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Chanchal
Department of Nutrition and Dietetics, Faculty of Allied Health Sciences, SGT University, Gurugram, Haryana, India

Akanksha Yadav
Department of Nutrition and Dietetics, Faculty of Allied Health Sciences, SGT University, Gurugram, Haryana, India

Kunal
Department of Microbiology, Faculty of Allied Health Sciences, SGT University, Gurugram, Haryana, India

Correspondence
Chanchal
Department of Nutrition and Dietetics, Faculty of Allied Health Sciences, SGT University, Gurugram, Haryana, India

Nutritional and therapeutic potentials of wholesome plant-based fermented food products of India

Chanchal, Akanksha Yadav and Kunal

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Abstract
Fermentation is an age-old technology that has been practiced since time immemorial. Application of fermentation techniques have a drastic impact on the production of numerous food items. There are a variety of traditional plant-based fermented foods and beverages developed through the process of fermentation in India. Plant-based fermented food products have many nutritional and functional properties such as high fiber, protein, phytochemicals, phytonutrients, antioxidant content, vitamins, and minerals which exhibit many health benefits and help in the prevention of certain diseases. In India a variety of plant-based fermented foods and beverages are found due to different geographical indications, cultural diversity, and variance of the raw material availability. The rural population of India prepares these products at home and markets them locally, which serves as a source of income for them. The traditional fermentation process in India promotes nutritional and therapeutic properties of the food thereafter making them shelf-stable. This study summarizes some of the most popular plant-based fermented products developed in India using traditional methods and are believed to have a beneficial impact on health. Intricate study of nutritional and therapeutic properties of these food products can be essential in providing salubrious knowledge which will provide valuable guidance for the use and development of new products on a wider scale.

Keywords: Fermentation, health benefits, probiotic, traditional and modern fermented foods

Introduction
Fermentation is a primeval method for the preservation of food performed for thousands of years to produce and develop different varieties of food and beverages. Although initially, it was only a means of preservation, now fermented foods proved to possess many desirable attributes such as (distinctive aroma, taste and flavor) (Tamang *et al*., 2020) [17]. The process of fermentation enhances the sensory properties of the food through the development of a diverse flavor, and aroma, enriching the nutritional composition of the food through the synthesis of essential amino acids, fatty acids, and vitamins. It also decreases cooking times and fuel requirements, as well as provides natural ways of improving the digestibility of food. It also has a detoxification function, that is elimination of undesirable substances naturally present in food such as tannins and phytates. Nowadays, fermented foods and beverages are regarded as part of our daily diets. Yielding over 500 varieties of fermented foods and beverages worldwide the main substrates used in the commercial production of fermented products are, cereals, fruits, vegetables, milk, fish, and meat.
Animal derived fermented food products remain highly in demand and play a significant role in the dietary consumption for the general population, which are not only a means of enjoyment but are also considered nutritional rich and are believed to have several health promoting factors. Regardless of the healthy profile of fermented animal derivatives, especially dairy based products, they have many detrimental concerns including hormonal dis-balance inside the human body, environmental deterioration and ethical implications on animal welfare (Cagno *et al*., 2013) [11]. Due to this the rise of popularity for the plant- based fermented foods and beverages can be clearly observed among consumers as they are vegan friendly, and do not contain lactose, cholesterol, and casein which may cause allergic reactions to some people. The health-conscious consumers are aiming for better and more convenient options to fulfill their nutritional needs by opting for vegetarian meal courses which come with a diverse range of products to choose from with whole plant-based ingredients as their principal constituent. By the addition of probiotics in plant-based ingredients namely, cereals, legumes, fruits and vegetables have shown to possess high

nutritional qualities including high amino acids contents, dietary fiber, vitamin, minerals, phytochemicals, along with many other essential nutrients and shelf-life stability. According to the World Health Organization (WHO), daily consumption of vegetables and fruits in diet can help in the prevention of various life-threatening diseases like CVD, hypertension, and stroke. Generally, consumers would rather have the food and beverages which are fresh, healthy, and nutritious or are ready to eat or drink (Prado *et al*., 2008) [13]. It is a common practice to preserve the nutritional and sensory features of fruits and vegetables using lactic acid fermentation. In traditional Indian fermented foods, a variety of lactic acid bacteria (LAB) were isolated from different sources. Usually, LAB involving *Lactobacillus plantarum, L. pentosus, L. brevis, L. fermentum, L. casei, Leuconostoc mesenteroides, and Pediococcus pentosaceus,* are used in Asian fermented foods. Various researchers have reported that the addition of probiotics to food gives many health benefits like regulating gastrointestinal function, lowering serum cholesterol, improving immune function, and decreasing the risk of colon cancer (Anandharaj *et al*., 2014) [13]. In India several fermented foods and beverages are developed using plant-based ingredients.

Conventional fermented products formulated using fruits and vegetables in India

In the Himalayan region of India, fermentation technology is being practiced to preserve numerous perishable food products such as khalpi, sinki, and gundruk, which are preserved by the lactic acid fermentation method. *Lactobacillus brevis, L. plantarum, P. pentosaceus, P. acidilactici,* and *Leuconostoc fallax* are the dominant and most common species of lactic acid bacteria which are involved in the fermentation of vegetables traditionally which helps in the improvement of the overall nutritional content of the food. Juices of fruits are rich sources of certain biochemical compounds such as vitamins, minerals, fiber, and antioxidants which can be synthesized by various probiotics. And are also a healthy and refreshing alternative means of delivering probiotics to consumers of all ages. Fruits and vegetables naturally do not contain any lactose, which is well suited for people with special conditions like lactose intolerant. They are also rich in many health-promoting compounds which include phytochemicals, and phytonutrients. Beetroot, cabbage, tomato, carrot, palm fruit, and grapes, are popular substrates used to manufacture probiotic products. Some of the Indian fermented products formulated using fruits and vegetables as key ingredients are listed below in table 1 and photographs of some common products are given in figure 1.

Table 1: Nutritional and therapeutic prospects of fermented fruits and vegetable products of India

Local/Popular name	Principal constituent	Nutritional content/ 100 g					Therapeutic potentials	References
		Calorific value (kcal)	Carbohydrate (%)	Protein (%)	Fat (%)	Calcium (mg)		
Gundruk	Leafy vegetables	321.9	38.3	38.7	2.1	234.6	Boost milking efficiency, alternate first meal course, rich in ascorbic acid, lactic acid, carotene, and anticancer properties	(Tamang *et al*., 2005) [16], (Tamang and Tamang, 2010) [2]
Khalpi	Cucumber	356.2	70.9	12.3	2.6	6.4	-	(Tamang and Tamang, 2010)
Sinki	Radish taps root	344.2	68	14.9	1.4	223.9	Cure against diarrhea and stomach disorder	(Tamang *et al*., 2005) [16], (Tamang *et al*., 2010) [2]
Ziang-sang/ Ziang-dui	Mustard leaves	348.4	41.2	38.7	38.7	240	-	(Tamang *et al*., 2005) [16]
Kallu/toddy	Fruit	245	4	1	0.3	1	-	
Ekung	Tender bamboo shoot	363	52.1	30.1	3.8	35.4	Antioxidant, antimicrobial, nutritional	(Tamang and Tamang, 2009) [23]

Fig 1: Some common fermented products formulated using fruits and vegetables in India

Fermented products formulated using cereal, legume, and millet

Cereals are generally fermented to develop either alcoholic or non-alcoholic food and beverages, examples of such food products are confectionery items like bread loaves, or gruels, or even as foods for infants and children (Yonzan *et al*., 2012) [21]. Cereal-based food and beverages are good sources of fiber, carbohydrate, protein, vitamins and minerals, and many essential phytochemicals. Cereals act as a prebiotic medium that exhibits several necessary corporal functions in the human body, such as encouraging the growth of *Bifidobacteria* and *Lactobacilli* species of micro-organisms inside the colon (Shori, 2016; Vasudha and Mishra, 2013) [1, 36]. Furthermore, to be used as substrates for fermentation, cereals and their components are also known for their capability as 'novel prebiotics' as they contain water-soluble fibers like arabinoxylan, β-glucan, resistant starches, and oligosaccharides. Hence fermentation of cereal as ingredients with certain probiotics leads to overall health benefits and thus promotes the bioavailability of essential compounds naturally present in the fibrous bran of the cereals (Lamsal *et al*., 2009; Russo *et al*., 2017) [5, 41]. The high content of galacto-oligosaccharides and resistant starch in cereals is known for its efficiency towards gut microbiota, which promotes the survival and growth of several probiotics used to develop low processed food products which altogether is advantageous for the microbial quality and quantity enhancement for the developed product. Traditional fermented food products developed using cereals, legumes and millets are discussed in table 2.

Table 2: Traditional Indian fermented cereal, legume and millet products, their nutritional and therapeutic aspects

Local/Popular name	Principal constituent	Nutritional content/ 100 g					Therapeutic potentials	References
		Calorific value (kcal)	Carbohydrate (%)	Protein (%)	Fat (%)	Calcium (mg)		
Koozh	Cereal and millet	328	6	1	0.3	2	A meal replacer, Carbohydrate, fiber, and protein-rich, a good source of calcium	(Tamang *et al*., 2020) [17]
Idli	Cereal and legume	210	41	8	-	-	Energy-rich, protein, and fiber-rich, ease indigestion	(Tamang *et al*., 2020) [17]
Dosa/Dosai	Cereal and legume	163	18	4	-	-	Rich in carbohydrates, fiber, and protein. Alternate meal course	(Tamang *et al*., 2020) [17]
Appam	Cereal, vegetables	96	6	2	4	0.2	Rich in carbohydrates, fiber, protein, and B- group vitamins	(Tamang *et al*., 2020) [17]
Bhaati jaanr	Rice	404.1	86.9	9.5	2	12.8	To gain strength, ailing persons and post-natal women in the Himalayas consume bhaati jaanr extract	(Tamang and Thapa, 2006) [24]
Selroti	Rice	410	91.3	5.7	2.7	23.8	-	(Yonzan and Tamang, 2012) [21]
Hawaijar	Soybean	521.21	23.4	43.9	27.9	357.8	Organoleptic properties	(Jeyaram *et al*., 2010) [27]
Kinema	Soybean	454	28.1	47.7	17	432	The cholesterol-lowering effect, antioxidant activities	(Tamang *et al*., 2009)
Kodo ko Jaanr	Millets	4389.6	83.7	9.3	2	281	-	(Thapa *et al*., 2006) [24]

Fig 2: Some common fermented products formulated using cereal, legume and millet products in India

General microbial variations used in the development of different plant-based fermented foods and beverages

Lactic acid bacteria, which is responsible for lactic acid fermentation, is mainly carried out in cereals, and vegetables, whereas ethanol is formed as a result of alcoholic fermentation. Yeast is the main organism used in the production of alcoholic beverages like beer, wines, and whiskey and even in the development of non-alcoholic food products such as bread. Acetobacter species produce acetic acid which leads to the conversion of alcohol to acetic acid in the presence of oxygen (most common example: - vinegar). Fermentation of soybean and some leguminous

seeds is carried out in an alkaline medium, which is further used in various recipes as a condiment (Jeyaram *et al*., 2010) [27]. The variety of fermented foods and beverages plays a very significant role in the identification of distinguished ethnic groups. Likewise, in the northeastern region of India, some of the traditionally fermented plant-based food and beverages are consumed as an excellent source of nutrients, carbohydrates, protein, fat, vitamins, and minerals by their local people (Tamang *et al*., 2012) [21]. The most common fermented food mainly comprises locally available raw materials such as cereals, vegetables, bamboo, milk, soybean, fish, and meat (Tamang *et al*., 2012) [21]. Certain factors are of significance for the production of different varieties of foods and beverages using the technique of fermentation some of which includes, regional climatic conditions, temperature, and tropic and subtropic climate. Some of the most commonly found microorganisms in plant-based fermented food products are summarized in table 3.

Table 3: Microorganisms involved in the fermentation of plant-based fermented food products, and their major constituents

Common fermented food product	Type/ major ingredient	Microorganism involved	References
Sinki	Leafy vegetable	*L. plantarum* *L. brevis* *L. fermentum* *L. fallax* *P. pentosaceous*	(Swain *et al*., 2014)
Soidon	Root vegetable	*L. brevis* *L. fallax* *L. lactis*	
Sauerkraut	All vegetables	*L. mesenteroides* *L. plantarum* *L. brevis* *L. rhamanous*	
Inziangsang	Leafy vegetable	*L. plantarum* *L. brevis* *Pediococcus acidilactis*	
Gundruk	All vegetables	*Pediococcus and Lactobacillus spp.*	

Nutritional Components of the plant-based fermented food products

Plant-based fermented food products have been receiving attention from the scientific world as well as consumers due to increased interest in personal health and heightened awareness about the food consumed, it is expected that the food should have some health benefits and be able to meet the purpose of development. Furthermore, plant-based food products made out of the fermentation of cereals, vegetables, and fruits are gaining popularity among modern consumers (Gupta and Ghannam., 2011) [38]. Plant-based fermented food and beverages are an excellent source of energy, dietary fiber, protein, carbohydrates, antioxidants, phytochemicals, and phytonutrients. The process of fermentation in plant-based sources enhances the bioavailability of vitamins especially the B-group and several minerals (Gustaw *et al*., 2021) [29]. Some majorly popular plant-based fermented foods and beverages such as 'dosa, idli, dhokla, appam, and toddy' serve as an alternate food source for the population unable to consume animal products, which includes vegetarians. Plant-based fermented products have been proven to increase the overall content of vitamins and minerals as well as several phytosterols (Vijayendra and Halami 2015) [39].

Therapeutic potential of the plant-based fermented food products

Fresh foods including all the fruits and vegetables go through various important changes mainly in their biochemical components, and enrichment in nutritional and therapeutic properties while being fermented by the interaction of various beneficial microorganisms, with their enzymes and various metabolites produced (Vijayendra and Halami 2015) [39]. An increased shelf-life along with the enhancement of favorable organoleptic properties and increased therapeutic and nutritional values is generally observed as a result of fermentation. They are also proven to have a positive effect on relieving conditions like diarrhea, inflammation of the GI tract, and improved immune function. The fermentation process in foods and beverages has a positive impact on the improvement of the quality of bioactive components and the number of secondary metabolites which is essential for the enhancement of their antioxidant and antimicrobial prospects (Vijayendra and Halami 2015) [39].

Consumption of vegetable-based fermented food has shown to be associated with anti-diabetic and anti-obesity activity in the human body. Inside the food matrix, the probiotic microbes present in fermented plant-based food and beverages are protected against gastro-intestinal tract barrier involving bile salts, high acidity, and enzymes and modification of intestinal permeability, and help in the prevention of several diseases like irritable bowel syndrome (IBD), colon cancer, breast cancer, and atherosclerosis. By the fermentation of faba bean, the bioactive peptides are formed which have an anti-oxidative and anti-hypertensive response when consumed. Through the fermentation of dietary fibers through the action of gut microflora and probiotics, short-chain fatty acids (SCFA) are produced. Fermented foods prepared using plant-based raw materials such as soya, barley, and alfalfa have proven to have a positive impact on gut microflora, thus preventing type 2 diabetes mellitus and gestational diabetes (Baruah *et al*., 2022) [6].

The local tribal region in India has been consuming plant-based fermented beverages and foods in abundance as a daily practice whereas in urban regions of the country the consumption is comparatively low due to urbanization. For example, a fermented plant-based beverage product of the northeastern region known as 'Kinema' has an increased

level of total amino acid content, niacin, and riboflavin, which are proven to have cholesterol-lowering effects in the human body. It is also said to have a high antioxidant value, rich in linoleic acid and essential amino acids (Tamang *et al*. 2009) [23]. Correspondingly, chyang which is formulated by the fermentation of finger mill*et al*so known as ragi is consumed by the women after the delivery and is believed to have to strengthen properties to build internal fortitude. A fermented radish taproot product known as 'sinki' is consumed as a cure for stomachache and diarrhea by the local tribe in northeast India (Tamang, 2010) [2]. Gundruk improves the milking efficiency of new mothers. Another plant-based ingredient is 'gundruk' which is said to increase the efficiency of milk in lactating mothers, its soup is eaten as an appetizer that possesses high quantities of lactic acid, carotene, and ascorbic acid and exhibits anti-cancerous properties (Tamang *et al*. 2005) [16]. The fermentation process of bamboo shoots makes the resulting product a rich source of phenolic compounds such as tannins which have antioxidant, anti-aging, and anticancer effects on the body when consumed for a long period (Tamang and Tamang 2009a) [4]. In addition to this, plant-based fermented food and beverage products are exceedingly great contributors of indispensable amino acids, essential fatty acids, and an abundance of vital sources as minerals and vitamins which are compulsory for the development and growth of human health and proper metabolic functioning (Tamang and Tamang 2010) [2].

Conclusion

India is popularly known for producing a miscellany of tropical and traditional plant-based fermented foods and beverages utilizing an extensive variety of raw ingredients and microorganisms using distinctive methods of fermentation. Several kinds of research are propitious towards the viable fortuity for the use of these plant-based fermented products and attainable health benefits after the consumption. Upon reviewing the available data on plant-based fermented products we can draw the interference that they do not lack in any aspect of providing nutritional and therapeutic benefits, but they act as an incomparable source in delivering essential probiotics to the consumer. Many of the locally produced fermented foods and beverages consumed in India are alternate meal courses that help in delivering vital nutritional sources to meet daily dietary requirements along with treatment and prevention of several ailments. In recent years the awareness and curiosity about the quality, raw materials used, type, purpose, safety, and even health benefits of the product are rising among the consumers, especially among the newest generation of customers who always strive for justification for the food consumed and their health claims. It can now be stated that all types of plant-based products mainly, fermented foods and beverages, are on par with any alternative non-plant-based food products in every manner. This has led to the increased consumption of plant-based nourishment supply and has opened a gateway for the innovation of new products, there can be certain challenges in the production and processing of these products which can be easily resolved by incorporating traditional knowledge with the modern technological processes currently present in the country for the preparation and development of innovative products. India has boundless possibilities when it comes to the development and manufacturing of a wide range of fermented plant-based products, through apprehension of the food industry improvement in quality can be achieved, which can be useful for large-scale marketing and promotion of these plant-based fermented products.

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