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The Functional Properties of Kimchi for the Health Benefits

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Kimchi is a fermented vegetable consumed in Korea every day as a side dish. Nowadays kimchi became a world wide food based upon the scientific evidences showing the health promoting activities of kimchi. The beneficial effects of kimchi on human health may come from nutrients in kimchi such as vitamins, minerals, fibers and photochemical, or from the biological compounds present either in kimchi ingredients such as garlic, ginger, red pepper powder, the fermented products of kimchi, or from lactic acid bacteria in kimchi. The functional properties of kimchi responsible for the health benefits have been claimed as follows. 1) Anti-oxidative activity, 2) Anti-aging activity, 3) Anti-mutagenic, anti-tumor activities, 4) Anti-microbial activity, 5) Immune-stimulatory activity, 6) Weight-controlling activity, 7) lipid-lowering activity, 8) Anti-atherogenic activity, etc.

ANTI-OXIDATIVE ACTIVITY OF KIMCHI

The antioxidant properties of kimchi come from raw materials used to make kimchi and from other biological compounds produced during fermentation. Carotenoids, flavonoids, polyphenols, Vt C, Vt E, chlorophyll present in kimchi ingredients are known to be primary antioxidants and 3-(4′-hydroxyl-3′5′-dimethoxyphenyl) propionic acid in Chinese cabbage kimchi was identified as an active principle to have free radical scavenging ability (1). Antioxidant effect of kimchi has been confirmed *in vitro*, *in vivo*, and clinical studies. Kimchi retarded linoleic autooxidation (2) and LDL oxidation (3), and scavenged free radicals (4-6). Many researchers have suggested that anti-oxidative property of kimchi is one of the mechanisms for anti-mutagenecity/anti-cancer, anti-atherogenecity (7,8), and anti-aging (4-6).

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ANTI-AGING ACTIVITY OF KIMCHI

Free radical theory is the one of the most acceptable hypothesis that explains the aging process. The active oxygen species or lipid radicals react with bio-chemicals in the body result in damaging. Thus animals try to reserve antioxidants in addition to the antioxidative enzymes in the body to get rid of free radicals. Kimchi and kimchi ingredients enhanced the activities of antioxidative enzymes such as superoxide dismutase, catalase, glutathione reductase/peroxidase as well as increased Vt E and carotene levels in the plasma and liver (3,9). The concentration of total free radicals and hydroxyl radical in the plasma of elderly who consumed kimchi more than mean intakes (112 g) was lower than the elderly consumed kimchi less, while GSH and GSH/GSSG were increased. These results informed that kimchi might have a role either inhibit the production of free radicals or discard the free radicals more efficiently (10). This observation was confirmed in the animal study. Free radical production in the brain of SAM due to senescence (1 year feeding) was decreased by kimchi consumption and the activities of the antioxidative enzymes in the brain were increased (11).

ANTI-MUTAGENIC, ANTI-TUMOR ACTIVITIES OF KIMCHI

The biological compounds in kimchi having anti-mutagenic and anti-tumor activities are vitamin C, β-carotene, phenolic compounds, isothiocyanate, indole compound, β-sitosterol, diallysulfide, dietary fiber, fermented products, and lactic acid bacteria (12). The chemo-preventive or chemo-therapeutic effect of kimchi may be due to enhanced detoxifying ability of the liver that metabolites the carcinogens into water-soluble compounds to be excreted, or to inhibit the transformation of pro-carcinogen to carcinogen by retarding responsible enzyme activities, or to inhibit the DNA replication and protein synthesis of tumor cells, or to stimulate the apoptosis of the tumor cell. Increased activity of hepatic glutathione S-transferase (GST) classified as phase II enzyme in the detoxification system was observed when kimchi ingredients- radish, Chinese cabbage, garlic, green onion, leek, or kimchi was given to rats. Sulforaphane or S-containing compounds in these materials are partially responsible for the increased activity of GST. Lactic acid bacteria in kimchi is claimed to have antimutagenic and anticancer activity by inactivating or inhibiting the production of carcinogens in gastro-intestinal tract, or stimulating the immune system that retards the carcinogenic process (13). The low incidence of colon cancer in Korea was explained that the activity of β-glucosidase and β-glucuronidase was inhibitedby lactic acid bacteria in kimchi arrived at large intestine (23), thus less carcinogen was produced in the colon (14). Both viable and non-viable lactic acid bacteria showed antimutagenic ability informing that cell wall components, glycopeptides, of the lactic acid bacteria is responsible for these activities (13,15). The extracts of cell wall of *Lactobacillus plantarum* exhibited a direct anticancer effect against abdominal cancer induced by Sarcoma-180 (15). The short-chain fatty acids produced by lactic acid bacteria in the colon may induce the apoptosis (16,17). And apoptosis by kimchi extracts may occur to stimulate the DNA fragmentation (18) or to arresting the cell cycle. Kimchi extracts also showed anti-tumor activity by enhancing the phagocytic cell activity (19). Beside these effects, Chinese cabbage kimchi, radish-kimchi, and yulmu kimchi showed anti-genotoxic effect against DNA damage (20). The active principles in kimchi for anti-cancer were not identified yet however the dichloromethane fraction of Chinese cabbage kimchi showed the highest anti-cancer activity (21).

ANTI-MICROBIAL ACTIVITY OF KIMCHI

The S-containing compounds in garlic, green onion, red pepper, and ginger have an antimicrobial activity against pathogens (22) and lactic acid bacteria in kimchi is also known to have an anti-microbial activity. One hundred fifty seven strains of lactic acid bacteria were isolated from home made Chinese cabbage kimchi and 144 out of 157 showed a strong resistance to the artificial gastric juiceand bile informing that most of the lactic acid bacteria in kimchi will arrive at the intestine (23). Bateriocin produced by lactic acid bacteria is responsible for this anti-microbial activity and the fermented environment of kimchi, of pH is between 4.1~4.5, augmentedthis activity. In addition to this, lactic acid bacteria can absorb the harmful substances and excrete them into the feces. There has been no reports of food born disease related to the kimchi consumption since the anti-microbial action of lactic acid bacteria will destroy the harmful microorganisms exist in the intestine.

IMMUNOSTIMULATORY ACTIVITY OF KIMCHI

Immunostimulatory effects of kimchi have been studied with lactic acid bacteria in kimchi. *Lactobacillus plantarum* isolated from kimchi stimulated the proliferation of splenocytes and Payer's patch, increased the production of NO by peritoneal macrophages, increased the production of intestinal secretary IgA, increased TNF-α and IL-2 concentration of rats, and IgG secretion against sheep red blood cell (24). These immunostimulatory effects of *Lactobacillus plantarum* was also observed in tumor induced rats. The IgA secretion, NO production by macrophage, cytokine production, and phagocytic activity of macrophage were greatly increased (15). Kimchi extracts showed effects on stimulating the growth of spleen cell, bone marrow cell and thymus cell in the cell culture system (25), on increasing the B cell proliferation in the spleen lymphocytes of rats (26), and on increasing the phygocytic movement of macrophage. Fermented kimchi showed greater effects than fresh kimchi on immune stimulation informing that fermented products including lactic acid bacteria besides might be responsible for these effects.

WEIGHT-CONTROLLING ACTIVITY OF KIMCHI

Kimchi is a natural health food that is low in carbohydrate and lipids, and abundant in vitamins, minerals, fibers, and phytochemicals. The calorie for the Chinese cabbage kimchi is approximately 32 kcal/100 g and that for the soup based radish kimchi is 9 kcal/100 g. Among the nutrients in kimchi, vitamin A, beta-carotene, chlorophyll and flavonoids are from Chinese cabbage, green anion, carrot, red pepper powder, and vitamin C mainly comes from Chinese cabbage and red pepper powder. Ca, Mg, and P are from fermented fish sauce, red pepper powder and oyster. Crude fiber in Chinese cabbage kimchi is approximately less than 10% by dry base (27). The biologically active substancesin kimchi ingredients known to have lipid-lowering activities are β-sitosterolin Chinese cabbage, S-methylcysteine sulfoxide and S-allylcystein sulfoxide in garlic, capsaicin in red pepper. Lipolytic activity in adipocytes was observed by red pepper and the activity was increased with the degree of pungency of red pepper suggestingthat capsaicin is the compounds responsible for this activity (28). Besides these, many researches have reported that kimchi has a lipid-lowering activity.

The weight reduction of rats by kimchi is positively correlated with the amount of kimchi consumed (27). Rats fed 10% kimchi for 4 weeks showed significant reduction in body weight but this phenomenon was not observed in rats fed less amount of kimchi, suggesting that large dose of Chinese cabbage kimchi intake for long term will show the diet effect (27). The size and number of adipocytes of rats fed high fat diet was reduced by kimchi, especially with fermented kimchi. This research group emphasized that the duration of fermentation was rather important than the amount of kimchi intake on reducing the epididymal fat pad size and adipose cell number (26). Plasma leptin concentration of rats fed high fat diet supplemented with kimchi for 8 weeks was decreased (Table 1, $p<0.05$) (29). In clinical trial, obese girl whose BMI is over 25 consumed 3 g of freeze-dried kimchi for 6 weeks as a pill form, total body fat content was decreased (-5.11%) but changes in the body weight and abdominal fat was not significant (30). This result was in agreement with the observation from the animal study. Thus large dose and long-term intake of Chinese cabbage kimchi is recommended for the weight reduction.

LIPID-LOWERING EFFECT OF KIMCHI

The biologically active substances in kimchi ingredients known to have lipid-lowering activities are beta-sitosterol in Chinese cabbage, S-methylcysteine sulfoxide and S-allylcystein sulfoxide in garlic, capsaicin in red pepper.

Table 1. Serum leptin concentrations rats fed high fat diets supplemented with kimchi for 8 weeks (mg/dL)

Group[1]	Serum leptin
HFD	0.29±0.02[2)a3)]
HCK	0.15±0.12[b]
HFK	0.12±0.01[b]
HJK	0.12±0.05[b]

[1] HFD: High fat diet.
HCK: HFD+10% freeze dried Korean cabbage kimchi (control kimchi, CK), Brined Korean cabbage 100 g, raddish 13 g, green onion 2 g, red pepper powder 3.5 g, ginger 0.6 g, galric 1.4 g, fermented anchovy juice 2.2 g.
HFK: HFD+10% freeze dried Seatangle added (20%) CK (Functional kimchi, FK), Brined Korean cabbage 60 g, sea tangle 20 g, raddish 15 g, carrot 5 g, red, red pepper powder 3.2 g, ginger 0.5 g, galric 1.4 g, fermented anchovy juice 2.0 g, sugar 0.9 g.
HJK: HFD+10% freeze dried J-kimchi dried that is commercially avaiable.
[2] Values are mean±SD (n=10).
[3] Data are significantly different by one-way ANOVA followed Duncan's multiple range test at the 0.05 level of significance.

And lactic acid bacteria in kimchi are also known to lipid-lowering effect, especially cholesterol lowering activity. The mechanisms for lipid-lowering of these compounds have been studied extensively. Beta-sitosterol is phyto-cholesterol that competes with cholesterol in the intestine for absorption. The alliin in onion enhances the lipolytic activity through the hormonal regulation by increasing the adrenalin and glucacon secretion. Allicin in garlic inhibits cholesterol synthesis by inhibiting the acetyl-CoA synthetase or HMG-CoA reductase activity. Capsicin stimulates the 7α-hydroxylase activity to convert cholesterol into the bile acids (31), and it increases the energy expenditure via thyroid hormone regulation (32). Certain strain of lactic acid bacteria such as *Lb. acidophilus* can bind the cholesterol in their cell wall besides it can decompose the cholesterol for assimilation and de-conjugates the bile acids (33,34). Based on the accumulated knowledge of individual kimchi ingredients in terms of lipid-lowering activities, kimchi should have hypolipidemic effects. Nutritional survey of kimchi intake and lipid analysis showed that daily kimchi consumption level and HDL cholesterol concentration was positively correlated while LDL cholesterol was negatively correlated in 102 of healthy Korean men aged between 40 to 64 years old (35). Researches about kimchi on lipid-lowering effects have been extensively carried out with feeding various kinds of kimchi to the animals and human subjects. The results concluded that kimchi has lipid-lowering effects in the plasma, liver and other organs. Triglyceride, cholesterol, LDL cholesterol in the plasma was decreased and HDL cholesterol was increased in studies with SAM (36), rats (26,27,37) and rabbits (Table 2, 3, $p<0.05$) (7,8,38,39) fed kimchi. HMG-CoA reductase activity in the liver, CETP activity in the plasma (Fig. 1, $p<0.05$), ACAT activity in the liver of rat and rabbit were decreased by kimchi diet. A pilot-scale clinical study, six nonlipidemic persons with four Caucasians and two Chinese Americans consumed 150 g kimchi (1/2 cup) daily with regular meal for 2 weeks. Lag phase duration of LDL oxidation at 2nd week in Caucasians never been exposed to kimchi was extended two times compared to that of baseline (0 week). But plasma lipid profiles and vitamin C, E, homocystein, in the plasmawas not changed. Kimchi supplementation study with 12 middle aged healthy Korean who took 3 g of freeze-dried kimchi as a form of pill every day for 6 weeks showed significant decreased in plasma TG (-16.8%) than placebo group, and atherogenic index (AI) for kimchi group was decreased by 10.8% (40). Lipid-lowering activity of kimchi observed in the animal and

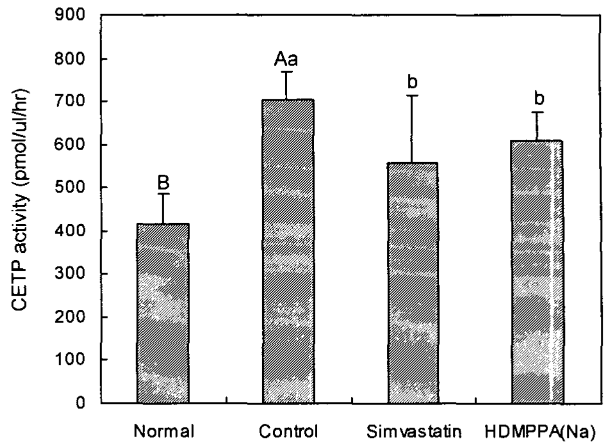


Fig. 1. The effect of HDMPPA (Na)[1] injected into ear vein on CETP activity of hypercholesterolemia induced rabbits.
[1]Sodium-3-(4-hydroxy-3,5-dimethoxyphenyl)propanoate is derivative of HDMPPA originally isolated from Chinese cabbage Kimchi.
[A,B]Data are significantly different from normal by Student *t*-test at 0.05 level of significance.
[a,b]Data are significantly different by one-way ANOVA followed Duncan's multiple range test at 0.05 level of significance.

Table 2. The effect of HDMPPA[1] injected into ear vein on plasma lipid cholesterol concentration of rabbits fed a high cholesterol diet[2] for 30 days (mg/dL)

Group[3]	Total cholesterol	Triglyceride	HDL cholesterol	LDL cholesterol
Control	1706.67±321.66[4)NS5)]	334.33±37.26[NS]	91.00±71.06[NS]	1354.13±285.81[NS]
Simvastatin	1493.33±441.12	313.33±66.67	69.67±39.57	1166.07±373.76
HDMPPA	1381.67±387.99	266.33±50.26	83.83±50.97	1098.57±343.55

[1]HDMPPA is 3-(4'-hydroxyl-3',5'-dimetoxyphenyl)propionic acid. HDMPPA, molecular weight 226 is originally identified from Chinese cabbage Kimchi. The HDMPPA used in this study is chemically synthesized.
[2]The amount of cholesterol given was 0.5% of chow diet.
[3]Control: EtOH (50%) was injected (0.33 mg/kg/day).
Simvastatin: Simvastatin dissolved in 50% EtOH was injected (0.33 mg/kg/day).
HDMPPA: HDMPPA dissolved in 50% EtOH was injected (0.33 mg/kg/day).
[4]Values are mean±SD (n=6).
[5]Values are not significantly different among groups at 0.05 level of significance.

Table 3. The effect of HDMPPA[1] injected into ear vein on hepatic lipid concentration of rabbits fed a high cholesterol diet[2] for 30 days

Group[3]	Lipids (mg/g)			
	Cholesterol	Triglyceride	Free cholesterol	Cholesteryl ester
Control	63.31±16.54[4)b5)]	52.50±1.18[a]	29.31±2.20[b]	34.00±14.34[c]
Simvastatin	87.50±9.69[a]	52.08±1.77[a]	36.24±3.89[a]	51.26±5.79[a]
HDMPPA	65.05±5.25[b]	34.79±7.95[b]	20.69±0.51[c]	44.23±7.92[b]

[1-3]See the legend of Table 2.
[4]Values are mean±SD (n=6).
[5]Date in column are significantly different by one-way ANOVA followed Duncan's multiple range test at 0.05 level of significance.

clinical studies might be due to the inhibition of HMG-CoA reductase, CETP and ACAT activity by biological compound in kimchi identified as 3-(4'-hydroxyl-3',5'-dimethoxyphenyl)propionic acid (1,41).

ANTIARTHEROGENIC EFFECTS OF KIMCHI

Oxidized LDL and hypercholesterolemia are one of the major symptoms to develop the atherosclerosis. The functional properties of kimchi or kimchi ingredients such as antioxidant activity, free radical scavenging activity, hypolipidemic activity will be responsible for retarding the atherosclerosis. Rabbits fed high cholesterol diet developed atherosclerosis but it was prevented by kimchi ingredient. The lipid deposition in the aorta arch of rabbit fed Chinese cabbage (7), red pepper powder (42), or garlic (43) was decreased informing that these ingredients might have anti-atherogenic property. The active principle, 3-(4'-hydroxyl-3',5'-dimethoxyphenyl) propionic acid (HDMPPA) in Chinese cabbage kimchi responsible for lipid-lowering activity showed anti-atherogenic effect also (Fig. 2). HDMPPA showed both preventive and therapeutic effect on hypercholesterolemic rabbits and these beneficial effects were comparable to that of Simvastatin which is widely used drug for treating the hypercholesterolemia inthe clinic. The plasma cholesterol and LDL cholesterol was decreased while HDL cholesterol was increased due to the decreased activity of HMG-CoA reductase, CETP, and ACAT (41) and the thickness of aorta arch of rabbit fed cholesterol was

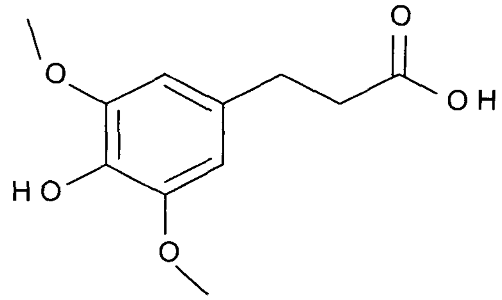
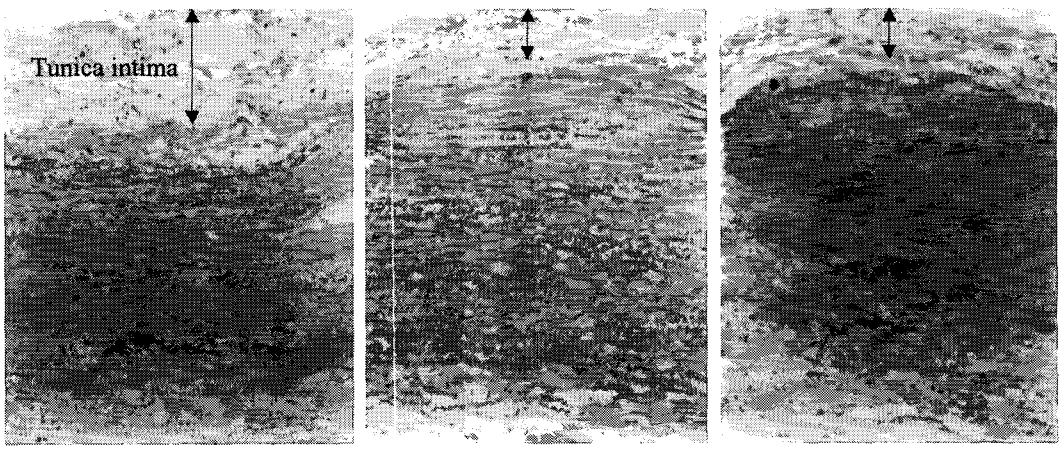


Fig. 2. [3-(4'-hydroxyl-3',5'-dimetoxyphenyl)propionic acid].

significantly reduced (Fig. 3) (8). The mechanisms of 3-(4'-hydroxyl-3',5'-dimethoxyphenyl) propionic acid preventing atherosclerosis was not fully understood however HDMPPA seems to inhibit form cell formation in the smooth muscle cell of aorta by prohibiting the migration of macrophage to the aorta and to inhibit inflammatory response in aorta by increasing NO synthesis (Fig. 4, $p<0.05$) and inhibiting COX-2 expression (Fig. 5, $p<0.05$) (8). HDMPPA increased GSH level and suppressed NO production in Murine macrophage cell (44) Besides this animal study, anti-atherogenic effects of kimchi were observed in the clinical studies. Non-lipidemic Caucasians (4 peoples) consumed 150 g kimchi (1/2 cup) daily with regular meal for 2 weeks showed that lag phase duration of LDL oxidation was extended two times compared to that of baseline (0 week) suggesting that kimchi might have ability to reduce the incidence of arteriosclerosis. And kimchi pill supplementation (3 g daily) study with 12 middle aged healthy Korean adults showed that atherogenic index for kimchi



Control Simvastatin HDMPPA

Fig. 3. Effect of HDMPPA[1)] injected into ear vein on aorta tissue morphology of rabbits fed a high cholesterol diet[2)] for 30 days. Aorta dyed with hematoxylin-eosin was seen under light microscope equipped with automated image analysis (×200).
[1,2)]See the legend of Table 2.

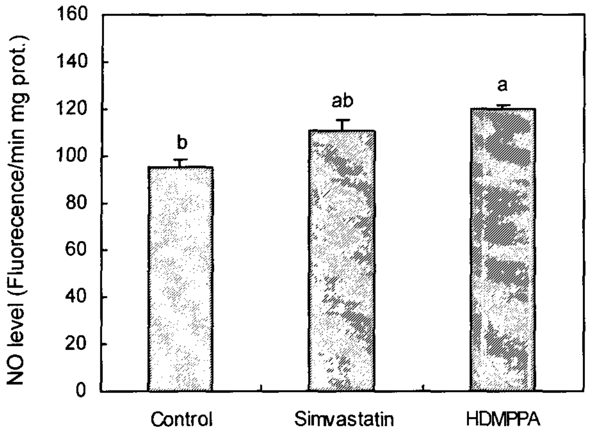


Fig. 4. The effect of HDMPPA[1)] injected into ear vein on NO level of the aorta of rabbits fed a high cholesterol diet[2)] for 30 days.

Values are mean±SD (n=6).

[1,2)]See the legend of Table 2.

[a,b]Data are significantly different by one-way ANOVA followed Duncan's multiple range test at 0.05 level of significance.

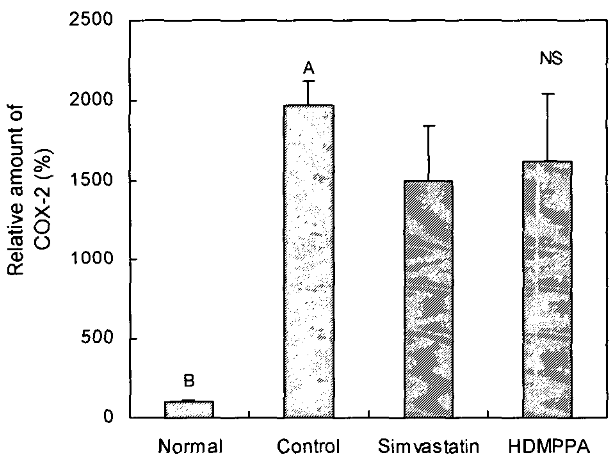


Fig. 5. The effect of HDMPPA[1)] injected into ear vein on COX-2 protein expression of the aorta in rabbits fed a high cholesterol diet[2)] for 30 days.

Values are mean±SD (n=6).

[1,2)]See the legend of Table 2.

[A,B]Data are signifcantly different from normal by Student *t*-test at 0.05 level of significance.

[NS]Data are not significantly different by one-way ANOVA followed Duncan's multiple range test at 0.05 level of significance.

group was decreased compared to that for placebo group (40).

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