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Functional probiotic fermented dairy foods for a healthy life-style – a review

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Surajit Sarkar,[1] Ananya Chakraborty,[2] Shreya Mallick,[3]

[1]Deputy General Manager (Production), Keventer Agro Limited, Barrackpore-Barasat Link Road, Subashnagar, P.O. Neelgunj Bazar, Kolkata-700121, West Bengal, India
[2]Food & Nutrition, Hooghly Women's College, Hooghly, West Bengal, India
[3]Nursing, College of Nursing, Calcutta National Medical College & Hospital, West Bengal, India

Correspondence: Surajit Sarkar, Deputy General Manager (Production), Keventer Agro Limited, Barrackpore-Barasat Link Road, Subashnagar, P.O. Neelgunj Bazar, Kolkata-700121, West Bengal, India Tel +91 124 4947200 (Company number)

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Abstract

Purpose: Health consciousness, increased interest in healthy foods, and rising medical costs have all contributed to the strong global trend of consumers favouring functional and nutritious foods. Prophylactic properties of traditional fermented dairy products can be enhanced with dietary interventions such as probiotics, prebiotics, synbiotics and postbiotics. Fermented dairy products are considered as a suitable matrix in comparison to non-fermented dairy products for probiotic carrier owing to its healthy image and protection of probiotic viability due to the milk protein. Retention of normal gut flora is of prime importance for good health as any disturbance in gut composition results in dysbiosis. The purpose of this paper was to review the functional properties of probiotics to project probiotic fermented dairy foods as a new dimension in the functional food market in the current era of self-care and complementary medicine.

Design/methodology/approach: An attempt was made to search the literature (review and researched papers) to highlight the beneficial features of probiotics and their suitability during the formulation of fermented dairy functional foods. Key factors for successful application of probiotics during functional food formulation was also considered. Keywords used for data searched included dairy-based functional foods, probiotic functional foods, factors affecting probiotic viability and health benefits of probiotic containing fermented milk functional foods.

Findings: Functional dairy products, formulated with the inclusion of probiotic are efficacious in alleviating diverse diseases like diabetes, lactose-intolerance, obesity, non-alcoholic fatty liver disease, immune function, necrotizing enterocolitis, Respiratory tract infections, high cholesterol levels, diarrhoea, inflammation, irritable bowel syndrome, osteoporosis, halitosis, colonic cancer etc. For success of probiotic fermented dairy foods, appropriate selection of probiotic strains, dairy food matrix and processing technologies are of prime importance. Systematic clinical trials must be performed prior to its application as functional foods.

Originality/value: Functional probiotic fermented dairy foods may attract food manufacturers to cater health-conscious consumers in the current era of self-care and complementary medicine.

Keywords: probiotics, gut flora, health benefits, functional foods, fermented dairy foods

Introduction

Fermentation is known as the oldest method of preservation. Fermentation of milk under the influence of beneficial microorganisms results in formulation of diverse range of fermented dairy products like yoghurt (Indian *dahi*), acidophilus milk, bifidus milk, kefir, kumiss etc. Fermented dairy products are superior to un-fermented dairy products in terms of their nutritional and therapeutic profiles. Globally, consumer's inclination towards functional foods is noticed due to their greater health consciousness coupled with enhanced health-care cost, especially in ageing populations due to heart disease, cancer, diabetes[1] or to combat with the severe side effects of drugs and pharmaceuticals.[2] According to Functional Food Center, functional food may be defined as natural or a processed food that contains known or unknown biologically active compounds, the foods, in defined, effective and non-toxic amounts, provide a clinically proven and documented health benefit for the prevention, management or treatment of chronic disease.[3] Later, Granato et al.,[4] defined "functional foods" as industrially processed or natural foods that when regularly consumed within a diverse diet at efficacious levels have potentially positive effects on health beyond basic nutrition. It has been declared that for consideration of any fresh, unprocessed or processed food as functional, its efficacy should be confirmed by randomized, double-blind, placebo-controlled clinical trials[5] and supported by substantial experimental evidence of safety.[4]

Consumer demand, societal attitudes,[1] scientific proof of the health benefits of a specific ingredient for humans,[2] and commercial interest in enhancing the value of current foods6 could all contribute to the widespread acceptance of functional foods. Intense consumer inclination towards much healthier foods and innovative fermented milk products containing probiotic organisms[7] coupled with documented health benefits of probiotics have led to an aggravated interest in probiotics as functional foods in the current era of self-care and complementary medicine.[8,9,10] Proficiency of probiotics to promote a healthier gut microbiome has led to projection of probiotic foods as functional foods for improvement of human health,[11] that basically provide health benefits in addition to their fundamental nutrients.[12,13] The global market for functional food is booming and is expected to get projected from \$281.14 billion to \$529.66 billion from 2021 to 2028, with a Compounded Annual Growth Rate (CAGR) of 9.5%[14] whereas for probiotics products, it is expected to get projected from \$48.88 billion to \$94.48 billion from 2019 to 2027, with a CAGR of 7.9%.[15] Probiotics are "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host"[16] and health benefits extended by probiotic dairy food have been reviewe.[17] Fermented milk products may be considered as most suitable food matrix for functional food formulation due to its healthy image[18,19] and capability of milk proteins to confer protection to the probiotic bacteria during passage through the stomach.[20] Ecological balance in GIT can be maintained by dietary interventions such as probiotic, probiotics, synbiotics and postbiotics and their supplementation results in diverse functional foods.[11] In the present review, potentiality of probiotic dairy foods as functional food and their limitations have been highlighted.

Significance of gut flora

At birth the intestinal flora of human is sterile and undergoes significant developments during the first three years of life.[21–24] Microbiome diversity at different stages during the first 1000 days of life has been shown in (Table 1).

Table 1 Microbiome diversity at different stages during the first 1000 days of life.[25]

Neonatal (First 4 Weeks of Life)		Early infancy (1-6 Months)		Mid infancy (6-12 Months)	Late infancy to early toddlerhood (12-24 Months)	Toddlerhood (Around 2-3 Years)
Vaginal	Cesarean	Dominant in Exclusively Breast-fed infants	More common in formula-fed infants	Shifts due to solid food introduction	Continued Diverfication	Resembling Adult Microbiome
Bifidobacterium	Klebsiella	B. infanti,	Collinsella	Bacteroides	Bacteroides,	Bacteroides
Bacteroides	Clostridia	B. breve	Enterococcus	Faecalibacterium	Faecalibacterium	Faecalibacterium
Parabacteroides	Enterobacter	B. Bifidum	Escherichia	Blautia,	Lachnospiraceae	Lachnospiraceae
Lactobacillus	Streptococcus,	B. longum Bacteroides	Clostridia	Roseburia,		
Collinsella	Staphylococcus			Anaerostipes		
Escherichia						

Development of the intestinal microbiota of infants is influenced by the mode (vaginal or cesarean) of delivery,[26,27] feeding (breast milk or formula) practices,[28–30] gestational,[31–33] maternal microbiome,[34,35] maternal diet,[36,39] antibiotic exposure,[29,40] diseases and therapies used[41] and lifestyle.[42,43]

It has been established that human microbiota is linked with health and disease[44] and the individual bacterial species of the gut microbiota is positively correlated with an overall health[45] by development and adaptation with the host,[46] thus maintaining the immune homeostasis and host energy metabolism.[47] Key factors of intestinal microbial flora towards positive health effects may be attributed to the production of different nutrients, prevention of pathogenesis of intestinal mucosa, protection of epithelial cells barriers and metabolism of the body.[48] Any imbalances in gastro-intestinal (GI) microbiota have been referred as dysbiosis, which results in several health problems such as allergies, obesity, diabetes,[49] cardiovascular diseases and tumour development.[44] Ormazabal et al.,[50] noticed a significant abatement in metabolic diseases resulting from changes in dietary habits, sedentary lifestyles, and rising obesity rates. Additionally, a gradual decline in the proportion of beneficial bacteria in the intestine was also encountered with the age resulting in physiological disturbances, malfunctions of the immune system and several metabolic disorders.[51] Ecological balance in GIT can be maintained by dietary interventions with the inclusion of probiotic dairy products as functional foods.

Concept of probiotics as a functional food

Recent trend of consumers towards healthful foods due to increased awareness and knowledge[52] has led to the development of functional dairy products that basically provide health benefits in addition to their fundamental nutrients.[12] Functional foods have been defined by various agencies and there is no globally recognized definition. The Academy of Nutrition and Dietetics recognized that although all foods provide some level of physiological function and defined functional foods as whole foods along with fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis at effective levels based on significant standards of evidence.[53] Definition of Functional foods has also been modified by different scientists or organizations and are chronologically presented in (Table 2).

Table 2 Chronological presentation of definitions of Functional Foods

Year	Definition of functional foods	Reference
1994	Any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains.	IOM/NAS.,[54]
1999	Foods that, by virtue of the presence of physiologically-active components, provide a health benefit beyond basic nutrition.	ILSI[55]
1999	Whole, fortified, enriched, or enhanced, but, more importantly, states that such foods must be consumed as a part of a varied diet on a regular basis, at effective levels.	ADA (1999)
1999	A food can be regarded as functional if it satisfactorily demonstrated the beneficial effects for one or more target functions in the body, beyond adequate nutritional effects in such a way which is relevant to either the state of well-being and health or reduction in disease risk.	Diplock et al.,[56]

Table 2 Continued...

2000	Functional foods are those providing health benefits beyond basic nutrition and include whole, fortified, enriched or enhanced foods which have a potentially beneficial effects on the health, when consumed as part of a varied diet on a regular basis at efficacious levels.	Hasler.,[57]
2000	A food or beverage that imparts a physiological benefit that enhances overall health, helps prevent or treat a disease/condition, or improves physical or mental performance via an added functional ingredient, processing modification, or biotechnology.	Sloan.,[58]
2001	The term "functional food" was coined in Japan in late 1980s and includes foods that have been fortified with ingredients capable of manifesting health benefits.	Stanton et al.,[59]
2002	Nutrients that are separated from their established nutritional functions and some of these nutrients are proposed to promote GI mucosal integrity.	Duggan et al.,[60]
2004	Functional foods as similar in appearance to a conventional food, consumed as part of the usual diet, with demonstrated physiological benefits, and/or to reduce the risk of chronic disease beyond basic nutritional functions.	Health Canada.[61]
2005	Functional food refers to foods or ingredients of foods providing an additional physiological benefit beyond their basic nutritional needs.	Riezzo et al.,[62]
2013	Whole foods along with fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis at effective levels.	Crowe and Francis.,[53]
2015	Natural or a processed food that contains known or unknown biologically active compounds, the foods, in defined, effective and non-toxic amounts, provide a clinically proven and documented health benefit for the prevention, management or treatment of chronic disease	Martirosyan and Singh.,[3]
2020	Industrially processed or natural foods that when regularly consumed within a diverse diet at efficacious levels have potentially positive effects on health beyond basic nutrition.	Granato et al.,[4]

Source: Author's own creation

Globally, intensified inclination of consumers towards much healthier foods or innovative fermented milk products containing probiotic organisms have mushroomed the market for functional foods. Functional properties of probiotics have projected them as a new ingredient in functional food market in the current era of self-care and complementary medicine. Probiotics have always been a vital component and commercial target for providing potential health benefits.[63,64] "Probiotics" is derived from Greek and means "pro-life". Definition of probiotics has also been modified by different scientists are chronologically presented in (Table 3).

Table 3 Chronological presentation of definitions of Probiotics.

Year	Definition of Probiotics	Reference
1965	Substances secreted by one microorganism which stimulates the growth of another.	Lilly and Stillwell.,[65]
1974	Organisms and substances, which contribute to intestinal microbial balance.	Parker.,[66]
1989	A live microbial feed supplement, which beneficially affects the host animal by improving its intestinal microbial balance.	Fuller.,[67]
1992	A viable mono-or mixed culture of microorganisms which applied to animal or man, beneficially affects the host by improving the properties of the indigenous microflora.	Havenaar and Huis in'tVeld.,[68]
1996	A live microbial culture or cultured dairy product, which beneficially influences the health and nutrition of the host	Salminen.,[69]
1996	Oral probiotics are living microorganisms which upon ingestion in certain numbers exert health effects beyond inherent basic nutrition.	Schaafsma.,[70]
2001	A preparation of or a product containing viable, defined microorganisms in sufficient numbers, which alter the microflora (by implantation or colonization) in a compartment of the host and by that exert beneficial health effects in this host.	Schrezenmeir and de Vrese.,[71]
2001	Live microorganisms which when administered in adequate amounts confer a health benefit on the host.	FAO/WHO.,[72]
2003	Living microorganisms in foodstuffs which when ingested at certain levels provide equilibrium of the intestinal flora thus exhibiting a positive effect of consumer's health.	Tomasik and Tomasik.,[73]
2006	Living microorganisms, which upon ingestion in certain numbers have beneficial effects on human health beyond inherent general nutrition.	Dinkci et al.,[74]
2006	Live microbial food ingredient that, when ingested in sufficient quantities, exert health benefits on the consumer.	Donor and Gorbach.,[75]
2014	Live strains of strictly selected microorganisms which, when administered in adequate amounts, confer a health benefit on the host.	Hill et al.,[16]

Source: Author's own creation

It has been established that probiotic-based functional foods should provide 10^6 cfu/g live microorganisms[76,77] for exhibiting clinical effects and multispecies probiotics are more efficacious than single species preparations.[78,79] Therefore viability of probiotic cultures is the critical factor for exhibiting health benefits, which is governed by diverse factors such as food matrix, processing and storage conditions as well as stability during gastric transit. Lower viability of probiotics in dairy products have been reported due to the concentration of lactic acid acetic acid, hydrogen peroxide, oxygen content,[80] low pH, storage temperature[81] and osmotic stress.[82,83]

Selection of probiotics

Four categories can be used to categorise the selection criteria for probiotic strains used in food or nutraceutical applications: technological, safety, functional, and physiological properties.[84–87] Probiotics are Generally Recognized as Safe (GRAS) but safety and effectiveness of a probiotic stain must be evaluated for the following factors prior to its application as probiotics:

Probiotic strains should be non-pathogenic, non-immunogenic nature, resistance to antibiotic-resistant, prolonged stability in the gastrointestinal tract, during production, processing and preservation[88,89]

1) Identification by genus, species and strain[90]
2) Ability to adhere to the intestinal epithelial cells
3) Ability to produce antimicrobial compounds
4) Ability to inhibit the known gut pathogens[91,92]
5) Sufficiently characterized
6) Safe for the intended use
7) Supported by at least one positive human clinical trial
8) Alive in the product at an efficacious dose throughout the shelf life[16]
9) Incorporating with Probiotic strains must be accurately characterized to ensure identification, purity, and viability[93]
10) Capability to inactivate enzymes (nitrate reductase, β-glucosidase, β-glucuronidase) involved in carcinogen activation[94]
11) Capability to secrete conjugated linoleic acid for exhibiting anti-carcinogenic activity[95]
12) Should have clinically documented and validated health effects[96]

Health benefits of functional probiotic fermented dairy foods

The gut microbiota is the largest population of bacteria that changes and adapts with the host, greatly influencing human health and diseases.[46] Pathogenesis is caused by an imbalance in the gut microbiota, compromised gut integrity, bacterial invasion, and weakened immunity.[97] Positive impact of gut microbiota on human metabolic health has been extensively documented[38,98] and colonization of the gut with beneficial microbes are able to ameliorate the overall health of humans by restructuring the gut microbial balance.[99] Reviewed literature indicated that probiotics are linked with diverse health benefits.[100–103] and prophylactic properties of fermented milk products can be enhanced with the inclusion of probiotic organisms in conjugation of normal starter cultures and recommended application of probiotics as a pharmaceutical agent.[8,9] Maftei et al.,[102] delineated that diverse probiotic organisms extend wide spectrum of health benefits including diarrhea, inflammatory bowel disease, cancer, cholesterol, anti-inflammatory, diabetic, urinary tract Infections, irritable bowel disease, gingivitis, anti-inflammatory, anti-mutagenic effects, ulcerative colitis etc. Health benefits of functional probiotic milk products are enumerated in Table 4.

Table 4 Health benefits of functional probiotic fermented dairy foods

Ailments	Probiotic Organisms	References
Diabetes	Lactobacillus acidophilus La5, Bifidobacterium lactis Bb12	Ejtahed et al.[104]
	Lactobacillus casei 2 W, Lactobacillus rhamnosus 27	Chen et al.[105]
	Lactobacillus plantarum, Lactobacillus fermentum, Lactobacillus casei	Panwar et al.[106]
Lactose-intolerance	Lactobacillus delbrueckii subsp. bulgaricus, Streptococcus thermophilus	Shah et al.[107]
Anti Obesity	B. pseudocatenulatum SPM 1204, B. longum SPM 1205, B. longum SPM 1207	An et al.[108]
	Lactobacillus gasseri SBT 2055, Lactobacillus rhamnosus ATCC 53103, L. rhamnosus ATCC 53102, Bifidobacterium lactis Bb12	Mekkes et al.[109]
	Lactobacillus plantarum, Lactobacillus gasseri	Million et al.[110]
Normalization of gut flora	Bifidobacterium animalis subsp lactis Bb-12	Merenstein et al.[111]
	L. rhamnosus GG, L. reuteri 17938, VSL #3, Bifidobacteria species	Larroya-García et al.[112]
Non-alcoholic fatty liver disease	Lactobacillus acidophilus La5, Bifidobacterium lactis Bb12	Nabavi et al.[113]
Immune function	Lactobacillus rhamnosus GR-1	Irvine et al.[114]
Necrotizing Enterocolitis	Lactobacillus casei, Bifidobacterium breve	Braga et al.[115]
	Bifidobacterium infantis, Streptococcus thermophilus, Bifidobacterium lactis	Jacobs et al.[116]
	Bifidobacterium infantis, Lactobacillus, Bifidobacterium lactis	Roy et al.[117]
	Lactobacillus reuteri	Shadkam et al.[118]
	Bifidobacterium breve, Streptococcus, L. rhamnosus GG, Lactobacillus acidophilus, Lactobacillus reuteri DSM 17938	Cruchet et al.[119]
	Lactobacillus acidophilus, Bifidobacterium spp.	Denkel et al.[120]
Respiratory tract infections	Bifidobacterium lactis Bb12	Kabeerdoss et al.[121]
	Lactobacillus acidophilus SPP, Bifidobacterium bifidum	Salarkia et al.[122]
Cholesterol	Lactobacillus acidophilus La5, Bifidobacterium lactis Bb12	Ejtahed et al.[114]
Diarrhoea	Lactobacillus acidophilus LA-5, Bifidobacterium lactis Bb-12	Holzwarth et al.[123]
	Streptococcus thermophilus	Tims et al.[124]

Table 4 Continued...

Anti-inflammatory	Limosilactobacillus reuteri	Howarth and Wang,[97]
Irritable Bowel Syndrome	Escherichia coli Nissle 1917	Kruis et al.[125]
Osteoporosis	L. reuteri	Yu et al.[126]
Halitosis	Streptococcus salivarius K12	Bustamante et al.[127]; Shringeri et al.[128]
Colonic Cancer	Escherichia coli K-12, Lactobacillus rhamnosus, Bifidobacterium latis	Altonsy et al.[129]

Source: Author's own creation

Avadhani[130] classified available evidence for health benefits conferred by probiotics into three groups:

1) Level A recommendation is based on strong, positive, well-conducted controlled studies in the primary literature, which are not in abstract form.

2) Level B recommendation is based on positive controlled studies, but in the presence of some negative studies.

3) Level C recommendation is based on some positive studies, but clearly an inadequate amount of data to establish the certainty of Levels A or B recommendation.

All probiotic cultures are not capable of alleviating all disease and are dependent on diverse factors such as stains of probiotic cultures, gastrointestinal physiological status, endogenous gut environment, gut microbiota prior to probiotic intervention, dosages and intervention period.[44] International Scientific Association for Probiotics and Prebiotics (ISAPP) have extended following recommendations to arrive upon a consistent health benefits due to probiotic supplementation.[131]

a) Clearly define the end goal

b) Design the study

c) Base the selection of the intervention on scientific investigations

d) Carefully select the study cohort

Mechanisms of probiotic action

It has been established that probiotic cultures employed for the formulation of functional dairy foods exert diverse health benefits through a combination of different mechanisms as depicted below.

1) Competitive exclusion of pathogens for adhesion sites, improvement of the intestinal mucosal barrier, gut immunomodulation, and neurotransmitter synthesis[101,132]

2) Bile salt deconjugation and secretion

3) Lactose hydrolysis

4) Reduction in toxigenic and mutagenic reactions in gut[133]

5) Competing with pathogens for nutrients and receptor-binding sites[134]

6) Production of anti-microbial agents[135,136]

7) Regulation of the expression of tight junction proteins and the immune response[137,138]

8) Production of anti-inflammatory cytokines while interacting with intestinal epithelial cells and attracting macrophages and mononuclear cells[139]

Limitations of probiotic application

1) All probiotic strains are not equally efficacious towards all human diseases and are also strain specific. Million et al.[110] declared that administration of *Lactobacillus plantarum* and *Lactobacillus gasseri* resulted in weight loss whereas *Lactobacillus acidophilus*, *Lactobacillus fermentum*, *Lactobacillus reuteri* and *Lactobacillus ingluviei* resulted in a significant weight gain.

2) All probiotic cultures may not have similar biotechnological activities and retain its viability in a particular food matrix.[140,141] Therefore, selection of a suitable food system to deliver probiotics is a vital factor[142] and retention of viability and sensory characteristics are the major criteria for the success of these products in the market.[143]

3) Adverse effect of probiotic administration has been reported in critically ill patients.[144]

4) Probiotics may not be equally efficacious for all individuals due to variation in the gastrointestinal physiological status, endogenous gut environment, gut microbiota prior to probiotic intervention, dosages and intervention period.[44]

5) Viability of probiotic cultures in considerable number is required for exhibiting health benefits. It has been reported that the "minimum therapeutic" level of probiotics should be 10^6 cfu/g throughout the product shelf-life[145] and must be ingested daily at a level of 10^8-10^9 cfu/ml for conferring health effects.[146]

6) Health benefits extended by probiotics are disease-specific[147] and dependent on the host's innate immune system.[148,149]

Conclusion

Functional fermented dairy foods formulated with the inclusion of probiotic cultures is an attracting functional food for consumers, who are inclined towards healthful foods. Efficacy of functional fermented dairy foods towards health restoration will primarily depend on the strain of probiotic cultures employed, processing technology, product matrix, viability of probiotics, gastrointestinal physiological status, endogenous gut environment, gut microbiota prior to probiotic intervention, dosages and intervention period. Clinical trials are suggested prior to the consideration of functional fermented dairy foods as dietary adjunct.

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Conflicts of interest

No potential conflict of interest was reported by the author.

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