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Perspectives

Fermented Vegetables as a Potential Treatment for Irritable Bowel Syndrome

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A B S T R A C T

Foods and supplements containing microorganisms with expected beneficial effects are increasingly investigated and utilized in the treatment of human illness, including irritable bowel syndrome (IBS). Research points to a prominent role of gut dysbiosis in the multiple aberrations in gastrointestinal function, immune balance, and mental health seen in IBS. The proposition of the current Perspective is that fermented vegetable foods, in combination with a healthy and stable diet, may be particularly useful for addressing these disturbances. This is based on the recognition that plants and their associated microorganisms have contributed to shaping human microbiota and adaptation over evolutionary time. In particular, lactic acid bacteria with immunomodulatory, antipathogenic, and digestive properties are prevalent in products such as sauerkraut and kimchi. Additionally, by adjusting the salt content and fermentation time, products with a microbial and therapeutic potential beyond that of regular ferments could potentially be produced. Although more clinical data are required to make firm assertions, the low-risk profile, combined with biological considerations and reasoning and considerable circumstantial and anecdotal evidence, indicate that fermented vegetables are worthy of consideration by health professionals and patients dealing with IBS-related issues. To maximize microbial diversity and limit the risk of adverse effects, small doses of multiple products, containing different combinations of traditionally fermented vegetables and/or fruits, is suggested for experimental research and care.

Keywords: fermented food, probiotics, irritable bowel syndrome, IBS, sauerkraut, kimchi, microbiome, gut health

Introduction

Irritable bowel syndrome (IBS) is a common disorder, affecting approximately 10% of the human population globally, with significantly higher prevalence rates reported in some regions and population groups [1]. It is an umbrella term, covering a variety of intestinal complaints, including flatulence, irregular bowel movements, recurrent diarrhea, and constipation. A distinction is made between IBS predominantly involving diarrhea, constipation, or a mixture of both. The Rome criteria, which define IBS on the basis of the nature and duration of symptoms, are frequently used in clinical settings [2]. Typically, diagnosis is set after exclusion of gastrointestinal diseases, such as celiac disease and inflammatory bowel disease, which involve many of the same symptoms as IBS.

The gut is the largest interface between the body and the external environment, home to complex microbial communities and an abundance of immune cells [3,4]. In addition to nutrients, it is a source of neurotransmitters (e.g., serotonin), toxins, and hormones, which may enter systemic circulation and affect distant organs (e.g., the brain) [5–10]. This picture has prompted an increasing awareness of the gut as a cornerstone of health and implies that any distortions in this area can have widespread adverse effects. Additionally, recurrent, chronic gastrointestinal distress incurs a psychological burden. In line with this, inflammation, depressive symptoms, anxiety, and reduced quality of life have been reported in IBS [11–13]. In combination with the frequency at which persistent gastrointestinal issues occur in the population and are encountered by clinicians, this highlights the need for effective treatment strategies.

Abbreviations used: IBS, irritable bowel syndrome; LAB, lactic acid bacteria.

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At present, patients presenting symptoms of IBS may not be offered any treatment beyond general advice on stress management and meal scheduling, as there is a scarcity of established, effective treatment procedures. Certain medications can aid in the management of gastrointestinal distress, but no drug effectively treats or cures IBS. Diet is significant; however, there is a lack of nutrition training in medical schools [14,15], and a majority of physicians report not feeling confident in providing dietary advice to their patients [15]. Dieticians and nutritionists frequently prescribe the low-FODMAP (-fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) diet for IBS [16]. While having proved effective at alleviating symptoms in many patients [17], the diet involves major restrictions that can be difficult and cumbersome to follow, particularly in the long run. Furthermore, it centers on the removal of substances (dietary fibers) that cause discomfort in IBS, but that are required for the growth of beneficial bacteria and the maintenance of a diverse and rich gastrointestinal biota [18,19]. Hence, it is by no means a perfect solution. Another approach involves supplying bacteria, such as in the form of fecal microbiota transplantation or probiotic supplements. As a source of potentially beneficial bacteria, fermented foods can also be utilized.

To date, the applicability of fermented vegetable foods has received little scientific attention. The argument and proposition offered here is that such products hold particular medicinal promise. To limit the scope of the discussion, the primary focus is on IBS; however, other gut-related disorders are also relevant. The notion of a therapeutic potential is rooted in 3 interconnected lines of evidence and reasoning.

A Savory Opportunity: Evidence and Reasoning

Gut dysbiosis is a characteristic and pathogenetic central feature of IBS

Gut dysbiosis has been documented and implicated in a variety of diseases [20,21]. In IBS, a number of studies have found altered fecal microbiota compared with controls [22–25]. The differences are heterogenous; however, decreased levels of certain beneficial genera, as well as increased abundance of pathobionts, have been repeatedly reported [22,25]. In a recent systematic review and meta-analysis of case–control studies, including a total of 1340 participants from North America, Europe, and Asia, *Lactobacillus*, the dominant bacterial genus in lacto-fermented food, was lower in both diarrhea-predominant and constipation-predominant IBS compared with controls [22]. However, this finding is not consistent across all studies. As discussed by Agnello et al. [26], this may be due to interstrain variation in effects on host immunity and health and increased intake of lactobacilli in the form of probiotics by some patients with IBS. The effect of particular strains of bacteria may further depend on the overall microbial community structure of the ingested product and intestine.

Although different factors can cause and contribute to IBS, there is increasing evidence for a predominant microbial pathogenesis [25,27]. Multicellular organisms, including humans, have always lived in the presence of microorganisms and have therefore been dependent on evolving systems and mechanisms for sensing and appropriately reacting to microbial stimuli. Certain bacteria are beneficial as a result of coevolutionary processes [28,29], and hence, should be tolerated, whereas others are noxious and should be evicted. One method of expulsion is diarrhea. This is well recognized in cases of acute gastrointestinal infection and distress; however, it is underappreciated as a bodily defense mechanism in more chronic states, such as IBS. Diarrhea may here represent a reaction to chronic infection or a pathogenic microbiota. In both cases, improving gut microbiota composition would be expected to bring relief. The link between pathogens and chronic diarrhea is clearly evident in postinfectious IBS, where bacteria, such as pathogenic *Escherichia coli*, *Shigella*, *Salmonella*, or *Campylobacter jejuni,* cause gastrointestinal discomfort and diarrhea that does not resolve [30–32], plausibly due to a lingering of the relevant organisms and/or a disruption of the gut ecosystem.

In cases of constipation, increasing dietary fiber intake is frequently recommended to improve stool consistency and colonic transit time; however, the success of such a measure would be expected to be dependent on microbiota composition, as a diversity of bacteria are required to digest the diversity of nonstarch polysaccharides and oligosaccharides that constitute dietary fibers [33]. A recent analysis of data from the American Gut Project revealed decreased gut microbiota richness and evenness in participants with constipation ($N = 262$) compared with controls ($N = 262$) [23].

The gut dysbiosis in IBS helps explain the intolerance to indigestible (to the human host) carbohydrates that are frequently seen in this condition. Humans are dependent on an arsenal of microbially produced enzymes to digest the variety of dietary fibers in plant foods, as this enzymatic capability is absent from the human genome. From an evolutionary point of view, it makes sense to allocate certain digestive functions to bacteria, which are both highly adaptive and genetically diverse. However, it does carry the risk of dysfunction if the required microbial elements are removed or thrown into disarray. In contemporary societies, a number of factors are problematic in this regard, including, but not limited to, highly processed foods, antibiotics, cesarean section, infant formula feeding, and a disconnect from nature and natural biodiversity [34–41]. Instead of removing dietary substances that have long been a part of the human diet, Darwinian reasoning suggests addressing the gut dysbiosis that is present in IBS and seeking to reconstitute and maintain a microbiota that is capable of digesting otherwise indigestible dietary components. In addition to having a healthy and somewhat stable diet, this would entail providing any missing microbial elements.

Fermented vegetables contain a diversity of bacteria with digestive, antipathogenic, and immunomodulatory properties

Plants harbor diverse microorganisms [42]. The quantity and types present on vegetable foods depend on several factors, including the production method (e.g., organic versus conventional), soil composition, and handling [42–46]. In the case of traditionally fermented vegetables, bacteria that are naturally present on the surfaces of the vegetables serve as the starter culture for the fermentation process. Covered in brine that produces an anaerobic environment, bacteria utilize and convert plant carbohydrates into lactic acid [47]. Other compounds, such as carbon dioxide, acetic acid, and bioactive substances, are also produced [47,48]. There is a stark increase in microbial cells, particularly during the initial phase of fermentation, and the ecosystem changes over time, with different species dominating at different stages [47,49]. The exact microbial profile will depend on the types and source of the vegetables, amount of salt that is used, and the fermentation time, container, and temperature [47,49–51]. Additionally, other foods, such as fruits or berries, may be added to the mix and affect the microbial nature of the product.

In commercial sauerkraut and kimchi ferments, a diversity of species of lactic acid bacteria (LAB) has been documented, including *Lactobacillus plantarum, Lactobacillus brevis,* and *Lactobacillus sakei* [47,52,53]. Previous reviews have highlighted that these organisms can support general and gastrointestinal health by providing immunomodulatory signals, aiding digestive processes, generating bioactive compounds (e.g., isothiocyanates), and suppressing pathogens via their production of acids and bacteriocins [48,53–55]. In particular, their antipathogenic properties are of relevance to IBS, considering the overgrowth of pathogenic microbes that has been reported in this condition. Some bacterial isolates have been shown to exert antimicrobial activity against human pathogens, such as *Listeria monocytogenes*, *Escherichia coli O157*, and *Candida albicans* [55–58], highlighting the potential of fermented plant foods to serve as an alternative to antibiotics for combatting infections.

In deriving from an acidic environment, fermented vegetable bacteria would be expected to be fairly tolerative of the harsh environment of the stomach. In a simulated upper gastrointestinal digestion procedure, high microbial survival rates (72%) were reported for low-salt (0.6% and 1.5%) sauerkraut [59]. Simulated 24-hour colonic fermentation of digested sauerkraut samples using porcine feces revealed significant effects on the microbiota composition, including up to an 85-fold increase of *Megasphaera* [59]. Certain *Megasphaera* spp. have been shown to produce vitamins, SCFAs, and essential amino acids that could benefit human health [60,61]. Ingested food-associated bacteria may only be transiently present in the intestine; however, provided a suitable ecologic niche is available, colonization is possible. In harboring a natural and dynamic ecosystem, fermented vegetables differ from probiotic supplements, which often only contain a small number of bacterial species and are static and artificial in nature.

With respect to the dietary fiber intolerance commonly seen in cases of IBS, fermented vegetables can plausibly be produced in such a way as to provide significant quantities of microorganisms with fiber-digesting properties. During the fermentation process, it is primarily simple sugars that are broken down for energy by bacteria [47]; however, some digestion of plant fibers may be achieved. As an evolving ecosystem, there is a selection pressure for adaptation to and exploitation of the available nutritional substrates. Reduced salt content, coupled with longer fermentation time, is probably crucial. The degree to which degradation of plant fibers is achieved may be ascertained through an evaluation of the texture of the product, with a more "mush"-like consistency being indicative of fiber degradation.

In the production of fermented vegetables, salt helps draw water and sugars out of the vegetables and decrease the risk of yeast overgrowth, hazardous chemical formation, and spoilage [50,62]. Hence, a balance must be struck between decreasing salt and maintaining viability. In a 2020 study, Chinese northeast sauerkraut was successfully produced using 4 different salt concentrations (0.5%, 1.5%, 2.5%, and 3.5%, w/w) [50]. In a sensory analysis conducted by 15 trained panelists, the lower salt ferments (0.5% and 1.5%) scored significantly lower on crispness than the higher salt ferments [50]. Overall, the sample with 2.5% salt was given the most favorable sensory reviews. Differences in the microbial community and metabolite composition were reported in the different samples.

The prospect of creating fermented vegetables with a therapeutic potential beyond that of regular ferments appears an interesting and important avenue for "fermentistas" to explore. In practice, consuming a diversity of products, with different plant foods, salt concentrations, and duration of the fermentation process, appears the most reasonable way to maximize microbial and fiber diversity exposure. If one ferments at home, it is possible to take out and eat some of the product at different stages of the fermentation process, thereby increasing the diversity of microbial exposure.

The proposition that introducing bacteria with adaptations to a particular substrate can improve the digestion of the relevant substrate is supported by research showing that dairy LAB reduce symptoms of lactose intolerance [63–65]. Alteration of the colonic microbiota has been offered as an explanation for this effect [63]. Theoretically, healthy digestion would depend on possessing gut bacterial populations adapted to feeding and cross-feeding on the introduced compounds and that do not produce noxious substances. Particularly in cases of moderate-to-severe gut dysbiosis, this ability would be expected to be compromised. To grow and maintain the populations, feeding of the relevant substances would be required. This highlights the issue with the method of severely restricting dietary fiber.

Plants and their associated microorganisms have been a part of the human diet for millions of years

Darwinian thinking suggests that efforts aimed at increasing and improving microbial exposure should be focused on exposures that have been consistently present over significant evolutionary time, as those are the exposures to which the human biology is best adapted. Similar to how *Homo sapiens* have become dependent on a supply of vitamin C from food, certain microbial inputs are required for proper functioning and health [28,29,66]. One source of bacteria throughout evolution has been food. The diets of ancestral, naturally living humans varied depending on geographic location and climate; however, they generally contained significant quantities of plant matter [67–70]. In addition to providing vitamins, minerals, antioxidants, and other dietary substances, plant matter serves as a source of bacteria located in and on the roots and leaves [46,71,72]. Although accessing the natural environment involves a risk of pathogens and infections, it is also a source of beneficial bacteria. As stated by Leff and Fierer [43], "the consumption of raw produce may represent an important means by which new lineages of commensal bacteria are introduced into the human gastrointestinal system." A striking loss of microbiota diversity has been documented in urban, westernized populations compared with traditionally living groups [41,73,74]. The departure from eating wild, unwashed foods, with their natural microbial blanket intact, to eating industrially produced, "sterile" food would be expected to have contributed to this disappearance.

Extensive, controlled fermentation of food is a recent phenomenon, evolutionarily [75]. Human hunter–gatherer ancestors may in some instances and regions have consumed food that had undergone spontaneous fermentation; however, they did not have access to the abundance and variety of fermented products present in the market today. As compared with raw plants, fermented products contain significantly greater quantities of microorganisms [76], and in particular LAB, which are present in the phyllosphere and soil, but only at low abundance [71]. The salted, anaerobic environment of fermentation strongly favors LAB, which may reach concentrations of 10^8 to 10^9 CFU/g [52, 76]. This is not necessarily a positive, as high LAB intakes could destabilize the gut microbial community, for example, through the production of bacteriocins [77]. However, the markedly greater microbial abundance makes them more potent and suitable as therapeutic products. Furthermore, in fermented foods, LAB act as a preservative, by generating an acidic environment that is hostile to molds and toxigenic bacteria.

The microbial assemblages of plants vary depending on source and handling, with significant differences reported between conventional and organic produce [43,44]. This is an underappreciated factor in nutrition and health that should be investigated and considered in the fermentation of food, as it would be expected to affect the nutritional and microbial profile of the products.

An overview of the mechanisms by which fermented vegetable foods can be therapeutic in IBS is shown in Figure 1.

From Theory to Practice: Applications, Effects, and Risks

The 3 points presented in the previous section give a rationale and plausibility to the idea that fermented vegetables can aid in the treatment of IBS. The experiences of this author, who is clinically nutritionally trained and has been advising individuals with IBS, are that the theoretical basis and justification are matched by real-life benefits, with some individuals reporting marked or complete relief of IBS symptoms following the introduction of fermented vegetables into their diet. Although anecdotal and subject to individual perceptions, such reports, which may also be found in fermentation groups and communities online, do provide an additional impetus for considering and experimentally investigating fermented vegetables as a potential treatment for gastrointestinal discomforts.

To date, 2 published clinical trials have specifically investigated the effects of fermented vegetables in IBS. In a 2022 randomized, double-blind placebo-controlled trial published in *Food & Nutrition Research*, an intervention involving 3 types of kimchi was found to alleviate symptoms of IBS [78]. The study included 90 participants, who each consumed 210 g of kimchi a day for 12 wk. In another smaller trial, published in 2017, similar effects were seen for a sauerkraut intervention lasting 6 wk [79]. Other studies have reported beneficial effects of fermented foods on microbiota diversity, inflammation, and digestion [80,81]. Results on probiotic supplements show some heterogeneity; however, a number of trials in IBS have found beneficial effects of supplements containing LAB similar to those present in fermented vegetables [82,83]. Together with the theoretical basis, this research points to a therapeutic potential of fermented vegetables in IBS and related pathologies.

Nevertheless, the current research has significant limitations. Many of the studies that have been conducted on probiotic foods and supplements do not include a follow-up period or evaluation; hence, the long-term effects, if any, are not documented. Symptom alleviation during the intervention may not necessarily reflect a true improvement in the causal factors of the condition but could be a manifestation of a transient antipathogenic and immunomodulatory impact of the ingested bacteria. Additionally, neither the study on kimchi nor sauerkraut included a true control group that were not given any substance with a possible impact (this is more easily achieved in studies on probiotic supplements). This increases the uncertainty of the true benefits as it makes it difficult to distinguish real symptom improvements from potential placebo effects. Finally, and perhaps most importantly, studies on probiotic foods and supplements generally involve a single product, with a particular microbial make-up, provided continuously, in fairly large doses, for a set period of time. This is counter to the idea that diversity trumps uniformity, and it is not reflective of human evolutionary microbial experience. Furthermore, from an ecologic point of view, the infusion of significant quantities of a particular set of microbial strains (e.g., LAB) into a complex microbial community carries the risk of disturbing the community. This risk appears particularly evident in cases in which the community is of low diversity and unbalanced; and hence, less resilient to perturbation. Such perturbation may only be transient; however, with repeated exposure, the situation is more chronic in nature, and the risk of more lasting injury increases.

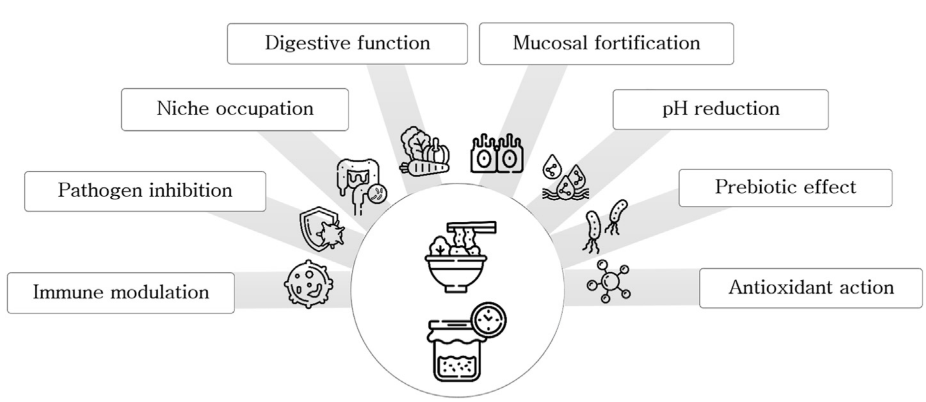

FIGURE 1. Potential beneficial effects of fermented vegetables in irritable bowel syndrome.

TABLE 1
Suggestions for experimental interventions and care

Variable	Application	Explanation
Amount	Low-to-moderate (e.g., 20–70 g total/d)	High doses may have adverse effects and are probably best reserved for special cases (e.g., as part of the initial treatment of severe gut dysbiosis)
Frequency	1–3 intakes per d, 4–7 d per wk	Consumption may be adjusted based on tolerance, treatment stage, and observed effects
Duration	2–8 wk (or longer)	The required duration will depend on IBS severity and treatment outcomes
Variation	High	A variety of products, made with different plant foods, salt concentration, and ferment time, is required to maximize fiber and microbial diversity
Salt	Restrictive usage (max. 2.5%)	High salt hinders microbial growth and diversity
Bacteria	Organisms that are naturally present on plants	Commercial starter cultures would be expected to produce a more generic and nonvaried microbiota
Additives	No	Artificial preservatives and additives are unnecessary and can affect the bacterial make-up of the product

IBS, irritable bowel syndrome.

Such considerations indicate that it is better to consume smaller quantities, of a diversity of fermented plant products, than larger amounts of a single type, at least if the intervention is to be continued for some duration. In addition to incurring a lower microbial and acidic load, this involves a lower risk of other potential adverse effects of fermented vegetable food consumption. This includes effects related to excess sodium, which is linked with hypertension, gut dysbiosis, autoimmunity, and CVD [84–88], and biogenic amines (e.g., histamines), which have received attention due to their potential for eliciting symptomatic reactions in some individuals [89–91]. It also suggests that clinicians, researchers, and patients should be focused on any lasting impacts the intervention may have, as opposed to acute effects on symptoms.

At present, it is premature to assert which cases will benefit the most from microbial interventions. However, the widespread significance of microbiota and gut dysbiosis in human health and disease points to broad applicability and potential. In general, fermented vegetables hold promise in cases with a documented or suspected gut microbial dysbiotic component. An outline of practical recommendations is provided in Table 1.

Summary

- IBS is a prevalent and sometimes debilitating disorder involving a variety of gastrointestinal issues, such as bloating, constipation, and irregular bowel movements. At present, there is a scarcity of established, effective treatment strategies for the condition.
- Probiotic foods and supplements are increasingly investigated and utilized in the treatment of human illness, including IBS. This frontier builds on the recognition that gut microbiota has widespread effects on digestion, immunity, and health, and that many health disorders, including IBS, are associated with an imbalanced gut microbial community.
- Fermented vegetables (possibly with the addition of fruit, berries, and/or other plant foods), made with the bacteria that are naturally present on the plants, may be particularly therapeutic. This suggestion is based on the recognition that fermented vegetable foods contain a natural ecosystem comprising multiple organisms with beneficial properties, and that plants and their associated bacteria have contributed to informing our coevolutionary development.
- To maximize biodiversity exposure and avoid undesirable effects, small doses of different types of fermented vegetables (made from different vegetable foods and of varying salt content and fermentation time) appear preferable. This represents a low-risk intervention that investigators, health professionals, and individuals dealing with IBS-related issues may want to explore.

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