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Review Article

The gut microbiome, obesity, diabetes mellitus, and Indian traditional foods for gut health

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Abstract

The human gastrointestinal (GI) tract hosts a complex microbial ecosystem, with approximately 1,000–1,150 bacterial species potentially colonizing it, and each individual harbouring around 160 distinct species. This gut microbiota plays a critical role in digestion, immune function, and metabolic health. Recent research has highlighted its influence on obesity, a global health challenge with increasing prevalence in India and worldwide. The gut microbiota is highly dynamic, responding to dietary changes within hours in both animals and humans. Beyond diet, the microbiota modulates host inflammatory responses and metabolic pathways, contributing to obesity and related metabolic disorders. This article explores the mechanisms by which gut microbiota influences obesity, focusing on inflammatory pathways, microbial metabolites, and intestinal permeability. Additionally, it examines Indian traditional foods rich in prebiotics and probiotics that can support gut health and potentially mitigate obesity.

Keywords: Microbiome, Gut health, Non-communicable disease, Diabetes mellitus, Inflammation, Indian traditional foods

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1. Introduction

The human gastrointestinal (GI) tract hosts a complex microbial ecosystem, comprising approximately 1,000–1,150 bacterial species, with each individual harbouring around 160 distinct species.[1] This gut microbiota plays a pivotal role in digestion, immune regulation, and metabolic homeostasis. The gut microbiota is highly dynamic, responding to dietary changes within hours in both animals and humans.[2,3] It also modulates host inflammatory responses and metabolic pathways, contributing to the pathogenesis of NCDs. In recent years, research has increasingly focused on the gut microbiota's influence on non-communicable diseases (NCDs), including obesity, diabetes mellitus, cardiovascular diseases, and certain cancers. In India, where NCDs account for over 60% of deaths [4], understanding the gut microbiome's role is critical, especially given the rising prevalence of obesity and type 2 diabetes mellitus (T2DM). This article explores the mechanisms by which the gut microbiota influences obesity and diabetes, with a broader discussion on NCDs, and highlights Indian regional traditional foods rich in prebiotics and probiotics that can support gut health and potentially mitigate these conditions.

2. The Gut Microbiome and Obesity

2.1. Inflammatory pathways and metabolic endotoxemia

The gut microbiota contributes to obesity through inflammatory mechanisms triggered by bacterial components, notably lipopolysaccharide (LPS), a cell wall component of Gram-negative bacteria. LPS activates innate immune responses via Toll-like receptor 4 (TLR4), leading to low-grade systemic inflammation known as metabolic endotoxemia.[5] This chronic inflammation promotes weight gain and insulin resistance.

A rodent study demonstrated that rats infused with low-dose LPS exhibited weight gain comparable to those fed a high-fat diet over four weeks.[5] Conversely, CD14-deficient rats, lacking a co-receptor for LPS signalling, showed no weight gain when exposed to LPS, highlighting the role of

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LPS-mediated inflammation.[6] Similarly, TLR4-deficient mice are protected from high-fat diet-induced obesity and insulin resistance, underscoring TLR4's critical role.[7]

2.2. Microbial metabolites: Short-chain fatty acids

Certain gut bacteria, such as *Eubacterium rectale*, *Clostridium coccoides*, and *Faecalibacterium prausnitzii*, produce short-chain fatty acids (SCFAs) like butyrate, acetate, and propionate.[8] Butyrate, in particular, serves as an energy source for colonocytes and exerts anti-inflammatory effects by inhibiting lymphocyte proliferation and the production of pro-inflammatory cytokines such as interleukin-2 (IL-2) and interferon-gamma (IFN-γ).[9] These properties make butyrate a potential therapeutic agent for inflammatory bowel disease (IBD) and obesity-related inflammation. Acetate and propionate also influence lipid metabolism and appetite regulation via G-protein-coupled receptors (GPCRs) like GPR41 and GPR43, potentially reducing fat accumulation.[10] Gut microbiota modifies primary bile acids into secondary bile acids. These act on receptors like FXR and TGR5, affecting- Lipid metabolism, Energy expenditure, Inflammation control. Dysbiosis alters bile acid pools and signalling, leading to metabolic disturbances. Loss of beneficial microbes (e.g., *Akkermansia muciniphila*) and overgrowth of pathogenic species weakens tight junctions, resulting in increased intestinal permeability, allowing: translocation of bacterial endotoxins (like LPS). Trimethylamine-N-oxide (TMAO)- Produced from choline and L-carnitine by gut microbes → linked to insulin resistance, obesity, and cardiovascular risk.

2.3. Modulation of host gene function and intestinal permeability

The gut microbiota influences host metabolism by modulating gene expression, notably the Fasting-Induced Adipose Factor (Fiaf), a glycoprotein that inhibits lipoprotein lipase (LPL) in adipose tissue and promotes fatty acid oxidation in adipocytes and skeletal muscle.[11] Obesogenic microbiota suppresses Fiaf expression, leading to increased LPL activity, enhanced fat storage, and adiposity.[11] Additionally, the microbiota affects intestinal barrier integrity by downregulating tight junction proteins such as zonula occludens-1 (ZO-1) and occluding.[6] This increases intestinal permeability, allowing LPS and other bacterial components to enter the bloodstream, exacerbating metabolic endotoxemia and systemic inflammation.[6]

2.4. Differences in gut microbiota composition

The gut microbiota of obese individuals differs significantly from that of lean individuals, characterized by a reduced abundance of butyrate-producing bacteria and an increased presence of pro-inflammatory taxa.[12] A higher Firmicutes-to-Bacteroidetes ratio has been observed in obese individuals, though this finding varies across populations.[13] This dysbiosis enhances energy harvest from the diet, promotes fat storage, and triggers inflammatory pathways, contributing to obesity and related metabolic dysfunction.

3. The Gut Microbiome and Diabetes Mellitus

Type 2 diabetes mellitus (T2DM), a major NCD, is closely linked to gut microbiota dysbiosis. The gut microbiome influences glucose homeostasis, insulin sensitivity, and inflammation, all of which are critical in T2DM pathogenesis. Dysbiosis in T2DM patients is characterized by reduced abundance of SCFA-producing bacteria and increased opportunistic pathogens.[13] SCFAs, particularly butyrate, enhance insulin sensitivity by promoting glucagon-like peptide-1 (GLP-1) secretion, which stimulates insulin release and inhibits glucagon.[15] Conversely, LPS-induced inflammation via TLR4 signalling impairs insulin signalling, contributing to insulin resistance.[5]

A landmark study found that T2DM patients have a lower abundance of *Roseburia* and *Faecalibacterium prausnitzii*, both butyrate producers, compared to healthy controls.[16] This reduction correlates with increased systemic inflammation and hyperglycemia. Moreover, gut microbiota dysbiosis alters bile acid metabolism, affecting farnesoid X receptor (FXR) and TGR5 signalling, which regulate glucose and lipid metabolism.[17] In India, where T2DM prevalence is projected to reach 134 million by 2045,[18] targeting the gut microbiome through diet offers a promising strategy. Resistant starch, a type of fiber that resists digestion in the small intestine, may offer benefits for managing diabetes, particularly type 2. It can improve insulin sensitivity, potentially lower post-meal blood glucose levels and contributing to better glycemic control.

4. Other Non-Communicable Diseases

The gut microbiome also influences other NCDs, including cardiovascular disease (CVD) and certain cancers. In CVD, microbial metabolites like trimethylamine N-oxide (TMAO), produced from dietary choline and carnitine, promote atherosclerosis by enhancing foam cell formation and platelet activation.[19] Dysbiosis is also linked to colorectal cancer, where reduced SCFA production and increased pro-inflammatory bacteria disrupt colonic epithelial integrity.[20] These findings underscore the gut microbiome's broad impact on NCDs, mediated through inflammation, metabolite production, and host gene regulation.

5. Clinical Implications

Modulating the microbiota using prebiotics, probiotics, dietary fiber, or faecal microbiota transplant (FMT) is a potential strategy to improve gut barrier function**,** reduce inflammation and regulate energy balance. Personalized microbiome-based interventions are an emerging frontier in obesity and diabetes mellitus prevention. To support and enhance gut health, it is beneficial to regularly include fermented foods in your daily meals. Incorporating curd or

buttermilk can significantly improve gut microbial diversity, while traditional items like kanji, lassi, and fermented rice-based foods such as idli and dosa contribute to microbial richness. Diversifying fiber sources is also essential—this can be achieved by including at least two types of legumes each day (for instance, moong and chana), opting for whole millets like bajra, jowar, and ragi instead of refined grains, and adding prebiotic-rich ingredients like raw onions, garlic, and green bananas to everyday dishes. Traditional Indian cooking methods, such as slow cooking, sprouting dals, and fermenting batters, enhance the availability of prebiotic fibers and improve digestibility and nutrition**.**

Indian regional traditional foods for gut health- Indian cuisine, diverse and rooted in ancient traditions, offers a wealth of foods rich in prebiotics and probiotics that can modulate the gut microbiome, supporting health and potentially mitigating obesity and T2DM. Below is an expanded exploration of regional Indian foods, categorized by their probiotic and prebiotic properties, with few examples from various regions.

6. Probiotic-Rich Indian Foods

Curd (Dahi): A staple across India, curd is a fermented dairy product rich in Lactobacillus and Bifidobacterium species. In North India, it is consumed as plain curd or lassi, a yogurt-based drink often flavored with cumin or mint. In South India, curd rice (thayir sadam) is a popular dish. Probiotics in curd enhance gut microbial diversity, reduce inflammation, and improve intestinal barrier function.[15]

Buttermilk (Chaas/Mor): Known as chaas in North India and mor in South India, this fermented beverage is made by diluting curd with water and adding spices like cumin, curry leaves, or asafoetida. It contains live probiotic cultures that aid digestion and support gut health. In Gujarat, chaas is a daily staple, often consumed with khichdi.

Idli and Dosa: These South Indian fermented rice and lentil dishes, popular in Tamil Nadu, Karnataka, and Andhra Pradesh, are prepared through natural fermentation involving Lactobacillus species. The fermentation process enhances probiotic content, which may improve gut microbial composition and reduce metabolic endotoxemia. In Kerala, appam, another fermented rice dish, offers similar benefits.[21]

Dhokla: A steamed, fermented dish from Gujarat made with chickpea flour (besan) and rice, dhokla is rich in probiotics due to its fermentation process. It is often served with green chutney, adding prebiotic-rich ingredients like coriander and garlic.

Kanji: A North Indian fermented drink, particularly popular in Punjab and Rajasthan, kanji is made from black carrots, mustard seeds, and water. The fermentation process introduces Lactobacillus species, making it a potent probiotic beverage that supports gut health.

Handvo: A savory cake from Gujarat made with fermented rice and lentil batter, handvo is rich in probiotics and often includes vegetables like bottle gourd, enhancing its prebiotic content. It is a nutrient-dense option for gut health.

Panta Bhat: A fermented rice dish from West Bengal and Odisha, panta bhat is prepared by soaking cooked rice in water overnight, allowing natural fermentation by Lactobacillus and other microbes. It is typically consumed with green chilies, onions, and salt, providing both probiotics and prebiotics.

Also find below a **Table 1** with brief description of few probiotic rich foods as consumed regionally in India.

Table 1: Probiotic-rich Indian foods

Food Item	Description & Probiotic Strains	Region Commonly Consumed	Notes
Curd/Dahi	*Lactobacillus*, *Bifidobacteria*	Pan-India	Homemade curd is ideal; avoid added sugars.
Buttermilk (Chaas)	Similar to curd; rich in cultures	Gujarat, Maharashtra, South India	Often seasoned with ginger, cumin – gut-soothing.
Lassi	Fermented yogurt-based drink	Punjab, Haryana	Sweet or salted; best when consumed fresh.
Kanji	Fermented black carrot drink	North India (esp. Punjab, UP)	Rich in *Lactobacilli*; consumed in winters.
Idli/Dosa batter	Naturally fermented rice-lentil batter	South India	Contains lactic acid bacteria; enhances nutrient bioavailability.
Pickles (Traditional)	Anaerobic lacto-fermentation (non-vinegar)	Pan-India (varies regionally)	Avoid commercial pickles with preservatives.
Handvo/Dhokla batter	Fermented gram and rice batter	Gujarat	Contains beneficial microbes' post-fermentation.

7. Prebiotic-Rich Indian Foods

1. Whole Grains (Millets, Brown Rice, Barley): Millets like ragi (finger millet), bajra (pearl millet), jowar (sorghum), and foxtail millet are staples in South India, Rajasthan, and Maharashtra. Rich in resistant starch and dietary fiber, they act as prebiotics, fueling butyrate-producing bacteria like *Faecalibacterium prausnitzii*. Brown rice, common in South and East India, similarly supports beneficial bacteria. In North India, barley (jau) is used in porridges and flatbreads, offering prebiotic benefits.
2. Lentils and Pulses: Indian dals, such as moong (green gram), urad (black gram), chana (chickpea), and masoor (red lentil), are rich in prebiotic fibers like galactooligosaccharides (GOS). These promote SCFA production and reduce gut inflammation. Regional dishes like Maharashtra's amti (spiced dal) and Punjab's dal makhani incorporate these pulses.
3. Vegetables: Onions, garlic, and green bananas are widely used across India. Onions, a key ingredient in North Indian gravies and South Indian sambar, contain inulin and fructooligosaccharides (FOS), which stimulate Bifidobacterium and Lactobacillus growth. Garlic, used in chutneys and curries, has similar prebiotic effects. Green bananas, used in dishes like Kerala's kachcha kela sabzi, are rich in resistant starch.
4. Spices and Herbs: Turmeric, a cornerstone of Indian cuisine, contains curcumin, which modulates gut microbiota and reduces inflammation. Fenugreek seeds, used in Tamil Nadu's sambar and North Indian parathas, contain galactomannan, a prebiotic fiber. Asafoetida (hing), common in Jain and South Indian cooking, supports gut health by promoting beneficial bacteria.
5. Root Vegetables and Tubers: Sweet potatoes (shakarkandi), used in North Indian fasting dishes, and yams (jimikand), common in South Indian curries, are rich in prebiotic fibers. In East India, taro root (arbi) is used in stews, providing resistant starch that supports gut microbiota.

Some more regionally used prebiotic foods-(**Table 2**)

Table 2: Prebiotic-Rich Indian Foods

Food Item	Prebiotic Compounds	Common Recipes/Use	Notes
Onions & Garlic	Inulin, fructooligosaccharides (FOS)	Curries, chutneys	Cooked or raw; foundational in Indian cuisine.
Raw Banana (Green Plantain)	Resistant starch	Thoran, stir-fries	South Indian dishes use this frequently.
Whole Grains (Ragi, Bajra, Jowar, Barley)	β-glucans, resistant starch	Rotis, porridges	Traditional staples across India.
Legumes (Chana, Rajma, Moong, Masoor)	Galacto-oligosaccharides (GOS), resistant starch	Curries, snacks	Soak well to reduce antinutrients.
Jackfruit (Raw)	Resistant starch, fiber	Kathal curry, stir-fries	Gaining popularity as a meat alternative.
Turmeric	Curcumin + polyphenols	Tadka, milk, tea	Supports gut integrity and anti-inflammatory pathways.
Moringa (Drumstick Leaves)	Fiber + polyphenols	South Indian dishes	Also, anti-inflammatory and antioxidant-rich.

8. Regional Dietary Patterns

1. North India: A meal of curd with bajra roti, chana dal, and onion-based sabzi combines probiotics and prebiotics. Kanji or lassi adds a probiotic boost.
2. South India: Idli or dosa with sambar (lentil and vegetable stew) and coconut chutney (with garlic) offers a synergistic mix of probiotics and prebiotics. Curd rice is a staple gut-friendly dish.
3. West India: Gujarat's dhokla or handvo paired with chaas and vegetable-based kadhi (yogurt curry) supports gut health. Maharashtra's amti with brown rice is another option.

4. East India: Panta bhat with mustard-based fish curry or aloo posto (poppy seed potato curry) incorporates probiotics and prebiotic-rich vegetables like onions.

Further find tabulated general regional dietary foods- (**Table 3**)

Table 3: Regional Dietary Patterns Supporting Gut Health

Region	Typical Gut-Friendly Foods	Probiotic/Prebiotic Role
South India	Idli, dosa, sambar, curd rice, buttermilk	Fermented batters, fiber from pulses/vegetables
North India	Paratha + curd, rajma-chawal, pickles	Fermented dairy, legumes, and raw onions
West India	Dhokla, handvo, thepla with pickles	Fermented grains, spices, fiber-rich chutneys
East India	Fermented rice (Pakhala Bhata), bamboo shoots, chura-curd	Traditional probiotic preparations
North-East	Fermented soybeans (Akhuni), fish, leafy greens	Rich in unique fermented foods and fiber

9. Practical Dietary Recommendations

To optimize gut microbiota and mitigate NCDs, Indian diets can incorporate regional foods strategically. A daily meal plan might include:

1. Breakfast: Fermented curd rice or Idli or dosa with sambar and coconut chutney, or panta bhat with green chilies and onions or overnight soaked rolled oats with chia seeds.
2. Lunch: Curd rice or dal makhani with brown rice, a side of vegetable sabzi (with onions and garlic), and a glass of buttermilk.
3. Snack: Kanji or lassi with roasted ragi porridge.
4. Dinner: Handvo or bajra roti with moong dal and a turmeric-spiced vegetable curry.

These combinations align with Indian culinary traditions, ensuring accessibility and cultural relevance. Regular consumption of fermented foods and prebiotic-rich ingredients can enhance SCFA production, reduce inflammation, and improve insulin sensitivity, addressing both obesity and T2DM.

The wise use of Indian herbs and spices—such as turmeric, cumin, ajwain, ginger, and fennel—not only supports digestion but also reduces inflammation, especially when combined with healthy fats like ghee to boost the absorption of beneficial polyphenols. It is equally important to limit disruptors of gut health by avoiding excessive sugar, fried snacks, preservative-laden pickles, unnecessary antibiotics, and ultra-processed foods, all of which can harm the gut microbiota balance. Eating seasonally and locally strengthens the gut through the intake of fresh, traditional produce such as jamun in the summer and amla in the winter, which are naturally rich in polyphenols and prebiotic fibres. Practicing mindful meal timing—such as avoiding late-night eating, allowing for an overnight fasting window of 12 to 14 hours, and spacing out meals—can promote healthy gut motility and microbial rhythms. Lastly, staying well-hydrated with clean water and herbal infusions like jeera or ajwain water, along with regular physical activity including yoga or walking, further enhances gut health by supporting digestion, improving motility, and reducing visceral fat.

10. Conclusion

The gut microbiome significantly influences obesity and NCDs, particularly T2DM, through mechanisms involving inflammation, microbial metabolites, and host gene modulation. Dysbiosis promotes metabolic endotoxemia, insulin resistance, and increased adiposity, contributing to the pathogenesis of these conditions. Indian regional traditional foods, rich in probiotics (curd, buttermilk, idli, dhokla, kanji, panta bhat) and prebiotics (millets, lentils, onions, garlic, turmeric), offer a culturally relevant strategy to modulate gut microbiota, reduce inflammation, and support metabolic health. By integrating these foods into daily diets, individuals can leverage India's culinary diversity to combat the rising burden of NCDs. Future research should focus on clinical trials evaluating these dietary interventions in Indian populations to establish their efficacy in preventing and managing obesity and T2DM.

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12. Conflict of Interest

None.

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