



Effects of Dietary Wild-ginseng Adventitious Root Meal on Growth Performance, Blood Profiles, Relative Organ Weight and Meat Quality in Broiler Chickens

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ABSTRACT : This experiment was conducted to evaluate the effects of dietary wild-ginseng adventitious root meal (WGM) on growth performance, blood profiles, relative organ weight and meat quality of broiler chickens. A total of 480, 2-day-old male broiler chicks (BW = 42.8±1.38 g) were randomly allocated to 1 of 4 dietary treatments (6 cages with 20 broilers per cage). Dietary treatments were: i) CON (basal diet), ii) WGM0.1 (basal diet+0.1% WGM), iii) WGM0.2 (basal diet+0.2% WGM) and iv) WGM0.3 (basal diet+0.3% WGM). Birds fed WGM0.3 diet ($p<0.05$) had a higher feed intake (FI) than those fed the CON diet during weeks 1 to 3. During weeks 3 to 5, dietary WGM0.1 treatment led to a higher ($p<0.05$) BW gain (BWG) and feed intake (FI) compared with the CON and WGM0.3 treatments. Overall, birds fed WGM0.1 improved BWG and FI compared with those fed the CON treatment. A greater lymphocyte count was observed ($p<0.05$) in WGM0.2 and WGM0.3 treatments compared with the CON treatment; dietary WGM decreased ($p<0.05$) the total cholesterol concentration compared with the CON group. The inclusion of WGM increased the relative weight of spleen and bursa of fabricius ($p<0.05$) compared with CON, while less abdominal fat was observed in the WGM0.3 treatment ($p<0.05$) compared with CON. The 2-thiobarbituric acid reactive substances (TBARS) of breast muscle were decreased ($p<0.05$) by WGM supplementation. Overall, our results indicated that the use of WGM at the 0.1% level could enhance growth performance in broilers. The supplementation of WGM could induce a decreased TBARS, abdominal fat and serum cholesterol in broiler chickens. (**Key Words** : Broiler, Ginseng, Polysaccharide, Saponin)

INTRODUCTION

Historically, ginseng is considered to be one of the most valuable medicinal herbs in East Asian countries such as China, Korea and Japan. Most notable features of ginseng have been suggested to be the modulation of the immune system, cancer and diabetes (Vogler et al., 1999; Dey et al., 2003). Kiefer and Pantuso (2003) also reported that ginseng may improve psychological function, immunity and conditions associated with diabetes.

It has previously been documented that ginseng contains various bio-active components such as saponins, antioxidants, peptides, polysaccharides, alkaloids, lignans and polyacetylenes, of which saponins (ginsenoside) are considered to be the principal bioactive ingredient (Jo et al., 1995; Sticher, 1998; Palazon et al., 2003), and are believed to have immune-stimulatory, anti-fatigue and hepato-

protective physiological effects (Wu and Zhong, 1999). However, ginseng root is very expensive because of difficulty with its cultivation, especially the wild ginseng. Therefore, plant tissue culture methods have been explored as a potentially efficient alternative for the mass production of ginseng cells and tissues. Ushiyama et al. (1991) suggested that cells derived from pilot-plant cultures have been applied commercially to various foods in Japan. Kevers et al. (1999) reported an *in vitro* adventitious root culture system, which could produce an adventitious root containing the same saponin (Ginsenoside) as the native roots (Choi et al., 2000; Yu et al., 2002), and can be produced in a large-scale bioreactor (Yu et al., 2002). Our previous study also reported that feeding fermented wild-ginseng culture by-product can increase egg production and egg quality (Jang et al., 2007).

Therefore, the objective of the present study was to investigate the effects of wild-ginseng adventitious root meal (WGM) on growth performance, blood profiles, relative organ weight and meat quality in broiler chickens.

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Received June 18, 2010; Accepted September 6, 2010

MATERIALS AND METHODS

Preparation of WGM

The WGM used in this study was supplied by CBN BIOTECH System Inc. (South Korea). Briefly, wild-ginseng were collected, sterilized, and cultured as described by Ali et al. (2006). Cultures were maintained at 25±2°C for 4 wk for callus induction. For callus proliferation, the callus was sub-cultured on fresh medium at 25±2°C in darkness. Callus was transferred to solid Murashige and Skoog (MS) medium (1965) containing 3.0 mg/L indole butyric acid (IBA) and 3% sucrose to induce adventitious root at 25±2°C in darkness. The induced adventitious roots were sub-cultured in a bioreactor culture containing liquid MS medium supplemented with 3.0 mg/L indole butyric acid (IBA) and 3% sucrose at 25±2°C in darkness. Adventitious roots were selected and proliferated further in a biomass factory containing MS liquid medium supplemented with 5.0 mg/L IBA, 0.1 mg/L kinetin, and 5% sucrose for 40 to 45 d, after which the adventitious root was harvested and dried for further experiments.

Experimental animals

A total of 480 2-d-old male Arbor Acres broiler chicks were purchased from a commercial hatchery. All birds were randomly allotted to different stainless steel cages (1.75×1.55 m) with concrete floors covered with clean rice bran. The temperature of the room was maintained at 33±1°C for the first 3 d, after which it was gradually reduced by 3°C per wk until reaching 24°C, and was maintained for the remainder of the experiment. Artificial light was provided 24 h/d by fluorescent lights. The experiment was conducted in 2 phases consisting of a starter phase (d 0 to 21) and a finisher phase (d 22 to 35). All birds used in this trial were handled in accordance with the guidelines set forth by the Animal Welfare Committee of Dankook University.

Experimental design and diets

Broilers were randomly allotted to 1 of 4 dietary treatments. Diet formulation is shown in Table 1. Dietary treatments were: i) CON (basal diet), ii) WGM0.1 (basal diet+0.1% WGM), iii) WGM0.2 (basal diet+0.2% WGM), and iv) WGM0.3 (basal diet+0.3% WGM). There were 6 replicated cages per treatment with 20 birds per cage. All diets were formulated to meet or exceed the NRC (1994) requirements for broiler chickens.

Sampling and measurements

The broilers were weighed and feed intake (FI) was recorded on d 0, 7, 21 and 35. This information was then used to calculate BW gain (BWG) and feed conversion ratio (FCR). At the end of the experiment, 3 broilers (without feed) were randomly selected from each treatment and

Table 1. Diet composition (as-fed basis)

Item	Starter ¹	Finisher ¹
Ingredients (%)		
Corn	55.67	63.21
Soybean meal (CP 48%)	28.25	24.61
Corn gluten meal (CP 60%)	6.50	3.50
Soybean oil	5.50	4.89
Tricalcium phosphate	2.46	2.29
Limestone	0.89	0.75
Sodium chloride	0.20	0.20
DL-methionine	0.07	0.07
L-lysine-HCl	0.06	0.08
Vitamin premix ²	0.20	0.20
Trace mineral premix ³	0.20	0.20
Chemical composition ⁴		
ME (MJ/kg)	12.97	12.76
CP (%)	22.00	19.00
Lysine (%)	1.10	1.00
Ca (%)	1.00	0.90
Available P (%)	0.80	0.75
Met+Cys (%)	0.89	0.84
Analysis composition (%)		
CP	22.30	20.10
Ca	1.00	0.91
Met+Cys	0.88	0.85
Available P	0.45	0.40

¹ Starter diets, provided during weeks 0 to 3; Finisher diets, provided during weeks 4 to 5.

² Provided per kg of diet: 15,000 IU of vitamin A, 3,750 IU of vitamin D₃, 37.5 mg of vitamin E, 2.55 mg of vitamin K₃, 3 mg of vitamin B₁, 7.5 mg of vitamin B₂, 4.5 mg of vitamin B₆, 24 mg of vitamin B₁₂, 51 mg of niacin, 1.5 mg of folic acid, 126 mg of biotin and 13.5 mg of pantothenic acid.

³ Provided per kg of diet: 37.5 mg of Zn, 37.5 mg of Mn, 37.5 mg of Fe, 3.75 mg of Cu, 0.83 mg of I, 62.5 mg of S and 0.23 mg of Se.

⁴ Calculated values.

blood samples were collected from the wing vein into a sterile syringe and stored at -4°C. Samples for serum analysis were then centrifuged at 3,000×g for 15 min, after which the serum was separated. IgG was analyzed using nephelometry (Dade Behring, Marburg, Germany). Concentrations of total protein, triglyceride and total cholesterol in the serum samples were analyzed with an automatic biochemical analyzer (RA-1000, Bayer Corp., Tarrytown, NY) using colorimetric methods. Blood cell counts [white blood cells (WBC), red blood cells (RBC), and lymphocytes] in the whole blood were analyzed using an automatic blood analyzer (ADVIA 120, Bayer, NY). After blood collection, the same broilers were weighed individually and euthanized by cervical dislocation. The liver, bursa of fabricius, spleen, breast muscle and abdominal fat were then removed by trained personnel and weighed. Breast muscle was stored at -20°C for subsequent

Table 2. Effect of dietary wild-ginseng adventitious root meal on growth performance in broiler chickens

Items	CON ¹	WGM0.1 ¹	WGM0.2 ¹	WGM0.3 ¹	SE ²
0 to 1 weeks					
Weight gain (g)	129	133	130	132	2.03
Feed intake (g)	170	171	174	172	2.33
Feed conversion ratio	1.32	1.29	1.34	1.31	0.031
1 to 3 weeks					
Weight gain (g)	645	647	629	646	9.93
Feed intake (g)	889 ^b	901 ^b	898 ^b	919 ^a	8.79
Feed conversion ratio	1.38	1.39	1.43	1.42	0.027
3 to 5 weeks					
Weight gain (g)	740 ^b	826 ^a	784 ^{ab}	728 ^b	24.24
Feed intake (g)	1,496 ^b	1,599 ^a	1,539 ^{ab}	1,492 ^b	30.26
Feed conversion ratio	2.02	1.94	1.98	2.05	0.062
0 to 5 weeks					
Weight gain (g)	1,514 ^b	1,606 ^a	1,542 ^{ab}	1,505 ^b	23.47
Feed intake (g)	2,555 ^b	2,671 ^a	2,612 ^{ab}	2,583 ^{ab}	27.86
Feed conversion ratio	1.69	1.67	1.70	1.72	0.032

¹ Each mean represents 6 pens with 120 chicks per treatment. Dietary treatments were as follows: CON = basal diet; WGM0.1 = basal diet+WGM 0.1%; WGM0.2 = basal diet+WGM 0.2%; WGM0.3 = basal diet+WGM 0.3%.

² Pooled standard error.

^{a,b} Means in the same row with different superscripts differ ($p < 0.05$).

analysis. All organ weights are expressed as a percentage (%) of BW.

The meat quality was evaluated by measuring the lightness (L*), redness (a*) and yellowness (b*) color values using a Minolta CR410 chroma meter (Konica Minolta Sensing, Inc., Osaka, Japan). At the same time, duplicate pH values for each sample were measured using a pH meter (Fisher Scientific, Pittsburgh, PA, USA).

The 2-thiobarbituric acid reactive substances (TBARS) of breast muscle (*P. major*) were measured using the method described by Witte et al. (1970). The TBARS values were expressed in terms of milligrams of malonaldehyde per kilogram of muscle. Trichloroacetic acid solution (TCA, 20% wt/vol) was utilized for the extraction. UV absorption spectrophotometry (UV-1201, Shimadzu, Japan) was employed for the spectrophotometric analyses.

Statistical analyses

Data were analyzed by ANOVA using the GLM procedure of SAS (SAS Institute, 1996), with the pen being defined as the experimental unit. Differences among all treatments were separated by Duncan's multiple range test. Results were expressed as the least squares mean and SE. Probability values less than 0.05 were considered significant.

RESULTS

Growth performance

During the first week, no differences were observed in BWG, FI and FCR among treatments (Table 2). During

weeks 1 to 3, the FI of birds fed WGM0.3 was higher ($p < 0.05$) than that of birds fed other treatment diets. Dietary WGM0.1 treatment improved ($p < 0.05$) BWG and FI compared with CON and WGM0.3 treatments during weeks 3 to 5. Overall, the BWG of birds fed WGM0.1 was increased ($p < 0.05$) compared with CON and WGM0.3 diets, while the FI of birds in WGM0.1 was greater ($p < 0.05$) than that of CON birds. No difference was observed in FCR throughout the experiment.

Blood profiles

No effect was observed on total protein, triglyceride, IgG, RBC and WBC among treatments (Table 3). The lymphocyte count was higher ($p < 0.05$) in WGM0.2 and WGM0.3 groups than in the CON treatment, with WGM0.1 showing an intermediate value. Dietary WGM significantly decreased ($p < 0.05$) total cholesterol concentration compared with the CON treatment.

Relative organ weight

The relative organ weight of liver, breast meat and gizzard did not differ among treatments (Table 4). The weight of bursa of fabricius of the birds increased ($p < 0.05$) in response to WGM0.2 and WGM0.3 treatments compared with CON. A greater ($p < 0.05$) relative spleen weight was observed with dietary WGM supplementation. Additionally, the level of abdominal fat was decreased ($p < 0.05$) with the WGM0.3 compared with CON treatment.

Meat quality

The pH, L*, a* and b* values did not differ among

Table 3. Effect of dietary wild-ginseng adventitious root meal on blood profiles in broiler chickens

Items	CON ¹	WGM0.1 ¹	WGM0.2 ¹	WGM0.3 ¹	SE ²
Total protein (g/dl)	3.50	3.17	3.67	3.45	0.178
Total cholesterol (mg/dl)	147 ^a	129 ^b	130 ^b	121 ^b	7.3
Triglyceride (mg/dl)	46.7	45.3	44.0	45.7	4.08
IgG (mg/dl)	0.42	0.48	0.43	0.46	0.06
RBC ($\times 10^6/\mu\text{l}$)	2.05	2.09	2.22	2.03	0.061
WBC ($\times 10^4/\mu\text{l}$)	34.99	34.96	35.99	32.01	2.713
Lymphocyte (%) ³	75.67 ^b	80.17 ^{ab}	83.17 ^a	83.17 ^a	3.336

¹ Each mean represents 6 pens with 18 chicks per treatment. Dietary treatments were as follows: CON = basal diet; WGM0.1 = basal diet +WGM 0.1%; WGM0.2 = basal diet+WGM 0.2%; WGM0.3 = basal diet+WGM 0.3%.

² Pooled standard error.

³ Values are presented as the percentage of the total WBC count.

^{ab} Means in the same row with different superscripts differ ($p < 0.05$).

Table 4. Effect of dietary wild-ginseng adventitious root meal on relative organ weight in broiler chickens

Items (%)	CON ¹	WGM0.1 ¹	WGM0.2 ¹	WGM0.3 ¹	SE ²
Liver	2.58	2.43	2.42	2.56	0.267
Bursa of fabricius	0.17 ^b	0.19 ^{ab}	0.23 ^a	0.22 ^a	0.024
Spleen	0.09 ^b	0.12 ^a	0.13 ^a	0.14 ^a	0.013
Gizzard	1.60	1.50	1.53	1.40	0.102
Breast (P. major)	8.00	7.32	7.46	7.47	0.426
Abdominal fat	1.93 ^a	1.75 ^{ab}	1.65 ^{ab}	1.50 ^b	0.202

¹ Each mean represents 6 pens with 18 chicks per treatment. Dietary treatments were as follows: CON = basal diet; WGM0.1 = basal diet +WGM 0.1%; WGM0.2 = basal diet+WGM 0.2%; WGM0.3 = basal diet+WGM 0.3%.

² Pooled standard error.

^{ab} Means in the same row with different superscripts differ ($p < 0.05$).

treatment (Table 5). The inclusion of WGM decreased the TBARS value ($p < 0.05$) compared with CON treatment.

DISCUSSION

As demonstrated elsewhere, ginseng is one of the most valuable medicinal herbs in East Asian countries such as China, Korea and Japan. It was previously found that its most notable features are modulation of the immune system, and activities against stress effect, cancer and diabetes (Vogler et al., 1999; Dey et al., 2003). Kiefer and Pantuso (2003) reported that ginseng may improve psychological function and immunity. Our previous study also reported that the inclusion of fermented wild-ginseng culture by-

product can increase the performance of laying hens (Jang et al., 2007). Therefore, in this study we hypothesized that dietary WGM could improve the performance of broilers. As expected, dietary WGM0.1 increased BWG and FI compared with the CON treatment during weeks 3 to 5 and the overall period. However, the higher level (3 g/kg) of WGM supplementation did not affect BWG compared with the CON treatment; the reason is likely to be the negative effect of higher dosage supplementation on FI and growth performance, similarly to the results of Jenkins and Atwal (1994), who suggested that dietary saponins (gypsophila saponins 3 g/kg) had adverse effects on feed consumption and growth of chicks because of their bitter taste (Milgate and Roberts, 1995). Interestingly, a higher FI was observed

Table 5. Effect of dietary wild-ginseng adventitious root meal on meat quality in broiler chickens

Item	CON ¹	WGM0.1 ¹	WGM0.2 ¹	WGM0.3 ¹	SE ²
pH	6.13	6.11	6.10	6.14	0.024
TBARS (mg MDA/kg)	0.043 ^a	0.025 ^b	0.021 ^b	0.022 ^b	0.005
Meat color					
Lightness (L*)	57.66	56.62	55.69	56.90	1.108
Redness (a*)	15.27	13.40	15.35	14.72	0.818
Yellowness (b*)	10.40	9.18	9.25	8.62	0.782

¹ Each mean represents 6 pens with 18 chicks per treatment. Dietary treatments were as follows: CON = basal diet; WGM0.1 = basal diet +WGM 0.1%; WGM0.2 = basal diet+WGM 0.2%; WGM0.3 = basal diet+WGM 0.3%.

² Pooled standard error.

^{ab} Means in the same row with different superscripts differ ($p < 0.05$).

during weeks 1 to 3 in WGM0.3 than in the CON group. The reason for this increase is currently unknown, it may have been due to the higher feed waste and lower feed intake in this group.

Moreover, the inclusion of WGM significantly increased the lymphocyte count compared with the CON treatment. It was previously suggested that the addition of ginsenosides to bacerin could increase lymphocyte proliferation in response to specific *S. aureus* antigen (Hu et al., 2003). Zhang et al. (2009) also found that ginseng polysaccharides can enhance T and B lymphocyte proliferation *in vitro*. Therefore, it is evident that dietary ginseng can increase lymphocyte proliferation in animals. However, animal studies on the effect of ginseng on immunity are limited, and no comparison could be made with the results of this study. Furthermore, previous studies suggested that dietary ginseng impaired avian hepatic cholesterogenesis and reduced serum total cholesterol and LDL cholesterol levels in avian species (Qureshi et al., 1983; Muwalla and Abuirmeileh, 1990). Lindahl et al. (1957) suggested that saponins can form insoluble complexes with cholesterol because of their hydrophobic portion (the aglycone or sapogenin), which could be associated (lipophilic bonding) with the hydrophobic sterol nucleus. Moreover, Qureshi et al. (1983) also reported dietary ginseng reduced the β -hydroxy- β -methylglutaryl-CoA (HMG-CoA) reductase activity and cholesterol 7 α -hydroxylase activity when compared with a diet without ginseng, and suggested ginsenoside (saponins) are the active agent for the suppression of cholesterogenesis and lipogenesis. In our study, dietary ginseng significantly decreased total cholesterol levels in broilers, which confirms the relationship between saponins and cholesterol and accords with Jang et al. (2007), who suggested that fermented ginseng culture by-product could decrease cholesterol in laying hens.

Furthermore, measurement of immune organ weight is a common method to evaluate the immune status of chickens (Heckert et al., 2002). Good development of these organs is also considered to be crucial for optimal site of immunoglobulin synthesis (Glick, 1977). In this study, the inclusion of dietary WGM increased the relative weight of the bursa of fabricius and spleen of broilers compared with CON treatment, which accords with Dong et al. (2007) who suggested polysavone (main saponin and polysaccharides) supplementation increased the relative spleen weight and bursa weight in comparison with CON treatment. However, to the best of our knowledge, this is the first study conducted with ginseng product in broilers and thus no comparison could be made with other studies. Therefore, further research is still needed to investigate the effect of ginseng in broilers. Moreover, abdominal fat of broilers is considered to be a waste product in the poultry industry; it

represents an added expense during treatment, as well as a loss in the market. Our results revealed that this type of waste could be reduced by WGM supplementation. Furthermore, lipid oxidation is a major cause of chemical spoilage in the food system, which can adversely affect the texture, color, flavor, nutritive value and safety of muscle foods (Buckley et al., 1995). In our study, the inclusion of WGM decreased TBARS value, indicating that dietary WGM could induce an anti-oxidative effect to the broiler meat, which is similar to McCarthy et al. (2001), who suggested that various plant extracts (rosemary, tea catechin, vitamin E and ginseng) could decrease TBARS of raw pork patties and cooked pork patties.

Collectively, the results of this study indicated that the use of 0.1% WGM added to the diet could increase growth performance, while the supplemental WGM induced a linear decrease in abdominal fat and serum cholesterol in broilers.

IMPLICATION

Massive amounts of information indicate that WGM has many functional and nutritional properties that may have application for animal nutrition. These beneficial effects include anti-tumor activity, immune-stimulating activity, lipid metabolism and reduced cholesterol. However, there is little data about WGM utilization in livestock. Therefore, the effects of WGM supplementation to livestock should be further evaluated.

REFERENCES

- Ali, M. B., E. J. Hahn and K. Y. Paek. 2006. Copper-induced changes in the growth, oxidative metabolism, and saponin production in suspension culture roots of panax ginseng in bioreactors. *Plant Cell Rep.* 25:1122-1132.
- Buckley, D. J., P. A. Morrissey and J. I. Gray. 1995. Influence of dietary vitamin E on the oxidative stability and quality of pig meat. *J. Anim. Sci.* 73:3122-3130.
- Choi, S. M., S. H. Son, S. R. Yun, O. W. Kwon, J. H. Seon and K. Y. Paek. 2000. Pilot-scale culture of adventitious roots of ginseng in a bioreactor system. *Plant Cell Tissue Organ. Cult.* 62:187-193.
- Dey, L., J. T. Xie, A. Wang, J. Wu, S. A. Maleckar and C. S. Yuna. 2003. Anti-hyperglycemic effects of ginseng: comparison between root and berry. *Phyomedicine* 10:600-605.
- Dong, X. F., W. W. Gao, J. M. Tong, H. Q. Jia, R. N. Sa and Q. Zhang. 2007. Effect of polysavone (alfalfa extract) on abdominal fat deposition and immunity in broiler chickens. *Poult. Sci.* 86:1955-1959.
- Glick, B. 1977. The bursa of Fabricius and immunoglobulin synthesis. *Int. Rev. Cytol.* 48:345-402.
- Heckert, R. A., I. Estevez, E. Russek-Cohen and R. Pettit-Riley. 2002. Effects of density and perch availability on the immune status of broilers. *Poult. Sci.* 81(4):451-457.
- Hu, Y. J., Y. C. Lin, G. L. Zhou and D. Q. Yu. 2003. Effect of

- Chinese extracts on performance and T lymphocyte cell subset of yellow broilers. *China Poult.* 12:14-17.
- Jang, H. D., H. J. Kim, J. H. Cho, Y. J. Chen, J. S. Yoo, B. J. Min, J. C. Park and I. H. Kim. 2007. Effect of dietary supplementation of fermented wild ginseng culture by products on egg productivity, egg quality, blood characteristics and ginsenoside concentration of yolk in laying hens. *Kor. J. Poult. Sci.* 34:271-278.
- Jenkins, K. J. and A. S. Atwal. 1994. Effects of dietary saponins on fecal bile acids and neutral sterols, and availability of vitamins A and E in the chick. *J. Nutr. Biochem.* 5:134-135.
- Jo, J. S., Y. N. Han, H. I. Oh, H. Park, H. S. Sung and J. I. Park. 1995. Korean ginseng has a characteristic shape. In *Understanding of Korean Ginseng*. pp. 37-38. Hanrimwon Publishing Co., Seoul Korea.
- Kevers, C., P. Jacques, P. Thonart and P. Gaspar, 1999. *In vitro* root cultures of panax ginseng and *P. quinquefolium*. *Plant Growth Regul.* 27:173-178.
- Kiefer, D. and T. Pantuso. 2003. Panax ginseng. *Am. Farm Physician* 68:1539-1542.
- Lindahl, I. L., W. T. Shalkop, R. W. Dougherty, C. R. Thompson, G. R. Van Atta, E. M. Bickoff, E. D. Walter, A. G. Livingston, J. Guggolz, R. H. Wilson, M. B. Sideman and F. De Eds. 1957. Alfalfa saponins. Studies on their chemical, pharmacological, and physiological properties in relation to ruminant bloat. USDA Technical Bulletin No. 1161, Washington, DC.
- McCarthy, T. L., J. P. Kerry, J. F. Kerry, P. B. Lynch and D. J. Buckley. 2001. Evaluation of the antioxidant potential of natural food/plant extracts as compared with synthetic antioxidants and vitamin E in raw and cooked pork patties. *Meat Sci.* 57:45-52.
- Milgate, J. and D. C. K. Roberts. 1995. The nutrition and biological significance of saponins. *Nutr. Res.* 15:1223-1249.
- Muwalla, M. M. and N. M. Abuirmeileh. 1990. Suppression of avian hepatic cholesterogenesis by dietary ginseng. *J. Nutr. Biochem.* 1(10):518-521.
- NRC. 1994. Nutrient requirements of poultry. 9th rev. ed. Natl. Acad. Press, Washington, DC.
- Palazon, J., R. M. Cusido, M. Bonfil, A. Mallol, E. Moyamo, C. Marales and M. T. Pinol. 2003. Elicitation of different Panax ginseng transformed root phenotypes for an improvement ginsenoside production. *Plant Physiol. Biochem.* 41:1019-1025.
- Qureshi, A. A., Z. Z. Din, N. Abuirmeileh, W. C. Burger, Y. Ahmad and C. E. Elson. 1983. Suppression of avian hepatic lipid metabolism by solvent extracts of garlic. Impact on Serum Lipid. *J. Nutr.* 113:1746-1755.
- SAS. 1996. SAS User's Guide: Statistics. Version 7.0. SAS Institute, Cary, NC.
- Sticher, O. 1998. Getting to the root of ginseng. *Chemtech* 28:26-32.
- Ushiyama, K. 1991. Large-scale culture of ginseng. In *Plant cell culture in japan: progress in production of useful plant metabolite by Japanese enterprises using plant cell culture technology* (Ed, A. Komamine, M. Misawa and F. Dicosmo). CMC, Tokyo. pp. 92-98.
- Vogler, B. K., M. H. Pittler and E. Ernst. 1999. The efficacy of ginseng: A systematic review of randomized clinical trials. *Eur. J. Clin. Pharmacol.* 55:567-575.
- Witte, V. C., G. F. Krause and M. E. Bailey. 1970. A new extraction method for determining 2-thiobarbituric acid values for pork and beef during storage. *J. Food Sci.* 35:585-592.
- Wu, J. and J. J. Zhong. 1999. Production of ginseng and its bioactive components in plant cell culture: Current technological and applied aspects. *J. Biotechnol.* 68:89-99.
- Yu, K. W., W. Gao, E. J. Hahn and K. Y. Paek. 2002. Jasmonic acid improves ginsenoside accumulation in adventitious root culture of Panax ginseng C. A. Meyer. *Biochem. Eng. J.* 11:211-215.
- Zhang, X., L. Yu, H. T. Bi, X. H. Li, W. H. Ni, H. Han, N. Li, B. Q. Wang, Y. F. Zhou and G. H. Tai. 2009. Total fractionation and characterization of the water-soluble polysaccharides isolated from Panax ginseng C. A. Meyer. *Carbohydr. Polym.* 77:544-552.