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# Effects of cranberry powder on serum lipid profiles and biomarkers of oxidative stress in rats fed an atherogenic diet

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## Abstract

This study investigated that the antioxidative effect of freeze-dried cranberry powder against protein and lipid oxidation and ameliorative effect of serum lipid profile in rat fed atherogenic diet. Six weeks old male Sprague-Dawley rats were divided into the following four groups: normal diet group with 5% corn oil (control), atherogenic diet group with 5% corn oil, 10% lard, 1% cholesterol, and 0.5% sodium cholate (HFC), atherogenic plus 2% cranberry powder diet group (HFC + C2), and atherogenic plus 5% cranberry powder diet group (HFC + C5), and respective diet and water were fed daily for 6 weeks. After the experimental period, the serum lipid profile, such as total cholesterol, HDL-cholesterol, LDL-cholesterol, and triglyceride, ferric reducing ability of plasma (FRAP), plasma phenolics content, superoxide dismutase (SOD) activity, serum protein carbonyl and thiobarbituric acid reactive substances (TBARS) levels were examined. Total phenolic compound and total flavonoid levels in freeze-dried cranberry powder were 9.94 mg/g and 8.12 mg/g, respectively. Serum total cholesterol and LDL-cholesterol levels were not significantly different for cranberry powder treatment, but serum HDL-cholesterol level was significantly increased in HFC + C5 group compared with HFC group. Plasma FRAP value tended to be increased by cranberry powder treatment though there was no significant difference. Plasma total phenol concentrations and SOD activities were not significantly different among all groups. Serum protein carbonyl and TBARS levels were significantly decreased in HFC + C5 group compared with HFC group. Overall results suggested that freeze-dried cranberry powder might have the serum lipid improving effect, as well as antioxidative effect demonstrated by its protective effect against protein and lipid oxidation.

**Key Words: Antherogenic diet, protein carbonyl, TBARS, FRAP, cranberry powder**

## Introduction

In recent years, there has been increasing interest in health and disease prevention in relation to oxidative stress. Enhanced oxidative stress was shown to cause general damage on cells by promoting the oxidation of protein and DNA and lipid peroxidation (Cadenas & Davies, 2000). Several studies have found that biomarkers of oxidative stress were improved by various plant food materials such as tea (Sriram *et al.*, 2008), cocoa (Ramiro-Puig *et al.*, 2007), red wine (Das *et al.*, 2007), and grape juice (Dani *et al.*, 2008), which are known to be high in phenolic compounds. In addition, polyphenolic constituents of wines and grapes juices have been reported to act as free radical scavengers and antimicrobial agents (Sanchez-Moreno *et al.*, 1999; Shahidi & Wanasundara, 1992).

Cranberry has been shown to prevent urinary tract infections, inhibit peptic ulcer-associated bacterium, *Helicobacter pylori*, and induce apoptosis of carcinoma cell (Gotteland *et al.*, 2008; Kontiokari *et al.*, 2001; Krestry *et al.*, 2008). In addition, cranberry was known to have antioxidant properties as shown in plasma antioxidant status, protection of RBC against hemolysis and a cellular antioxidant activity (Villarreal *et al.*, 2007; Wolfe & Liu, 2007).

Cranberry is rich in phenolic phytochemicals such as phenolic acids, flavonoids and ellagic acid. These phytochemicals act as antioxidants, and showed health benefits including reduction of oxidative damage that can cause cancer, heart disease, and other degenerative diseases (Çelik *et al.*, 2008; Vattem *et al.*, 2005). Chu and Liu (2005) reported that phytochemicals in cranberries could inhibit LDL oxidation and induce expression of LDL receptors. Mckay and Blumberg (2007) also reported that cranberry reduced the risk of cardiovascular disease (CVD) by inhibition of LDL oxidation and platelet aggregation, and reducing blood pressure via other anti-thrombotic and anti-inflammatory mechanisms.

Typical forms of cranberry found in markets are dried and ground whole fruits or dried juice. Recently, freeze-dried cranberry powder and 100% cranberry juice are available and introduced their health benefit on prevention of urinary tract infections (UTIs). Piljac-Žegarac *et al.* (2008) reported that total

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phenolics level in cranberry juice was 1546.9 mg/L and Chen *et al.* (2001) reported that cranberry juice had 400 mg/L of total phenolics. Vinson *et al.* (2008) reported that the amount of total phenols in cranberry foods was higher in dried or frozen products than in 100% cranberry juices.

However, most studies used cranberry extract or juice for testing its *in vivo* antioxidant function. In addition, it is limited that investigators studied freeze-dried cranberry powder and its antioxidant and cardiovascular protective effects. Therefore, we employed freeze-dried cranberry powder and investigated its possible health benefits using animal model. In the present paper, we report the antioxidative effect against protein and lipid oxidation and serum lipid profile ameliorative effect of freeze-dried cranberry powder in rats fed atherogenic diet.

## Materials and Methods

### *Animals and diet*

Six-week-old, 30 male Sprague-Dawley rats, weighing 160-190 g, were obtained from Animals Co. (Daehan, Korea) and maintained under a specific condition with a temperature-controlled (23 ± 2℃) and humidity-controlled (50 ± 10%). After a 7-day acclimation period, animals were divided into the following four groups on the basis of comparable mean body weight: 5% corn oil normal diet group (Control, n=7), atherogenic diet group containing 5% corn oil, 10% lard, 1% cholesterol, and 0.5% sodium cholate (HFC, n=7), atherogenic plus 2% cranberry powder diet group (HFC + C2, n=8), and atherogenic plus 5% cranberry powder diet (HFC + C5, n=8). Freeze-dried cranberry powder was purchased from Mastertaste Co. (USA) and all diets were the modified AIN-76 (American Institute of Nutrition, 1977) (Table 1). The experimental

**Table 1.** Composition of control and experimental diet (%)

| Ingredient \ Grou | Control | HFC | HFC + C2 | HFC + C5 |
|---|---|---|---|---|
| Casein | 20 | 20 | 20 | 20 |
| DL-methionine | 0.3 | 0.3 | 0.3 | 0.3 |
| Corn starch | 29.0 | 17.5 | 15.5 | 12.5 |
| Sucrose | 40 | 40 | 40 | 40 |
| Cellulose | 1.0 | 1.0 | 1.0 | 1.0 |
| Corn oil | 5 | 5 | 5 | 5 |
| Lard | - | 10 | 10 | 10 |
| AIN-mineral Mix[1)] | 3.5 | 3.5 | 3.5 | 3.5 |
| AIN-vitamin Mix[2)] | 1.0 | 1.0 | 1.0 | 1.0 |
| Choline chloride | 0.2 | 0.2 | 0.2 | 0.2 |
| Cranberry powder | - | - | 2.0 | 5.0 |
| Cholesterol | - | 1.0 | 1.0 | 1.0 |
| Sodium cholate | - | 0.5 | 0.5 | 0.5 |

Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1)] Composition of AIN-76 salt mixture
[2)] Composition of AIN-76 vitamin mixture

diets and water were fed ad libitum for 6 weeks from the beginning of the experiment. Food intake was recorded daily and the body weight was measured weekly. The end of the experimental period, the animals anesthetized with ethyl ether after 12 hours fasting and blood from the saphenons vein and the liver samples were collected. Blood samples were collected in vacuum tube (Becton-Dickinson, Meylan, France) without anticoagulant for lipid profiles and biochemical analysis, and with heparin for erythrocyte lysate preparation. All blood samples were immediately centrifuged (3,000 rpm, 20 min, 4℃) for the separation of serum, plasma, and erythrocyte. Erythrocyte samples were lysed in 4 times with ice cold HPLC-grade water and centrifuged (10,000 g, 15 min, 4℃), and the supernatant (erythrocyte lysate) was collected for erythrocyte superoxide dismutase (SOD) activity analysis. All samples were stored at -80℃ and thawed only once, just before analysis.

### *Lipid profiles*

Serum total cholesterol, HDL-cholesterol, and triglyceride were detected by enzymatic assay using automatic biochemical analyzing system (Vitalab Selectra E, Vital Scientific N.V., the Netherlands). LDL-cholesterol level was calculated by a formula of Friendewald *et al.* (1972).

### *Ferric reducing ability of plasma (FRAP)*

Plasma antioxidant status was evaluated using ferric reducing ability of plasma (FRAP) assay (Benzie & Strain, 1996). At low pH, the ferric-tripyridyltriazine (Fe(III)-TPTZ) complex is reduced to ferrous tripyridyltriazine (Fe(II)-TPTZ), which is color marker, depends on the ability of sample. Two hundred seventy μl of pre-warmed (at 37℃) freshly prepared FRAP reagent (25 ml of 300 mM sodium acetate buffer pH 3.6, 2.5 ml of 10 mM 2,4,6-tri(2-pyridil)-s-triazine (TPTZ) in 40 mM HCl, 2.5 ml of 20 mM ferric chloride solution) were mixed with 30 μl of plasma diluents. After 15 min incubation at 37℃, absorbance was read at 550 nm. FRAP values are measured by detection of the absorbance change of test sample as the reducing power of antioxidants present in the plasma comparing with that of trolox standard.

### *Total phenolics and total flavonoid assay*

The total soluble phenolic compounds were determined in cranberry powder and plasma with the Folin-Ciocalteu reagent according to the method of Singleton *et al.* (1965) using gallic acid as standard. Mixture of 50 μl sample (plasma or 100 mg freeze-dried cranberry powder in 1 ml of distilled water) and 865 μl distilled water was incubated with 75 μl Folin-Ciocalteu reagent at room temperature for 5 min. Two hundred twenty five μl of 20% $Na_2CO_3$ and 285 μl of distilled water were added to the reaction mixture which was incubated at room temperature for 2 hours, and the absorbance was read at 760 nm. The total

phenolic content is expressed as gallic acid equivalent (GAE) in mM of plasma and milligrams per gram of dried sample.

The total flavonoid level in freeze-dried cranberry powder was measured by spectropotometric method using catechin as standard (Jia *et al.*, 1999). Five hundred μl of diluted sample with distilled water and 75 μl of 5% $NaNO_2$ solution were mixed and incubated at room temperature for 5 min. This mixture was added 150 μl of 10% $AlCl_3$ and allowed to stand for a further 5 min before 0.5 ml of 1 M NaOH was added. The solution was measured the absorbance at 510 nm. The results were expressed as catechin equivalent in milligrams per gram of freeze-dried cranberry powder.

*Plasam and erythrocyte lysate superoxide dismutase (SOD) activity*

Superoxide dismutase (SOD) activities of plasma and erythrocyte lysate were measured by microplate assay method based on the detection of superoxide radicals generated by xanthine oxidase and hypoxanthine using the commercial kit (Cayman chemical superoxide dismutase assay kit, Cayman Chemical Co., USA).

*Serum protein carbonyl and thiobarbituric acid reactive substances levels*

Serum protein carbonyl levels were determined by enzyme linked immunosorbent assay (ELISA) based on the detection of protein hydrazones form from the reaction of dinitrophenylhydrazine (DNP) with protein carbonyl using the Biocell PC test kit ( BioCell Corp., Ltd., New Zealand).

Serum thiobarbituric acid reactive substances (TBARS), which is the important marker of lipid peroxidation, was determined by spectrophotometric method using the OXItek TBARS kit (ZeptoMetrix Co., USA).

*Statistical analysis*

Statistical programs available in SAS program (version 9.1, SAS Inc, Cary, NC, USA) were utilized for data analysis. The significance of difference among the groups was assessed using one-way analysis of variance and Duncan's multiple range tests. Values are presented as the mean ± standard deviation, and a significance test on all results was conducted at level of $p<0.05$ unless otherwise stated.

## Results

*Total phenolics and total flavonoids in cranberry powder*

Total phenolic compound and total flavonoid levels in freeze-dried cranberry powder were 9.94 mg/g and 8.12 mg/g respectively (Table 2).

**Table 2.** Total phenolic compound and total flavonoid levels in cranberry powder

| | Content |
|---|---|
| Total phenolic compound (mg gallic acid equivalents/g) | 9.94 ± 0.13 |
| Total flavonoid (mg catechin equivalents/g) | 8.12 ± 0.25 |

Values are mean ± SD.

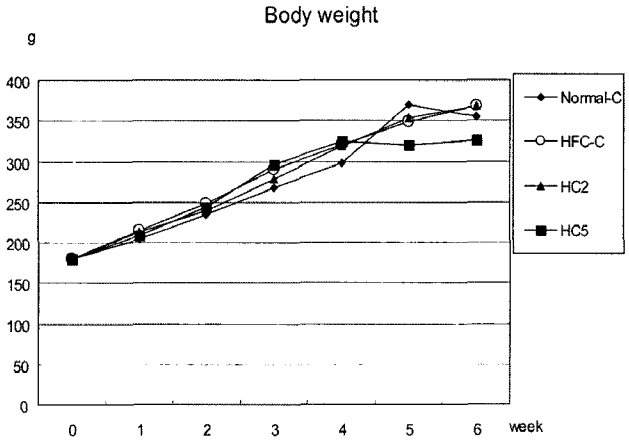


**Fig. 1.** Change of body weights in rat. Values are mean.

*Weights and food intake*

Weight gains, mean of food intake, and food efficiency ratio (FER) are shown in Table 3 and body weight change are shown in Fig. 1. Body weights were gradually increased in all groups, and the weight gains and mean of food intake were decreased in HFC + C5 group (146.2 g, 13.5 g/day) compared with control (182.5 g, 15.5 g/day) or HFC groups (194.5 g, 15.4 g/day), but FER was not significant difference between HFC + C5 (0.25 g/100 g body weight) and control (0.26 g/100 g body weight) or HFC group (0.31 g/100 g body weight).

The final body weight also was decreased in HFC + C5 group compared with control or HFC groups (Table 3). The liver weight and relative liver weight were significantly increased in all atherogenic diet groups than in normal diet group, but the liver weight was decreased in HFC + C5 group (17.8 g) compared with the HFC group (23.0 g) (Table 3).

*Lipid profiles*

The results about the effect of cranberry powder on serum lipid profiles are shown in Table 4. Average of serum triglyceride level in control group was significantly higher than that in all atherogenic diet groups. Serum total cholesterol and LDL-cholesterol levels were significantly increased by atherogenic diets, but there was no significant difference for cranberry powder treatment. Serum HDL-cholesterol level and HDL/LDL ratio were significantly decreased in all atherogenic diet groups compared with normal diet group. However serum HDL-

**Table 3.** Effects of cranberry powder on food intake, food intake efficiency ratio (FER), weight gains, final body weight, liver weight, and relative liver weight in diet-induced hyperlipidemia rat

| Group (n) | Food intake (g/day) | FER[2] (g/100 g body weight) | Weight gains[3] (g) | Final body weight (g) | Liver weight (g) | Relative liver weight (g/100 g body weight) |
|---|---|---|---|---|---|---|
| Control (7) | 15.5 ± 0.6$^{a}$ | 0.26 ± 0.03$^{ab}$ | 182.5 ± 16.3$^{a}$ | 362.5 ± 19.6$^{a}$ | 12.4 ± 1.6$^{c}$ | 3.42 ± 0.36$^{b}$ |
| HFC (7) | 15.4 ± 0.9$^{a}$ | 0.31 ± 0.04$^{ab}$ | 194.5 ± 34.4$^{a}$ | 374.5 ± 34.5$^{a}$ | 23.0 ± 3.6$^{a}$ | 6.13 ± 0.42$^{a}$ |
| HFC + C2 (8) | 14.7 ± 0.5$^{b}$ | 0.31 ± 0.06$^{a}$ | 192.9 ± 38.7$^{a}$ | 372.9 ± 40.0$^{a}$ | 21.3 ± 3.9$^{a}$ | 5.66 ± 0.53$^{a}$ |
| HFC + C5 (8) | 13.5 ± 0.5$^{c}$ | 0.25 ± 0.06$^{b}$ | 146.2 ± 28.5$^{b}$ | 326.3 ± 24.8$^{b}$ | 17.8 ± 2.5$^{b}$ | 5.48 ± 0.86$^{a}$ |

n: number of animals,
Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1] Values are mean ± SD,
Means with the different superscripts are significantly different at $p<0.05$ by Duncan's multiple range test.
[2] FER: food intake efficiency ratio
[3] Total body weight gains for 6 weeks

**Table 4.** Effects of cranberry powder on serum lipid profiles in diet-induced hyperlipidemia rat[1]

| Group (n) | Triglyceride (mg/dl) | Total cholesterol (mg/dl) | HDL-cholesterol (mg/dl) | LDL-cholesterol (mg/dl) | HDL/LDL ratio |
|---|---|---|---|---|---|
| Control (7) | 112.5 ± 49.2$^{a}$ | 200.5 ± 20.8$^{b}$ | 62.9 ± 3.3$^{a}$ | 113.3 ± 14.1$^{b}$ | 0.535 ± 0.040$^{a}$ |
| HFC (7) | 51.9 ± 15.6$^{b}$ | 456.1 ± 82.5$^{a}$ | 38.7 ± 8.3$^{c}$ | 407.0 ± 81.8$^{a}$ | 0.098 ± 0.023$^{b}$ |
| HFC + C2 (8) | 71.3 ± 35.2$^{b}$ | 468.8 ± 170.3$^{a}$ | 36.6 ± 6.1$^{c}$ | 417.9 ± 171.2$^{a}$ | 0.098 ± 0.036$^{b}$ |
| HFC + C5 (7) | 70.0 ± 29.2$^{b}$ | 504.1 ± 99.1$^{a}$ | 49.7 ± 12.6$^{b}$ | 436.3 ± 95.5$^{a}$ | 0.106 ± 0.046$^{b}$ |

n: number of animals,
Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1] Values are mean excluding one of the data over 2SD ± SD,
Means with the different superscripts are significantly different at $p<0.05$ by Duncan's multiple range test.

**Table 5.** Effects of cranberry powder on plasma FRAP and total phenolic levels in diet-induced hyperlipidemia rat[1]

| Group (n) | FRAP[2] (μM) | Total phenolic level (mM gallic acid equivalents) |
|---|---|---|
| Control (7) | 172.9 ± 54.2$^{NS}$ | 6.08 ± 0.20$^{NS}$ |
| HFC (6) | 180.6 ± 59.0 | 6.27 ± 0.17 |
| HFC + C2 (8) | 228.8 ± 82.5 | 6.16 ± 0.39 |
| HFC + C5 (8) | 217.4 ± 64.2 | 6.06 ± 0.30 |

n: number of animals,
Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1] Values are mean ± SD,
Means with the different superscripts are significantly different at $p<0.05$ by Duncan's multiple range test.
[2] FRAP: the ferric reducing ability of plasma

**Table 6.** Effects of cranberry powder on plasma and erythrocyte lysate SOD activity in diet-induced hyperlipidemia rat[1]

| Group (n) | SOD[2] activity in plasma (U/ml) | SOD activity in erythrocyte (U/ml) |
|---|---|---|
| Control (7) | 23.1 ± 9.8$^{NS}$ | 653.6 ± 338.1$^{NS}$ |
| HFC (7) | 27.0 ± 12.3 | 657.8 ± 218.1 |
| HFC + C2 (8) | 29.0 ± 10.9 | 578.7 ± 273.4 |
| HFC + C5 (8) | 26.2 ± 8.1 | 422.7 ± 205.4 |

n: number of animals,
Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1] Values are mean ± SD,
Means with the different superscripts are significantly different at $p<0.05$ by Duncan's multiple range test.
[2] SOD: superoxide dismutase

cholesterol was significantly increased in HFC + C5 group (49.7 mg/dl) compared with HFC group (38.7 mg/dl) (Table 4).

### *Plasma FRAP, total phenolics levels and SOD activity*

Plasma FRAP and total phenolics levels were detected to examine the effects of cranberry powder on antioxidant status. Average of plasma FRAP value shown tended to be increased by cranberry powder treatment, but there was no significant difference (control; 172.9 μM, HFC; 180.6 μM, HFC + C2; 228.8 μM, HFC + C5; 217.4 μM). Plasma total phenolic content was not significantly different for atherogenic diet or cranberry powder treatment (Table 5).

Plasma SOD activity was also not significantly different by atherogenic diet or cranberry powder treatment, but erythrocyte SOD activity showed a tendency to be decreased by cranberry powder treatment although there was not significant (Table 6).

### *Serum protein carbonyls and TBARS levels*

Serum protein carbonyl and TBARS levels were measured to investigate the antioxidant effects of cranberry powder against

**Table 7.** Effects of cranberry powder on serum protein carbonyl and TBARS levels in diet-induced hyperlipidemia rat[1)]

| Group | (n) | Protein carbonyl (nmol/mg) | TBARS[2)] (nmol/ml) |
|---|---|---|---|
| Control | (7) | 0.58 ± 0.11[a] | 14.7 ± 3.3[ab] |
| HFC | (7) | 0.51 ± 0.05[ab] | 15.9 ± 3.8[a] |
| HFC + C2 | (8) | 0.47 ± 0.04[b] | 15.6 ± 6.0[a] |
| HFC + C5 | (8) | 0.24 ± 0.05[c] | 10.7 ± 3.6[b] |

n: number of animals,
Control: normal diet control group,
HFC: atherogenic diet control group,
HFC + C2: atherogenic plus 2% cranberry power diet group,
HFC + C5: atherogenic plus 5% cranberry power diet group.
[1)] Values are mean ± SD,
Means with the different superscripts are significantly different at $p<0,05$ by Duncan's multiple range test.
[2)] TBARS: thiobarbituric acid reactive substances

oxidative damage such as protein oxidation and lipid peroxidation. Mean serum protein carbonyl level was found to be significantly decreased in HFC + C2 (0.47 mmol/mg) and HFC + C5 groups (0.24 nmol/mg) as compared to control group (0.58 nmol/mg) and significantly decreased in HFC + C5 group as compared to HFC group (0.51 nmol/mg) (Table 8). Serum TBARS level was also significantly decreased in HFC + C5 group (10.7 nmol/ml) compared with HFC group (15.9 nmol/ml) (Table 7).

## Discussion

This study examined the serum lipid profile ameliorative and antioxidative effects of freeze-dried cranberry powder in rats fed atherogenic diet. Cranberry is known to be a good source of antioxidants, which have health benefits such as anti-adhension activity, antiviral, and anticancer properties (Bomser *et al.*, 1996; Howell *et al.*, 2005).

In this study, we used freeze-dried cranberry powder, and its total phenolics and total flavonoid levels were 9.94 mg/g and 8.12 mg/g, respectively. Sun *et al.* (2002) reported that cranberry had the highest total phenolic content, followed by apple, red grape, strawberry, pineapple, banana, peach, lemon, orange, pear, and grapefruit. Çelik *et al.* (2008) reported that total phenolics contents of cranberry fruits were different among each maturation stage and dark red cranberry had 4.745 mg gallic acid equivalents/g of total phenolics. Vinson *et al.* (2005) also reported that the average total phenols were 663 mg/100 g for fresh cranberries and 870 mg/100 g for dried cranberries, which was a similar level with our study. According to the study of Vinson *et al.* (2008), the amount of total phenols in cranberry foods on fresh weight basis was higher in dried or frozen products than in juice or sauce forms. Piljac-Žegarac *et al.* (2008) reported that total phenolics level in cranberry juice was 1546.9 mg/L. Chen *et al.* (2001) reported that cranberry juice had 400 mg/L of total phenolics including flavonoids, and the major forms of phenolics and flavonoids were benzoic acid, quercetin and myricetin. In a study of Bailey *et al.* (2007), concentrated cranberry extract with 30% phenolics was used to investigate its effects on the recurrent urinary tract infections (UTIs) in women, since the concentrated active phenolics might be more effective in preventing UTIs. However, the optimum level and form of administration was not suggested. In the current study, we used just freeze-dried powder because its total phenolics level was higher than fresh or juice type of cranberry and it was a natural food form without excess processes such as concentration and extraction.

Mckay and Blumberg (2007) suggested that polyphenols in cranberry might reduce the cardiovascular disease risk factor such as LDL oxidation, platelet aggregation, and high blood pressure. Ghazala *et al.* (2008) also reported that plasma LDL-cholesterol and LDL oxidation were reduced by cranberry extract fortification. However, Ruel *et al.* (2006) reported that total and LDL-cholesterol were not changed but HDL-cholesterol was increased by cranberry juice consumption in men. In the current study, we also observed similar results that serum total cholesterol and LDL-cholesterol levels were not significantly different in rats with and without cranberry powder treatment, but serum HDL-cholesterol level was significantly increased by 5% cranberry powder fortification. Deyhim *et al.* (2007) also reported that drinking cranberry juice increased plasma antioxidant capacity but did not change the cholesterol concentrations in liver and plasma of rat and it assumed that cranberry juice might increase antioxidant status without affecting cholesterol homeostasis.

In case of *in vitro* study, cranberry was known that it has abundant phytochemicals and the highest cellular antioxidant activity among tested food materials including apple, red grape and green grape (Wolfe & Liu, 2007). Villarreal *et al.* (2007) also reported that plasma antioxidant status was increased and red blood cell was protected against hemolysis by drinking cranberry juice in rats. In this study, plasma total antioxidant capacity measure by FRAP tended to be increased by cranberry powder treatment, although there was no significant difference. In several short-term intervention studies for cranberry juice, it was shown that plasma antioxidant capacity was increased by cranberry juice consumption (Ruel *et al.*, 2005; Zhang & Zue, 2004).

Pedersen *et al.* (2000) reported that total phenolics level in plasma was slightly increased four hours following 500 ml cranberry juice consumption for one time. However, according to the study of Ruel *et al.* (2005), dietary and possibly active compounds from cranberry juice were rapidly degraded in plasma after consumption. This metabolic degradation might explain in part the findings observed in a study by Duthie *et al.* (2006) and the current study. Duthie *et al.* (2006) showed that total phenols in fasting plasma were not different between cranberry juice consumption and placebo groups in their 2 week study. When rats were fed atherogenic diet fortified with cranberry powder, we also failed to observe the significant changes in total phenolics content of fasting plasma.

In this study, plasma and erythrocyte SOD activities were not significantly different by atherogenic diet or cranberry powder treatment. Similarly, Duthie *et al.* (2006) found that plasma SOD activities were not different between cranberry juice consumption and placebo groups. However, there was a conflict finding observed in a study by Deyhim *et al.* (2007), which reported that cranberry juice increased plasma SOD activity. For biomarkers of protein and lipid oxidation, mean serum protein carbonyl and TBARS levels were significantly decreased in 5% cranberry powder treated group compared with atherogenic diet fed group in this study. Serum protein carbonyl formation has been proposed to be an early marker for protein oxidation (Reznick & Packer, 1994) and serum TBARS is regarded as a marker of lipid peroxidation. In a human intervention study with the dried cranberry juice, serum protein oxidation level was significantly decreased by a 1200 mg of dried cranberry juice consumption (Valentova *et al.*, 2007). Deyhim *et al.* (2007) reported that cranberry juice increased plasma antioxidant capacity and reduced malondialdehyde concentrations. Vattem *et al.* (2005) also reported that cranberry phenolics decreased MDA formation in oxidatively stressed porcine muscle and it suggested that exogenously treated phenolic phytochemicals could be reducing the oxidative stress. Including the results from the current study, several trials have shown beneficial effect of cranberry consumption on protein and lipid oxidation. These consensus outcomes may explain the antioxidative effect of cranberry powder and juice against oxidative damage.

Overall results of the present study showed that 5% of the freeze-dried cranberry powder treatment increased HDL-cholesterol and reduced protein carbonyl and TBARS levels in rat fed atherogenic diet. It assumed that cranberry powder might have the plasma lipid improving effect and antioxidant effect against oxidative damage. However, since the current study was done in animal model, the findings from this study cannot be applied to the human diet directly. Therefore, further studies are needed to evaluate health benefits and effective dose of cranberry powder in humans. In addition, it is suggested that the mechanisms of antioxidant action and lipid improving effect of cranberry powder and its components should be elucidated for better understanding the health benefits of this plant food with high phenolics.

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