Traditional Ethnic Beverages as Sources of Phenolic Compounds: Antioxidant and Anti-inflammatory Properties—A Narrative Review

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Abstract
Indigenous groups have been consuming traditional ethnic beverages for generations, and they play a significant role in their dietary customs, cultural legacy, and traditional medical systems. These drinks are typically made using naturally occurring fermentation processes that improve the nutritional content and bioactive composition of cereals, fruits, herbs, and other locally accessible plant materials. Traditional fermented drinks are rich in phenolic compounds, flavonoids, organic acids, bioactive peptides, and beneficial microbes, which together support a variety of biological activities, according to mounting scientific data. Because of their ability to avoid oxidative stress and chronic inflammatory illnesses, antioxidant and anti-inflammatory capabilities have garnered significant interest. Fermentation increases the bioavailability and biological effectiveness of phytochemicals by facilitating their release and biotransformation. In experimental studies, a number of traditional beverages, such as Haria, Kanji, Pakhoi, Chubitchi, Makgeolli, Judima, and other native fermented drinks, have shown notable free radical scavenging activity, inhibition of lipid peroxidation, modulation of inflammatory cytokines, and regulation of oxidative stress pathways. However, due to variations in raw ingredients, fermentation techniques, microbial variety, and geographic origin, there is a great deal of variation in their phytochemical content and biological activities. The present understanding of the phenolic composition, antioxidant capacity, and anti-inflammatory potential of traditional ethnic beverages is summarized in this narrative review, with a focus on beverages that the Khasi population of Meghalaya, India, typically consumes.Furthermore, it highlights the underlying mechanisms responsible for their biofunctional properties, discusses existing research gaps, and outlines future perspectives for the scientific validation and development of traditional ethnic beverages as evidence-based functional foods.

Keywords: Traditional ethnic beverages; Fermented beverages; Phenolic compounds; Polyphenols; Antioxidant activity; Anti-inflammatory activity; Functional foods; Khasi tribe; Bioactive compounds.
How to cite this article: Borbhuyan IH, Choudhury AAK, Zakariya, Habib JA, Bhattacharya S, Rahman J, Aziz A. Traditional ethnic beverages as sources of phenolic compounds: antioxidant and anti-inflammatory properties—a narrative review. Int J Drug Deliv Technol. 2026;16(73s): 877-886. DOI: 10.25258/ijddt.16.73s.94

Introduction

For generations, traditional ethnic drinks have been an essential component of human civilization, acting as emblems of indigenous knowledge, social customs, and cultural identity in addition to being staple foods. Through controlled or spontaneous fermentation procedures that have been passed down through the generations, these drinks are made from locally accessible cereals, fruits, vegetables, herbs, flowers, and other plant materials. Fermented beverages are a significant part of both nutritional and cultural history in many indigenous societies because they are made using a special blend of customs, environmental adaptation, and microbial biodiversity.[1]

One of the earliest and most popular methods of food preservation is fermentation, which is known to enhance the safety, nutritional value, and sensory qualities of foods and drinks. Organic acids, ethanol, vitamins, enzymes, and a variety of secondary metabolites are produced during fermentation by

naturally occurring microorganisms, especially lactic acid bacteria and yeasts, which break down carbohydrates and other nutrients. Nutrient bioavailability is increased, anti-nutritional factors are decreased, digestibility is improved, and a variety of bioactive molecules with potential health benefits are produced. As a result, traditional fermented drinks are becoming more widely acknowledged as functional foods that offer advantages beyond simple sustenance.[2]

Because of their wide range of biological actions, phenolic compounds have garnered a lot of scientific interest among the bioactive components found in fermented beverages. Strong antioxidant qualities allow phenolic acids, flavonoids, tannins, anthocyanins, lignans, and other polyphenolic chemicals to neutralize reactive oxygen species, prevent lipid peroxidation, chelate transition metals, and shield cellular components from oxidative damage. Regular use of foods and beverages high in polyphenols has been linked to a lower risk of cardiovascular illnesses, diabetes mellitus, obesity, neurodegenerative disorders, metabolic syndrome, and several types of cancer, according to numerous epidemiological and experimental investigations.[3]

Numerous chronic non-communicable diseases are initiated and progressed by oxidative stress and chronic inflammation, two closely related pathological processes. Reactive oxygen species overproduction triggers inflammatory signaling pathways, which raise the expression of pro-inflammatory cytokines and mediators that accelerate tissue damage and the advancement of disease. By scavenging free radicals, reducing oxidative stress, controlling inflammatory signaling pathways, and modifying immunological responses, naturally occurring phytochemicals found in fermented drinks may thwart these processes. Due to these biological characteristics, traditional fermented beverages have drawn a lot of attention as possible dietary therapies for the management and prevention of illnesses linked to oxidative stress.[4]

Globally, traditional fermented drinks are remarkably diverse, especially in Asian nations where fermentation has long been a part of everyday eating customs. India has a wide variety of native fermented drinks made by different tribal and ethnic groups employing traditional fermenting methods and raw materials unique to their own regions. Drinks like Haria, Judima, Apong, Kanji, Pakhoi, and Chubitchi are excellent illustrations of fermented foods that have both nutritional value and possible medical advantages. Similar to this, fermented drinks with notable antioxidant, antimicrobial, anti-inflammatory, antihypertensive, and antidiabetic properties, such as Makgeolli from Korea, traditional rice wines from China, and native cereal-based beverages from Nepal, have been found to contain significant amounts of phenolic compounds.[5]

The Khasi tribe of Meghalaya is one of the indigenous groups in northeastern India that has maintained a long-standing custom of making fermented drinks from locally accessible cereals and plant materials. These drinks are consumed at social events, religious ceremonies, festivals, and customary medical procedures. Recent research has shown that many traditional Khasi drinks have significant polyphenol content as well as potential anti-inflammatory and antioxidant properties. The necessity for a thorough analysis of their biofunctional qualities and possible health advantages is highlighted by the fact that, in contrast to other conventional fermented beverages, the available scientific literature is still very small and dispersed.[6]

Traditional fermented beverages have seen a resurgence in popularity in recent years due to growing consumer demand for probiotics, plant-derived nutraceuticals, and natural functional foods. The intricate relationships between fermentation microbes and plant phytochemicals have been better understood because to developments in food chemistry, metabolomics, microbiology, and nutritional sciences. These advancements have made it possible to design evidence-based functional beverages with potential uses in illness prevention and health promotion, as well as to scientifically confirm traditional knowledge.[7]

With a focus on beverages drunk by the Khasi population in Meghalaya, India, the current narrative analysis attempts to give a thorough overview of the phenolic composition, antioxidant qualities, and anti-inflammatory effects of traditional ethnic beverages. The review also highlights future prospects for the use of traditional ethnic beverages as functional foods and nutraceutical resources, summarizes current experimental evidence, identifies research gaps, and addresses the impact of fermentation on the formation of bioactive compounds.

Phenolic Compounds in Traditional Ethnic Beverages

Many of the health-promoting qualities of traditional ethnic beverages are mainly due to phenolic compounds, which are among their most significant bioactive components. A wide range of substances, including as phenolic acids, flavonoids, tannins, anthocyanins, lignans, stilbenes, and other polyphenolic derivatives, make up these secondary plant metabolites. Cereals, fruits, vegetables, medicinal herbs, and plant materials that are frequently employed as substrates for the production of traditional fermented beverages are rich sources of naturally occurring phenolics. Microbial enzymes hydrolyze complex phenolic conjugates into simpler,

more accessible forms during fermentation, increasing their biological activity and boosting their absorption in the human digestive system.[8]

The botanical origin of the raw ingredients, location, climate, fermentation microorganisms, processing methods, and fermentation length all have a significant impact on the phenolic composition of traditional beverages. Lactic acid bacteria and yeasts facilitate the enzymatic breakdown of plant cell walls through fermentation, which releases bound phenolic chemicals that were not previously present in the raw substrate. Furthermore, new phenolic metabolites with higher antioxidant capacity than their precursor chemicals may be produced by microbial metabolism. Therefore, compared to their unfermented counterparts, fermented beverages often have higher quantities of bioactive phenolics.[9]

Significant amounts of phenolic chemicals have been found in a number of traditional ethnic beverages enjoyed throughout Asia. Black carrots are used to make kanji, a fermented beverage that is very high in phenolic acids and anthocyanins, which greatly enhance its antioxidant value. In a similar vein, Pakhoi, a traditional fermented beverage from Uttarakhand, has shown exceptional free radical scavenging activity along with high total phenolic and flavonoid contents. Traditional rice-based fermented drinks from eastern and northeastern India, called haria and judima, include a variety of phenolic components produced by microbial biotransformation and cereal fermentation. Additionally, research has shown that the traditional Korean rice wine Makgeolli is rich in flavonoids and phenolic compounds, which enhance its nutraceutical and functional qualities.[10]

Chubitchi, a fermented rice beverage made by the Khasi population of Meghalaya, is one of the traditional drinks of northeastern India that has recently drawn a lot of scientific attention due to its biofunctional qualities. According to Hati et al., Chubitchi has strong antioxidant, antibacterial, angiotensin-converting enzyme inhibitory, antidiabetic, and anti-inflammatory properties in addition to a notable phenolic content. The authors proposed that the biological activity of the beverage is significantly influenced by the synergistic interaction between rice-derived phytochemicals and fermentation microorganisms.[11]

Several studies have shown that traditional fermented beverages' total phenolic content and antioxidant capability are positively correlated. Higher phenolic compound concentrations in beverages typically result in increased reducing power, stronger free radical scavenging activity, and improved defense against oxidative damage. This connection emphasizes how important polyphenols are in defining the functional quality of fermented drinks. Additionally, through a variety of molecular mechanisms, such as cellular signaling pathway modulation, lipid peroxidation inhibition, inflammatory mediator regulation, and DNA protection from oxidative damage, the variety of phenolic compounds produced during fermentation may offer complementary biological effects.[12]

Traditional fermented beverages are promising candidates for the creation of functional foods and nutraceutical products because phenolic chemicals have antibacterial, antidiabetic, cardioprotective, neuroprotective, and immunomodulatory activities in addition to their antioxidant qualities. A growing body of research indicates that frequent drinking of fermented beverages high in polyphenols may help prevent chronic non-communicable diseases linked to oxidative stress and chronic inflammation. However, significant differences in the phenolic content of various beverages highlight the necessity of standardized analytical techniques and thorough phytochemical characterization to enable insightful cross-study comparisons and to pinpoint the precise substances in charge of their biological activities.[13]

Table 1. Traditional Ethnic Beverages, Major Raw Materials, Bioactive Compounds, and Reported Biological Activities

Traditional beverage	Region of origin	Major raw materials	Major bioactive compounds	Reported biological activities	Key references
Chubitchi	Meghalaya, India	Rice, traditional starter culture	Phenolic compounds, flavonoids, organic acids, bioactive peptides, probiotic microorganisms	Antioxidant, anti-inflammatory, antimicrobial, antidiabetic, ACE inhibitory activity	Hati et al.
Kanji	Northern India	Black carrot, mustard	Anthocyanins, phenolic acids, flavonoids	Antioxidant, antimicrobial, probiotic	Sharma et al.

		seeds		potential	
Pakhoi	Uttarakhand, India	Medicinal herbs, cereals	Polyphenols, flavonoids, organic acids	Antioxidant, antimicrobial	Bhardwaj and Rai
Haria	Eastern India	Rice, herbal starter culture	Phenolic compounds, amino acids, B-complex vitamins, organic acids	Antioxidant, probiotic, nutritional supplementation	Das et al.; Tamang
Judima	Assam, India	Rice, traditional starter cake	Polyphenols, flavonoids, organic acids	Antioxidant, digestive health, antimicrobial	Das et al.
Makgeolli	Republic of Korea	Rice, nuruk starter culture	Polyphenols, flavonoids, γ-aminobutyric acid (GABA), peptides, organic acids	Antioxidant, anti-inflammatory, antihypertensive, hepatoprotective	Park et al.; Nile

Antioxidant Properties of Traditional Ethnic Beverages

An imbalance between the body's antioxidant defense system and the production of reactive oxygen species (ROS) leads to oxidative stress. Overproduction of ROS can harm cellular lipids, proteins, carbohydrates, and nucleic acids. This can contribute to the pathophysiology of many chronic diseases, such as diabetes mellitus, cancer, neurodegenerative diseases, cardiovascular problems, and early aging. Antioxidants found in food are crucial for scavenging free radicals and shielding cells from oxidative damage. Because of their high concentrations of phenolic compounds and other bioactive metabolites, naturally fermented ethnic beverages have drawn more interest as possible sources of dietary antioxidants.[14]

Polyphenols, flavonoids, phenolic acids, anthocyanins, tannins, vitamins, and fermentation-derived metabolites are the main components responsible for the antioxidant action of traditional ethnic beverages. Microbial enzymes hydrolyze complex phytochemicals into smaller bioactive compounds with increased antioxidant potential during fermentation. Additionally, metabolites such organic acids, exopolysaccharides, and bioactive peptides that enhance antioxidant capacity are produced by lactic acid bacteria and yeasts. Fermented beverages perform better than many of their non-fermented counterparts due to these metabolic changes that increase the concentration and bioavailability of antioxidant chemicals.[15]

The most popular analytical techniques for assessing the antioxidant activity of traditional beverages are the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay, Ferric Reducing Antioxidant Power (FRAP) assay, Oxygen Radical Absorbance Capacity (ORAC) assay, and reducing power assay. Together, these techniques evaluate the capacity of bioactive substances to scavenge free radicals produced during oxidative stress, decrease oxidized intermediates, and donate electrons or hydrogen atoms.[16]

Because of its strong anthocyanin and phenolic acid content, which comes from black carrots, Kanji has shown exceptional antioxidant activity among the traditional drinks examined. In a similar vein, Pakhoi, an indigenous fermented beverage made from Himalayan medicinal plants, showed a high total phenolic content and significant free radical scavenging action. Due in great part to fermentation-mediated increase of phenolic compounds and flavonoids, traditional rice-based beverages including Haria, Judima, and Makgeolli have also demonstrated notable antioxidant potential. Chubitchi, a fermented rice beverage that is historically drank by the Khasi community in Meghalaya, has significant antioxidant activity, according to recent studies, suggesting its potential as a functional beverage with health-promoting qualities.[17]

According to experimental research, total phenolic content and antioxidant capacity are positively correlated, suggesting that polyphenolic chemicals have a significant role in the biological activity of fermented beverages. Through microbial enzymatic activity, fermentation improves the release of bound phenolics from plant cell walls, enhancing their

accessibility and antioxidant effectiveness. Furthermore, new antioxidant metabolites that work in concert with naturally present phytochemicals may be produced via microbial biotransformation. It is thought that these synergistic interactions increase fermented beverages' overall antioxidant efficacy beyond that of individual bioactive components.[18]

Traditional ethnic drinks' antioxidant qualities have significant effects on human health. These drinks may help prevent lipid peroxidation, maintain cellular integrity, retain mitochondrial function, and modify redox-sensitive signaling pathways by scavenging reactive oxygen species and lowering oxidative damage. Additionally, research indicates that regular consumption of fermented beverages high in antioxidants may help reduce the risk of disorders associated with oxidative stress, such as diabetes mellitus, metabolic syndrome, cardiovascular diseases, neurodegenerative diseases, and some types of cancer. Nevertheless, the majority of the information that is now available comes from in vitro and animal research, and more carefully planned clinical studies are needed to demonstrate their long-term health advantages in human populations.[19]

While describing the antioxidant qualities of traditional fermented beverages has advanced significantly, there is still a great deal of variation in published research. Direct comparisons are challenging since claimed antioxidant values are influenced by variations in raw materials, geographic origin, microbial composition, fermentation length, extraction techniques, and analytical approaches. To better understand the antioxidant potential of traditional ethnic beverages and enable their use as scientifically validated functional foods, future research should concentrate on standardized analytical protocols, thorough metabolomic characterization, and clinical validation.

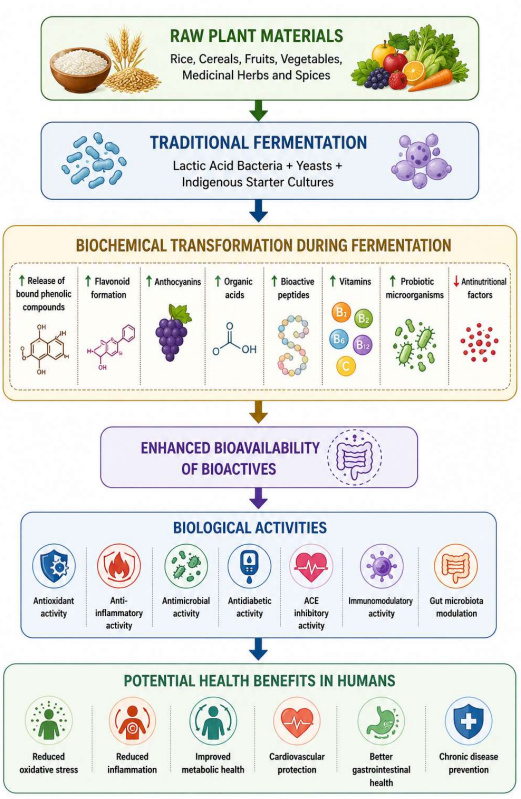

Figure 1. Effect of Fermentation on the Formation of Bioactive Compounds and Their Biological Activities[18]

Comparative Bioactive Profile of Major Traditional Ethnic Beverages

The phytochemical makeup, microbial diversity, fermentation methods, and biological activities of traditional fermented drinks vary greatly. The type of raw materials utilized, native starter cultures, ambient factors, fermentation time, and local processing methods are the main factors influencing these differences. As a result, the nutritional value and medicinal potential of each traditional beverage are determined by its own bioactive profile. Comparative analysis of these drinks helps identify prospective candidates for upcoming nutraceutical and functional food development and offers insightful information about their functional qualities.[19]

Among the drinks examined, Kanji—a traditional fermented beverage made from black carrots—is known for having a remarkably high concentration of flavonoids, phenolic acids, and anthocyanins. DPPH and ABTS radical scavenging tests show that the fermentation process increases the production of these phytochemicals, leading to potent antioxidant action. Kanji has been shown to have antibacterial action and probiotic qualities that support immunological regulation and gastrointestinal health in addition to its potential as an antioxidant.[20]

Pakhoi, a traditional fermented drink made from Himalayan medicinal plants, has shown notable free radical scavenging potential in addition to a remarkable total phenolic content. According to Bhardwaj and Rai, Pakhoi is rich in plant-derived polyphenols that can effectively lower oxidative stress. Additionally, the beverage has metabolites from fermentation and naturally occurring organic acids that may strengthen its antibacterial and antioxidant qualities. Despite the paucity of study on Pakhoi, what is known suggests that it has a lot of potential as a functional beverage.[21]

Tribal populations in eastern and northeastern India frequently drink traditional rice-based drinks like Judima and Haria. These drinks are made by natural fermentation using native starter cultures that include a variety of filamentous fungus, yeasts, and lactic acid bacteria. By raising the content of free amino acids, B-complex vitamins, organic acids, and phenolic compounds while concurrently lowering antinutritional components, fermentation enhances the nutritional quality of rice. Although more mechanistic research and human trials are needed to confirm their medicinal potential, experimental studies have shown antioxidant, antibacterial, and probiotic effects.[22]

Chubitchi, one of Meghalaya's native drinks, has become one of the fermented drinks that has been studied the most in recent years. Chubitchi has significant antioxidant, antibacterial, antidiabetic, angiotensin-converting enzyme inhibitory, and anti-inflammatory properties, according to Hati et al. In macrophage cell cultures, the beverage dramatically decreased the generation of intracellular reactive oxygen species and inhibited the release of pro-inflammatory cytokines. These results imply that rice's wide range of biological activities are a result of the cooperative relationship between fermentation-associated microbes and polyphenols synthesized from rice.[23]

One of the most researched fermented cereal drinks outside of India is Makgeolli, a traditional rice wine from Korea. A complex blend of phenolic substances, flavonoids, dietary fiber, γ-aminobutyric acid (GABA), organic acids, peptides, and probiotic microbes produced during fermentation can be found in makgeolli. Its antioxidant, anti-inflammatory, antihypertensive, antidiabetic, hepatoprotective, and immunomodulatory qualities have been shown in numerous research. The fermentation-induced biotransformation of rice phytochemicals and the metabolic processes of lactic acid bacteria and yeasts are primarily responsible for these advantageous effects.[24]

The positive correlation between fermentation and increased biological activity is a characteristic shared by all traditional beverages, despite variations in botanical origin and fermentation techniques. In addition to encouraging the production of new bioactive metabolites, fermentation continuously raises the concentration and bioavailability existing phenolic compounds. Consequently, stronger antioxidant and anti-inflammatory properties are typically found in beverages with higher total phenolic and flavonoid concentrations. However, due to variations in analytical techniques, measurement units, fermentation conditions, and microbial composition, direct comparison between research continues to be difficult. For meaningful comparisons between various traditional beverages, standardized procedures are therefore crucial.[25]

All things considered, the information that is now available suggests that traditional ethnic beverages are a rich and varied source of bioactive chemicals with significant functional potential. Many indigenous fermented beverages have not received enough scientific attention, despite the fact that some, like Chubitchi, Kanji, Pakhoi, and Makgeolli, have shown very promising antioxidant and anti-inflammatory properties. Finding new bioactive chemicals and confirming their health-promoting qualities will require further research using sophisticated metabolomic, microbiological, and clinical techniques.

Mechanisms Underlying the Bioactive Effects of Traditional Ethnic Beverages

Beneficial microbes, fermentation-derived metabolites, and naturally existing phytochemicals interact intricately to mediate the biological actions of traditional ethnic beverages. In addition to improving the nutritional value of plant substrates, fermentation increases the release, transformation, and bioavailability of bioactive substances that have a variety of physiological effects. Therefore, rather than a single bioactive component, these beverages' health-promoting qualities result from the synergistic interactions of phenolic compounds, flavonoids, organic acids, bioactive peptides, vitamins, and probiotic bacteria.[26]

The improvement of antioxidant defense is one of the main processes behind the positive effects of fermented drinks. In order to neutralize reactive oxygen species (ROS) and stop oxidative damage to cellular lipids, proteins, and nucleic acids, phenolic substances rapidly give hydrogen atoms or electrons. Polyphenols not only directly scavenge free radicals but also chelate transition metal ions like copper and iron, which lowers the production of extremely reactive hydroxyl radicals via the Fenton reaction. These antioxidant systems protect tissues from illnesses linked to oxidative stress and maintain cellular redox equilibrium.[27]

By producing physiologically active metabolites through microbial enzymatic processes, fermentation further boosts antioxidant activity. Lactic acid bacteria and yeasts produce enzymes that hydrolyze complicated phenolic glycosides into simpler aglycones with higher intestine absorption and biological activity. Additionally, organic acids, γ-aminobutyric acid (GABA), exopolysaccharides, and bioactive peptides are produced by microbial metabolism and contribute to the cytoprotective and antioxidant properties of fermented beverages. Therefore, when compared to their non-fermented raw materials, fermentation greatly increases the functional value of traditional beverages.[28]

Through the modification of several intracellular signaling pathways, traditional ethnic beverages have an anti-inflammatory effect. Nuclear factor-kappa B (NF-κB), a crucial transcription factor that controls the expression of inflammatory cytokines and enzymes, is suppressed by polyphenols, according to experimental research. Tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), interleukin-6 (IL-6), cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), and prostaglandin E_2 (PGE_2) are all produced less when NF-κB activation is inhibited, which attenuates inflammatory reactions. Further enhancing their anti-inflammatory qualities, phenolic substances also control mitogen-activated protein kinase (MAPK) signaling pathways and prevent the overproduction of reactive oxygen species.[29]

A healthy gut microbiota influences both local and systemic immunity, supporting the idea that fermented beverages exert beneficial effects through modulation of the gut–microbiota–immune axis. These microorganisms may also enhance nutrient absorption, improve digestive health, and increase the bioavailability of dietary phytochemicals. Lactic acid bacteria and yeasts contribute to intestinal microbial homeostasis by inhibiting pathogenic microorganisms found in traditional fermented beverages.[30]

A number of bioactive substances found in fermented drinks also show enzyme-inhibiting properties that help prevent illness. While α-amylase and α-glucosidase inhibition delays carbohydrate digestion and enhances postprandial glycaemic management, angiotensin-converting enzyme (ACE) inhibitory peptides produced during fermentation may help regulate blood pressure. Additionally, several metabolites produced by fermentation have shown antibacterial efficacy against opportunistic microorganisms and foodborne pathogens, improving food safety and promoting intestinal health. Together, these various biological processes account for the wide range of functional characteristics connected to traditional ethnic beverages.[31]

Despite significant advancements in our knowledge of these molecular pathways, many parts are still poorly understood. Individual phytochemicals, fermentation microbes, and host metabolic pathways interact in a complicated way that can change depending on the makeup of the beverage, the diversity of microorganisms, and the physiological state of the individual. It is anticipated that developments in systems biology, proteomics, metagenomics, and metabolomics will offer more profound understanding of the molecular underpinnings of various bioactivities. These methods will make it easier to find new biomarkers, enhance knowledge of the synergistic relationships between bioactive substances, and aid in the creation of functional beverages that have been scientifically proven to prevent illness and promote health.

Future Perspectives and Research Gaps

Because of their rich content of phenolic compounds, helpful microbes, and various bioactive metabolites, traditional ethnic beverages have drawn more and more interest from scientists. Despite significant advancements in the characterization of their antioxidant, anti-inflammatory, antibacterial, and other health-promoting qualities, there are still a number of significant knowledge gaps and fragmented evidence. Transforming traditional knowledge into evidence-based nutritional therapies and functional food products will need addressing these constraints.[32]

The absence of regulated fermentation and preparation procedures is one of the main obstacles. Traditional beverages are typically made at home or in a community utilizing procedures that vary greatly in terms of raw materials, local starter cultures, fermentation time, ambient factors, and processing methods. These differences make it challenging to compare research since they have a substantial impact on the phytochemical content, microbial diversity, and biological activity of the finished products. The creation of standardized fermentation processes that maintain these beverages' traditional qualities would increase reproducibility and make scientific validation easier.[33]

The inadequate description of the microbes that cause fermentation is another significant drawback. Comprehensive research utilizing next-generation sequencing, metagenomics, and metabolomics are still rare, despite the fact that lactic acid bacteria and yeasts have been identified as major microbial communities in a number of studies. Novel probiotic strains might be identified, their role in the synthesis of bioactive compounds responsible for the reported biological activities clarified, and a greater understanding of microbial succession during fermentation could be obtained by advanced molecular techniques.[34]

The majority of the data that is currently accessible about antioxidant and anti-inflammatory qualities comes from animal models and in vitro studies. There are few human clinical studies assessing the health effects of traditional ethnic beverages, and the ones that are available frequently have varied study designs, small sample sizes, and brief intervention durations. Therefore, to assess their effectiveness, ideal consumption patterns, long-term safety, and possible significance in the prevention and management of chronic diseases linked to oxidative stress and inflammation, well-designed randomized controlled trials are necessary.[35]

Future research should also concentrate on thorough phytochemical profiling employing cutting-edge analytical methods such as high-resolution metabolomics, nuclear magnetic resonance (NMR), gas chromatography–mass spectrometry (GC–MS), and liquid chromatography–mass spectrometry (LC–MS). These technologies would make it easier to identify and measure the specific phenolic chemicals, flavonoids, peptides, organic acids, and other metabolites that give traditional beverages their biological properties. Additionally, combining metabolomic data with microbiome analysis may offer insightful information about the relationships between phytochemicals generated from plants and fermentation bacteria.[36]

The preservation of indigenous knowledge related to traditional beverage preparation is another area that needs further focus. Urbanization, modernity, and shifting dietary preferences pose a growing danger to many oral fermentation techniques that are passed down through the centuries. In addition to aiding in cultural preservation, scientific documentation of these customs and cooperative research involving local communities will make it easier to find new functional foods and probiotic microorganisms with potential industrial uses.

Traditional ethnic beverages have a lot of potential to become commercially successful functional foods and nutraceuticals due to the increased consumer desire for natural health-promoting foods. Standardized manufacturing procedures, quality control procedures, microbiological safety assessments, shelf-life analyses, and adherence to national and international regulatory standards are necessary for effective commercialization. Therefore, in order to develop evidence-based guidelines for the manufacture and use of these beverages, future research should incorporate food science, microbiology, nutrition, pharmacology, and clinical medicine.

All things considered, traditional ethnic beverages are an important but little-studied resource with significant potential to support sustainable agricultural systems, human health, and the preservation of indigenous cultural heritage. Unlocking their full nutritional and medicinal potential will require ongoing multidisciplinary study that combines traditional knowledge with contemporary scientific methods.

Conclusion

With centuries of accumulated traditional knowledge and fermentation techniques, traditional ethnic beverages are a significant part of indigenous food systems and cultural history. These drinks have long been used as both dietary staples and natural medicines for preserving health and wellbeing. They are made from locally accessible cereals, fruits, vegetables, herbs, and medicinal plants. Many of these conventional assertions have been increasingly supported by scientific studies in recent years, which have shown the existence of a variety of bioactive substances with important functional characteristics. Their biological actions are mostly attributed to phenolic substances, flavonoids, organic acids, bioactive peptides, vitamins, and beneficial microbes.

The evidence that is currently available suggests that fermentation is essential to enhancing the functional and nutritional value of traditional drinks. Microbial metabolism produces new metabolites with strong biological activity, boosts nutrient bioavailability, decreases antinutritional factors, and improves the release and biotransformation of phenolic compounds. As a result, compared to their non-fermented counterparts, fermented drinks typically have higher antioxidant and anti-inflammatory potential. Research has repeatedly shown that drinks like Kanji, Pakhoi, Haria, Judima, Chubitchi, and Makgeolli have a significant ability to scavenge free radicals, prevent oxidative damage, regulate inflammatory mediators, and support cellular homeostasis. These results lend credence to their prospective use as natural functional meals that lower the risk of chronic diseases linked to oxidative stress.

A particularly encouraging illustration of the possible health benefits of locally produced fermented beverages is Chubitchi, a traditional fermented rice beverage that is enjoyed by the Khasi community in Meghalaya. Its antioxidant, antibacterial, antidiabetic, angiotensin-converting enzyme inhibitory, and anti-inflammatory properties have been shown in recent studies, underscoring the significance of maintaining and scientifically verifying ancient fermentation methods. However, despite their broad traditional use, many additional indigenous beverages have not received enough attention, suggesting significant potential for further study and exploration.

Despite promising results, methodological heterogeneity, variations in fermentation processes, discrepancies in analytical methodologies, and the comparatively small number of well-designed human

clinical studies continue to limit the present body of evidence. The majority of the data that is currently accessible comes from animal models and in vitro studies, which are useful for comprehending biological processes but cannot be directly applied to human clinical efficacy. Therefore, to develop evidence-based recommendations regarding the therapeutic potential and safe consumption of these beverages, standardization of fermentation protocols, thorough phytochemical characterization, advanced metabolomic and microbiome analyses, and randomized controlled clinical trials are necessary.

Traditional ethnic beverages have significant social and cultural value in addition to their nutritional value. In addition to opening doors for the creation of innovative functional foods, probiotics, and nutraceutical goods, the preservation of indigenous fermentation expertise supports the preservation of biodiversity, cultural heritage, and sustainable food systems. To guarantee that traditional knowledge is scientifically recorded, safeguarded, and turned into safe and efficient health-promoting products, cooperation between food scientists, microbiologists, nutritionists, doctors, and indigenous groups will be crucial.

To sum up, traditional ethnic drinks are an important source of bioactive substances with strong anti-inflammatory and antioxidant qualities. The acknowledgment of phytochemicals, fermentation-derived metabolites, and beneficial microbes as functional foods with potential uses in disease prevention and health promotion is supported by a solid scientific foundation. Unlocking their full therapeutic potential and encouraging their broader acceptance in evidence-based nutrition and functional food production will require ongoing multidisciplinary research that integrates traditional knowledge with contemporary analytical and clinical methodologies.

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