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Dietary Supplementation with Coriander (*Coriandrum sativum*) Seed: Effect on Growth Performance, Circulating Metabolic Substrates, and Lipid Profile of the Liver and Visceral Adipose Tissue in Healthy Female Rats

Trevor Nyakudya[1], Siyanda Makaula[2,3], Nompilo Mkumla[2] and Kennedy Erlwanger[2*]
[1]*Department of Human Anatomy and Physiology, Faculty of Health Sciences, University of Johannesburg, Doornfontein 2028, Johannesburg, South Africa*
[2]*School of Physiology, Faculty of Health Sciences, University of the Witwatersrand, Parktown 2193, Johannesburg, South Africa*
[3]*Walter Sisulu University, Private Bag X1, UNITRA 5117, South Africa*
*For correspondence: Kennedy.Erlwanger@wits.ac.za

Abstract

The rising incidence of metabolic syndrome globally has been attributed to sedentary lifestyles and the consumption of high energy diets with a low omega-3: omega-6 fatty acid ratio. Coriander seeds, commonly used for culinary purposes, have beneficial health effects. We investigated the effects of dietary supplementation with coriander seeds on growth performance, hepatic and visceral adipose tissue lipid storage and circulating metabolic substrates in healthy, growing rats. Female Sprague Dawley rats (150-200 g) were fed either standard rat chow (n = 8) or standard rat chow supplemented with crushed coriander seeds (n = 8; 500 mg kg^{-1} body mass). After five weeks, there were no significant differences in body mass gain, plasma free fatty acids and triglyceride concentrations of the rats ($p > 0.05$; t-test). Whilst dietary supplementation with coriander did not affect the lipid content of the liver, it significantly increased the amount of monounsaturated (22.62 ± 6.48% vs 0.65 ± 0.32%) and polyunsaturated (54.89 ± 5.10% vs 22.16 ± 7.79%) fatty acids in the visceral adipose tissue where it also decreased the saturated fatty acid content ($p < 0.05$; t-test). Coriander increased the omega 3: omega 6 ratio in the visceral adipose tissue which may explain its health benefits.

Keywords: Coriander; Visceral fat; Liver lipids

Introduction

Since time immemorial, herbs and spices have been used by indigenous communities for culinary and medicinal purposes (Sharma *et al*., 2011). The use of diet (nutraceuticals) is acknowledged as an important factor in the prevention and management of disease. The presence of a number of biologically active phytochemicals has been ascribed to the ability of most plant-based foods and medicines to prevent and manage disease progression. One such plant that has been identified and is currently being used as a spice for cooking and as an herb in ethnomedicine is *Coriandrum sativum* L.

C. sativum is described as "a glabrous, aromatic, herbaceous annual plant" (Pandey *et al*., 2011) that belongs to the family Umbelliferae (Apiaceae), order Apiales with over 30 genera and 300 species of trees (Asgarpanah and Kazemirash, 2012), is commonly known as coriander, "cilantro" in the USA or Chinese parsley (Asgarpanah and Kazemirash, 2012), and can grow up to 60 cm (Momin *et al*., 2012). Due to its medicinal properties, records of *C. sativum* use date back to 1550BC (Deepa and Anuradha, 2011). Coriander use is believed to have emanated from the Mediterranean region (Sharma *et al*., 2011), and its consumption has become widespread as its medicinal and culinary uses have been publicized.

Volatile phytochemical constituents that have been isolated from different parts of *C. sativum* include essential oils, flavonoids, fatty acids, sterols isocaumarins, phenolic compounds (caffeic acid, protocatechinic acid and glycitin) and coriandrones among others (Momin *et al*., 2012). The identified essential oils and phytochemical constituents in coriander are important in ethnomedicine, beverages, the pharmaceutical and the food industry (Burdock and Carabin, 2009). Green, fresh, coriander leaves are generally used as a spice for cooking soups and in curries due to their flavor enhancing properties (Asgarpanah and Kazemirash, 2012), while the dried seeds are used as herbs in ethnomedicine for the treatment of a variety of diseases (Chithra and Leelamma, 1999; Momin *et al*., 2012).

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The seed extracts have been used as an ingredient in cosmetic products such as shampoos and lotions (Asolkar *et al*., 1992; Raziq *et al*., 2012; Jahan *et al*., 2012).

Several phytochemical and pharmacological studies on the different parts of *C. sativum* have revealed its potential as a medicinal plant (Momin *et al*., 2012; Iqbal *et al*., 2012). Coriander seeds, leaves, flowers and fruit exhibit a wide range of pharmacological activities such as: antibiotic (Silva *et al*., 2011) anti-oxidant, anti-diabetic, anti-cholinesterase, anti-helminthic, sedative-hypnotic, anti-convulsant, cholesterol lowering (Wangensteen *et al*., 2004), anti-cancer, and hepatoprotective activity (Samojlik *et al*., 2010) among other functions.

Metabolic syndrome constitutes a set of metabolic and physiological risk factors such as hypertriglyceridemia, low high density lipoprotein cholesterol (HDL-C) levels, impaired glucose tolerance, poor glycaemic indices, diabetes, insulin resistance and abdominal obesity, which are all associated with the development of cardiovascular diseases (hypertension, atherosclerosis, myocardial infarction) (Spalding *et al*., 2009). The prevalence of diabetes, obesity and metabolic syndrome has reached global epidemic levels (Mokdad *et al*., 2003; Spalding *et al.*, 2009) and has been implicated as a major cause of morbidity and mortality in developed and developing societies (Olshansky *et al*., 2005). The rising incidence of diabetes and metabolic syndrome has been attributed to the adoption of Western high-energy diets and a lack of physical activity (Johnson *et al*., 2011). Western diets tend to be deficient in omega-3 fatty acids, and contain excessive amounts of omega-6 fatty acids which have been associated with an increased risk for cardiovascular disease and cancer (Simopoulos, 2002).

The use of spices and herbs for the treatment and management of diabetes has been widely reported (Yeh *et al*., 2003). Coriander has been identified as one of the herbs that can be used to treat diabetes (Swanston-Flatt *et al*., 1990) and alleviate the effects of other markers of metabolic syndrome (Aissaoui *et al*., 2011). Coriander seeds are rich in essential oils which have been shown to possess hypoglycaemic and hypolipidaemic effects in the obese and diabetics (Aissaoui *et al*., 2011). The anti-oxidant properties of coriander have been shown to decrease the oxidative burden that may be associated with diabetes mellitus (Deepa and Anuradha, 2011). Studies have shown that oral administration of aqueous extracts of coriander seed in obese-hyperglycaemic and hyperlipidaemic rats decreased metabolic syndrome and atherosclerotic indices, and increased the cardio-protective indices (Aissaoui *et al*., 2011).

The hypoglycaemic and hypolipidaemic effects of coriander have been extensively investigated and well-established in hyperglycaemic or obese hyperlipidaemic animal models (Chithra and Leelamma, 1999; Lal *et al*., 2004; Aissaoui *et al*., 2011).

Coriander is widely consumed by healthy individuals. According to our knowledge, there is a scarcity of information and research on growth performance, blood metabolites, lipid content of the liver and visceral fat tissue in non-obese and non-diabetic healthy animals.

Materials and Methods

Seed Collection, Oil Extraction and Fatty Acid Characterization

C. sativum seed used in the study was purchased from a local supermarket (Johannesburg, South Africa) samples were sent to the Agricultural Research Council's Irene Analytical Services, Pretoria, South Africa where standard ether extraction and lipid analysis was done using gas chromatography as previously described (Christopherson and Glass, 1969).

Animals and Housing

The experiments were performed on 16 female Sprague Dawley rats (*Rattus novergicus*) that weighed between 150-200 g at the beginning of the experiments. The rats were obtained from the University of the Witwatersrand, Central Animal Services, Johannesburg, South Africa. The rats were housed individually in solid-bottom cages that had wood shavings for bedding. A 12 h light: 12 h dark cycle was maintained (with lights on at 06:00) and air temperature was controlled at 18-21°C. The experimental procedures were performed in accordance with the principles and procedures described in the University of the Witwatersrand Guide for the Care and Use of Laboratory Animals and approved by the Animal Ethics Screening Committee, of the University of the Witwatersrand (Animal ethics clearance number 2008/28/2B).

Experimental Procedure

During the first week, the rats were habituated to the housing conditions and interventions before the commencement of the experimental protocol. During the second week, the rats were randomly divided into two groups. Group 1 (n = 8) served as a control and received commercially supplied rat chow (Epol, Johannesburg, South Africa) supplemented with placebo gelatine cubes administered orally. Group 2 (n = 8) received commercially supplied rat chow supplemented with 500 mg kg^{-1} day^{-1} of whole, crushed coriander seeds (local supermarket, Johannesburg, South Africa) incorporated in gelatine cubes. Rats in all groups were allowed access to water *ad libitum* and were weighed twice every week for five weeks, to monitor body mass gain and adjust the amount of coriander in the cubes so as to maintain a constant dose.

Blood Metabolites

Glucose and triglyceride analysis: After the five week feeding trial period, the rats were fasted overnight and two drops of blood collected from the tail (via a pin prick) with a sterile needle. One drop of blood was used to measure fasting plasma glucose with a glucometer (Acsensia Elite, Bayer Diagnostics, Ireland) and the other drop was used to measure fasting plasma triglycerides (TGs) with a triglyceride meter (Accutrend Plus Cobas, Roche, Germany). Prior to use, the glucometer and TG meter were calibrated according to manufacturer's instructions.

Free Fatty Acid Analysis

After the determination of blood glucose and TGs, the rats were euthanized by an intraperitoneal injection of sodium pentobarbitone (200 mg kg^{-1}; Euthanaze, Centaur Labs, South Africa) and 5 mL of blood was obtained by cardiac puncture and placed into heparinised tubes. To obtain plasma, the tubes were centrifuged at 5000 rpm for ten minutes at 4°C. The free fatty acids were determined using a non-esterified free fatty acid determining kit (Roche Diagnostics, Germany) according to the manufacturer's instructions.

Liver and Visceral Fat Lipid Profile Determination

The liver and visceral fat were dissected from the body, weighed and frozen at -20°C until further lipid profile analyses. Liver and visceral fat lipid extractions were done according to Bligh and Dyer (1959). Briefly the samples, liver (5 g) and visceral fat (2 g), were weighed and extracted overnight in chloroform: methanol (2:1) (Merck chemicals, South Africa and Labchem, South Africa respectively). The lipid profiles were determined with a Varian 3400 gas chromatograph.

Statistical Analysis

All results are presented as mean ± SEM. A Student t-test was used to compare the effects of feeding coriander seeds on the measured variables. Differences were considered to be significant if $p < 0.05$. All statistical analyses were performed using Graphpad Instat version 5 (Graphpad Software Inc., Oberlin, San Diego, USA).

Results

Body, Liver and Visceral Fat Mass

There were no significant differences in body mass gain of the rats in the different groups (Fig. 1A: t-test; $p > 0.05$). The relative mass of the liver and visceral fat was also not significantly different between the two groups of rats (Fig. 1B and C: t-test, $p > 0.05$).

Blood Metabolites

At the end of the 5-week study period, fasting blood glucose was 2.5% higher in coriander fed rats compared to the control rats (Table 1). Although fasting blood glucose was different between the two groups, it was within the normal fasting range for rats (Klueh *et al*., 2006).

Table 1: The effects of feeding coriander seeds on blood glucose, triglycerides, and, plasma free fatty acid concentrations of female rats

Metabolite	Control (n = 8)	Coriander (n = 8)
Glucose (mmol L^{-1})	4.08 ± 0.44	4.18 ± 0.18*
Triglyceride (mmol L^{-1})	1.55 ± 0.15	1.36 ± 0.08

Data represented as mean ± SEM. *p < 0.05; t-test *vs* control group. FFA = free fatty acids)

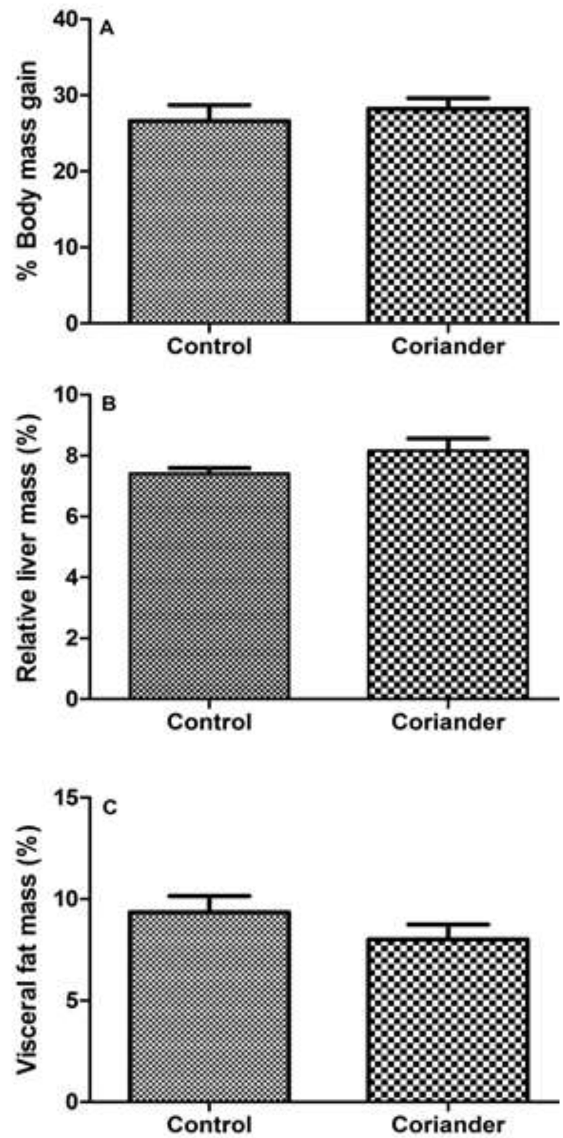

Fig. 1: The effects of 5 weeks of dietary supplementation with coriander seeds on (A) percentage body mass gain, (B) relative liver mass (% body mass) and (C) visceral fat mass (% body mass) across all different groups ($p > 0.05$; t-test). Data represented as mean ± SEM

There were no differences in the levels of blood triglycerides and plasma free fatty acids (FFAs) (Table 1: t-test, $p > 0.05$).

Lipid Profiles of the Liver and Visceral Adipose Tissue

There were no significant differences in the total lipid content and lipid profiles of the liver across all groups (Table 2: t-test, $p > 0.05$). The total oil content of the visceral fat, percentage yield of total monounsaturated fatty acids (TMUFA) and total n-3 polyunsaturated fatty acids (T3PUFA) were higher in coriander fed than in control animals (Table 2: t-test, $p < 0.05$); while total saturated fatty acids (TSFA) and total n-6 polyunsaturated fatty acids (Tn6PUFA) percentage yield in visceral fat was higher in the control than the coriander fed group (Table 2: t-test, $p<0.05$).

***Coriandrum sativum* Fatty Acid Profile**

The oil yield from the *C. sativum* seeds, on a dry matter basis, was 11.4%, (Table 3). The seed oil had a total yield of 6.55% saturated fatty acids (SFAs), 78.2% monounsaturated fatty acids (MUFAs) and 15.08% polyunsaturated fatty acids (PUFAs). The main SFAs in *C. sativum* seed oil extract were palmitic acid (4.11%) and stearic acid (1.35%). Oleic acid (77.82%) was the most abundant MUFA, while linoleic acid constituted 14.67% of the identified PUFAs.

Discussion

The current study investigated the effect of feeding *C. sativum* L (coriander) seeds on growth performance, circulating metabolites, lipid content of the liver and abdominal visceral fat tissue of healthy non-obese, non-diabetic growing female rats. The fatty acid profile and composition of coriander seeds was also determined in an effort to explain any changes in circulating metabolites and lipid content of the liver and visceral fat tissue.

The rats in all groups showed a normal growth pattern with no significant differences in the percentage body mass changes. In addition to the use of coriander as a remedy for a variety of diseases and ethnomedicinal uses, it has been used for weight loss (Swanston-Flatt *et al*., 1990). However, our results suggest that dietary coriander seeds do not alter body mass in healthy rats, an observation which is consistent with a previous study in normal mice (Swanston-Flatt *et al*., 1990). Studies on broiler chicks however showed that, supplementing coriander seed oil (Hamodi *et al*., 2010) and whole coriander seeds (Saeid and Al-Nasry, 2010) in broiler feed improved the growth performance, body weight, feed intake and feed conversion ratio.

The relative liver and visceral fat masses were not significantly different across all groups. Excessive accumulation of visceral fat and liver mass are used as indicators of the development of obesity and metabolic syndrome (Johnson *et al*., 2011). In human subjects, abdominal adiposity (visceral and hepatic) is associated with cardiovascular diseases, insulin resistance and diabetes, and is known to affect free fatty acid and glucose metabolism (Gastaldelli *et al*., 2007). The rising incidence of obesity, diabetes and cardiovascular diseases in affluent developed and developing societies has been attributed to the consumption of high energy diets, which impair carbohydrate and lipid metabolism. Our results suggest that dietary coriander seeds do not promote accumulation of fat

Table 2: The effects of dietary inclusion of coriander seeds on the lipid profile of the liver and visceral fat of female rats

Fatty acid (% yield)	Control (n = 8)	Coriander (n = 8)
	Liver	
Oil content (mg g^{-1})	1.07 ± 0.20	1.23 ± 0.30
TSFA (% yield)	34.33 ± 1.00	34.92 ± 0.80
TMUFA (% yield)	17.40 ± 2.68	16.14 ± 1.21
Tn6PUFA (% yield)	22.34 ± 1.12	20.28 ± 0.74
Tn3PUFA (% yield)	11.22±0.69	12.35 ± 0.40
	Visceral fat	
Oil content (mg g^{-1})	0.03 ± 0.001	2.77 ± 0.10*
TSFA (% yield)	25.20 ± 6.56	0.58 ± 0.28*
TMUFA (% yield)	0.65 ± 0.32	22.62 ± 6.48*
Tn6PUFA (% yield)	46.33 ± 7.46	21.21 ± 10.78
Tn3PUFA (% yield)	22.16 ± 7.79	54.89 ± 5.10*

Data represented as mean ± SEM. *$p < 0.05$; t-test *vs* control group. TSFA = total saturated fatty acids; TMUFA = total monounsaturated fatty acids; Tn3PUFA = total Omega-3 polyunsaturated fatty acids; Tn6PUFA = total omega-6 Polyunsaturated fatty acids

Table 3: Fatty acid profile of the *Coriandrum sativum* L (coriander) seed oil

Fatty acid	% yield of seed oil
Saturated (SFA)	
C10:0 (Capric acid)	0.02
C12:0 (Lauric acid)	0.05
C14:0 (Myristic acid)	0.13
C15:0 (Pentadecanoic acid)	0.04
C16:0 (Palmitic acid)	4.11
C17:0 (Margaric acid)	0.10
C18:0 (Stearic acid)	1.35
C20:0 (Arachidic acid)	0.15
C21:0 (Heneicosanoic acid)	0.02
C22:0 (Behenic acid)	0.15
C24:0 (Lignoceric acid)	0.42
Total saturated fatty acids (TSFA)	*6.55*
Monounsaturated (MUFA)	
C15:1 (cis-10-pentadecenoic acids)	0.01
C16:1 (Palmitoleic acid)	0.27
C17:1 (cis-10 Heptadecenoic acid)	0.04
C18:1n9c (Oleic acid)	77.83
C20:1 (*cis*-11-eicosenoic acid)	0.07
Total monounsaturated fatty acids (TMUFA)	*78.24*
Polyunsaturated (PUFA)	
C18:2n6t (Linolelaidic acid)	0.12
C18:2n6c (Linoleic acid)	14.67
C18:3n3 (α-linolenic acid)	0.27
C18:3n6 (γ-linoleic acid)	0.04
C20:2 (*cis*-11,14-eicosadienoic acid)	0.03
C22:1n9 (Erudic acid)	0.02
Total polyunsaturated fatty acids (TPUFA)	*15.08*
Trans fatty acids	0.12
Cis fatty acids	92.49
Omega 3	0.33
Omega 6	14.84
Omega 9	77.83
TPUFA: TSFA	2
n6PUFA: n3PUFA	45

in the liver and viscera, and thus may have beneficial effects on hepatic and visceral lipid metabolism. However, it is important to note that the current study was performed over a 5-week period and it is possible that feeding coriander seeds for a longer duration may result in different outcomes.

Traditional treatments and remedies for diabetes are used worldwide, either alone or in combination with conventional pharmaceutical therapies (Bnouhan *et al*., 2006). Coriander has been traditionally used and advocated as a remedy for diabetes and lowering cholesterol due to its hypoglycaemic and hypolipidaemic effect in animals (Aissaoui *et al*., 2011) and humans (Waheed *et al*., 2006). The proposed mechanism of the hypoglycaemic effect of coriander, which justifies its use in ethnomedicine for diabetes, involves the normalisation of glycaemia and decreasing elevated levels of insulin, low density lipoproteins (LDL), cholesterol and triglycerides in obese, hyperglycaemic and hyperlipidaemic animal models (Chithra and Leelamma, 1999; Aissaoui *et al*., 2011). Our observation showed that fasting blood glucose in animals fed with whole crushed coriander seeds was significantly higher than in control animals. Although fasting blood glucose was statistically significantly higher in the coriander fed animals compared to the control group, it may not be biologically significant as it represents less than 2.5% change. The fasting blood glucose levels are also within the normal range of a rodent (Klueh *et al*., 2006).

It is evident from the results that supplementation with 500 mg $kg^{-1}day^{-1}$ of coriander seeds did not cause significant changes in blood triglycerides (TGs) and plasma free fatty acids (FFAs). Some studies have attributed the hypolipidaemic effect of coriander to its ability to decrease the uptake and enhance the breakdown of lipids (Lal *et al*., 2004). As such coriander can therefore be used as a cheap and readily accessible remedy for hyperlipidaemia. Although we did not observe any differences in triglyceride concentrations in our coriander fed animals, a study on day-old Arbor Acer broiler chicks showed that triglyceride levels were higher in chicks that were fed with coriander seeds (Al-Jaff, 2011). The use of diabetic and obese animal models in previous studies, compared to the healthy animals in our study could explain the observed differences in blood triglyceride and plasma fatty acid profiles. Long term studies on the effect of coriander and are recommended in healthy and diabetic rats in future.

The current study also investigated changes in visceral fat and hepatic lipid profiles after feeding coriander seeds and explored a possible link between these profiles and the fatty acid profile of coriander seeds. Administration of dietary coriander seeds did not alter liver lipid profiles across all groups, suggesting that dietary coriander seeds may not have affected the lipid metabolism and possibly liver function. These data possibly confirm the previously reported benefits of coriander in hepatic lipid metabolism (Lal *et al*., 2004). We however did not perform specific tests to assess liver function and recommend such assessments in future.

Feeding rats with coriander seeds resulted in an increase in oil content, total MUFA and total n-3 polyunsaturated fatty acids (T3PUFA) in the visceral adipose tissue. We identified and quantified fatty acids in coriander seed oil using gas chromatography and our results showed that the seed oil contains saturated fatty acids (6.55%), monounsaturated fatty acids (78.2%) and polyunsaturated fatty acids (15.08%) such as palmitic acid, oleic acid and linoleic acid, respectively. The presence of polyunsaturated fatty acids (PUFAs) in coriander seeds from our study confirms the report from Jaworski and Cahoon (2003), which showed that coriander is a good dietary source of PUFAs. Polyunsaturated fatty acids (PUFAs) cannot be synthesised naturally in mammals, as such they are obtained from dietary supplementation. Most PUFAs, especially n-3 fatty acids (Omega 3) are known to reduce the risk of cardiovascular diseases (Walter, 2007), improve insulin sensitivity and reduce lipolysis, triglyceride synthesis and free fatty acid concentration (Rustan *et al*., 1993). Dietary sources of PUFAs such as coriander have been shown to activate AMP-activated protein kinase which causes expression of proteins that promote fatty acid oxidation and suppression of fatty acid synthesis in the liver (Suchankova *et al*., 2005).

The increase in oil content, total MUFA and T3PUFA levels in visceral fat after coriander feeding may be ascribed to high levels of MUFAs and TPUFAs in the coriander seed oil, especially the contribution of oleic acid (OA) and linoleic acid (LA). Oleic acid and LA are commonly found in plant products and are important precursors of omega 9 and omega 6 unsaturated fatty acids respectively. Oleic acid plays a role in the lowering of blood pressure and LDL levels in the body (Terés *et al*., 2008), while LA is important in balancing the fatty acid ratio (French *et al*., 2000). Fatty acid accumulation in the visceral adipose tissue has been implicated in the production of inflammatory mediators. The pro-inflammatory cytokines produced by expanding adipose tissue affect energy balance in diseases that are associated with excessive accumulation of fat mass such as obesity and diabetes (Trayhurn and Wood, 2004). The inflammatory capacity of abdominal visceral fat is greater than other deposits and is a possible source of low grade systemic inflammation (Alvehus *et al*., 2010).

Total saturated fatty acids (SFA) and total n-6 polyunsaturated fatty acids (Tn6PUFA) percentage yield in visceral fat was higher in the control group than the coriander-fed group. Consumption of SFAs has been associated with increased levels of serum LDL cholesterol, which increases the risk for coronary heart diseases, as a result diets low in SFAs and high in PUFAs and MUFAs have been recommended for individual health (Marshall *et al*., 1997). Coriander seeds contain fatty acid desaturase enzymes whose activity promotes MUFA (Jaworski and Cahoon, 2003) and probably PUFA synthesis. The fatty acid desaturase enzyme (Δ^4-palmitoyl acyl carrier protein) in coriander catalyses the conversion of SFA to unsaturated fatty acids (Jaworski and Cahoon, 2003). We speculate that the desaturase enzyme activity could explain the reported decrease in SFA content in the visceral adipose tissue of coriander fed rats.

Although we found no changes in plasma metabolites with coriander supplementation, the effects of coriander on lipid metabolism in the liver and visceral adipose tissue are worth further investigation. Nevertheless, coriander is potentially beneficial in increasing insulin sensitivity by reducing visceral adipose tissue SFA and increasing PUFAs and MUFAs.

According to our knowledge this is the first study to investigate the effect of feeding dietary coriander seeds on growth performance, hepatic and visceral adipose tissue lipid storage and circulating metabolic substrates in healthy growing female rats. We showed that dietary coriander seeds had no effect on growth performance, plasma lipids and blood glucose. Dietary coriander seeds however promoted MUFA and PUFA storage, and decreased SFAs in visceral adipose tissue but not in the liver. These data suggest that dietary coriander supplementation may have beneficial effects on visceral adipose tissue lipid metabolism in healthy subjects.

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