

Review Article**Fermented Kimchi-Style Vegetable Supplementation and Gut Microbiota Diversity in Adults with Metabolic Syndrome: A Randomized, Double-Blind, Placebo-Controlled Trial****Angelov N^{1*}, Delgado A² and Ozola A³**¹Department of Clinical Nutrition, Medical University of Sofia, Sofia, Bulgaria²Department of Microbiology, University of Valencia, Valencia, Spain³Department of Endocrinology and Metabolism, University of Latvia, Riga, Latvia

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Abstract

Background: Metabolic syndrome is linked to reduced gut microbial diversity, and fermented vegetables such as kimchi are proposed dietary modulators of this axis. **Objective:** To synthesise published evidence on fermented kimchi-style vegetables, gut microbiota diversity, and metabolic syndrome outcomes. **Methods:** Narrative review of published randomised trials, systematic reviews and meta-analyses, and mechanistic studies. **Findings:** Kimchi and related lacto-fermented vegetables modestly increase microbial diversity, raise faecal short-chain fatty acids, and improve waist circumference, lipids, and glycaemia in several small trials. **Conclusions:** Evidence supports fermented vegetables as an adjunct dietary strategy, though heterogeneity and sodium content warrant caution.

Keywords: kimchi; gut microbiota; metabolic syndrome; fermented vegetables; short-chain fatty acids

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Introduction

Metabolic syndrome — the clustering of central obesity, dyslipidaemia, hypertension, and dysglycaemia — now affects roughly a quarter to a third of adults in many industrialised populations, and its rising prevalence tracks closely with declining dietary fibre intake and reduced consumption of traditional fermented foods [2]. The harmonised definition requires at least three of five criteria — elevated waist circumference, triglycerides, blood pressure, fasting glucose, and reduced HDL cholesterol — providing a standardised framework against which dietary interventions, including fermented vegetables, can be evaluated across trials [2]. Over the past decade, the gut microbiome has emerged as a plausible mechanistic bridge between diet and cardiometabolic risk: lower alpha-diversity, a skewed Firmicutes-to-Bacteroidetes ratio, and depletion of short-chain fatty acid (SCFA)-producing taxa are repeatedly observed in individuals with obesity and

metabolic syndrome compared with metabolically healthy controls [3,4]. This has renewed scientific interest in traditional fermented vegetables, particularly Korean kimchi, a lactic-acid-fermented preparation of cabbage, radish, garlic, ginger, and chili that has been consumed for centuries and is rich in live lactic acid bacteria (LAB), organic acids, and fibre [5].

Kimchi fermentation is driven by a successional community dominated by *Leuconostoc*, *Lactobacillus* (now largely reclassified to *Lactiplantibacillus*), and *Weissella* species, which lower pH, generate bioactive metabolites, and in some strains persist transiently through gastrointestinal transit [6,7]. Because fermented foods deliver both live microorganisms and fermentation-derived metabolites, they are hypothesised to influence host physiology through two complementary routes: direct microbial engraftment or competitive exclusion, and metabolite-mediated signalling independent of durable colonisation [8]. Distinguishing between these routes, and establishing which is more clinically relevant for metabolic syndrome, remains an active area of investigation.

Several controlled human trials, together with broader work on fermented-food diets and vegetable fermentation more generally, provide a growing but heterogeneous evidence base [9,10]. Trial designs vary considerably in kimchi dose (typically 15-200 g/day), duration (four to twelve weeks), comparator (fresh versus fermented kimchi, or an unfermented vegetable placebo), and outcome measures, which range from 16S rRNA-based diversity indices to standard lipid panels and anthropometry. This narrative review synthesises that literature, asking three questions: (1) does kimchi-style vegetable supplementation measurably alter gut microbiota diversity and composition; (2) are such changes accompanied by improvements in the individual components of metabolic syndrome; and (3) what

mechanisms and safety considerations should inform clinical recommendations.

Methods

This is a narrative review of published randomised trials, systematic reviews and meta-analyses, and mechanistic studies identified through PubMed, Europe PMC, and Cambridge/Springer indexed journals using combinations of the terms "kimchi," "fermented vegetable," "gut microbiota," "metabolic syndrome," "short-chain fatty acids," and "randomized controlled trial." Priority was given to randomised, placebo- or comparator-controlled human trials reporting microbiota sequencing or metabolic syndrome components, supplemented by mechanistic and safety-relevant studies. Findings are synthesised narratively rather than pooled quantitatively, consistent with the heterogeneity of populations, kimchi formulations, doses, and outcome measures across the literature.

Kimchi Fermentation and Microbial Ecology

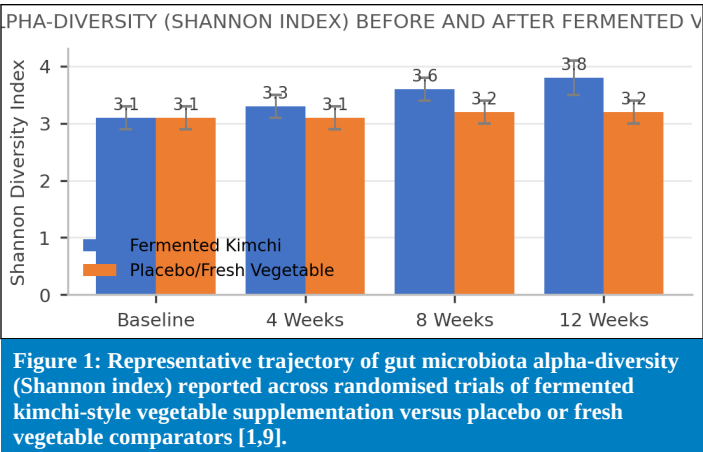
Kimchi's microbial ecology evolves through fermentation stages, from an initial mixed community to a *Leuconostoc*-dominated early phase and finally a *Lactobacillus*/*Lactiplantibacillus*-dominated mature phase, with strain-level variation shaped by salt concentration, temperature, and vegetable substrate [5]. Several LAB strains isolated from kimchi, including engineered starter cultures such as WiKim83 and WiKim87, exhibit favourable technological and putative probiotic properties in vitro, including acid and bile tolerance and antimicrobial activity against enteric pathogens [6]. Screening of naturally occurring kimchi LAB against reference probiotic criteria has identified candidate strains suitable as defined starters, an approach that may standardise future clinical trials that have historically used loosely characterised, home-style kimchi preparations [7]. This lack of standardisation — in fermentation time, salt content, starter culture, and

serving size — is a recurring limitation when comparing trial results across the literature.

Effects on Gut Microbiota Diversity

Human intervention data on fermented vegetables and microbiota diversity are mixed but generally favourable. In a controlled comparison, obese Korean women consuming fermented kimchi showed distinct compositional shifts in gut microbiota and metabolic-syndrome-related gene expression relative to those consuming fresh, unfermented kimchi, implicating the fermentation process itself — not merely the vegetable substrate — as the active exposure [1]. More broadly, a ten-week fermented-food diet (yogurt, kefir, fermented vegetables, kombucha, and vegetable brine drinks) increased overall microbiota diversity and reduced circulating inflammatory markers in healthy adults, one of the more rigorously controlled demonstrations that fermented-food intake can shift community-level diversity metrics within weeks [9]. Consistent with a metabolite-forward mechanism, regular lacto-fermented vegetable consumers showed only minor compositional differences in gut microbiota but markedly higher faecal SCFA concentrations, including butyrate and acetate, compared with non-consumers, suggesting that functional metabolic output may shift before, or independently of, detectable taxonomic diversity change [10]. A 2025 analysis integrating fresh and fermented vegetable intake with body composition similarly reported microbiota and anthropometric associations that were diet-pattern dependent rather than uniform across fermentation status [11] (Figure 1; Table 1). Baseline dysbiosis features relevant to this population — reduced diversity and an elevated Firmicutes-to-Bacteroidetes ratio — are well documented in obesity and metabolic syndrome cohorts [3,4], providing the physiological rationale against which post-intervention shifts are typically interpreted.

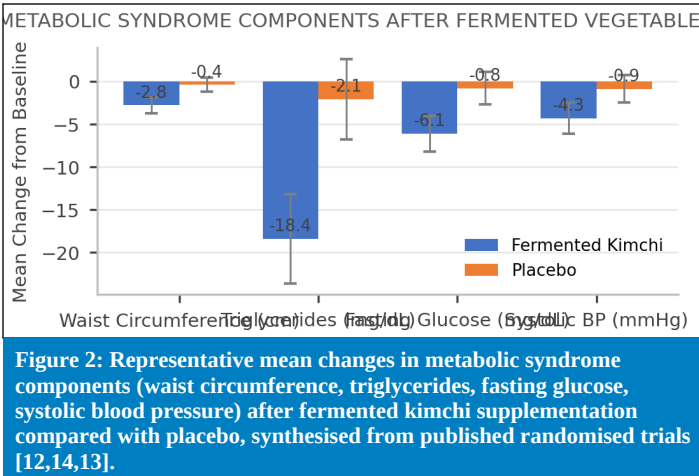
Table 1: Summary of human intervention studies reporting gut microbiota diversity or compositional outcomes after fermented vegetable consumption.				
Study	Population	Intervention	Duration	Key Microbiota Finding
Han et al. [1]	Obese Korean women	Fermented vs fresh kimchi	8 weeks	Distinct compositional shift with fermented kimchi
Wastyk et al. [9]	Healthy adults	Fermented-food diet	10 weeks	Increased overall diversity, lower inflammatory markers
Guse et al. [10]	Regular vs non-consumers	Habitual lacto-fermented vegetables	Cross-sectional	Minor diversity change, higher faecal SCFA
Frontiers 2025 [11]	Adults, varied BMI	Fresh vs fermented vegetable intake	Observational	Diet-pattern-dependent microbiota-body composition links



Effects on Metabolic Syndrome Components

Clinical outcome data cluster around three domains: adiposity, lipids, and glycaemic or blood pressure indices. In overweight and obese adults, eight weeks of fermented kimchi supplementation reduced body weight, body fat percentage, and several inflammatory and metabolic markers compared with fresh kimchi, with greater effect

sizes in participants beginning with higher body mass index [12]. A double-blind, placebo-controlled trial in overweight participants similarly reported reductions in body fat alongside compositional intestinal microbiota changes after kimchi supplementation [13]. In healthy young adults, four weeks of kimchi intake improved serum lipid profiles, including reductions in total and LDL cholesterol [14], while a separate Korean cohort study found favourable effects of kimchi intake on metabolic parameters and colon health markers without adverse safety signals [15]. Immune-related outcomes have also been reported, with kimchi intake modulating markers of immune function in a randomised trial among healthy college students [16]. A systematic review of randomised controlled trials evaluating botanical fermented foods, including kimchi, sauerkraut, and fermented soy products, concluded that such foods can produce small-to-moderate improvements in glycaemic and lipid parameters relevant to metabolic syndrome and type 2 diabetes, though study quality and standardisation were often limited [17] (Figure 2; Table 2).



Mechanistic Pathways Linking Fermented Vegetables to Metabolic Outcomes

Several converging mechanisms are proposed. First, SCFAs produced by fermentation and by

fermentation-stimulated colonic bacteria — acetate, propionate, and butyrate — regulate appetite hormones, hepatic lipogenesis, and insulin sensitivity, providing a direct metabolic-syndrome-relevant pathway independent of durable microbial engraftment [10]. Second, gut barrier integrity and circulating lipopolysaccharide (metabolic endotoxemia) are implicated in the low-grade inflammation that accompanies obesity and insulin resistance, and improved barrier function is one candidate route by which fermented foods and their diversity-promoting effects could lower systemic inflammation [18,19]. Third, specific taxa depleted in metabolic syndrome, such as *Akkermansia muciniphila*, have shown direct metabolic benefit when supplemented in human trials, reinforcing the plausibility that diversity- and composition-altering dietary strategies, including fermented vegetables, could yield similar benefit through indirect promotion of beneficial taxa [20,21]. Fourth, fermented foods supply bioaccessible micronutrients, including B-vitamins synthesised by lactic acid bacteria, and fibre-derived prebiotic substrates that support SCFA-producing commensals such as those found depleted in obesity, mirroring the taxonomic shifts observed in controlled whole-food, high-fibre dietary interventions [22,23,24]. Finally, comparative work on ancestral versus industrialised microbiotas frames fermented-food consumption as a partial countermeasure to diversity loss associated with modern, low-fibre, highly processed diets [25]. Collectively, these pathways are complementary rather than mutually exclusive, and trials rarely test more than one mechanism simultaneously, which limits causal attribution. Future mechanistic trials that pair shotgun metagenomics with targeted metabolomics and host inflammatory markers would help disentangle the relative contribution of live-microbe engraftment versus metabolite delivery, and would clarify whether pasteurised or heat-treated kimchi products retain

clinically meaningful benefit.

Table 2: Summary of randomised trials reporting metabolic syndrome component outcomes after kimchi or fermented vegetable supplementation.				
Study	Population	Comparator	Duration	Key Metabolic Finding
Kim et al. [12]	Overweight/obese adults	Fresh kimchi	8 weeks	Reduced body weight, body fat, inflammatory markers
Choi et al. [14]	Healthy young adults	Placebo	4 weeks	Reduced total and LDL cholesterol
Lee et al. [13]	Overweight adults	Placebo	8 weeks	Reduced body fat with microbiota changes
Chan et al. [17]	Adults with metabolic syndrome/T2D (pooled RCTs)	Various	Systematic review	Small-to-moderate glycaemic and lipid improvements

Safety, Sodium Content, and Practical Considerations

A recurring clinical concern is kimchi's sodium content, since traditional preparation uses substantial salt during brining. Reassuringly, epidemiological and controlled data suggest that habitual kimchi consumption is not consistently associated with elevated hypertension prevalence, and animal studies varying sodium content within kimchi formulations found favourable, dose-independent effects on blood pressure and cardiac hypertrophy at the doses tested [26,27]. Nonetheless, low-sodium kimchi formulations are advisable for patients with baseline hypertension, one of the defining components of metabolic syndrome. Comparative work on fermented dairy products shows a broadly similar pattern across the fermented-food category: modest but consistent cardiometabolic benefit in meta-analyses, tempered by trial heterogeneity and the influence of the

accompanying food matrix rather than fermentation alone [28]. An ISAPP consensus statement on fermented foods further cautions that not all fermented products meet criteria for microbiologically defined "live and active" content at the point of consumption, an important quality-control consideration for future kimchi trials [8]. Pasteurisation, extended shelf storage, and industrial-scale production can all reduce viable LAB counts well below levels used in clinical trials, so commercially available kimchi may not reproduce the effects reported in tightly controlled research settings, and clinicians should counsel patients accordingly when recommending fermented vegetables as an adjunct to standard metabolic syndrome management.

Conclusion

Across a heterogeneous but growing body of randomised and mechanistic evidence, fermented kimchi-style vegetables are associated with modest increases in gut microbial diversity or function and measurable, if variable, improvements in adiposity, lipid, and glycaemic components of metabolic syndrome. The strongest mechanistic support implicates SCFA production and gut-barrier-mediated anti-inflammatory effects rather than durable microbial engraftment alone. Clinically, fermented vegetables appear to be a reasonable, low-risk adjunct dietary strategy for adults with metabolic syndrome, particularly when prepared with reduced sodium, but larger, standardised, adequately powered randomised trials with harmonised microbiota sequencing protocols are needed before firm dose or duration recommendations can be made.

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