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Systematic Review

A Systematic Review (Before 01 February 2024) on the Health Benefits of Kimchi

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Abstract

Kimchi, a popular fermented salted vegetable from Korea, has been suggested to have potential benefits in weight and fat loss, gut modulation, improvement in gastrointestinal disorders, and possible reduction in formation of colon adenomas. There were some reviews on specific health benefits of kimchi such as gut health and weight loss, but in recent years there are some research that look at other kimchi health benefits such as bone loss, memory loss, allergy, and inflammation etc. Thus, a systematic review was conducted on this topic of interest. PubMed was the sole database used and 30 out of 158 articles were filtered through exclusion criteria. The articles were categorized into three main themes with fourteen subthemes: (i) Weight loss and lipid metabolism, (ii) Gastrointestinal disorders and diseases, and (iii) other health benefits. However, a main limitation of this review will be that more than half of the articles were of animal studies. Further research on human studies is required to validate and ascertain the current health benefits confer by kimchi.

Keywords: Gastrointestinal Disorders; Health Benefits; Foods; Kimchi

Introduction

In recent years, the benefits of consuming fermented foods and beverages are on the rise due to potential health benefits contributed by various active components and probiotics. Popular fermented foods included kefir from dairy milk, some examples of popular non-dairy fermented items are kimchi, sauerkraut, natto, kombucha, sourdough etc. The definition of fermented foods is described as, foods and beverages that are produced by microorganisms in a controlled process along with enzymatic transformation of food components [1]. In the past, fermentation was used to extend the shelf-life of foods by producing antibacterial compounds such as acids, ethanol and bacteriocins which plays important roles in the reduction of food pathogens and spoilage. Apart from food preservation, fermentation process also improves the texture and flavor of the food, and are known to enhance the food's nutritional value by production of vitamins, enzymes, and beneficial components such as short-chain fatty acids (SCFAs) [1]. Probiotics are microorganism that confers numerous health benefits and most research focused on gut health, as some studies found that certain probiotics has high survivability in the gut; thereby, facilitating their beneficial effects in the gastrointestinal tract (GI) [2].

Lactic acid bacteria (LAB) are found naturally in most fermented foods with a minimum concentration of 10E6 microbial cells per gram (CFU) and has potential benefits in various health aspects such as immunity, cardiovascular, metabolic through production of bioactive proteins and metabolites [2]. At different phases of fermentation, the type of LAB also differs, for example, leuconostoc spp. and weisella spp were the main LAB responsible for conversion of glucose into alcohol, lactic acid, and carbon dioxide. After which, lactobacillus and Lactiplantibacillus plantarum are responsible for the later part of fermentation, which they became the main beneficial bacteria in kimchi [1]. The microbial composition of kimchi is dependent on the ingredients used, as kimchi that has more garlic were found to have greater amounts of lactobacillus, while red pepper powder is associated with high amounts of weissella but lower leuconostoc and lactobacillus concentrations [2].

Kimchi is a traditional fermented vegetable that has been consumed for thousands of years by Koreans, and the term kimchi refers to a variety of fermented salted vegetable foods [3]. The most common kimchi variation uses the napa cabbage or Chinese cabbage and other main ingredients such as red pepper, garlic, onion, ginger, and fish sauce were used in the making of kimchi [3]. There are over 200 kimchi variations with radish and ponytail radish being the second common type, vegetables such as leeks, green onions, cucumber, mustard and perilla leaves were also used to make kimchi.

Benefits of kimchi in anti-cancer, weight loss, anti-diabetes, high antioxidant properties were associated with bioactive components of the ingredients used in kimchi making, in addition, the fermentation process were found to enhance the health properties of kimchi [3]. The type of LAB in kimchi were determined by the temperature, for example, kimjang kimchi which was characterized by long storage condition were dominated by lactobacillus sakei, while commercial kimchi had a different species, the weissella koreensis is the main LAB [4]. The LAB count of kimchi is at usually between 10^{7-9} CFU and several types of LABs such as Leu. citreum, Leu. mesenteroides, Lab. brevis, Lab. plantarum, Lactococcus lactis etc are responsible for the fermentation process which yields the many health benefits of kimchi [3]. The fermentation status of kimchi is dependent on consumption and storage needs requirements: fermentation at 25 °C for short-term consumption and 5 °C for kimchi that requires long storage period [4].

As the napa cabbage is the most common vegetable used to make kimchi, its nutritive component has been explored and was found to be abundant in vitamin A, C, amino acids, and minerals such as calcium, iron, magnesium, and potassium. Some compounds in kimchi, namely, β-sitosterol, benzyl isothiocyanate and thiocyanate had possible therapeutic effects on conditions like atherosclerosis, cancer etc [4]. Red pepper is one of the main ingredients in kimchi, its active component capsaicin, could stimulate fat loss by increasing metabolism when compared to kimchi prepared without red pepper where fat loss and weight loss was lower than normal kimchi prepared with red pepper powder [4].

As kimchi is made from green vegetables, it is also rich antioxidants and may be beneficial against free radicals. The health benefits of kimchi are varied according to the types of kimchi as the ingredients used will confer differing health effects, nonetheless, long-term kimchi consumption may improve overall health [3]. Hence, this systematic review aims to examine and highlight the different health benefits of kimchi consumption and understand how kimchi exert physiological effects in various health conditions and diseases.

Methods

A PubMed search was conducted on on February 4, 2024, for existing studies regarding health benefits of kimchi published before February 1, 2024. The search term "(kimchi AND benefi *)" were used (see supplementary material for search URL). The following exclusion criteria were used: (A) non-English articles; (B) articles without full text access; (C) non-primary literature; (D) articles not about fermented foods; (E) articles that are not about kimchi; (F) articles that are not about health benefits of kimchi.

Results and Discussion

A total of 158 literatures were retrieved from PubMed by using the search terms (Figure 1). After screening through the exclusion criteria, 30 studies are included, which includes 20 animal studies and 10 human studies, and separated into three main themes. The three main themes are further divided into sub-themes (Table 1).

Theme 1: Weight loss and lipid metabolism. Numerous studies on mice and humans have found that kimchi can prevent weight gain, induce weight loss and fat loss [6-13]. Several animal studies [6-9,11] induced obesity in mice and found that kimchi was able to reduced body weight at 8 weeks [6,11], 10 weeks [7] and 12 weeks [8,9]. Apart from weight loss, one study [7] found significant fat mass reduction in mice associated with inflammation reduction, while studies [8,9,11] found that kimchi can reduce fats in the adipose tissues of obesity-induced mice. Kim., *et al*. [7] found that kimchi can increase the amount of *Akkermansia muciniphila* in the gut, which might play a crucial role in the gut-brain axis and induced weight and fat loss in mice. *Akkermansia muciniphila* is involved in fatty acid oxidation and short-chain fatty acid (SCFA) productions, which are important for regulating lipid metabolism and has a role in weight maintenance [36]. However, Ji., *et al.* [10] reported that weight loss was less significant but found that kimchi has significantly reduced adipose tissues in 3 weeks. Furthermore, the amount of Firmicutes, Bacteroidetes and Clostridium cluster XIVab after treatment were significantly lower, suggesting that modulation of the microbiota might have a positive effect on reducing fat mass [10].

In addition to weight loss, improvement to other parameters such as reduction of serum leptin, total cholesterol (TC), triglyceride (TG) was also reported and could play a role in weight reduction in the form of fat loss [6]. There are two studies that examined the effects of fresh and fermented kimchi on obese individuals, with one study [12] found significant weight loss and fat loss and the other study [13] found reduction in weight loss, but fat loss is statistically insignificant. Han., *et al*. [13] found that kimchi had modulated the Firmicutes/Bacteroidetes ratio, an increased in actinobacteria and suggested that weight loss could be induced by gut alteration. The author suggested that weight loss of the subjects could be linked to an increase in Proteobacteria, Actinobacteria, Bacteroidetes and gene expression alteration of Acyl-CoA synthetase long chain family member 1 (ACSL1) and aminopeptidase N (ANPEP) [13]. ACSL1 is an enzyme involved in fatty acid oxidation (FAO) and deficiency or reduction results in decreased FAO in tissues such as muscle, and adipose [37]. Therefore, upregulation of ACSL1 by fermented kimchi might play a role in reducing obesity.

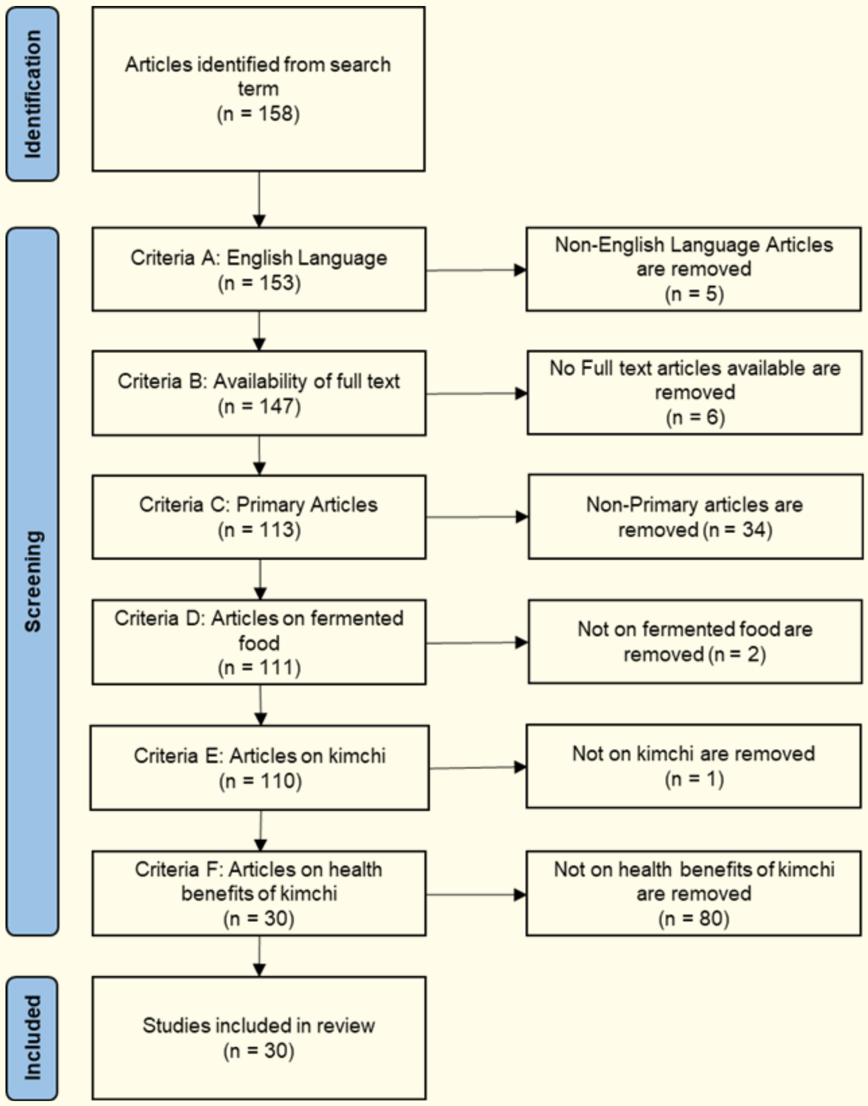

Figure 1: Research Process using the PRISMA [5].

Themes	Sub-Themes	Number of Articles	Percentage
Weight loss and fat loss effects of kimchi	Weight loss	8 [6-13]	26.7%
	Lipid Metabolism	2 [14,15]	6.7%
Gastrointestinal health and diseases	Gut microbiota	2 [16,17]	6.7%
	Irritable bowel syndrome Inflammatory	2 [18,19]	6.7%
	bowel disease	2 [20,21]	6.7%
	Colon adenoma	1 [22]	3.3%
Other health benefits	Diabetes	2 [23,24]	6.7%
	Immunity	2 [25,26]	6.7%
	Allergy	2 [27,28]	6.7%
	Anti atherosclerotic	2 [29,30]	6.7%
	Inflammation	1 [31]	3.3%
	Atopic dermatitis	1 [32]	3.3%
	Memory Health	1 [33]	3.3%
	Bone Health	1 [34]	3.3%
	Hair Growth	1 [35]	3.3%

Table 1: Thematic classification of studies on various health benefits of kimchi.

As high amounts of Proteobacteria are significantly associated with obesity while Actinobacteria and Bacteroidetes are largely associated with lean phenotype and are commonly found in healthy individuals [38]. Difference in kimchi dosage between both studies could have been the reason for the difference in weight loss effect, as first study [12] fed their subjects 300 g/day of kimchi per day and the latter [13] fed 180 g/day. Both studies highlighted that fermented kimchi had greater anti-obesity effects than fresh kimchi in 8 weeks [13] and 12 weeks [12]. It was suggested that fermented kimchi would have greater health benefits than fresh kimchi due to higher amounts of LAB contributed by longer fermentation periods and modulation of the microbiome has significant impact on metabolism and energy balance and could influence the body weight. Hence, kimchi has weight and fat loss effects as reported in six animal and two human studies despite varying forms of kimchi.

Abnormal lipid levels can lead to the development of metabolic disorders such as diabetes, non-alcoholic liver disease, as well as obesity [39]**.** Increased lipid levels also contribute to fatty depositions in the artery walls and could lead to atherosclerosis and cardiovascular diseases [39]. Two studies found that kimchi can regulate lipid metabolism and improve serum lipid profiles 1 week [14] to 8 weeks [15]. A randomized clinical trial examined the effects of fermented kimchi on the lipid profiles of 100 healthy adults where they are categorized into 2 kimchi intake groups: low intake, 15g/day, and high intake 210g/day and found that TC and low-density lipoprotein (LDL)-C were significantly reduced after 1 week [14]. Choi., *et al*. [14] also found the lipid lowering effects were greater in hypercholesterolemic subjects where their TC and LDL-C are above 190 and 130 mg/dL respectively. However, FBG improvements were different between high and low kimchi intakes, which the FBG is significantly improved for the high intake group [14]. β-sitosterol is a phyto-cholesterol that has lipid lowering effects and are commonly found in Chinese cabbage, other active compounds that can lower lipid are sulfur and capsaicin, which are found in garlic, onions, and red pepper [14]. β-sitosterol promotes lipolysis through suppression of cholesterol synthesis by preventing intestinal absorption of cholesterol in the intestines.

Woo., *et al*. [15] examined the effects of kimchi extracts on lipid metabolism using high cholesterol diet (HCD) induced mice and found significant reduction of serum TG, TC, and liver lipid accumulation. Capsaicin, is an active compound in red pepper powder and is commonly used to make kimchi is known to have lipolytic effects and might have exerted beneficial effects on lipid metabolism [15]. Suppression of fatty acid synthesis through downregulation of the sterol regulatory element binding proteins-2 (SREBP-2) and HMF-CoA reductase (HMGCR) increased lipolysis reaction and that reduced lipid accumulation in the liver which led to improvement of lipid metabolism. Both studies highlighted the beneficial and protective effects of kimchi and its ability in improving lipid metabolism and lipid profiles by suppressing fatty acid synthesis.

Theme 2: Gastrointestinal health and diseases

Several studies found that kimchi has beneficial effects in improving the gut microbiome [16,17], improve symptoms of irritable bowel syndrome (IBS) [18,19] and inflammatory bowel diseases (IBD) [20,21] and prevention of colon cancer [22] through microbiota modulation.

Two studies found that kimchi can increase the number of beneficial bacteria within 4 weeks [16, 17]. Ko., *et al*. [16] found that kimchi seaweed that uses *Laminaria japonica* (also known as *Saccharina japonica*) positively modulated the microbiome of 40 human subjects, with a significant increase in bifidobacterium and lactobacillus beneficial strains. *L. japonica* exhibited anti-inflammatory effects and has improved colitis symptoms in mice from their previous experiment, and they also observed a positive microbiota effect of the DUO probiotic on the number of LAB in their previous clinical study [16]. With that, *L. japonica* and DUO probiotic has potential benefits on preventing the reduction of beneficial gut bacteria due to its synergistic effects on healthy gut bacteria growth.

Bifidobacterium and Lactobacillus can exert beneficial effects on gastrointestinal disorders (GI), barrier protection, short chain fatty acids (SCFAs) production through microbiome modulation [40]. In particular, *Lactobacillus rhamnosus* and *Lactobacillus plantarum* were found to have anti-microbial effects against pathogens either through production of bacteriocins or prevent pathogens from binding to intestinal cells [41]. Furthermore, Lactobacillus is another dominant beneficial bacterium classified under the phylum Firmicutes and has been found to strengthen the gut intestinal barrier, regulate mucus production, and are involved in SCFAs production [41]. Therefore, the increase numbers of bifidobacteria and lactobacillus due to kimchi consumption exerts positive effects on the gut health by improving gut barrier, production of SCFA and pathogen inhibition.

Another study evaluated the effects of a symbiotic beverage enriched with kimchi bacterium, *Leuconostoc holzapfelii* on 21 healthy Koreans found that Akkermansia and Bacteroidetes were significantly increased along with reduction of Prevotella in the microbiome [17]. An increased in Prevotella spp. is strongly associated with chronic inflammation while Akkermansia and Bacteriodetes are dominant beneficial bacteria and can protect the gut against pathogens [36,42,43]. A key finding highlighted by the authors in this study was that the aspartate aminotransferase enzyme was reduced by the kimchi beverage, suggesting improvement in liver functions and might have potential in reducing non-alcoholic fatty liver disease (NAFLD) [17]. Hence, kimchi has positive effects on the gut microbiota by modulating major beneficial gut bacteria such as Akkermansia and Bacteroidetes, as well as reducing harmful bacteria like Prevotella.

The exact mechanism of irritable bowel syndrome (IBS) is unknown and is characterized by abdominal pain and dysbiosis and an increased levels of pro-inflammatory cytokines levels [44]. There are two studies that examined the effects of kimchi on IBS on humans and IBS-induced murine model [18,19]. In the animal study [18], among the three probiotic strains, *L. paracasei* and *L. plantarum* were more effective in alleviation of IBS symptoms and improvement in stool consistencies and weight than *L. salivarius* over 3 weeks. Dempsey and Corr [41] reported that *L. paracasei* and *L. plantarum* promote healthy intestinal barriers by strengthening junction proteins such as claudin, occludin and adhesion molecules. This could explain the positive effects of DK121 and V7 strains on the gut barrier as they belong to the lactobacillus probiotic strains.

In the human study [19] that examined the effects of 3 types of kimchi: standard kimchi (SK), kimchi with dead nano-sized *L. plantarum* (nLpSK) and functional kimchi (FK) on IBS symptoms, defecation frequencies and stool consistency, found that all groups experienced significant improvement in all IBS parameters. An increase in beneficial probiotics such as Lactobacillus and Bifidobacterium and a reduction in *Escherichia coli* in kimchi treatment groups were observed, suggesting that kimchi has beneficial effects in microbiota modulation [19]. Kim., *et al.* [19] also examined the inflammation serum levels and reported a decrease of TNF-α, IL-4, IL-10 and IL-12 in both nLpSK and FK group, suggesting that kimchi consumption can lower proinflammatory cytokines in IBS patients, which could translate to improved symptoms and stool parameters.

A study found that IBS-diarrhea patients have high levels of proinflammatory cytokines such as IL-6, TNF-α, IL-1β and were linked to inflammation in the body that leads to disruption of the gut-brain axis and cause IBS [45]. This is evident in the study [19] where IBS subjects had a dysregulated cytokine levels before treatment and symptoms were ameliorated by kimchi consumption. Another key finding highlighted that kimchi had reduced the amount of harmful fecal enzyme: β-glucosidase and β-glucuronidase significantly in the human subjects [19]. β-glucosidase and β-glucuronidase are dominant bacterial enzymes that can produce toxic aglycones and carcinogenic byproducts and high levels are associated with gut issues [46]. Last finding on the microbiome analyses of the subjects found that kimchi had positively modulated lactobacillus, bifidobacterium and had reduced *Escherichia coli*, and these changes in the microbiome might also play a role in reducing IBS symptoms. Hence, kimchi consumption could reduce the levels of harmful enzymes, modulate the gut microbiome positively and lower the levels of pro-inflammatory cytokines and lead to improvement of IBS symptoms and parameters [19].

Inflammatory bowel disease (IBD) is a chronic inflammatory disease of the intestinal tract, Ulcerative colitis (UC) and Crohn's disease (CD) are subtypes of IBDs however they differ in the location of inflammation site: UC affects the large intestine while inflammation in CD can be in any region of the GI. Two animal studies examined the effects of kimchi isolated probiotics on UC-induced mice and found improvement in various UC symptoms in 1 week [21] and 3 weeks [20]. Moon., *et al.* [20] investigated the effects of probiotic *Leuconostoc mesenteroides* DRC 1506 and freeze-dried kimchi on 32 mice and found that UC symptoms which are characterized by reduced colon length, increased colon weight/length ratio induced by weight loss, diarrhoea, stool with blood and continuous inflammation were significantly improved [20]. Dextran sulfate sodium (DSS) was used to induced ulcerative colitis in the mice model. The authors also reported that kimchi reduces the population of pathogenic bacteria in the microbiota of the subjects, along with significant upregulation of TJ protein complex such as ZO-1, claudin which are responsible for maintaining a health gut barrier and has a vital role in IBD pathogenesis, thereby suggesting that kimchi has potential in improving IBD through various mechanisms [20]. ZO-1 and claudin are vital components found in the epithelial cells and are needed to maintain a tight junction in the epithelial barrier so as to prevent leaky barrier and toxic substances.

Another study found that *L. paracasei* significant improvement survival rate, reduced rectal bleeding, stool consistency and lesser weight lost in UC-induced mice [21]. Park., *et al.* [21] highlighted that colonic myeloperoxidase (MPO), a measure for tissue inflammation that assesses the amount of neutrophil infiltration into damaged tissues were significantly downregulated by *L. paracasei* when compared to control. In addition, pro-inflammatory cytokines TNF-α, IFN-γ, IL-6, IL1β were also significantly reduced, suggesting that kimchi derived probiotics can reduce inflammation induced by UC. They also found that Th1 cells were significantly suppressed by *L. paracasei* and are correlated with high amounts of $CD4^+$ $FOXP3^+$ T regulatory cells. In IBD, high Th1 cells are found to induce inflammation in the GI, and this study found that *L. paracasei* was able to mediate the imbalance of Th1 cells and upregulate $CD4^+$ $FOXP3^+$ T regulatory cells, leading to improved UC symptoms. Therefore, kimchi probiotics has potential in reducing tissue inflammation and improvement of the gut barrier permeability for IBD through regulation of Th1 cells and $CD4^+$ $FOXP3^+$ T regulatory cells mechanisms [20,21].

A study on 32 patients from mild to severe colon adenoma conditions found that fermented kimchi can positively alter the microbiota in 10 weeks [22]. Park., *et al,* [22] found that fermented kimchi can prevent the formation of colon adenoma by increasing the microbiota diversity, in addition, pro-inflammatory cytokine 1L-1β was significantly reduced and high levels are found to promote colon cancer. Park., *et al*. [22] reported that there was no significant difference in the firmicutes, proteobacteria, bacteroidetes abundance in the groups, however, the microbiota diversity was significantly altered by kimchi consumption suggesting that kimchi has potential in preventing colon adenoma formation through gut modulation. The fecal microbiota changes are associated with colorectal cancer development (CRC) where an increase of *Fusobacterium nucleatum*, *E. coli*, and *Bacteroides fragilis* is strongly linked to CRC development [47]. Another finding highlighted was that kimchi had significantly reduced IL-1β levels, which high levels are known to promote colon cancer cells, this suggest that kimchi might have potential in cancer prevention [22]. Therefore, kimchi might be able to prevent colon adenoma and cancer through microbiota modulation, however, this is the only study on kimchi and colon adenoma.

Theme 3: Other health benefits.

Two human studies on prediabetic subjects found that kimchi and *L. plantarum* probiotic improves anthropometric measurements [23] and glucose related parameters [23,24]. An., *et al.* [23] reported that fresh and fermented kimchi significantly improve body weight, body mass index (BMI), waist circumference (WC), FBG, IR, BP in 16 weeks. Large WC is caused by accumulation of visceral fats and is strongly associated with diabetes and high blood pressure [48]. Abdominal fat can stimulate the production of inflammatory cytokines and accumulation of lipids which can result in reduction of insulin receptors lead to diabetes [48]. The study also highlighted that kimchi improves IR, insulin sensitivity (IS), HOMA-IR and further confirmed the effect of kimchi on alleviating diabetes-related markers [23]. The other study examined the effects of *L. plantarum* on 37 prediabetic Koreans over 8 weeks and found significant improvement in the 2-hour postprandial glucose test (2h-PPG) and HbAc1 levels. Oh., *et al*. [24] found that no changes in microbiota and suggested that it is partly due to the short study duration and low probiotic dosage, nevertheless, *L. plantarum* had exhibited beneficial effects on prediabetic patients.

Two studies on mice that used probiotic strains isolated from kimchi has found improvement in immune functions immunoregulatory effects at 2 weeks [25] and 4 weeks [26]. Hong., *et al*. [25] used *L. sakei* and *L. plantarum* on sepsis-induced mice and found that both strains reduced sepsis; however, *L. sakei* exhibited stronger immune-inducing abilities than *L. plantarum*. The authors observed a suppression of Th1 immune response, reduced pro-inflammatory cytokines levels that correlates with significant reduced inflammation [25]. Another study [26] examined the effects of high and low dosage of *Weissella cibaria* and *L. rhamnosus* on 18-month-old aged mice and found improvement in immunity response through increased cytokine levels, furthermore, increased numbers of white blood cells (WBC) and red blood cells (RBC), spleen cell growth rate were also observed and are associated with improved immunity. Spleen is an immune organ that regulates immune response, immunity indicators such as size and number of spleen cells and these indicators were upregulated by both kinds of probiotics regardless of dosage. Park., *et al.* [26] also found that both *W. cibaria* and *L. rhamnosus* were able to upregulate T cells which in turn reduce pro-inflammatory cytokine production and resulted in a delay in aging response in aged mice. During aging, T cell functions are associated with a reduction of T cell indicators, and in this study, kimchi derived probiotics significantly delay aging through regulating T cell indicators like TNF-γ and IL-2. Hence, both studies showed that kimchi isolated probiotics has potential in immunity regulation, inflammation reduction and can delay aging through regulation of immune cytokines and T cell functions.

Increasing evidence suggested that dysbiosis could be associated with allergy through influence on the immune system, metabolism, and modulation of the adaptive immunity system [49]. Two mice studies examined the effects of kimchi isolated probiotics on allergy induced mice and found significant reduction in allergy symptoms at 4 weeks [27] and 8 weeks [28]. Kim., *et al*. [27] examined the effects of *B. longum*, *L. plantarum* and a mixture of both probiotics on allergic rhinitis (AR) induced mice and found reduction of symptoms. The effects of probiotic on dysbiosis induced by AR found that there was an increased in beneficial bacteria such as Bacteroidetes and Proteobacteria which were suppressed by AR, therefore, kimchi probiotics has potential in reducing AR symptoms [27]. The authors also found improvement in immunity response, suggesting that kimchi has potential in alleviation of AR as the condition is characterized with reduced immunity [27]. Another animal study [28] examined the immunomodulatory effects of *Enterococcus faecium* (FC-K) isolated from kimchi on AR induced mice found that the probiotic reduced allergic activities by regulating T cell response. Rho., *et al.* [28] highlighted that *E. faecium* was able to stimulate IFN-γ production under Th2 condition *in vitro* which shows the effect of the probiotic on regulating the Th2/Th1 balance in mice. In allergic conditions, the T-cell response of Th2 will dominant over Th1 cells, Th1 cells are responsible for production of IFN-γ which has a role in stimulate macrophage activity [28]. *E. faecium*, a kimchi derived probiotic can regulate the Th2/Th1 balance and improve allergic response in AR mice. In addition, a reduction of serum immunoglobulin E was also observed, and an increased IgE levels are associated with AR [28]. Therefore, kimchi derived probiotics such as *B. longum*, *L. plantarum* and *E. faecium* has potential benefits in reduction of AR symptoms due to its positive effects on microbiota alteration and immune regulation.

Benefits of kimchi on atherosclerosis

Atherosclerosis begins with endothelial inflammation and certain molecules and enzymes are involved in inducing the process, leading to vascular wall and tissue damage known as atherosclerosis [50]. Two animal studies found that kimchi might have anti-atherosclerotic effects [29,30]. A study by Noh., *et al.* [29] examined the effects of an active principal compound from kimchi known as 3′-(4′-hydroxyl-3′,5′-dimethoxyphenyl) propionic acid (HDMPPA) in atherosclerotic induced animal model can reduce atherosclerosis development by increasing nitric oxide (NO) levels in the aorta. NO is needed for health vascular wall functions and reduced NO levels were found to induce atherosclerosis [29]. Other important finding in this study found that HDMPPA significantly upregulated NO concentration in the aorta and reduced ROS and asymmetric dimethylarginine (ADMA) levels and suggested that HDMPPA can prevent NO bioavailability reduction and lead to amelioration of atherosclerosis in mice [29]. ADMA (asymmetric dimethylarginine) is an endogenous inhibitor that reduces NO production is considered a major risk factor for cardiovascular diseases and increased ADMA levels are associated with atherosclerosis [51]. Noh., *et al*. [29] reported that HDMPPA had significantly reduce ADMA in the plasma in the study, which means that kimchi has anti-atherosclerotic benefits. Noh., *et al*. [29] also highlighted that HDMPPA markedly reduced the expression of VCAM-1, ICAM-1 and COX-2 along with downregulation of COX-2 expression. VCAM-1 and ICAM-1 are responsible for the initiation of leucocyte-endothelial cell interaction that exposes the vascular wall and tissues to be damaged and leads to the development of atherosclerosis [50]. COX-2 is an enzyme that is responsible for the production of inflammatory cytokines that stimulates the progression of atherosclerosis [50]. Another study [30] also examined the effects of HDMPPA on mice for 8 weeks found that the kimchi component also reduces superoxide activity and reduce inflammation in the vascular wall like the previous study. NADPH oxidase is an enzyme that induces inflammation through production of superoxide or free radicals and has been found to stimulate atherosclerosis formation. Noh., *et al*. [30] also highlighted that HDMPPA had significantly reduced p47phox and rac-1, which are subunits of the NADPH oxidase enzyme. The results suggested that HDMPPA can reduce inflammation and thereby improve atherosclerosis by reducing ROS activity. Both studies reported similar effects of the kimchi component, HDMPPA and suggest that it has potential in preventing atherosclerosis by reducing free radical activities such as reactive oxygen species (ROS) and increase NO levels.

One study looks at strains of lactobacillus isolated from kimchi on human cell lines and mouse cells found that kimchi can prevent infection and inflammation through regulating the vitamin D receptor (VDR) [31]. Vitamin D has a role in preventing infection and inflammation and deficiency of vitamin D could exacerbate IBD, also VDR is a risky gene for IBD due to its ability in cell differentiation, anti-inflammatory effects in the microbiome [31]. Lu., *et al*. [31] found that the kimchi derived lactobacillus strain increases VDR and autophagy signaling and resulted in reduced inflammation on infection-induced mice. Furthermore, there are two proteins in the strain that were identified to have anti-inflammatory effects and could have play a role in reducing inflammation [31]. This study was able to determine the mechanism of probiotics in VDR regulation by identification of proteins P40 and 75 and their functions in VDR signaling which suggest that kimchi have potential roles in reducing inflammation and infection.

Atopic dermatitis (AD) is a chronic inflammatory condition of the skin that is characterised by severe itching, rash, skin lesions, increased IgE levels and dominance of Th2 cells over Th1 are hallmarks of AD [32]. Won., *et al*. [32] found that different strains of *L. plantarum* were able to prevent AD in a dermatitis-induced mice model. Symptoms of AD such as lesions, redness, bleeding, scaling etc were inhibited by *L. plantarum* strains, in addition, IgE levels were significantly reduced after 55 days of treatment [32]. In AD, Th1/Th2 balance was disrupted leading to dominant Th2 condition. Won., *et al.* [32] found that these kimchi probiotic strains were able to modulate the effects of AD which led to overall improvement in the symptoms. Therefore, these lactobacillus strains have potential in improving AD, however, this is the only study that used kimchi on treatment of AD.

Alzheimer's disease (AD) is a neurodegenerative disease caused by an aggregation of amyloid-beta peptide's (Aβ) and loss of brain cholinergic activity in the medial temporal lobe and the neocortical region of the brain [52]. Symptoms manifest as gradual decline of memory thinking and reasoning skills and symptoms includes misplacement of items, memory loss, repetition of questions to others and themselves etc [52]. Jung., *et al*. [33] conducted a preliminary study on kimchi and scopolamine-induced memory deficit mice found that the supernatant of kimchi had memory protective effects on mice during the passive avoidance test, hence, screening of the LABs in the kimchi was conducted and they found that *L plantarum* had greater probiotic effects than other strains. Scopolamine is an anti-cholinergic drug that impairs memory in humans and is used to induce memory loss in animals as an Alzheimer study model [33]. *L plantarum* is the kimchi probiotic used in this study and the mice showed significant improvement in escape latencies in several test. Jung., *et al*. [33] also found an increase in cAMP response element binding (CREB) expression and brain-derived neurotrophic factor (BDNF) after kimchi treatment. CREB is a transcription factor that has main roles in cognitive functioning and is involved in long term memory and learning, a reduction of CREB expression could be one mechanism of AD [53]. CREB is needed to regulate BDNF, a transcriptional factor that has crucial role in memory formation and synaptic plasticity, hence, a reduction of BDNF leads to degradation of neuronal populations and gradual decline of neurons [53]. Therefore, an increase in CREB and BDNF expression by the kimchi postbiotic strain suggested that kimchi might have memory protective effects on AD.

An animal study [34] examined the effects of postbiotics MD35 of *L. plantarum* from kimchi on an ovariectomized mice model for 8 weeks, found that the strain had reduce bone resorption or prevent postmenopausal osteoporosis in mice. Osteoporosis typically affects women of older age, though it can occur at any age regardless of gender, there are multiple factors that can cause osteoporosis, such as oestrogen deficiency, reduced intake of calcium and vitamin D etc [54]. An impaired bone remodelling is characterized with increased bone resorption and lowered bone formation, leading to brittle and weak bones over time [54]. Myeong., *et al*. [34]

found that osteoclast was inhibited along with downregulation of Nfatc 1 gene expression, which increased levels result in bone resorption and manifest as osteoporosis. In addition, the kimchi postbiotic strain was found to increase the volume and amount of trabecular bone, significant improvement in growth plate volume as well as reduction of weight gain in the mice [34]. These results suggested that MD35 postbiotic strain might be useful in preventing postmenopausal osteoporosis.

A clinical pilot study by Park., *et al*. [35] examined the effects of kimchi and cheonggukjang probiotic on improvement of lipid profiles and blood flow in androgenetic alopecia patients found that 93% of patients had improvement in the hair parameters, while the portion of patients who experienced no hair improvements reduced over time from 10.9% to 6.5%. Park., *et al*. [35] administered the probiotic product in 46 men and women for 4 months which men had improvement in either hair parameter at 39.1%, while women had higher improvements for both parameters. The hair promoting effects were thought to derived from the ultra-high molecular weight poly-γ-glutamic acid (UHMW γ-PGA), found in cheonggukjang and can inhibit the acitivity of 5-α reductase, an enzyme that causes hair loss [35]. The effects of kimchi or LAB in the study was not determined; therefore, could not associate hair growth to kimchi or LAB; hence, it is a limitation of this study.

Main findings

In this systematic review, kimchi and its probiotic derivatives were found to have significant benefits on specific health conditions and diseases through mechanisms such as modulation of the gut, anti-inflammation. LAB and certain functional compounds of kimchi such as capsaicin, β-sitosterol etc also plays a role in the improvement of health and diseases. The first theme had 2 subthemes: weight loss and lipid metabolism and number of articles are 8 and 2 respectively. The subtheme on weight loss has the highest weightage at 26.7% and it suggested that kimchi has strong effects on weight loss. Second theme and third theme had similar weightage ranges from 3.3% to 6.7% for individual subthemes as presented in table 1 suggesting that there were insufficient studies for specific topics. Out of the 3 themes, theme 3 has the most subthemes, which adds up to 36.7% and this implies that kimchi has extended health benefits for other health conditions such as bone and memory health.

In addition, 33% of the articles were on humans and the remaining 66.7% were mice studies and this implies that more research has yet to be done on human subjects. Nonetheless, majority of the animal studies used in this systematic review were used to study the effects and mechanism of kimchi on amelioration of disease symptoms such as IBS and IBD. In general, based on the findings it can be concluded that kimchi has an apparent effect in weight reduction due to a substantial amount of research articles on weight. As for the effects of kimchi on gastrointestinal health, diseases and other health benefits, many studies were limited in certain topics while some are recent within the last 5 years.

Strengths and limitations of this review

This review uses PRSIMA, a specific guideline with a set of criteria and search approach to screen and assess relevant scientific articles. Adherence to PRISMA ensures the validity of the literature work and transparency of this review. Moreover, the review uses the thematic classification to determine the percent weightage of each theme by the number of articles (Table 1). The other strength of this review will be that this systematic review on kimchi identified the various health benefits of kimchi instead of a specific health topic such as gut modulation and incorporate recent research of kimchi health benefits into this systematic review.

This review has a few limitations. Firstly, more than half of the articles were made up of animal studies and only 10 out of 30 articles were of human studies. The current research of kimchi on other health benefits were numbered and only a few studies used human subjects, which required further research onto human health benefits with kimchi. As most studies used the mice model, symptom parameters used to determine the effectiveness of kimchi were not very suitable. For example, two mice studies on IBS could not determine level of "pain "experienced which is the main symptom of IBS. There was no instruments or method to assess the pain parameter in IBS-induced mice, hence, a limitation for using animal studies. Another limitation will be the source of kimchi used in these studies as there were many variations, for example, in the hair growth study, kimchi was not the only component used as cheonggukjang, a fermented soybean paste common in Korea was also incorporated together with kimchi. Therefore, the effect of kimchi on hair growth was overshadowed by the other fermented product and results became inaccurate. Hence, a lack of substantial human studies is the main limitation of this review despite the extensive potential benefits of kimchi in other areas of health.

Future research directions

Further research for this topic should focus on human studies as there are limited human studies on kimchi health benefits. Also, focused research studies on the mechanisms of specific kimchi active components on gut microbiome, lipid metabolism, allergy, inflammation and etc as it remains poorly understood. The variety of kimchi was also limited to napa cabbage variation as there were few studies in this review that looked at the differences between kimchi types and their health benefits. In addition, further studies onto disease alleviation using kimchi should be considered as several studies in this review suggested that kimchi has potential in treatment of diseases such as dermatitis, allergy rhinitis and prevention of memory loss and formation of colon adenoma formation. As kimchi contains LAB, more research should focus on the mechanisms of kimchi derived LAB on the modulation of beneficial and harmful bacteria as it also remains poorly understood. As kimchi contains probiotics, longer duration is needed to determine the long-term health effects of kimchi on various health conditions as it takes time for probiotics to colonize the gut and show benefits.

Conclusion

This systematic review highlighted the potential health benefits of consuming kimchi with 3 main themes; namely, (i) Weight loss and lipid metabolism, (ii) Gastrointestinal disorders and diseases, and (iii) other health benefits.

Supplementary Materials

The URL for PubMed search, containing the search terms and date range, is https://pubmed.ncbi.nlm.nih.gov/?term=kimchi+AND+benefi* and filter=dates.1000/1/1-2024/2/1. Supplementary materials can be downloaded from https://bit.ly/Kimchi_SR.

Conflict of Interest

The authors declare no conflict of interest.

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