary fiber, polyphenol, polyunsaturated fatty acids [66], kandali (nettle) rich in antioxidants, dietary fibers and vitamins [67], and chachinde (snake gourd) and a local variety of cucumber which is normally called pahadi kheera or mountain cucumber rich in dietary fiber, which are beneficial to maintain the body weight and blood glucose level. Similarly, the locally available legumes (gahath, bhatt, chickpea, urad, and rajma) are rich source of various nutrients and bioactive molecules such as dietary fiber and isoflavanoids. Higher dietary fiber content lowers the risk of obesity and diabetes by avoiding sudden increase in blood sugar level, along with that dietary fibers are further metabolized by the gut microbes to produce short-chain fatty acids (SCFAs; acetate, propionate, and butyrate) [3]. It has been established that gut microbes play a significant role in maintaining host health, specially SCFAs decrease the insulin resistance and hyperlipidemia, providing the functional aspects of the food [68]. Further, the staple diet of this region contains maize and various millets such as mandua/kodo (finger millet), kauni (foxtail millet), fapar (buckwheat), and chaulai (Amaranth). Instead of completely depending on wheat or rice consumption, adding these locally available millet and grains to the diet maintains the blood sugar level and lowers the possibility of obesity [3]. Other than being the rich source of minerals (calcium, phosphorus, iron, etc.), millets are also gluten-free and high in complex carbohydrates (prebiotics), which helps to control obesity and diabetes. Millets also contain phytic acid, which lowers the digestibility of carbohydrates and is favorable to control the obesity, and lowers the risk for diabetes patients [3].

Further, the local naturally fermented drinks and products also provide bioactive molecules and various probiotic, which also enriches the microbial diversity in the gut. These fermented food products of western Himalayas have also been enlisted with their respective substrate and probiotic diversity. In a study isolated 6 yeast strains and 11 probiotic bacteria from fermented food western Himalayas and screened these strains for antimutagenicity and antigenotoxicity and compared to *L. rahmnosus GG* [69]. Further investigation was also conducted on these strains to evaluate the impact of prebiotics on their growth behavior and adherence potential [70, 71]. Still, more research and studies are needed to explore microbial diversity and the probiotic benefits of local fermented products.

Conclusion

The western Himalayan region (Uttarakhand and Himachal Pradesh) of India is home to different ethnic groups and tribes. Along with their distinct ethnicity and culture, this region offers diversified food and culinary habits. The local vegetable and grains (mandua, jhangora, makka, bhang seed, etc.) are the core of local dishes, which have numerous health benefits such anti-obesity, antidiabetic, and protects against the kidney diseases and cardiovascular diseases. These benefits are attributed to their higher level of micronutrients (vitamins and minerals), dietary fiber (prebiotics), antioxidants, and polyphenols. Other than grains and vegetables, locally produced fermented beverages are also beneficial for the gut health, as they enrich the gut health and provide the different probiotics (*Lactobacillus* sp. and *Bacillus* sp.). Besides its nutritional values, the local food also reflects a vibrant variation based on ethnicity and region, which needs to be preserved for future generations and therefore documented.

Abbreviation

SCFAs Short chain fatty acids

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42779-024-00236-4.

Supplementary Tables.

Acknowledgements

The authors acknowledge the NGS-center, Kyungpook National University, Daegu, South Korea, for providing support in data collection.

Author contributions

VS conceptualized the article; SD, VS and KM participated in writing; KM and KS participated in illustration and data collection, VS, MB and JHS reviewed the writing; MB and JHS supervised and approved the final draft.

Funding

This research was supported by the Korea Basic Science Institute (National Research Facilities and Equipment Center) grant funded by the Ministry of Education (2021R1A6C101A416).

Availability of data and material

Not applicable.

Declarations

Ethics approval and consent to participate

All authors gave their consent before starting the study.

Consent for publication
All authors agree for this publication.

Competing interests
Authors have no conflict of interest to declare.

Received: 15 November 2023 Accepted: 9 May 2024
Published online: 10 June 2024

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