

# NUTRITIONAL BENEFITS AND EMERGING PROCESSING TECHNOLOGIES OF FRUITS AND VEGETABLE-BASED FERMENTED BEVERAGES FROM THE HIMALAYAS

Vinod Kumar<sup>1</sup>, Gulshan Kumar<sup>2</sup>, Rolika Gupta<sup>1</sup>

<sup>1</sup>Division of Microbiology, Career Point University, Hamirpur, Himachal Pradesh 176041, India

<sup>2</sup>Botany, Biosciences, Career Point University, Hamirpur, Himachal Pradesh 176041, India

**ABSTRACT-** Fermented fruit and vegetable-derived beverages from the Himalayas have gained attention for their potential health benefits and nutritional value. These traditional drinks are rich in probiotics, bioactive compounds, and essential nutrients that support gut health, immune function, and overall well-being. This review explores the wide variety of fermented beverages from the region, focusing on their nutritional composition and associated health benefits. It also discusses emerging processing technologies, such as novel fermentation techniques, which enhance probiotic content, flavour, and shelf life. Advanced methods like controlled fermentation environments and biotechnology are improving production efficiency and product consistency. By examining these developments, the review offers insights into how these beverages promote health and their potential for entry into the global functional food market. Finally, it emphasizes the importance of further research to unlock the untapped potential of these traditional drinks and expand their application in modern nutrition.

**Keywords:** Fermented Beverages, Probiotics, Nutritional Benefits, Himalayas, Bioactive Compounds.

## I. INTRODUCTION

The Himalayas, spanning regions of India and Nepal, are home to a diverse array of traditional fermented beverages that are deeply rooted in the cultural heritage and societal framework of communities. Such drinks, often crafted from indigenous fruits including vegetables, are not merely consumed for refreshment but play a crucial role in various aspects of life, including social gatherings, religious rituals, and daily sustenance<sup>19</sup>. Their significance extends beyond tradition, as they harbour unique microbial populations that contribute to their distinct flavours, textures, and potential health benefits<sup>30</sup>. The fermentation process involved in their preparation enhances their nutritional profile by producing bioactive compounds that may offer various health-promoting properties<sup>25</sup>. These include improved gut health, immune system support, and possible protective effects against certain diseases. Given the growing scientific interest in probiotics and functional foods, traditional Himalayan fermented beverages have

gained attention for their potential contributions to human health<sup>12</sup>.

The Himalayan region, with its diverse landscape and climate, supports a rich variety of fruits, vegetables, and grains, forming the basis for unique fermented beverages<sup>10</sup>. These traditional drinks, rooted in indigenous knowledge, offer both cultural significance and nutritional benefits. Fermentation enhances the bioavailability of nutrients and promotes beneficial microorganisms, improving digestion and immunity. These beverages play a vital role in local customs, ceremonies, and daily sustenance. Reflecting the region's biodiversity, they showcase the resourcefulness of Himalayan communities in maintaining sustainable food traditions<sup>25</sup>.

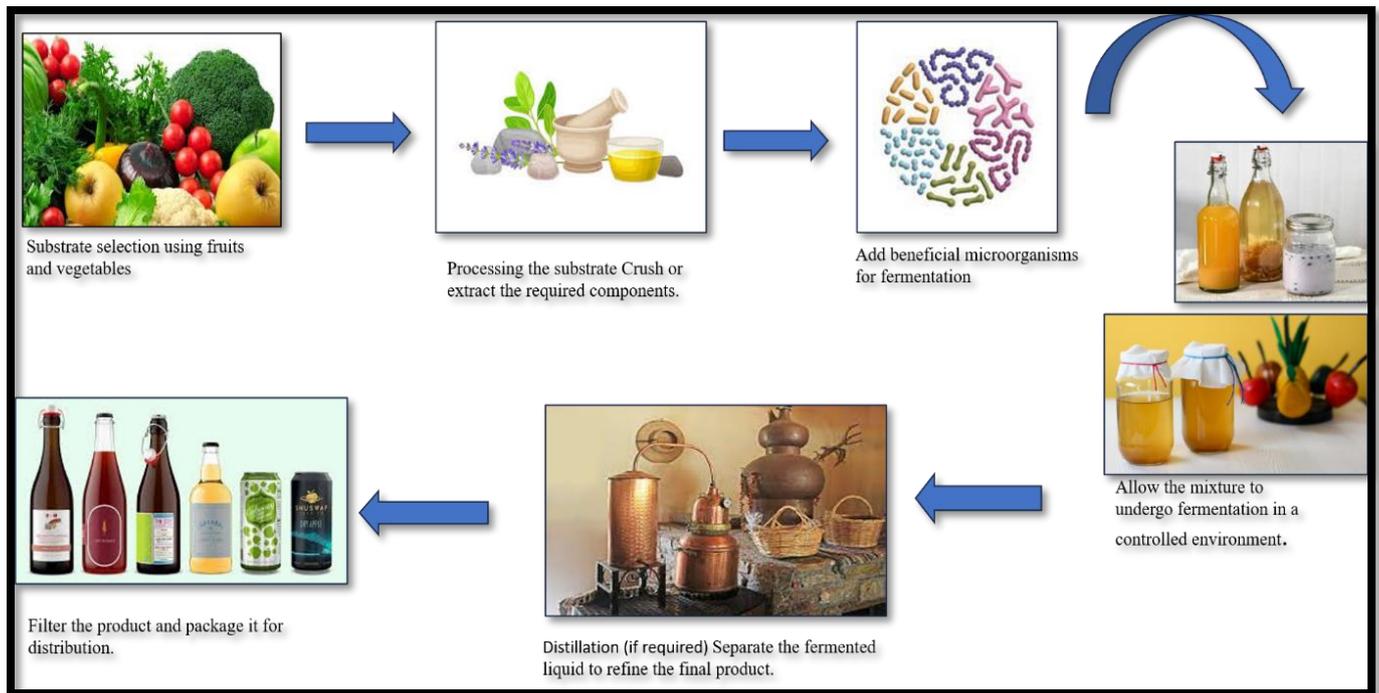
The Himalayan region, known for its exceptional ecological diversity, is home to an extensive range of fermented foods and traditional drinks. These traditional drinks, primarily crafted from locally sourced fruits and vegetables, have become increasingly recognized for their distinctive flavours and potential health benefits. The agitation procedure enhances the nutritional value of these potables, introducing beneficial microorganisms that support digestive health and promote general wellness. Their unique taste profiles and therapeutic properties make them a vital element of the area's food traditions and cultural legacy<sup>30</sup>.

As interest in natural and functional foods grows, these Himalayan fermented beverages continue to gain recognition for their role in promoting both traditional dietary practices and modern health-conscious consumption<sup>34</sup>.

The Himalayan region presents a challenging environment with extreme cold, high altitudes, and low oxygen levels, shaping the lifestyles of its ethnic communities. To adapt, indigenous populations rely on traditional knowledge of medicinal plants and fermented foods, which are

essential for their sustenance and overall health (Tamang *et al.*, 2021). Due to harsh climatic conditions, limited agricultural opportunities, and poor transportation networks, food preservation is essential for sustaining communities. Fermentation emerges as a practical solution, also extending the durability of food further more enhancing its nutritional content. Unlike common misconceptions that associate fermentation solely with alcohol production, in the Himalayas, it serves as a vital method for ensuring year-round food security<sup>33</sup>. Traditional fermented beverages such as chhang, soor, tongba, jaanr, raksi, apong, yu, zutho, sjudima, chu, qingke, and *ara* are widely taken in the region. These drinks are more than just refreshments; they provide relaxation and essential health benefits. Many are fortified with native ethnomedicinal ingredients, which help locals and travellers adapt to altitude-related stresses and extreme climatic conditions. By integrating fermentation with medicinal plant use, Himalayan communities have developed a sustainable dietary practice that supports both nutrition and resilience in their demanding environment<sup>19</sup>. Fermentation-based alcohol production serves both cultural and economic purposes in the Himalayan high-altitude regions. Many tribal women engage in home-based brewing, using their deep-rooted knowledge of fermentation to sustain livelihoods. The production of these beverages not just supports regional economies but also serves an important function in religious and community gatherings. Among these beverages, Chhang holds special significance in the Lahaul-Spiti tribal regions. A purified form of chhang, known as Sra, is further produced for stronger alcoholic content<sup>15</sup>. Vegetable- and fruit-based fermented beverages offer enhanced nutritional and probiotic benefits over non-fermented drinks, including improved gut health, increased bioavailability of vitamins, and natural preservation without artificial additives<sup>30</sup>. These beverages also contain bioactive compounds that contribute to antioxidant activity and immune modulation<sup>29</sup>. Himachal Pradesh is home to a diverse range of traditional fermented drinks made from locally available grains, cereals, and fruits. These traditional drinks are deeply embedded in the cultural practices of tribal communities and are often prepared using age-old fermentation techniques (Rana *et al.*, 2022). One such beverage, Sura (Sur), is commonly produced in the Lug Valley of Kullu using finger millet (*Eleusine coracana*)<sup>35</sup>. The preparation process begins with naturally fermenting finger millet dough over ten days, followed by the addition of half-baked rotis mixed with water. After two days, an herbal fermenting agent known as *Dhehli* is introduced, allowing the mixture to ferment further for eight to ten days. Sura is a significant part of local festivities, including weddings and the shoerisaja festival<sup>8</sup>. Himachal Pradesh, particularly the Kinnaur district, is well known for its wide variety of fruit-derived fermented beverages. Traditional drinks such as rak, arak (*ara*), and angoori/kinnauri are prepared using locally available fruits, including chulli (wild apricot), apples, pears, and wild almonds. Such brews hold traditional importance and serve as an integral pillar of local traditions<sup>8</sup>. Scientific analysis of fermented alcoholic drinks from the Lahaul and Spiti regions has shown that these beverages are naturally acidic. Their ethanol content ranges for 5–12% (v/v) when undistilled and 13–19% after distillation, indicating variations in alcohol concentration based on the production method. Microbial studies have identified *Saccharomyces* and *Endomyces* as the dominant yeast species responsible for fermentation. Additionally, bacteria from the *Bacillus*, *Lactobacillus*, and *Acetobacter* genera contribute to the fermentation process, enhancing both the flavour and preservation of these beverages<sup>15</sup>. Several factors contribute to the popularity of fermented vegetable beverages, including their convenience, unique flavors, cultural significance, and potential health benefits. These drinks blend ethnic traditions with modern dietary trends, making them appealing to a wide range of consumers. The production of vegetable beverages involves extracting liquid from fruits or vegetables and optimizing it with small quantities of additives to facilitate fermentation. This technique can be carried out in two ways: spontaneous fermentation using naturally occurring microbes or controlled fermentation involving selected microbial strains for consistent quality.

Vegetables, as a base for these beverages, offer fruits unsuitable for fresh consumption and the exceptional nutritional advantages. They are appeal of creating drinks with distinct fruit-based essential to the individuals' diet because of their flavours and aromas. Fruits used in these beverages richness in vitamins, minerals, antioxidants, and result in undiluted alcoholic drinks, commonly dietary fiber (Joshi and Kumar, 2015). The presence referred to as fruit wines, which are typically more of plant-derived phytochemicals further enhances flavorful, nutritious, and contain a lighter alcohol their health benefits, contributing to the prevention content compared to traditional grape wines. These of age-related diseases such as cardiovascular beverages undergo fermentation and aging disorders, cancers, neurodegenerative diseases, and processes, usually containing between 5% and 13% osteoporosis. In recent years, an increased intake of alcohol and around 2–3% sugar. They are notable vegetables has been strongly recommended for for their unique aromatic profiles, antioxidant better intestinal health and overall well-being<sup>26</sup>. levels, phenolic compounds, and other defining Despite their nutritional benefits, fresh vegetables qualities. possess limited shelf stability and remain prone to Despite variations in ingredients, most Himalayan spoilage by microorganisms. While processing tribes follow a similar diet. The raw material is methods such as blanching, boiling, and boiled, dried, and then inoculated with a starter microwaving help in preservation, they often lead culture, allowing fermentation to occur before the to alterations in the chemical profile and structural final product is extracted. Further scientific research properties of vegetables. Fermentation has emerged could help explore new uses for these traditional as an effective method to enhance product safety, beverages, and modern advancements in prolonging storage duration, and fermentation technology could improve their improving the nutritive content of food. Traditional quality and commercial potential. Fermented fermented vegetable products primarily include vegetable juices are gaining increasing attention pickles and sauerkraut, but mustard leaf, radish, red due to their rich phytochemical content and high pepper, ginger, mango, onion, garlic, turnip, nutritional value. These beverages are particularly broccoli, cauliflower, pumpkin, tomato, ash gourd, valued for their health-promoting properties, and bitter gourd have been incorporated into the including their role in preventing gastrointestinal fermentation process<sup>8</sup>. Fruits such as oranges, disorders and supporting overall well-being. Their mangos, raspberries, pineapples, apples, pears, global consumption has been rising steadily, apricots, peaches, cherries, bananas, and papayas reflecting a growing preference for functional and have increasingly been used in recent years for probiotic-rich beverages<sup>8</sup>. Figure 1 represents the producing fermented beverages. This rise is mainly process used for making fruit and vegetable-derived due to the availability of surplus or lower-quality fermented beverages.



**Fig 1. General process of preparing fruit and vegetable-based fermented beverages.**

A. Fruit and vegetable-based fermented beverages

B. Gundruk

As the global population continues to grow, lactic acid fermentation is anticipated to become increasingly important for maintaining the freshness of fruits, vegetables, and various other food items, particularly in developing nations. This method of preservation can help extend shelf life, reduce food waste, and ensure food availability in regions where access to fresh produce is limited. Fermented fruit and vegetable products such as sauerkraut, kimchi, gundruk, khalpi, and sinki have been integral to human diets for centuries<sup>33</sup>. These traditional foods not only provide essential nutrients but also hold cultural and social significance in various communities. Due to their high-water content and rich nutritional profile, fruits and vegetables are highly perishable, making fermentation a valuable technique for enhancing their longevity and usability<sup>29</sup>.

As the Himalayan regions of India are of plethora of fruits and vegetables which are used to make health-promoting fermented beverages, out of which some are listed here - Nepal, Sikkim, and Bhutan, Uttarakhand, Jammu and Kashmir, Himachal Pradesh.

Gundruk, a well-known fermented vegetable product from the Himalayas, is prepared without the use of salt and has a distinct acidic taste. To produce gundruk, fresh leaves of local vegetables such as *rayosag* (*Brassica rapa* subsp. *campestris* var. *cuneifolia*), mustard greens (*Brassica juncea*), cauliflower leaves (*Brassica oleracea* var. *botrytis*), and cabbage (*Brassica* sp.) are slightly dehydrated for a duration of 24 to 48 hours. The wilted leaves are then slightly crushed, packed into airtight containers or earthen pots, and left to ferment naturally for 15 to 22 days. Once fermentation is complete, the product is sun-dried for two to four days before consumption. Gundruk is commonly eaten as a pickle or added to soups and shares similarities with other fermented acidic vegetable products such as kimchi from Korea, sauerkraut from Germany, and sunki from Japan. The dominant microflora found in gundruk includes LAB species such as *L. fermentum*, *L. plantarum*, *L. casei*, *L. casei* subsp. *pseudoplantarum*, and *Pediococcus pentosaceus*<sup>29</sup>.

C. Sinki

Sinki is a traditional, salt-free fermented product made from radish taproots and is widely taken in the Darjeeling district of West Bengal, Sikkim, Nepal, and some regions of Bhutan. Its origins trace back to ancient times, and although it was initially associated with Nepali communities, it has gained popularity among a broader population in these areas. Sinki is typically prepared during winter when humidity levels are low, and fresh radish is available in abundance. The traditional method of making sinki involves cleaning radish taproots (*Raphanus sativus* L.) by drying them in the sun for one to two days until they soften, shredding them, washing them again, and then tightly packing them into an earthen jar using a heavy wooden pestle. The jar is covered tightly with radish leaves and an earthen lid and set aside for fermentation in a warm, dry environment for a period ranging from 15 to 30 days. In some places, fermentation takes place underground in a pit about one meter deep and wide, which is dried by fire and coated with mud while still warm. The hole is lined with dry leaves from bamboo, banana, or radish before the grated radish is put inside, compacted, and topped with additional dry leaves. Large stones are employed to press the mixture, and the hole is sealed with mud or cow manure. After 30 to 40 days, the fermented radish is taken out and dried in the sun. Properly stored sinki can last for about a year if periodically exposed to sunlight. It has a distinct, appealing flavour and is commonly used as a base for soups and pickles. Sinki soup is made by soaking it in water, squeezing out the liquid, and frying it with salt, tomatoes, onions, and green chilies before boiling it in rice water. The soup is typically served hot alongside main meals and is believed to aid digestion. Sinki pickle is prepared by soaking and squeezing the fermented radish before mixing it with mustard oil, salt, onions, and green chilies for a tangy and flavourful side dish<sup>31</sup>.

#### D. Khalpi

Khalpi also known as khalpi, is a traditional fermented cucumber (*Cucumis sativus* L.) product widely utilized by the Brahmin Nepali community in Sikkim. This unique fermented food is prepared using mature, ripened cucumbers, which undergo a

natural fermentation process to develop their characteristic taste and texture. The preparation of khalpi involves cutting the cucumbers into suitable pieces and sun-drying them for two days. Once dried, the pieces are placed inside a bamboo container, locally known as *dhungroo*, and securely closed to create an airtight environment. The fermentation process occurs under ambient conditions and lasts between three to seven days. Once ready, khalpi is commonly eaten in the form of a pickle by mixing it with mustard oil, salt, and powdered chilies, enhancing its flavour and making it a popular accompaniment to traditional meals<sup>32</sup>.

#### E. Angoori

Angoori is a cultural fruit-based fermented beverage from Kinnaur, a region in Himachal Pradesh. It is one of the most popular local drinks, especially prepared during weddings and cultural festivals. Known by the alternative name "Kinnauri," this beverage undergoes a fermentation process lasting approximately 15 days to develop its distinct taste and properties. Angoori is considered a mild laxative and is known for its beneficial effects on digestion, particularly in relieving constipation. Like other fermented alcoholic beverages, such as rice beer, it is believed to offer various health benefits. It has traditionally been used to help with conditions like insomnia, headaches, diarrhea, urinary issues, body aches, and even cholera treatment<sup>13</sup>.

Chulli is a traditional fermented beverage prepared from wild apricots, generally produced by the people of Kinnaur in Himachal Pradesh. This fruit-based drink undergoes a fermentation process that typically lasts between 10 to 15 days, allowing it to develop its distinct flavor and characteristics. Chulli holds cultural significance in Kinnauri society, as it is an essential part of social gatherings, including weddings, festivals, and fairs. It is also widely consumed by locals to help them endure the harsh, dry, and cold climatic conditions of the region<sup>13</sup>.

#### F. Apple ciders

Apple is a widely cultivated fruit with numerous varieties, making it highly adaptable for different

uses, including cider production. The global popularity of apple cider is driven by the fruit's versatility and ability to thrive in diverse climates. Different regions have developed unique making traditions, influenced by local varieties and cultural preferences<sup>14</sup>. The fermentation process in cider production involves complex chemical transformations that depend on several factors. The content of apple-derived liquid, the specific microorganisms present, and the technological methods used all contribute to determining this final product's flavour, aroma, as well as alcohol content. Variations in these elements contribute to the diversity of apple ciders produced worldwide<sup>5</sup>.

G. Sur

In the hill states of Uttarakhand and Himachal Pradesh, local tribes also produce a traditional alcoholic beverage called Sur, which has an alcohol concentration of 30–40%. Made using cereals and apple fruits, Sur is consumed not only during family gatherings and festivals but also to help people endure harsh climatic conditions in these regions<sup>25</sup>. Fresh and natural beverages made from celery, carrots, cucumbers, and apples offer detoxifying effects that promote overall body function. Another beneficial blend includes banana, kiwi, pineapple, carrot, and red beetroot, which supports liver health and provides naturally occurring nitrates that improve blood flow to the brain, heart, and muscles<sup>4</sup>. Table 1 represents the area-wise list of Fermented beverages prepared using fruits and vegetables from the Himalayan region.

**Table 1: List of Vegetable and Fruit-based beverages in the Himalayan region: Microorganism**

	S.no.	Beverage Name	Substrate (Fruits/Vegetables)	Region	Microorganisms	Fermentation process	Source
Fruits	1.	Apple Cider	Apple	Himachal Pradesh, Uttarakhand	<i>Saccharomyces cerevisiae</i> strains (Sc21, Sc01)	Different yeast strains were studied for their brewing properties.	(13)
	2.	Chhang	Various fruits (including wild berries)	Himachal Pradesh	<i>Lactobacillus plantarum</i> F22	Boiled rice undergoes solid-state fermentation for 4–5 days using phab as the starter culture followed by filtration to obtain the beverage	(10)
	3.	Chulli	Apricot, Apple	Wild Apricot	<i>Saccharomyces</i> , <i>Endomyces</i> , <i>Lactobacillus</i> , <i>Acetobacter</i>	Boiling, drying, starter culture addition, fermentation	(10)

	4.	<b>Angoori/Kinnauri</b>	Grapes/Pears	Kinnaur, HP	<i>Saccharomyces cerevisiae</i>	Natural fermentation of grapes and pears for alcohol extraction	(10)

	5.	<b>Jann</b>	Wild Berries, Apple	Himachal Pradesh, Uttarakhand	<i>Saccharomyces</i> spp., <i>Lactobacillus</i> spp., <i>Acetobacter</i> spp.	This beverage is made by fermenting rice and barley along with jaggery, using a unique starter culture known as balam, which is prepared from roasted wheat flour blended with assorted herbs and incubated for a period of two weeks.	(10)
	6.	<b>Jad (Fermented Apple Drink)</b>	Apples	Jammu & Kashmir, Himachal Pradesh, Uttarakhand	<i>Saccharomyces cerevisiae</i> , <i>Pichia</i>	involves yeast and lactic acid bacteria converting apple sugars into alcohol and organic acids.	(7)

<b>Vegetables</b>	<b>1.</b>	<b>Soup</b>	Vegetables (cabbage, carrots, Beans, peas, etc.)	Himachal Pradesh, Uttarakhand	<i>Saccharomyces cerevisiae</i> , <i>Lactobacillus plantarum</i>	Natural fermentation of rice/barley; consumed as an alcoholic beverage	(27)
	<b>2.</b>	<b>Soor/Sur</b>	Finger Millet	Lug Valley, Kullu, Himachal Pradesh	<i>Saccharomyces cerevisiae</i> , <i>Lactobacillus</i> spp.	Finger millet dough is fermented for 10 days, using a herbal starter culture ( <i>Dhehli</i> )	(27)
	<b>3.</b>	<b>Thukpa (Fermented Vegetable Soup)</b>	Vegetables (cabbage, carrots, etc.)	Ladakh, Himachal Pradesh, Uttarakhand	<i>Lactobacillus</i> , <i>Leuconostoc</i>	involves <i>Lactobacillus</i> and <i>Leuconostoc</i> , which ferment vegetables like cabbage and carrots, enhancing flavour and preserving the soup	(23)
	<b>4.</b>	<b>Gundruk</b>	Leafy Greens (Mustard, Radish leaves)	Himachal Pradesh, Uttarakhand	<i>Lactobacillus plantarum</i> , <i>Pediococcus pentosaceus</i>	Lactic acid fermentation for preservation; traditionally consumed in soups and side dishes	(10)

	<b>5.</b>	<b>Sinki</b>	Radish Taproot	Himachal Pradesh, Uttarakhand	<i>Lactobacillus plantarum</i> , <i>Leuconostocmesenteroides</i>	Radish taproots are fermented in pits for several weeks	(10)
	<b>6.</b>	<b>Khalpi</b>	Cucumber	Himachal Pradesh	<i>Lactobacillus plantarum</i> , <i>Leuconostoc spp.</i>	Salted cucumbers are naturally fermented; consumed as a pickle-like side dish	(10)

#### H. Nutritional Benefits to human health

Conventional fermented beverages and foods are recognized for their health benefits with inflammation-reducing effects, cardioprotective, neuroprotective, hepatoprotective, as well as antibacterial qualities. These benefits are especially relevant in high-altitude regions where they help combat high-altitude sickness and infections. Furthermore, certain fermented foods act as staple foods providing essential energy<sup>19</sup>.

Himachal Pradesh is recognized for producing a variety of commercial fruits and grains to fulfil local dietary needs<sup>10</sup>. The use of probiotic bacteria during fermentation may also produce bacteriocins, enhancing product quality as well as preservation time<sup>20</sup>.

#### I. Bioactive compounds

Fermented fruit and vegetable-based beverages offer numerous health benefits due to their rich content of bioactive compounds, including phenolic acids, flavonoids, vitamins, minerals, and probiotics. These beverages have been reported to improve gut health, enhance immunity, reduce cholesterol, show free-radical fighting and anti-inflammatory activities, while lowering the chances of cardiac ailments, diabetes, and certain cancers. Probiotics present in these beverages, such as *Lactobacillus* and *Saccharomyces cerevisiae*, contribute to improved digestion, nutrient absorption, and overall well-being. Their potential therapeutic properties make them valuable components of a healthy diet aimed at preventing

and managing various health issues. Fruits are rich sources of various phytochemicals such as alkaloids, phenolic compounds, terpenes, terpenoids, saponins, proteins, fats, carbohydrates, vitamins, and minerals. These components offer significant therapeutic effects such as antioxidants, antimicrobial, and inflammation-reducing effects. Moreover, underutilized fruits have potential as alternative commercial food items, emphasizing their crucial function in human dietary intake<sup>2</sup>.

Fermented fruit beverages offer a rich source of various essential nutrients and bioactive compounds that offer numerous health benefits. These beverages are known to contain phenolic acids, flavonoids, vitamins (especially B-group vitamins like B12 and folate), minerals, and organic acids. For instance, fermented mulberry juice and cider are rich in phenolic acids such as gallic acid, caffeic acid, and ferulic acid, as well as flavonoids like catechin, rutin, and quercetin, contributing to antioxidant, anti-inflammatory, and antidiabetic properties. Additionally, the fermentation process boosts the levels of B-series nutrients, including a notable increase in folate and vitamin B12, improving their nutritional profiles and promoting gut health (Kesaet *et al.*, 2021).

Vegetable juices, especially fermented ones, are increasingly recognized for their phytochemical content and nutritional value. Their popularity has grown globally due to their potential to prevent gastrointestinal issues and promote overall health<sup>8</sup>.

#### J. Antioxidants

Fruit and vegetable-enriched drinks are rich in antioxidants, which contribute significantly to fostering physical well-being and preventing chronic diseases. These functional drinks derive their antioxidant power from bioactive compounds such as carotenoids, polyphenols, betalains, and chlorophylls. Carotenoids like beta-carotene, lycopene, lutein, and zeaxanthin are found in colourful produce such as carrots, tomatoes, pumpkins, leafy greens, and mangoes. Polyphenols—including flavonoids like quercetin, catechins, and anthocyanins—are abundant in fruits, vegetables, teas, and dark chocolate. Additionally, betalains from red beet and pitaya, along with chlorophylls in green leafy vegetables, further contribute to the antioxidant profile. These compounds help neutralize free radicals, support immune function, and reduce inflammation, making antioxidant-rich beverages a valuable part of a health-conscious diet<sup>24</sup>.

#### K. Antidiabetic features

Beverages made from fruit and vegetable have garnered attention for their potential antidiabetic properties, largely due to their abundance of bioactive compounds, antioxidants, and micronutrients. These beverages, when derived from ingredients like berries, leafy greens, citrus fruits, and cruciferous vegetables, offer a natural means of supporting glucose regulation. Many fruits such as blueberries, oranges, and apples are rich in polyphenols, including flavonoids like quercetin and anthocyanins, which are known to increase insulin sensitivity and help decrease glucose concentrations in the blood. Similarly, vegetables like spinach, kale, and carrots provide essential vitamins such as vitamin C and vitamin K, both of which contribute to enhanced insulin action. Vitamin C, a strong antioxidant, not only counters oxidative stress commonly found in prediabetic and diabetic patients but also competes with glucose for cellular absorption, potentially improving glucose metabolism. Vitamin K, on the other hand, modulates inflammation by reducing cytokine levels, which is crucial in mitigating insulin resistance. Additionally, phenolic acids such as ferulic (FA) and caffeic acids (CA) found in many

#### L. LDL – Cholesterol

Drinks made from fruits and vegetables may offer notable wellness advantages, particularly in lowering LDL-cholesterol levels, a key risk factor for coronary artery disease. These beverages are typically rich in dietary fiber, antioxidants, and plant sterols, all of which have been shown to support cardiovascular health by reducing oxidative stress and inhibiting cholesterol absorption. While traditional dietary guidelines have emphasized reducing saturated fat and cholesterol to manage LDL levels, growing evidence suggests that increasing fruit and vegetable intake can also be effective. Although studies have shown mixed outcomes, many indicate a trend toward lower LDL concentrations with higher consumption of these foods. For instance, fiber found in fruits and vegetables can bind to cholesterol in the digestive system, aiding its removal from the body. Moreover, phytochemicals present in these foods may play a role in improving lipid profiles. Beverages derived from whole fruits and vegetables offer a convenient way to incorporate these nutrients into the diet, especially for individuals with limited access or time for meal preparation. Therefore, promoting Drink made from fruits and vegetables as a component of healthy diet plan may serve as a practical, natural approach to improving

heart health and managing cholesterol levels without the need for drastic dietary restrictions or medication<sup>9</sup>.

### M. Probiotics

Probiotics refers to beneficial microbes which promote well-being when taken in sufficient quantities. They enhance gut health by inhibiting harmful bacteria, aiding digestion, and exhibiting antimicrobial properties. Microorganisms used as starter cultures in fermented drinks contribute to the fermentation process by synthesizing vitamins, minerals, and bioactive peptides, such as conjugated linoleic acids (CLA), that possess health benefits including circulatory pressure reduction and antimicrobial effects. Studies indicate that these drinks can be improved by fortification and reducing their alcohol content<sup>36</sup>. Probiotics can enhance enzyme activity, strengthen the intestinal barrier, produce antibacterial substances, alter pH levels, support immune function, influence intestinal carcinogenesis, reduce cholesterol absorption, and outcompete harmful bacteria<sup>18</sup>.

Probiotic organisms block disease-causing microbes from adhering to colonizing the intestines through competition for adhesion sites along with nutrients, producing antibacterial molecules, and stimulating the immune system. Early gut colonization with probiotics is essential for developing a protective gut barrier<sup>21</sup>.

The probiotic strain *Saccharomyces cerevisiae* var. *bouardii*, often paired with industrial *S. cerevisiae*

strains, is widely utilized in the brewing sector to improve probiotic functionality<sup>30</sup>. *Saccharomyces cerevisiae* improves food digestibility, flavour, and nutritional quality of food, making it a valuable microorganism in the fermentation practices<sup>10</sup>.

Lactic acid bacteria (LAB) have been proven to enhance the nutritional quality and shelf life of fermented foods, with benefits including antimicrobial activity and diarrhea control. However, further research is required to the novel uses of LAB as probiotics<sup>21</sup>.

Furthermore, probiotics present in these beverages, especially lactic acid bacteria and yeast species like *Saccharomyces cerevisiae* and *Lactobacillus* strains, enhance gut health by improving enzyme activity, modulating immune function, reducing cholesterol uptake, and producing antibacterial substances<sup>30</sup>. Studies show that Traditional Fermented Functional Beverages (TFFB) improve immune response, metabolism, body composition, blood pressure, brain health, stress relief, and mental health, including reduced risks of anxiety, depression, and cancer<sup>11</sup>. Recent research highlights the importance of gut microbiota in regulating metabolic functions, immune responses, cardiovascular health, and glucose and lipid metabolism. Fermented beverages have been identified as a potential source of novel probiotics contributing positively to gut health<sup>11</sup>. Table 2 represents the nutritional components and health benefits of popular probiotic beverages:

**Table 2: Nutritional profile and health benefits of probiotic beverages**

Beverage	Primary Ingredients	Microorganisms	Nutritional Components	Health Benefits	References
<b>Chulli</b>	Wild apricot	<i>Lactobacillus spp.</i> , <i>Saccharomyces cerevisiae</i>	Vitamin A, polyphenols, flavonoids	Supports digestion, boosts immunity, anti-inflammatory properties	(28)

<b>Angoori/Kinnauri</b>	Locally available grapes	<i>Saccharomyces cerevisiae</i> , <i>Lactobacillus plantarum</i>	Resveratrol, antioxidants, vitamin C	Cardiovascular health, anti-aging effects	(37)
<b>Apple cider</b>	Apple	<i>Saccharomyces cerevisiae</i> , <i>Acetobacter spp.</i>	Vitamin B6, vitamin C, Iron, Magnesium, potassium	reducing your chance of developing diabetes, heart disease, and some forms of cancer	(16)
<b>Jann</b>	Wild almond, apple, chulli	<i>Lactobacillus fermentum</i> , <i>Saccharomyces spp.</i>	Healthy fats, vitamin E, polyphenols	Neuroprotective, heart health, anti-inflammatory	(33)
<b>Sura</b>	Finger millet (Eleusine coracana)	<i>Lactobacillus delbrueckii</i> , <i>Saccharomyces spp.</i>	Iron, calcium, protein, dietary fiber	Improves bone health, aids in digestion, energy booster	(6)
<b>Beverage</b>	<b>Primary Ingredients</b>	<b>Microorganism</b>	<b>Nutritional Components</b>	<b>Health Benefits</b>	<b>References</b>
<b>Chhang</b>	Fruits, barley	<i>Saccharomyces cerevisiae</i> , <i>Lactobacillus spp.</i>	Essential amino acids, vitamins B1, B2	Improves gut microbiota, provides warmth in winter	(10)
<b>Gundruk</b>	Leafy greens, (Mustard, radish leaves)	<i>Lactobacillus plantarum</i> , <i>pediococcus pentosaceus</i>	Vitamins and ascorbic acid, Minerals, Fiber, Lactic acid, Carotene	Bone health, weight management, immune system, Anti carcinogenic	(22)
<b>Sinki</b>	Radish taproot	<i>Pediococcus</i> , <i>lactobacillus spp.</i>	Fiber, vitamin C (Ascorbic acid), Carotene, and lactic acid	Improve digestion, and gut health, Antioxidant Potential, Potential anti-cancer effects	(33)

<b>Khalpi</b>	Cucumber	<i>Lactiplantibacillus plantarum</i> , <i>Lactobacillus brevis</i> , <i>Leuconostoc fallax</i>	Iron, Magnesium, vitamin B, Minerals	Stimulate appetite digestive issues like diarrhea and constipation, Manage blood sugar level	(33)
---------------	----------	--	---	--	------

II. EMERGING TECHNOLOGIES USED FOR PROCESSING OF THESE BEVERAGES

A. Conclusion

The manufacturing of fermented beverages made from fruits and vegetables is being revolutionized by new non-thermal processing technologies that maximize efficiency while enhancing quality, safety, and nutritional content. These cutting-edge techniques lessen processing time and energy usage while preserving sensory qualities and bioactive components.

Emerging technologies are being explored to improve the stability and reproducibility of fermented drinks derived from fruits by managing the microbial ecosystem. A crucial aspect of controlling the fermentation stage is selecting an appropriate starter strain. As a result, research efforts focus on developing and improving microbial starters, in addition to maximizing the use of lactic acid bacteria (LAB). Various yeast and bacterial strains have demonstrated the ability to inhibit biogenic amine activity, while specific enzymes in *Lactobacillus plantarum* and *Pediococcus acidilactici* contain multicopper oxidases<sup>1</sup>.

High-pressure homogenization (HPH) is a physical system used to modify specific size in polydisperse liquid systems. It has recently been applied in the wine industry, showing potential for reducing chemical usage while improving wine quality. Additionally, the application of HPH in carrot juice and lupin-based beverages has demonstrated promising results in terms of serviceable life and functional properties<sup>22</sup>.

A variety of methods and advancements are utilized to reduce the likelihood of microbial contamination and harmful agents while ensuring the safety and quality of fruit-derived beverages. Key strategies include preventive measures at the orchard level,

such as adhering to good agricultural practices (GAPs) and good manufacturing practices (GMPs). Additional processing steps, including chemical rinsing, pressurized water treatments and thermal pasteurization, further enhance product safety. Innovative fruit processing technologies include pulsed electric fields (PEF), ultraviolet (UV) treatment, and high hydrostatic pressure (HHP) or ultrahigh pressure (UHP). The implementation of Hazard Analysis and Critical Control Points (HACCP) systems is also essential for upholding consistent quality control measures. However, it is essential to apply these technologies in a way that preserves the distinctive aromatic characteristics and sensory attributes of the beverages to maintain consumer acceptance<sup>1</sup>. Some of the new emerging techniques are mentioned below:

B. Enzymatic Procedures

Biological decontamination methods using microorganisms (bacteria and fungi) and their enzymes have been evolving since the 1960s. Recent research has primarily focused on bacterial applications for mycotoxin removal, with investigations involving 33 species from various genera, including *Alcaligenes*, *Bacillus*, *Brevibacterium*, *Cupriavidus*, *Devosia*, *Escherichia*, *Enterobacter*, *Lysinibacter*, *Lysinibacillus*, *Pediococcus*, *Pseudomonas*, *Rhodococcus*, *Streptomyces*, and lactic acid bacteria. Numerous enzymes of microbial origin derived from yeast, bacteria and fungi have demonstrated the ability to detoxify mycotoxins and convert aflatoxins in fermented grape beverages and juice into less harmful or harmless metabolic byproducts. Notable microorganisms contributing to this process include *Oenococcus oeni*,

*Saccharomyces cerevisiae*, *Candida famata*, and *Aspergillus Niger*.

Microbial decontamination occurs primarily through two mechanisms: adsorption, in which mycotoxins bind to specific cell wall components like peptidoglycan and glucans, and biotransformation, where enzymes convert mycotoxins into less toxic forms. Enzyme applications have significantly impacted the food industry by providing a cost-effective solution to enhance the standards and security of fruit-derived fermented drinks. Enzymatic techniques are commonly used to improve product clarity, reduce viscosity and turbidity, and enhance shelf stability. For instance, the use of immobilized porcine pancreatic lipase (PPL) in calcium carbonate was studied for patulin (PAT) degradation in apple juice, achieving a degradation rate of over 70% under optimal conditions. Additionally, microorganisms such as *Lactobacillus plantarum* encapsulated in polymeric matrices have demonstrated the ability to eliminate more than half of the ochratoxin A (OTA) present in tainted red wines. Yeast cells also show potential for OTA removal, as observed in studies where *Rhodospiridium paludigenum* completely eliminated PAT within two days. Similarly, *Candida intermedia* cells, whether suspended freely or immobilized within magnetic alginate matrices, significantly reduced OTA level in grape juice by nearly 80%.

Despite their benefits, biological decontamination methods can be less effective and more costly compared to chemical and physical alternatives. However, their environmentally friendly nature and potential health benefits make them an attractive choice for food safety applications<sup>1</sup>.

### C. Pulsed Electric Fields (PEF)

PEF applies short bursts of high-voltage electricity to food between electrodes, disrupting cell membranes through electroporation. This technique enhances the extraction of bioactive compounds and accelerates fermentation. Studies have shown that PEF treatment of date palm fruit beverages increases phenolic content and carotenoid levels<sup>18</sup>. Pulsed electric field (PEF) technology, a non-heat-based preservation technique, effectively inactivates

enzymes and microorganisms within a brief duration. This technique enhances beverage quality attributes and has been applied to pomegranate beverages, kombucha analogs, wine, and fermented apple beverages. Similarly, ultrasound processing treatment has gained popularity in natural food production, as it promotes microbial functions to boost output and enhance product standards<sup>1</sup>.

### D. High Hydrostatic Pressure (HHP) Treatment

HHP is a non-heat-based processing method that involves applying high pressures ranging from 100 to 800 MPa for short durations (3–15 minutes) to both solid and liquid foods. This method ensures uniform pressure distribution through a non-compressible medium, typically water, without compromising the biological components of the product. Over the years, HHP has been widely utilized to enhance food safety, maintain nutritional value, and preserve fresh flavors. It effectively inactivates spoilage microorganisms and enzymes while retaining the sensory and nutritional properties of beverages. Research has shown that HHP-treated litchi juice maintains its color, flavor, and antioxidant activity while extending shelf life<sup>18</sup>. Unlike pulsed electric fields (PEF) and ultrasound (US), HHP is primarily employed for preserving fermented beverages by inactivating bacteria and yeasts while maintaining sensory and nutritional properties. The efficiency of HHP in eliminating microorganisms is influenced by variables such as the applied pressure level, exposure time, microbial characteristics, and food matrix composition. Comparative studies on HHP and thermal pasteurization have shown that HHP-treated beverages often retain more antioxidants and bioactive compounds. For instance, in a study on fermented pomegranate beverages, HHP processing (500–600 MPa for 5–10 minutes) resulted in microbiologically stable products throughout 42 days of storage while preserving higher levels of phenolic compounds and flavonoids than heat-treated counterparts. Similarly, applying HHP (500 MPa for 2 minutes) to fermented litchi juice with *Lactobacillus casei* preserved its colouring and appetizing qualities while enhancing antioxidant retention, offering a

higher-quality alternative to conventional heat treatment<sup>22</sup>.

#### E. Ultrasound (US)

High-frequency sound waves in ultrasound processing create cavitation, which enhances mass transfer, microbial inactivation, and bioactive compound extraction. The application of ultrasound in fruit juice processing improves clarity and stability while preserving nutritional properties<sup>3</sup>.

#### F. Membrane Filtration

This technique utilizes semi-permeable membranes to separate components based on molecular size, aiding in beverage clarification and sterilization without thermal damage. Ultrafiltration has been successfully used to remove microorganisms from coconut water, significantly extending its shelf life without affecting quality.

#### G. Ohmic Heating (OH) and Moderate Electric Fields (MEF)

OH, and MEF pass electrical currents through food, generating heat through resistance. These methods allow rapid and uniform heating, reducing processing times while preserving heat-sensitive nutrients and flavors. They are widely applied in fruit and vegetable product processing for enhanced safety and quality.

The adoption of these innovative technologies in beverage processing leads to improved product stability, safety, and nutritional retention. Ongoing research and development efforts continue to optimize these methods for greater efficiency and broader commercial applications.

In conclusion, this review has provided an overview of traditional fermented fruit- and vegetable-based beverages from the Northwestern Himalayas, emphasizing their deep cultural roots and significant health benefits. These naturally fermented drinks serve as rich sources of essential nutrients, probiotics, and bioactive compounds, offering a wide range of wellness advantages, including antimicrobial, anti-inflammatory, cardioprotective, neuroprotective, and immune-enhancing effects. The probiotics present support digestive health, enhance nutrient absorption, and help prevent various diseases. With growing global

interest in natural and functional foods, these traditional beverages hold great promise for commercialization and integration into modern diets, supporting both public health and the economic sustainability of local communities. Nonetheless, further scientific research and technological innovation are essential to optimize fermentation practices, ensure product safety, and fully realize their potential as health-promoting functional foods.

#### Acknowledgements

The authors are thankful to the Career Point University for providing research facilities.

#### Conflict of interest

The authors declare no conflict of interest.

#### REFERENCES

1. Avirvarei A. C. (2023). Fruit-based fermented beverages: Contamination sources and emerging technologies applied to assure their safety. *Foods*, 12, 838.
2. Bachheti A. (2023). Bioactive constituents and health-promoting compounds of underutilized fruits of the northern Himalayas of India: A review. *Food Production, Processing and Nutrition*, 5, 24.
3. Bevilacqua A. (2018). Nonthermal technologies for fruit and vegetable juices and beverages: Overview and advances. *Comprehensive Reviews in Food Science and Food Safety*, 17, 2–62.
4. Butu M. and Rodino S. (2019). Fruit- and vegetable-based beverages: Nutritional properties and health benefits. *Natural Beverages*, 13, 303–308.
5. Calugar P. C. (2021). Factors influencing apple cider sensory and microbial quality from raw materials to emerging processing technologies: A review. *Processes*, 9, 457.
6. Chandra D. (2016). Review of finger millet (*Eleusine coracana* (L.) Gaertn): A powerhouse of health-benefiting nutrients. *Food Science and Human Wellness*, 5, 149–155.
7. Choudhary R. P. (2023). Ethnic alcoholic beverages of Nepal Himalaya. *Natural Products in Beverages*, 1, 1–34.
8. Devaki C. S. and Premavalli K. S. (2019). Fermented vegetable beverages. *The Science of Beverages*, 5, 321–367.
9. Djousse L. (2004). Fruit and vegetable consumption and LDL cholesterol: The National Heart, Lung, and Blood Institute Family Heart

- Study. *American Journal of Clinical Nutrition*, 79, 213–217.
10. Dwivedi S. (2024). Functional foods in the northwestern Himalayan region of India and their significance: A healthy dietary tradition of Uttarakhand and Himachal Pradesh. *Journal of Ethnic Foods*, 11, 20.
  11. Garcia L. C. (2022). Traditional fermented foods and beverages from around the world and their health benefits. *Microorganisms*, 10, 1151.
  12. Harmayani E. (2019). Healthy food traditions of Asia: Exploratory case studies from Indonesia, Thailand, Malaysia, and Nepal. *Journal of Ethnic Foods*, 6, 1–18.
  13. Heer K. (2019). Traditional fermented foods and beverages of Himachal Pradesh. *Plant Cell Biotechnology and Molecular Biology*, 21, 136–141.
  14. Kanwar S. S. and Keshani (2016). Fermentation of apple juice with a selected yeast strain isolated from fermented foods of Himalayan regions and its organoleptic properties. *Frontiers in Microbiology*, 7, 978.
  15. Kanwar S. S. (2011). Cereal-based traditional alcoholic beverages of the Lahaul and Spiti area of Himachal Pradesh. *Indian Journal of Traditional Knowledge*, 10, 251–257.
  16. Li Y. N. (2023). Metabolomic analysis of the effects of a mixed culture of *Saccharomyces cerevisiae* and *Lactiplantibacillus plantarum* on apple cider vinegar. *Frontiers in Nutrition*, 10, 111.
  17. Lian J. (2022). Health benefits of plant-based fermented food and beverages on type 2 diabetes mellitus. *Highlights in Science, Engineering and Technology*, 11, 229–238.
  18. Liliana K. (2021). Strategies to improve the potential functionality of fruit-based fermented beverages. *Plants*, 10, 2301.
  19. Majumder S. and Bhattacharya M. (2024). Himalayan fermented beverages and their therapeutic properties with scientific validations: A comprehensive review. *Journal of Ethnic Foods*, 11, 44.
  20. Manoj P. M. (2023). Fruit-based probiotic functional beverages: A review. *Journal of Agriculture and Food Research*, 14, 100630.
  21. Mokoena M. P. (2016). Perspectives on the probiotic potential of lactic acid bacteria from African traditional fermented foods and beverages. *Food & Nutrition Research*, 60, 29630.
  22. Morales-de la Peña M. (2023). Recent trends in fermented beverage processing: The use of emerging technologies. *Beverages*, 9, 51.
  23. Pandey N. K. (2017). Analysis of indigenous food items of the Monpa tribal community of Tawang district, Arunachal Pradesh, India. *International Journal of Current Microbiology and Applied Sciences*, 6, 633–640.
  24. Purkiewicz A. and Pietrzak-Fiecko R. (2021). Antioxidant properties of fruit and vegetable whey beverages and fruit and vegetable mousses. *Molecules*, 26, 3126.
  25. Rawat J. M. (2021). Preparation of alcoholic beverages by tribal communities in the Indian Himalayan region: A review on traditional and ethnic considerations. *Frontiers in Sustainable Food Systems*, 5, 642258.
  26. Ruiz A. B. (2024). The role of fermented vegetables as a sustainable and health-promoting nutritional resource. *Applied Sciences*, 14, 38.
  27. Savitri (2019). Present status and future prospects of traditional fermented beverages of Himachal Pradesh, India. *International Journal of Food and Fermentation Technology*, 9, 67–72.
  28. Sharma R. (2014). Value addition of wild apricot fruits grown in North-West Himalayan regions: A review. *Journal of Food Science and Technology*, 51, 2917–2924.
  29. Swain M. R. (2014). Fermented fruits and vegetables of Asia: A potential source of probiotics. *Biotechnology Research International*, 2014, 1–19.
  30. Tamang J. P. and Lama S. (2022). Probiotic properties of yeasts in traditional fermented foods and beverages. *Journal of Applied Microbiology*, 132, 3533–3542.
  31. Tamang J. P. and Sarkar P. K. (1993). Sinki: A traditional lactic acid fermented radish tap root product. *Journal of General and Applied Microbiology*, 39, 395–408.
  32. Tamang J. P. (2005). Ethnic fermented foods and beverages of the Eastern Himalayas. *International Journal of Food Microbiology*, 103, 1–11.
  33. Tamang J. P. (2016). Ethnic fermented foods and beverages of India. *Ethnic Fermented Foods and Alcoholic Beverages of Asia*, 17, 17–72.
  34. Thakur K. (2016). Fermented bamboo shoots: A rich niche for beneficial microbes. *Journal of Bacteriology and Mycology*, 2, 87–93.
  35. Thakur N. (2004). Characterization of some traditional fermented foods and beverages of Himachal Pradesh. *Indian Journal of Traditional Knowledge*, 3, 325–335.
  36. Tomar S. (2023). Unravelling the hidden ethnic fermented treasure of the Himalayas: Traditionally fermented beverages of the Northwest Indian Himalayan region. *Food Chemistry Advances*, 2, 100126.
  37. Zhou D. D. (2022). Bioactive compounds, health benefits and food applications of grape. *Foods*, 11, 2755.